WILSON COUNTY, SOUTHEASTERN KANSAS, U.S.A.
ITS GEOLOGIC ENVIRONMENT, CYCLIC SEDIMENTATION
BASIC INTRUSIVE ROCKS, AND MINERAL AND PETROLEUM
RESOURCES

BY

HOLLY CLYDE WAGNER

A Dissertation Presented to the
FACULTY OF THE GRADUATE SCHOOL
UNIVERSITY OF LEICESTER
In Partial Fulfillment of the
Requirements of the Degree
DOCTOR OF PHILOSOPHY
Department of Geology

June 1995
ABSTRACT

Wilson County is situated in the southern part of the Midcontinent region of the United States. The Nemaha Ridge lies to the west, the Bourbon Arch to the north, the Ozark Dome to the east, and the Amarillo-Wichita-Arkabuck complex to the south. Extensive field mapping was done in order to determine the geologic characteristics of the strata and to delineate the limits of deposits of limestone (for cement, lime, and road aggregate), of clay (for brick, tile, and other building materials, and as a mixer in the rock-wool industry), and of coal (for heating purposes); this study and an associated study of bore-hole data from thousands of wells drilled for oil and gas have provided new insight into many fascinating aspects of Kansas geology.

The Precambrian basement, encountered at depths below 355 m, includes granite, syenite, schist and gneiss. Through the Paleozoic there was extensive sedimentation ranging from varied coarse detritus from surrounding areas of orogenic uplift to Pennsylvanian epicontinental carbonates containing deltaic and channel filling clastics from the east, south, and west. Five unconformities were recognized below the Pennsylvanian which can be seen throughout the area as cyclic sequences of limestone, sandstone and shale. Six major cyclic units can be recognized over several hundred square kilometers with persistent sedimentary and biological features. They are attributable to Milankovitch-type cycles invoked to explain the nature of glacial deposits of Northern Europe. The great variety and abundance of marine plants and invertebrates reflect the changing geological environment. The mound lithofacies is dominantly a calcilutite with phylloid algae, the channel and rim lithofacies are calcarenites with echinoderm debris and brachiopods respectively.

The area contains only two contrasting structural features of interest. The Fredonia Dome is a short complex anticlinal feature which is important for oil and gas production. The Silver City Dome is attributed to intrusion by several Cretaceous sills of lamproite encountered in boreholes; a very micaceous yellowish clay represents the lamproite at the outcrop.

The youngest strata encountered are Tertiary and Quaternary gravels containing abundant chert pebbles derived from chert-rich limestones to the northwest; the gravels were deposited by vigorous migrating streams and rivers.
This comprehensive geologic investigation of Wilson County was planned in order to identify and describe the origin of Pennsylvanian cycloths for an area in southeastern Kansas that lies between the type Kansas River Valley cyclic sediments as described by R. C. Moore in the 1930's and 1940's (Moore, 1930, 1931, 1932, 1936, 1937, 1948, 1949) and the more clastic-dominated cyclic sediments of northern Oklahoma (Moore and Dott, 1937; Moore and others, 1937, 1944; Dott, 1941). The study was envisioned by W. H. Monroe, Central States Regional Supervisor of the Fuels Branch of the U. S. Geological Survey, as a means to provide continuity to an unbroken cooperative effort, begun in 1917, between the Federal Geological Survey and the Kansas State Geological Survey. This effort would otherwise have terminated with the retirement of Wallace Lee in 1953. Continuity of the cooperative program was desired by both the Federal and State Geological Surveys. Wilson County was selected for several reasons the chief of which were: (1) that in southeastern Kansas only Wilson County was covered by new, detailed topographic maps at a scale of 1:48,000 in 1950, (2) that Wilson County had shown promise of large oil and gas resources for which data concerning the occurrence related to stratigraphy and structure were needed in order to determine areas worthy of future petroleum exploration, (3) that Wilson County had
unresolved questions concerning the occurrence of unusual metamorphic effects at the northern border of the county, and (4) that Wilson was one of the counties not yet remapped geologically for use in the preparation of a new geologic map of the State of Kansas. The detailed geologic mapping and ancillary investigations were approved by R. C. Moore, Professor of Geology at the University of Kansas and State Geologist of the State Geological Survey of Kansas as an adequate Ph. D. dissertation in 1951. However, prior to completion of all requirements for the doctoral degree, I was reassigned to Washington, D. C., as Assistant Chief of the Fuels Branch of the U. S. Geological Survey, a three-year assignment. Upon its completion I was assigned to high-priority structural and stratigraphic research in the Pacific Coast states of California, Oregon and Washington dealing with nuclear reactor power plant siting. In 1990, a further revision of the Geologic Map of Kansas was underway, and I was asked to update the geology of Wilson County. I agreed to the task as a means to complete my doctorate, and I have incorporated into this dissertation most of the results of a large number of geologic investigations that were undertaken within the county limits during the intervening 40 years. A table of contents and lists of illustrations follow.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Sectionermal</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>PREFACE</td>
<td>iii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xiii</td>
</tr>
<tr>
<td>Plates</td>
<td>xvii</td>
</tr>
<tr>
<td>Tables</td>
<td>xix</td>
</tr>
<tr>
<td>CHAPTER ONE: INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>8</td>
</tr>
<tr>
<td>CHAPTER TWO: GEOGRAPHY</td>
<td>11</td>
</tr>
<tr>
<td>Historical summary</td>
<td>12</td>
</tr>
<tr>
<td>Geographic overview</td>
<td>12</td>
</tr>
<tr>
<td>Physiographic expression</td>
<td>13</td>
</tr>
<tr>
<td>Drainage systems</td>
<td>15</td>
</tr>
<tr>
<td>Climate</td>
<td>18</td>
</tr>
<tr>
<td>Vegetation and farm products</td>
<td>19</td>
</tr>
<tr>
<td>Population, transportation and industry</td>
<td>21</td>
</tr>
<tr>
<td>CHAPTER THREE: GEOLOGY</td>
<td>24</td>
</tr>
<tr>
<td>Geologic overview</td>
<td>25</td>
</tr>
<tr>
<td>Previous investigations</td>
<td>26</td>
</tr>
<tr>
<td>Methods of investigation</td>
<td>31</td>
</tr>
<tr>
<td>SECTION 3A: THE CENOZOIC ERA</td>
<td>33</td>
</tr>
<tr>
<td>Quaternary and Tertiary Systems</td>
<td>33</td>
</tr>
<tr>
<td>Recent Stage (Pleistocene Series)</td>
<td>35</td>
</tr>
<tr>
<td>Stream valley alluvium</td>
<td>35</td>
</tr>
<tr>
<td>Pleistocene and Pliocene Series</td>
<td>36</td>
</tr>
<tr>
<td>Chert gravel deposits</td>
<td>37</td>
</tr>
</tbody>
</table>
Milankovitch theory and isotopic variations .................... 52
Summary statement .................. 57
SECTION 3B: THE MESOZOIC ERA .................... 59
Cretaceous System .................... 59
Intrusive rocks .................... 59
SECTION 3C: THE PALEOZOIC ERA .................... 72
Pennsylvanian System .................... 72
General statement .................... 72
Cyclic sedimentation .................... 74
Dolomitization .................... 86
Virgilian Stage .................... 93
Shawnee Group .................... 97
Oread Limestone .................... 98
Naming, distribution, and thickness .. 98
Lithologic character ............ 102
Plattsmonth Limestone Member .... 103
Heebner Shale Member .... 111
Leavenworth Limestone Member .... 117
Snyderville Shale Member .... 123
Toronto Limestone Member .... 125
Stratigraphic and structural implications .... 129
Douglas Group ............ 137
Lawrence Formation ............ 138
Naming, distribution, and thickness .. 138
Lithologic character ............ 139
<table>
<thead>
<tr>
<th>Stratigraphic and structural implications</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wathena Shale Member</td>
<td>140</td>
</tr>
<tr>
<td>Amazonia Limestone Member</td>
<td>142</td>
</tr>
<tr>
<td>Ireland Sandstone Member</td>
<td>144</td>
</tr>
<tr>
<td>Robbins Shale Member</td>
<td>148</td>
</tr>
<tr>
<td>Haskell Limestone Member</td>
<td>151</td>
</tr>
<tr>
<td>Stranger Formation</td>
<td>163</td>
</tr>
<tr>
<td>Naming, distribution, and thickness</td>
<td>163</td>
</tr>
<tr>
<td>Lithologic character</td>
<td>164</td>
</tr>
<tr>
<td>Vinland Shale Member</td>
<td>164</td>
</tr>
<tr>
<td>Westphalia Limestone Member</td>
<td>166</td>
</tr>
<tr>
<td>Tonganoxie Sandstone Member</td>
<td>171</td>
</tr>
<tr>
<td>Weston Shale Member</td>
<td>178</td>
</tr>
<tr>
<td>South Bend Limestone Member</td>
<td>201</td>
</tr>
<tr>
<td>Rock Lake Shale Member</td>
<td>211</td>
</tr>
<tr>
<td>Stoner Limestone Member</td>
<td>215</td>
</tr>
<tr>
<td>Eudora Shale Member</td>
<td>221</td>
</tr>
<tr>
<td>Captain Creek Limestone Member</td>
<td>225</td>
</tr>
</tbody>
</table>

Stratigraphic and structural implications

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>233</td>
</tr>
<tr>
<td>Page</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>243</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>252</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>278</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>286</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>299</td>
</tr>
</tbody>
</table>

viii
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naming, distribution, and thickness</td>
<td>299</td>
</tr>
<tr>
<td>Lithologic character</td>
<td>301</td>
</tr>
<tr>
<td>Cottage Grove Sandstone Member</td>
<td>301</td>
</tr>
<tr>
<td>Noxie Sandstone Member</td>
<td>306</td>
</tr>
<tr>
<td>Unnamed Shale Member</td>
<td>308</td>
</tr>
<tr>
<td>Stratigraphic and structural implications</td>
<td>309</td>
</tr>
<tr>
<td>Drum Limestone</td>
<td>312</td>
</tr>
<tr>
<td>Naming, distribution, and thickness</td>
<td>312</td>
</tr>
<tr>
<td>Lithologic character</td>
<td>313</td>
</tr>
<tr>
<td>Stratigraphic and structural implications</td>
<td>315</td>
</tr>
<tr>
<td>Cherryvale Shale</td>
<td>316</td>
</tr>
<tr>
<td>Naming, distribution, and thickness</td>
<td>316</td>
</tr>
<tr>
<td>Lithologic character</td>
<td>316</td>
</tr>
<tr>
<td>Stratigraphic and structural implications</td>
<td>317</td>
</tr>
<tr>
<td>Bronson Subgroup</td>
<td>318</td>
</tr>
<tr>
<td>Dennis Limestone</td>
<td>318</td>
</tr>
<tr>
<td>Naming, distribution, and thickness</td>
<td>318</td>
</tr>
<tr>
<td>Lithologic character</td>
<td>319</td>
</tr>
<tr>
<td>Stratigraphic and structural implications</td>
<td>323</td>
</tr>
<tr>
<td>Subsurface strata of the Pennsylvanian, Mississippian, Devonian, Ordovician, and Cambrian Systems</td>
<td>324</td>
</tr>
<tr>
<td>Subsurface strata of the Pennsylvanian System</td>
<td>326</td>
</tr>
<tr>
<td>Kansas City Group</td>
<td>327</td>
</tr>
<tr>
<td>Pleasanton Group</td>
<td>330</td>
</tr>
<tr>
<td>Desmoinesian Stage</td>
<td>335</td>
</tr>
<tr>
<td>Harmatton Group</td>
<td>337</td>
</tr>
<tr>
<td>Cherokee Group</td>
<td>340</td>
</tr>
<tr>
<td>Section/Chapter</td>
<td>Title</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Strata</td>
<td>Mississippian age</td>
</tr>
<tr>
<td></td>
<td>Pre-Mississippian sedimentary rocks</td>
</tr>
<tr>
<td>SECTION 3D:</td>
<td>THE PROTEROZOIC ERA</td>
</tr>
<tr>
<td>Precambrian</td>
<td>Rocks</td>
</tr>
<tr>
<td>CHAPTER FOUR:</td>
<td>STRUCTURAL GEOLOGY</td>
</tr>
<tr>
<td>SECTION 4A:</td>
<td>SURFACE INDICATIONS OF STRUCTURE</td>
</tr>
<tr>
<td></td>
<td>Faults</td>
</tr>
<tr>
<td></td>
<td>Folds</td>
</tr>
<tr>
<td></td>
<td>Joints</td>
</tr>
<tr>
<td>SECTION 4B:</td>
<td>SUBSURFACE INDICATIONS OF STRUCTURE</td>
</tr>
<tr>
<td>SECTION 4C:</td>
<td>MAJOR STRUCTURAL FEATURES</td>
</tr>
<tr>
<td></td>
<td>Fredonia Dome</td>
</tr>
<tr>
<td></td>
<td>Silver City Dome</td>
</tr>
<tr>
<td>CHAPTER FIVE:</td>
<td>GEOLOGIC HISTORY</td>
</tr>
<tr>
<td>CHAPTER SIX:</td>
<td>ECONOMIC GEOLOGY</td>
</tr>
<tr>
<td></td>
<td>Economic overview</td>
</tr>
<tr>
<td>SECTION 6A:</td>
<td>FUELS RESOURCES</td>
</tr>
<tr>
<td></td>
<td>History of petroleum development in Wilson</td>
</tr>
<tr>
<td></td>
<td>County</td>
</tr>
<tr>
<td></td>
<td>Oil production</td>
</tr>
<tr>
<td></td>
<td>Relation of oil accumulation to structure</td>
</tr>
<tr>
<td></td>
<td>and stratigraphy</td>
</tr>
<tr>
<td></td>
<td>Secondary recovery</td>
</tr>
<tr>
<td></td>
<td>Oil refining</td>
</tr>
<tr>
<td></td>
<td>Gas production</td>
</tr>
<tr>
<td></td>
<td>Gas storage</td>
</tr>
<tr>
<td></td>
<td>Oil and gas fields</td>
</tr>
<tr>
<td>Mineral Resource</td>
<td>Page</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Altoona oil and gas field</td>
<td>473</td>
</tr>
<tr>
<td>Altoona East oil and gas field</td>
<td>478</td>
</tr>
<tr>
<td>Benedict oil and gas field</td>
<td>479</td>
</tr>
<tr>
<td>Buffalo oil and gas field</td>
<td>482</td>
</tr>
<tr>
<td>Burton oil and gas field</td>
<td>485</td>
</tr>
<tr>
<td>Coffeyville-Cherryvale oil and gas field</td>
<td>485</td>
</tr>
<tr>
<td>Coyville oil and gas field</td>
<td>486</td>
</tr>
<tr>
<td>Coyville West oil and gas field</td>
<td>487</td>
</tr>
<tr>
<td>Fall River oil and gas field</td>
<td>487</td>
</tr>
<tr>
<td>Farmdale gas field</td>
<td>489</td>
</tr>
<tr>
<td>Fredonia oil and gas field</td>
<td>489</td>
</tr>
<tr>
<td>Humboldt-Chanute oil and gas field</td>
<td>496</td>
</tr>
<tr>
<td>LaFontaine oil and gas field</td>
<td>497</td>
</tr>
<tr>
<td>Neodesha oil and gas field</td>
<td>498</td>
</tr>
<tr>
<td>Neodesha East Oil and gas field</td>
<td>508</td>
</tr>
<tr>
<td>New Albany Townsite oil and gas field</td>
<td>509</td>
</tr>
<tr>
<td>Vilas oil and gas field</td>
<td>509</td>
</tr>
<tr>
<td>Shale-oil, phosphate, and fertilizer resources</td>
<td>511</td>
</tr>
<tr>
<td>Coal resources</td>
<td>513</td>
</tr>
<tr>
<td>Fuels-dependent industries</td>
<td>520</td>
</tr>
<tr>
<td>Smelters</td>
<td>520</td>
</tr>
<tr>
<td>Glass</td>
<td>521</td>
</tr>
</tbody>
</table>

SECTION 6B: OTHER MINERAL RESOURCES

<table>
<thead>
<tr>
<th>Mineral Resource</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone</td>
<td>523</td>
</tr>
<tr>
<td>Cement</td>
<td>524</td>
</tr>
<tr>
<td>Crushed rock and agricultural lime</td>
<td>527</td>
</tr>
</tbody>
</table>
Shale ........................................... 529
Brick and tile ................................. 529
Rip-rap ......................................... 533
Light-weight concrete and aggregate 534
Rock wool ...................................... 537
Sandstone ...................................... 538
Chert ........................................... 539

CHAPTER SEVEN: SUMMARY AND CONCLUSIONS 541
CHAPTER EIGHT: REFERENCES .................. 555
CHAPTER NINE: APPENDICES .................... 672
A. Chemical analyses of limestones ........... 673
B. Silver City Dome -- additional data ........ 680
C. Pennsylvanian fauna of Wilson County ...... 757
D. Selected measured sections in Wilson County 771
ILLUSTRATIONS -- FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Index map of Kansas showing the location of Wilson County and its relation to physiographic subdivisions</td>
<td>3</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Index map of Wilson County showing general positions of drainage divides and areal extents of the drainage basins of the Verdigris, Fall, Elk, and Neosho Rivers</td>
<td>16</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Generalized physiographic diagram of Wilson County</td>
<td>17</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Reconstruction of Quaternary and late Tertiary drainage systems in Wilson County as interpreted from chert gravel deposits</td>
<td>40</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Chert gravel deposit lying about 20 m (60 ft) above the flood plain of the Verdigris River</td>
<td>44</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Correlated drillers logs in the area of the Silver Dome showing intrusive rocks</td>
<td>66</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Correlated drillers logs in the area of the Silver City Dome; intrusive rocks removed</td>
<td>68</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Phylloid algal limestone buildups in eastern Kansas</td>
<td>78</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Basic cyclothems showing transgressive and regressive patterns of cyclic sedimentation in Pennsylvanian time</td>
<td>79</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Basic transgressive-regressive depositional cycle of Heckel</td>
<td>81</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Pennsylvanian circulation patterns and thermocline in the Midcontinent region</td>
<td>101</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Plattsmouth Limestone Member of the Oread Limestone</td>
<td>105</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Growth habits of the Recent Phaeophycean alga Thalassiophyllum clathrus and the Pennsylvanian Chlorophycean alga Eugonophyllum johnsonii</td>
<td>107</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Leavenworth Limestone Member of the Oread Limestone</td>
<td>118</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Toronto Limestone Member of the Oread Limestone</td>
<td>127</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>16</td>
<td>Uppermost and lowermost parts of the Lawrence Formation in Wilson County.</td>
<td>141</td>
</tr>
<tr>
<td>17</td>
<td>Lower part of the Ireland Sandstone Member of the Lawrence Formation.</td>
<td>147</td>
</tr>
<tr>
<td>18</td>
<td>Haskell Limestone Member of the Lawrence Formation.</td>
<td>153</td>
</tr>
<tr>
<td>19</td>
<td>Westphalia Limestone Member of the Stranger Formation.</td>
<td>167</td>
</tr>
<tr>
<td>20</td>
<td>Upper part of the Tonganoxie Sandstone Member of the Stranger Formation.</td>
<td>174</td>
</tr>
<tr>
<td>21</td>
<td>Basal part of the Tonganoxie Sandstone Member of the Stranger Formation.</td>
<td>176</td>
</tr>
<tr>
<td>22</td>
<td>Middle part of the Weston Shale Member of the Stranger Formation.</td>
<td>180</td>
</tr>
<tr>
<td>23</td>
<td>Outcrop pattern of the Stanton Limestone in eastern Kansas showing positions of major facies belts.</td>
<td>190</td>
</tr>
<tr>
<td>24</td>
<td>Algal mound tracts of Wilson and adjacent counties.</td>
<td>193</td>
</tr>
<tr>
<td>25</td>
<td>South Bend Limestone Member of the Stanton Limestone.</td>
<td>204</td>
</tr>
<tr>
<td>26</td>
<td>South Bend Limestone Member of the Stanton Limestone.</td>
<td>208</td>
</tr>
<tr>
<td>27</td>
<td>Stoner Limestone Member of the Stanton Limestone.</td>
<td>219</td>
</tr>
<tr>
<td>28</td>
<td>Captain Creek Limestone Member of the Stanton Limestone.</td>
<td>228</td>
</tr>
<tr>
<td>29</td>
<td>Contact between the Stanton Limestone and the Vilas Shale.</td>
<td>234</td>
</tr>
<tr>
<td>30</td>
<td>Limestone bed near the top of the Vilas Shale.</td>
<td>246</td>
</tr>
<tr>
<td>31</td>
<td>Sponges of the Spring Hill Limestone Member of the Plattsburg Limestone.</td>
<td>255</td>
</tr>
<tr>
<td>32</td>
<td>Spring Hill Limestone Member of the Plattsburg Limestone.</td>
<td>256</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>33</td>
<td>Spring Hill Limestone Member of the Plattsburg Limestone</td>
<td>258</td>
</tr>
<tr>
<td>34</td>
<td>Angular discordance between the Iola Limestone and the Chanute Shale</td>
<td>288</td>
</tr>
<tr>
<td>35</td>
<td>Iola Limestone in Wilson County</td>
<td>290</td>
</tr>
<tr>
<td>36</td>
<td>Chanute Shale (Cottage Grove Sandstone Member) and Drum Limestone</td>
<td>303</td>
</tr>
<tr>
<td>37</td>
<td>Coal sections showing variations in number and thickness of coal beds in the Chanute Shale in Wilson County</td>
<td>305</td>
</tr>
<tr>
<td>38</td>
<td>Stratigraphic classification of the Kansas City, Pleasanton, Marmaton and Cherokee Groups in Wilson County</td>
<td>330</td>
</tr>
<tr>
<td>39</td>
<td>Radioactivity log of the Cherokee Group in Wilson County</td>
<td>344</td>
</tr>
<tr>
<td>40</td>
<td>Strata of the Cherokee Group in Wilson County</td>
<td>347</td>
</tr>
<tr>
<td>41</td>
<td>Isopachous map showing the thickness of Mississippian strata in Wilson County</td>
<td>364</td>
</tr>
<tr>
<td>42</td>
<td>Map showing locations of wells that have tested Mississippian and older strata in Wilson County</td>
<td>366</td>
</tr>
<tr>
<td>43</td>
<td>Diagrams showing three wells that have tested strata of Mississippian age in Wilson County</td>
<td>368</td>
</tr>
<tr>
<td>44</td>
<td>Map showing locations of wells that have tested “Arbuckle” and older rocks in Wilson County</td>
<td>377</td>
</tr>
<tr>
<td>45</td>
<td>Stratigraphic relations of “Arbuckle” and older rocks in Wilson County</td>
<td>378</td>
</tr>
<tr>
<td>46</td>
<td>Rock type and generalized structure contour map of the top of Precambrian rocks in Wilson County</td>
<td>384</td>
</tr>
<tr>
<td>47</td>
<td>Map showing major structural uplifts and basins of post-Mississippian age in Kansas</td>
<td>390</td>
</tr>
<tr>
<td>48</td>
<td>Normal faults in the Tonganoxie Sandstone</td>
<td></td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>49</td>
<td>Vertical joint system in the Stanton Limestone at the Wilson County State Lake quarry.</td>
<td>398</td>
</tr>
<tr>
<td>50</td>
<td>Joint systems in the Stanton Limestone as shown on aerial photographs. Scale: 1:20,000.</td>
<td>402</td>
</tr>
<tr>
<td>51</td>
<td>Joint systems in the Stanton Limestone as shown on aerial photographs. Scale: 1:8000.</td>
<td>403</td>
</tr>
<tr>
<td>52</td>
<td>Structure contour map of the top of the Fort Scott Limestone in Wilson County.</td>
<td>404</td>
</tr>
<tr>
<td>53</td>
<td>Structure contour map on the top of rocks of Mississippian age in Wilson County.</td>
<td>407</td>
</tr>
<tr>
<td>54</td>
<td>Structure contour map on the top of rocks of Ordovician age in Wilson County.</td>
<td>410</td>
</tr>
<tr>
<td>55</td>
<td>Vertical intensity magnetic map of the northern part of Wilson County.</td>
<td>411</td>
</tr>
<tr>
<td>56</td>
<td>Aeromagnetic map of Wilson County.</td>
<td>413</td>
</tr>
<tr>
<td>57</td>
<td>Cable-tool and rotary rigs in Wilson County.</td>
<td>415</td>
</tr>
<tr>
<td>58</td>
<td>Graph showing viscosity of “Bartlesville sand” crude oils from Wilson County.</td>
<td>434</td>
</tr>
<tr>
<td>59</td>
<td>Gravity of oil in the “First Bartlesville sand” in Wilson County.</td>
<td>436</td>
</tr>
<tr>
<td>60</td>
<td>Gravity of oil in the “Second Bartlesville sand” in Wilson County.</td>
<td>451</td>
</tr>
<tr>
<td>61</td>
<td>A.P.I. gravity and boiling point of crude oils from Wilson County.</td>
<td>452</td>
</tr>
<tr>
<td>62</td>
<td>Limits of oil and gas fields of Wilson County as established by the Kansas Nomenclature Committee</td>
<td>454</td>
</tr>
<tr>
<td>63</td>
<td>Excelsior Brick Company operation near Fredonia.</td>
<td>492</td>
</tr>
<tr>
<td>64</td>
<td>Map showing the locations of samples taken by Runnels and Schleicher (1957) in Wilson County.</td>
<td>534</td>
</tr>
</tbody>
</table>
Figure 65. Map showing the locations of samples taken by Galle (1967) and a measured section in Wilson County. ................. 677

Figure 66. Compositions of phlogopite mica, Hills Pond Lamproite. ........................................ 738

Figure 67. Compositional variations of spinels from lamproites ........................................... 740

Figure 68. Selected Pennsylvanian brachiopods ............... 763
Figure 69. Selected Pennsylvanian pelecypods ................. 764
Figure 70. Selected Pennsylvanian gastropods ................. 765
Figure 71. Selected Pennsylvanian ostracodes ................. 766
Figure 72. Selected Pennsylvanian sponges and bryozoans 767

Figure 73. Selected Pennsylvanian foraminifers and a fusulinid 768

Figure 74. Selected Pennsylvanian crinoids and an echinoid 769

Figure 75. Selected Pennsylvanian conodonts and corals, a holothurian, a trilobite and a cephalopod 770
ILLUSTRATIONS--PLATES

(In pocket in rear. Page of first reference only is indicated.)

<table>
<thead>
<tr>
<th>Plate</th>
<th>Illustration</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Geologic map of Wilson County, Kansas</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>Correlated sections of the Oread Limestone, Stanton Limestone, Plattsburg Limestone, and Iola Limestone in Wilson County</td>
<td>84</td>
</tr>
<tr>
<td>3</td>
<td>Correlated sections of the Lawrence Formation, Stranger Formation, Vilas Shale and Lane-Bonner Springs Shale in Wilson County</td>
<td>122</td>
</tr>
<tr>
<td>4</td>
<td>Map and sections showing correlation of coal beds and other stratigraphic units in the Chanute Shale in Wilson County</td>
<td>285</td>
</tr>
<tr>
<td>5</td>
<td>Petroleum resources map of Wilson County</td>
<td>317</td>
</tr>
<tr>
<td>6</td>
<td>Typical drillers, electric, and radioactivity logs from Wilson County</td>
<td>318</td>
</tr>
<tr>
<td>7</td>
<td>Map showing the structural configuration of the top of the Fort Scott Limestone (&quot;Oswego Lime&quot;) in Wilson County</td>
<td>406</td>
</tr>
<tr>
<td>8</td>
<td>East-west subsurface cross section across central Wilson County</td>
<td>448</td>
</tr>
<tr>
<td>9</td>
<td>Generalized well log showing important stratigraphic units and producing zones in the subsurface of Wilson County</td>
<td>449</td>
</tr>
<tr>
<td>10</td>
<td>Maps showing areas of oil production in Wilson County</td>
<td>465</td>
</tr>
<tr>
<td>11</td>
<td>Maps showing areas of gas production in Wilson County</td>
<td>472</td>
</tr>
<tr>
<td>12</td>
<td>Map showing locations of measured sections in Wilson County</td>
<td>757</td>
</tr>
</tbody>
</table>
Table 1. Nomenclature of the outcropping Pennsylvanian rocks of Wilson County...  [5]
Table 2. Viscosity and other physical properties of crude oils from Wilson County ....  448
Table 3. Distillation data and other physical properties of crude oil from Wilson County .  455
Table 4. Typical characterization factors for various oil stocks. .................. [456]
Table 5. Permeability and porosity of strata in the subsurface of Wilson County ....  459
Table 6. Water-flood and salt water-disposal projects in Wilson County .............  465
Table 7. Composition of natural gas from Wilson County ..........................  471
Table 8. Proximate analyses of coals from Wilson County ..........................  516
Table 9. Chemical analyses of limestone from Wilson County ........................  524
Table 10. Spectrochemical analyses of limestone from Wilson County ..............  524
Table 11. Chemical analyses of shale from Wilson County ...........................  529
Table 12. Ceramic data for the shales from Wilson County ...........................  529
Table 13. Bloating results from rapid firing of bricks made from the Weston Shale Member of the Stranger Formation in an electric kiln. ...  529
Table 14. Results of experimental production of lightweight aggregate in a batch-type rotary kiln 529
Table 15. Size distributions and unit weights of lightweight aggregate after single pass through rollers, Wilson County shales ............  529
Table 16. Chemical analyses of selected limestones from Wilson County .......... [678]
Table 17. Chemical analyses of members of the Oread Limestone from Wilson County .......... [679]
Table 18. Chemical analyses of igneous, metamorphic, and sedimentary rocks, Silver City Dome .. [727]
Table 19. Major and trace element contents of the Hills Pond Lamproite .............. [729]
Table 20. Major and trace element contents of lamproite, Silver City Dome ............. [730]
Table 21. Compositions of mica, Silver City Dome ....... [734]
Table 22. Compositions of titanium potassic richterite [735]
Table 23. Composition of spinels from the Hills Pond Lamproite .................. [736]
Table 24. Modal analyses of the Hills Pond Lamproite .. [745]
CHAPTER ONE: INTRODUCTION

Being a statement concerning the history of geologic investigations in Wilson County, the methods and procedures used during my study, and my acknowledgments to those who not only aided me during the field work but also to those who helped in preparation of this written record.
INTRODUCTION

Wilson County is located in southeastern Kansas about 50 km (30 mi) north of the State of Oklahoma and 80 km (50 mi) west of the state of Missouri (Figure 1). It is adjoined on the north by Woodson County, on the east by Neosho County, on the south by Montgomery County, and on the west by Greenwood and Elk Counties. Wilson County is bounded approximately by parallels 37°23 1/2' and 37°44'N latitude and by meridians 95°31 1/2' and 95°57 1/2'W longitude. The county is roughly 40 km (24 mi on a side) and contains about 1,490 km² (576 mi² or 368,000 acres) within its boundaries.

The study of Wilson County reported here was undertaken in order to identify and describe the origin of the Pennsylvanian cyclothems of Kansas that occur in an area between the type Kansas River Valley cyclothems described by R. C. Moore in 1932 and the more clastic-dominated cyclic sediments in southeastern Kansas and northern Oklahoma. The study will also supplement current knowledge of an important oil- and gas-producing area of Kansas, will add data for a new geologic map of the State, and through careful lithologic descriptions of the outcropping rock formations will make possible the reconstruction of former depositional environments. The report should also serve as an aid in recognizing the same
Figure 1. Index map of Kansas showing the relation of Wilson County to physiographic subdivisions. (modified after Schoewe, 1949, p. 276). Heavy dots show possible position of Pliocene-Pleistocene drainage system in southeastern Kansas.
strata in the subsurface beneath Wilson County and in areas far to the west and northwest where they are encountered in the deep drilling for oil and gas. Following a precedent established in earlier published reports of the State Geological Survey of Kansas (Moore and others, 1951; O'Connor and others, 1953; Merriam, 1963), and because it is anticipated that the major use of the data in this report will be by individuals and companies exploring for oil and gas, the formations are discussed in the order in which they would be encountered by the drill, that is, from youngest to oldest. Those formations that crop out comprise (downward) the Oread Limestone, Lawrence Shale, Stranger Formation, Stanton Limestone, Vilas Shale, Plattsburg Limestone, Lane-Bonner Springs Shale, Iola Limestone, Chanute Shale, Drum Limestone, Cherryvale Shale and Dennis Limestone of Pennsylvanian age (Table 1).

Strata encountered in the subsurface include shale, sandstone, and limestone of Pennsylvanian age, cherty limestone and dolomite of Mississippian age, the black Chattanooga Shale of Mississippian and Devonian (?) age, and dolomite and dolomitic limestone of Ordovician and Cambrian age. Oil and gas are obtained from sandstones and limestones above the Cherokee Group, from four or more sandstone beds in the Cherokee Group, from porous zones at the top of strata of Mississippian age, and from rocks of
<table>
<thead>
<tr>
<th>System</th>
<th>Series</th>
<th>Group</th>
<th>Formation</th>
<th>Member</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oread Limestone</td>
<td>Plattesmouth Limestone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hashbitter Shale Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Leavenworth Limestone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Topeka Limestone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lawrence Formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wehme Shale Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Amazonic Limestone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ireland Sandstone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Robbins Shale Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Haskell Limestone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stranger Formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vianland Shale Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Westphalia Limestone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Teregenia Sandstone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Western Shale Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plainsburg Limestone</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spring Hill Limestone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>History Creek Shale Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mertens Limestone Member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Nomenclature of the outcropping Pennsylvanian rocks of Wilson County.
early Ordovician age. In drillers' parlance, the principal oil-producing zones in strata of Pennsylvanian age are the "First" and "Second Bartlesville sands." Lesser production is obtained from the "New Albany sand" of the Chanute Shale, the "Weiser sand" of the Bandera Shale, and the "Squirrel sand" and "Burbank Sand" of the Cherokee Group. Depths to production of both oil and gas range from 61 to 518 m (200-1700 ft), depending upon the stratigraphic position of the producing zone and the amount of uplift of the local structure. About 20 oil pools have been subjected to secondary recovery methods, and two gas pools have been converted to gas reservoirs.

The Chetopa and Dry Creek coal mining districts encompass more than 65 km² (25 mi²) in Wilson County, and approximately 13 million tons of coal in beds 25 to 61 cm (10-24 in) thick remain in the ground. Clay from the Weston, Vilas, and Lane-Bonner Springs Shales has been used in brick and tile manufacture at 9 brick plants since 1884. Cement manufacture, which utilizes about 500,000 tons of limestone each year, relies upon material from quarries in the Stanton and Plattsburg Limestones.

This dissertation contains descriptions of the stratigraphic and structural geology of the county and the relations of those geologic features to the occurrence of oil and gas. An outline of the tectonic and depositional history of the strata is included in order to put into proper perspective and sequence the many events and
conditions which led to variations in the lithology and thickness of the units. In order to do this, a section of the report discusses the factors that may be responsible for the cyclic nature of the sedimentary rocks that were deposited in the area during Cenozoic and Paleozoic times.

Sequence stratigraphy and its application to the carbonate banks and adjacent strata govern the mode of description of the field data. Three basic rules capture the peculiar nature of carbonate depositional systems: (1) carbonate sediments are largely of organic origin, (2) many of the organic components of the systems can build wave-resistant (wave-resilient) structures, and (3) the mineralogy undergoes extensive alteration (diagenesis) because many of the original minerals are metastable.

Of interest also are descriptions of the discovery, petrography, chemistry and metamorphic effects resulting from a Mesozoic igneous intrusion that extends from the north into Wilson County. However, most of the economic section of the report relates to oil and gas; other uses of the stratigraphic sequence are considered briefly. The treatment of each oil or gas field is separate and includes a history of discovery and a description of the producing zones. Data on many of the fields were never recorded and are now lost or incomplete; the descriptions are necessarily generalized. A few analyses of oil and gas are quoted, and the available statistics on production are given. Prior reports of this area by the author
include Wagner and Harris (1953), and Wagner (1954, 1961, 1964, 1972).

**Acknowledgments**

The writer wishes first to express his appreciation to Dr. Daniel F. Merriam who suggested in 1990 that I consider upgrading and recreating the doctoral dissertation written originally from field work done while at the University of Kansas, 1950-1955. I also thank Dr. John D. Hudson and Dr. M. Aftab Khan for acting as advisors and for many helpful suggestions for improvement of the dissertation and for encouragement in completion of writing and further research while at Leicester University during the summer periods of 1990, 1991, 1992, and 1995.

Secondly, I wish to acknowledge, posthumously, the help of W.L. and M.D. Stryker of Fredonia, Kansas who gave me their complete and unselfish cooperation in this study by contributing to many stimulating discussions of the geology and petroleum production of the Wilson County area and by making readily available to me their collection of well records and other pertinent information. The author also gratefully acknowledges the help provided by Wallace Lee, R. C. Moore, J. M. Jewett, W. W. Hambleton, E. D. Goebel, R. T. Runnels, Norman Plummer, W. H. Schoewe, Ada Swineford, and more recently by L. L. Brady and R. W. Knapp of the State Geological Survey of Kansas; and by C. W. Studt, of the Union Gas System who spent much time in fruitful discussion of diverse geological problems.
connected with the property boundaries, and economic products of the area. Special acknowledgment is also made of the help given by Albian Bailey of Neodesha and James Guinotte of Chanute for well locations and other data; by H.E. White, of the Kansas Well Log Bureau, for aid in the accumulation of logs of wells drilled in the area; by Carl Pate, of the Oilfield Research Laboratories, Chanute, for porosity and permeability data; and by Virgil Gamble of Altoona for oil gravity data. The cooperation of members of the Kansas Corporation Commission, Wichita, of the Cities Service Gas Company, Oklahoma City, and of the Sinclair Pipeline Company, Independence; the aid of many private companies and individuals who furnished additional oil-gravity data, water-flood data, pipe-line locations, and logs of wells drilled on their properties or leases is gratefully acknowledged. Permission to publish these data, as needed, is also much appreciated.

Assessment and other records in the County Court House, Fredonia, and unpublished maps, measured sections, and other data in the files of the State Geological Survey of Kansas were helpful on many occasions.

The field assistance in the summer of 1951 by L.D. Harris of the U.S. Geological Survey and in the summer of 1952 by John Bashor of the State Geological Survey of Kansas made possible the measurement by planetable and alidade of most of the longer stratigraphic sections. L. G. Henbest, D. A. Myers, and L. D. Harris of the U. S.
Geological Survey identified about one-third of the microfossils. Final drafting of illustrations was done by Helen T. Koelbl of the U.S. Geological Survey and the author.

Finally, I wish to acknowledge the unflagging encouragement and unswerving assistance provided by my wife, Leslie Charlotte Newton Wagner in typing and editing the manuscript. Without her devotion this dissertation would not have reached fruition.
CHAPTER TWO: GEOGRAPHY

Including a description of the history of naming, the physiography, the drainage, climate, vegetation, transportation and the industry of Wilson County.
Wilson County is named for Hiero Tennant Wilson, one of the first white settlers in southern Kansas. The county was one of the thirty-odd counties laid out by the "bogus" legislature of 1855; but, being entirely within the reserve of the Osage Indians, it was not subject to white occupation at that time. As defined in 1855, Wilson County extended 3.2 km (2 mi) more than eight townships north from the Oklahoma line and included all of present Montgomery County and the southernmost part of Woodson County. The legislature of 1867 removed the southern four townships from Wilson County and named it Montgomery County. The present boundaries of Wilson County were finally established in 1868, when the southern 3.2 km (2 mi) of Township 26 South were removed from the 1855 Wilson County and were placed in Woodson County (Andreas, 1883, p. 900; Gilmore, 1902, p. 818, 819).

Geographic Overview

Wilson County is in the Osage Plains section of the Central Lowland physiographic province of Kansas (Fig. 1), which lies in the Interior Plains physical division of the United States (Schoewe, 1949, p. 273, 276, and 280). Swanson (1989) places most of the county in the Cherokee Prairie major land resource area; the western one-third is
in the Cross Timbers land resource area (Swanson, 1989, p. 1.) The highest point, at about 400 m (1325 ft) altitude, is in the NE1/4 NE1/4 SE1/4 Sec. 18, T 28 S, R 14 E, about 0.8 km (0.5 mi) south of State Highway K96. The lowest point, at about 230 m (755 ft) altitude, is in the bed of the Verdigris River near its confluence with the Fall River at the south border of the county.

Physiographic Expression

The general surface configuration of Wilson County is dominated by a series of northeast-trending, east-facing escarpments separated by intervening gently undulating slopes. Each of these topographic units, termed cuestas, has two parts, an escarpment whose crest is topped by resistant limestone or sandstone, and a back slope underlain by less resistant shale. The base of the escarpment is generally underlain by shale also. The abundance of these physiographic features led Schoewe (1949, p. 282) to propose an Osage Cuestas subdivision of the Osage Plains section. This subdivision includes the eastern four-fifths of Wilson County (Fig. 1); the western one-fifth of the county is in the Chautauqua Hills subdivision of Adams (1899, p. 60, 61). The Chautauqua Hills are escarpment-faced low hills that are characteristically capped by sandstone upon which abundant blackjack oaks grow. Flat river valleys wander through and separate hills and escarpments. The general impression of
each physiographic subdivision is one of fairly low relief; the vertical difference between escarpment and valley seldom exceeds 61 m (200 ft). The escarpment fronts in both subdivisions are the result of differential erosion of low-dipping rocks of varying degrees of resistance.

The topography of the county can be divided into four fairly distinct groups of land forms: (a) the high uplands or prairies, which are the cuesta uplands or the dip slopes of resistant limestone layers; (b) the broken, hilly country that extends from the borders of the uplands to the valley floors; (c) the sandstone hills which are irregularly dissected and support a prominent oak tree growth; and (d) the creek and river valleys, including the alluvial floors and terrace remnants. Although the uplands are chiefly dip slopes formed on limestone and sandstone strata, the upland areas are covered in part by shale that overlies the scarp-making limestone.

East and south of the bolder sandstone or limestone escarpments are erosional remnants of sandstone or limestone that project above the general level of the soft shale units. West Mound and South Mound at Fredonia, Three Mounds and Five Mounds east of Altoona, and Buff Mound north of Neodesha are characteristic of such remnants.

An imaginary surface that connects the crests of the escarpments and mounds is very nearly a plane that dips
gently eastward. Although hilltops locally extend above it, this surface probably represents part of an old erosional plain that is now being dissected by the southeast-flowing Verdigris and Fall Rivers and their tributaries. Deposits of rounded chert that form indistinct gravel-strewn terraces at several levels along the cuesta surfaces attest to former drainages across the old erosional surface. The chert deposits are presumed to be related to episodes of glaciation to the north and northeast in Cenozoic time.

Drainage Systems

Nearly two-thirds of Wilson County is drained by the Verdigris River and its main tributaries, Ross Branch, Greathouse Creek, Sandy and Little Sandy Creeks, Buffalo Creek, Snake Creek, Little and Big Cedar Creeks, Chetopa Creek and Dry Creek. Approximately one-third of the county southwest of the Verdigris River drainage basin is drained by the Fall River and its tributaries, Willow Creek, Rainbow Creek, Salt Creek and Clear Creek. The remaining one-eighth of the county is drained to the southwest by the Elk River through its tributaries, Duck Creek and Sycamore Creek, and to the east by the Neosho River through Village Creek (Figures 2,3).

The Verdigris and Fall Rivers head about 80 km (50 mi) northwest of Wilson County in the Flint Hills Upland. Both rivers are nearly at grade in Wilson County, and
Figure 2. Index map of Wilson County showing the general positions of drainage divides and areal extents of the drainage basins of the Verdigris, Fall, Elk, and Neosho Rivers.
Figure 3. Physiographic diagram of Wilson County showing major drainage pattern and generalized subsurface geology (from Swanson, 1989).
their flood plains are well developed. The valleys are from 0.16 km (0.1 mi) to 4 km (2.5 mi) wide; they are narrowest where they cross outcrops of thick limestone units and widest where they cross shale terranes. The valley bottoms are almost level and contain remnants of former river channels now occupied by lakes. Wilson State Fishing Lake is the largest body of water in the county. Shafer Lake is located between Benedict and Coyville, and six unnamed lakes are on the Verdigris River flood plain; two unnamed lakes are on the Fall River flood plain.

Climate
Wilson County has a humid climate characterized by moderate precipitation, reasonably mild winters and fairly hot summers. Being located in the southeastern part of the state, the relative humidity is higher, the range between day and night temperatures is less, and the average annual precipitation is 25 to 38 cm (10 to 15 in) greater than in the central or western parts of the state. The winters are milder and the growing season is longer than is general in areas of Kansas to the west and north (Flora, 1948, p. 1,2). The average annual temperature at Fredonia is about 14°C (58°F); the average in winter is about 2°C (36°F); the average in summer is 26°C (78°F). The normal monthly temperature ranges from a degree or two above freezing in January to about 27° (80° F) in July.
The highest temperature recorded was about 49°C (121°F) recorded on July 18, 1936; the lowest temperature recorded was about -32°C (-26°F) on February 13, 1905 (Swanson, 1989, p. 2). The last killing frost of the year is generally in mid-April and the first is in mid-October, giving an average frost-free growing season of about 185 days.

The average annual precipitation at Fredonia, based on a 90-year record, is 89 cm (35 in), but it has ranged from a maximum of 140 cm (55 in) in 1915 to a minimum of 46 cm (18 in) in 1956. The maximum precipitation generally occurs between June and August and the lowest between December and February. Much of the precipitation in Wilson County falls in relatively brief, heavy thunderstorms. The greatest rainfall recorded at Fredonia in a 24-hour period was 18 cm (7 in) on July 3, 1976 (Swanson, 1989, p. 2). The average seasonal snowfall is 33 cm (13 in); the highest recorded seasonal snowfall was 112 cm (44 in) (Swanson, 1989, p. 2).

Vegetation and Farm Products

Native vegetation in most of Wilson County is characteristic of the Osage Plains section of the Central Lowland. The large amount of rainfall, combined with fairly high temperatures during the summer months, produces an environment well suited to the natural growth of prairie grass, weeds, shrubs and several varieties of
hardwood trees. Grasses and weeds include rice cutgrass, yellow nutgrass, rush, waterhemp, smartweed, pigweed, morning-glory, beggartick, velvetweed, ragweed, lambs-quarter, carpetweed, knotweed and buffalo burr. The most abundant shrubs are sumac and buttonbush. Trees along the streams include blackjack oak, hickory, walnut, hackberry elm, soft maple, pecan, sycamore, ash, cherry, basswood, and some cedar and cottonwood. The sandstone of the Chautauqua Hills section in the western part of the county supports good stands of post oak and black oak with scattered blackjack oak, chinquapin oak, hickory, black walnut and black cherry (Hale, 1955).

Soil properties, their uses, and locations are given in detail by Swanson who states (1989, p. 33) that about 244,633 acres (990 km², 380 mi²) or only about 66% of the total acreage 350,058 meet the soil requirements for prime farmland. About 176,000 acres (712 km²) are used for crops, mainly wheat (57,000 acres; 231 km²), soybeans (41,000 acres; 166 km²), grain sorghum (37,000 acres; 150 km²), and corn (7,000 acres; 28 km²), totaling 142,000 acres (595 km²). The remainder, which is hay and alfalfa (12,000 acres; 49 km²) and oats, barley, rye and high grade pasturage (22,000 acres; 89 km²), totals 34,000 acres (138 km²). An additional 68,000 acres (239 km²) are devoted to fruit trees such as apples, peaches, pears and cherries (about 2,000 acres; 8 km²); to cattle and milk cows (about 54,000 acres, 182 km²); and to chickens and
turkey farming (about 12,000 acres; 49 km²), giving a
grand total of more than 244,500 acres (990 km²).

Population, Transportation, and Industry

The first white settlers in Wilson County were H. H.
Opdike and G. J. and W. M. Caven, who settled near
Coyville in 1857. Probably more than 100 settlers had
located in the county by 1860, even though the area was
not removed from the Osage Indian Reservation or offered
for sale until 1866. United States Census records for the
county show 27 persons in 1860, 6,494 in 1870, and 13,776
in 1880. By 1880 the population was comparable to that of
the present time. County records show the population for
the 5-year period 1954 to 1958, inclusive, to be 14,643,
14,818, 14,388 14,236 and 14,098 (average 14,457). In
1981, the population was only 12,128 (Swanson, 1989,
p. 1).

Fredonia and Neodesha, the largest towns in the
county, had populations in 1958 of 3,373 and 3,595,
respectively; in 1981 their populations were 3,047 and
3,414 (Swanson, 1989, p. 1). Fredonia, the county seat,
is centrally located in relation to the productive farming
regions of the county and serves as the milling and
storage hub. It is also the site of a large cement plant
and brick plant. Neodesha is in the middle of the largest
oil and gas field of the county and has the second largest
refinery in southeastern Kansas. It also has a large
crushed rock quarry. All other towns in the county had populations of less than 600 people in 1958; Altoona had 516, Buffalo had 389, Coyville had 144, New Albany had 126, Benedict had 121, and LaFontaine, Vilas, Buxton and Roper were not reported separately. About 40 percent of the population of the county is rural.

Three major rail lines cross Wilson County. Buxton, Fredonia, Benedict, and Vilas are all serviced by the Atchison, Topeka and Santa Fe through line; New Albany, Fredonia, and Neodesha are on the Burlington Northern through line; and Neodesha, Altoona, Benedict, Roper and Buffalo are all on a through line of the Union Pacific. Fredonia, thus, is at the intersection of the Atchison Topeka and Santa Fe and the Burlington Northern lines.

Wilson County has more than 160 km (100 mi) of surfaced Federal and State highways. Fredonia, Neodesha, Altoona and Buffalo are each serviced by at least two Federal or State highways (Figures 2, 3, Plate 1). U.S. Highway 75 crosses the eastern half of the county from north to south and links Buffalo, Altoona, and Neodesha. State Highway 96 enters the county from the west, essentially connects Fredonia and Neodesha, and leaves the county at the south; State Highway 39 enters the county from the east, connects Roper, Benedict, Fredonia and LaFontaine, and leaves the county at the south; State Highway 47 enters the county from the east, passes through Altoona, and terminates at Fredonia; and State Highway 37
enters the county at the southeastern corner and terminates at Neodesha. In addition, many kilometers of surfaced and well-graded county roads as well as a fairly complete network of maintained section-line roads make nearly all points in the county readily accessible by car throughout the year.

The mineral resources produced in Wilson County were reported by Schoewe (1959a, p.250) to be $6,430,262 in 1958. Commodities, in order of decreasing value were cement, clay, oil and gas, and stone products; however, only the value of raw clay rather than that of the finished product, is included in this figure. Roughly, 75 percent of the total mineral value was in cement manufacture, slightly more than 15 percent was in oil and gas and stone products, and about 10 percent was in clay. In 1958, Wilson County had one cement plant, two brick plants, two rock products companies, and 339 oil properties; the refinery at Neodesha had a crude oil capacity of 23,100 barrels per calendar day.
CHAPTER THREE: GEOLOGY

Concerning the unconsolidated sediments of the Cenozoic Era, the igneous rocks of the Mesozoic Era, the sedimentary rocks of the Paleozoic Era, and the igneous and metamorphic rocks of the Proterozoic Era in Wilson County.
Geologic Overview

Rocks that crop out in Wilson County are of Cenozoic, Mesozoic, and Paleozoic age; those penetrated in the subsurface are of Mesozoic, Paleozoic, and Precambrian age. The total thickness of the sedimentary sequence is about 945 m (300 ft) (Plates 1 and 8); the thickness of igneous sill material averages about 50 m (165 ft).

Unconsolidated sediments of Quaternary and Tertiary age that overlie Cretaceous igneous rocks and Pennsylvanian strata consist of alluvium and chert gravels in stream valleys. Similar chert gravel deposits also occur at higher flood-plain levels and as several terrace remnants above the major streams. These gravel deposits rest mainly upon strata of the Pennsylvanian System which consist mainly of an alternating sequence of limestone, shale, and sandstone units that total about 500 m (1650 ft) in thickness. Sill-like lamproite bodies of Cretaceous age and as much as 50 m (165 ft) in total thickness intrude the Pennsylvanian sedimentary sequence in a few places. The Mississippian System is represented by about 130 m (420 ft) of cherty to noncherty dolomitic to nondolomitic limestone strata that overlie a relatively thin, black shale of Mississippian and probable Devonian age about 5 m (15 ft) in thickness, and a basal sandstone bed that is locally 2 m (6 ft) thick. Ordovician and Cambrian rocks are dominantly dolomite to a thickness of
about 275 m (900 ft). The recorded Precambrian rocks are mainly granite.

Previous Investigations

The general stratigraphy and structure of Wilson County have been known for many years, but none of the published reports on the entire county contains detailed descriptions of stratigraphy or structure, and only general statements have been made concerning the oil and gas fields and their development.

The first published report on the stratigraphic units of Wilson County is based upon a geologic reconnaissance of the Verdigris River by Haworth and Platt (1894), who traversed the county from southeast to northwest and noted the relative prominence of limestone and the presence of sandstone near the towns of Altoona and Benedict. The earliest map showing limestone outcrops was prepared by Haworth (1895a, map in rear; 1895b, p. 453; 1896b, end of report), but the map at a scale of about 10km per cm (16 mi per inch) shows only one prominent outcrop, that of the Stanton and Plattsburg Limestones\(^1\) [the Iola Limestone of Haworth], across the center of the county. Haworth (1898a, p. 106) published a more refined map of the outcrop pattern of essentially the same stratigraphic unit and included also the Drum [Erie] Limestone which crosses

\(^1\) Where terminology used in the old report differs from current terminology, or where miscorrelations were made, the correct term is used in context and the term used in the original report is in brackets.
the southeastern corner of the county. Adams (1899, p. 58) in a report to the Kansas Academy of Science in 1897, presented a physiographic map of southeastern Kansas which shows the escarpments of the Oread [Burlington] Limestone at the northwestern corner of the county, the Drum [Independence] Limestone at the southeastern corner, and that of the Stanton and Plattsburg [Iola] Limestones crossing the middle of the county in a northeasterly direction and branching into two escarpments north of Altoona. A more detailed map by Adams (Adams, Girty, and White, 1903, p. 28) shows three limestone units, the Stanton [Iola], Plattsburg [Earlton] and Drum. Adams correctly related the Stanton and Plattsburg Limestones to the intervening Vilas Shale in his statement (Adams, Girty, and White, 1903, p. 39). "These shales [Vilas] occupy the interval between the Earlton limestone and Iola limestone..." but he did not realize that the Vilas shale thins rapidly in northeastern Wilson County, and that he had overlooked it in that area. The error was corrected during the mapping of the Iola quadrangle (Adams, Haworth, and Crane, 1904, pl. 1), and the next published map covering Wilson County (Schrader and Haworth, 1906, pl. 2) shows the general positions of the Oread [Painterhood], Stanton [Piqua], Plattsburg [Allen], Iola, and Drum Limestones at a scale of 4 km per cm (6 mi per in). The geology and oil and gas wells in the southern third of Wilson County are shown on a map at a scale of about
1.3 km per cm (2 mi per in) from this same report (Schrader and Haworth, 1906, pl. 1). The report discusses the oil and gas industry of the area and also contains the first moderately detailed published description of the outcropping rocks (Schrader and Haworth, 1906, p. 11-16, 19-48). The results of this investigation also form a geologic folio report of the Independence quadrangle (Schrader, 1908). The next geologic map of Wilson County appeared in the comprehensive publication on oil and gas in Kansas by Haworth (1908, pl. 19). Most of the errors of previous reports are corrected on this map, additional units are shown, and much of the stratigraphic terminology presently in use is applied.

A second comprehensive report on the oil and gas resources of Kansas (Moore and Haynes, 1917) established, in many respects, an excellent pattern for later reports. Chief among its advantages are a concise but thorough treatment of the stratigraphy, and a county by county general discussion of geology, drilling and production. The report includes geologic maps on which are shown the locations of oil and gas wells. The map of Wilson County (Moore and Haynes, 1917, pl. 39) contains a few modifications in stratigraphic nomenclature, but the geologic boundaries are less accurate and more generalized than on the earlier map by Haworth (1908, pl. 19). In about 1919, a program was initiated by the State Geological Survey of Kansas to prepare detailed reports on
the oil and gas resources of the most important petroleum producing counties of southeastern Kansas. The second in the series, that on Wilson and Montgomery Counties (Moore and Boughton, 1921), includes general descriptions of the geography and geology of each county, a chapter on the history of oil development, a map showing oil and gas wells drilled in each county, and brief historical descriptions of the oil and gas fields.

The first published report dealing primarily with the subsurface geology of Wilson County was by W.L. Stryker (1925) whose observations concerning the relation of Pennsylvanian sand accumulation to Mississippian topographic highs and structures are verified in the present study. Stryker (1925 p. 1209) pointed out that (a) the erosion surface on the top of rocks of Mississippian age has considerable relief, (b) this relief exercised an influence on the deposition of sand lenses in the Cherokee Group and may be responsible for some of the structures in the subsurface and (c) many of the sand lenses lie on the southwestern flank of the irregularities on the Mississippian surface. Two soil surveys of Wilson County by the U.S. Department of Agriculture (Kerr, Whetzel, and Higbee, 1927; Swanson, 1989) contain descriptions of 6 soil associations, 8 soil classes, 23 soil types and 35 soil units and their utilization. Included are comprehensive maps which show that the soil
types and units reflect to a considerable degree the character and distribution of the underlying rocks.

Much of the geology of Wilson County and adjacent areas was carefully studied in the early 1930s by N.D. Newell in conjunction with compilation of the Geologic Map of the State of Kansas published in 1937. In connection with his doctoral dissertation concerning the upper part of the Missourian Series in eastern Kansas, Newell (1933) measured many stratigraphic sections of limestone units that crop out in Wilson County. His interpretations of the faunal variations in strata of this series provided data of considerable value in reconstructing depositional environments and the geologic history of Wilson County and the surrounding area. Other reports concerned with stratigraphic units in Wilson County contain the results of studies of formations in the Lansing Group by Chelikowsky and Burgat (1947), Davis (written communication, 1955; 1959), Wilson (1957), Eastwood (1958), Harbaugh (1959, 1960, 1962, 1965), and Heckel (1969, 1972, 1975, 1977, 1978, 1979, 1984, 1985, 1986, 1988, 1991). The most recent detailed maps of Wilson County were made by the author (Wagner, 1954, 1961, 1962, 1967, 1991). The results of those studies as well as results of a ground magnetometer survey by Hambleton and Merriam (1955) are incorporated in the present report. The chert gravel deposits in southeastern Wilson County were described in part by Davis in 1957.
Methods of Investigation

My field mapping in Wilson County was begun in July 1950 and completed in September 1953, except for short periods in 1991 and 1994. Most of the longer stratigraphic sections were measured with a plane table and alidade; others were measured with a hand level and steel tape. The county network of paved and unpaved roads were traversed by car or on foot; most streams and rivers were walked. Collection of drillers logs and dry-hole maps was begun in November 1950 and continued throughout 1955. Electric and other more sophisticated logs were obtained through the generosity of the State Geological Survey of Kansas between 1991 and 1994. Drillers logs were plotted graphically at a scale of 12 m per cm (100 ft per in); all well locations were plotted on topographic base maps at scales of 1:24,000 and 1:48,000; where necessary, elevations were interpolated from contour intervals of about 6 m (20 ft) vertical separation. Correlations between wells were based on key limestone beds; cross sections, structural maps and lithofacies maps of selected areas were prepared as needed.

Formation contacts, coal outcrops and prospects, and other geologic data as well as the locations of many of the productive and non-productive test-wells were plotted in the field on aerial photographs at a scale of 1:20,000. These observations were later transferred from the photographs to the contour and planimetric base maps using
an automatically focusing vertical projector. The 1955 base map was compiled from the Altoona and Fredonia topographic quadrangles, scale 1:62,500 of the U.S. Geological Survey, and from county maps obtained from files of the State Geological Survey of Kansas and the County Engineer of Wilson County. The present base map was compiled by the State Geological Survey of Kansas base map unit by using 7 1/2 minute quadrangle maps of the U.S. Geological Survey with dates between 1963 and 1984 at a scale of 1:24,000.

Except for those in published reports and unpublished theses or dissertations, most of the megafossil identifications were made by the author in the field. A few were made in the office in consultation with paleontologists of the State Geological Survey and the Department of Geology, University of Kansas. The microfossils were identified by the author and by members of the U.S. Geological Survey and the Kansas Geological Survey.

Following local usage, the term shale is used for fine-grained, fissile, clastic rocks that break into thin, flattish plates upon weathering. The term is restricted to rocks consisting entirely of clay-size material, unless a size modifier is added. Rocks of comparable grain size that break into cuboidal fragments upon weathering are classed as claystone or siltstone, depending upon the
dominant grain size. Color adjectives used in the report are from the Rock Color Chart (Goddard and others, 1948).

SECTION 3A: THE CENOZOIC ERA

Quaternary and Tertiary Systems

Strata of the Quaternary and Tertiary systems were deposited during times of climatic unrest in the Midcontinent region and elsewhere in the world. Relatively unconsolidated deposits indicate that the effects of only a small portion of this climatic activity is recorded in the sediments of the Pleistocene and Pliocene Series in Wilson County. At least ten major glacial advances and retreats and 40 minor fluctuations are recorded throughout the world in this time frame (Elsom, 1992, p. 98). During times of glacial transgression the ice stayed an average of 80,000 to 100,000 years; interglacial periods (times of glacial retreat and of transgression by the sea) generally lasted only 10,000-20,000 years. The last glacial event arrived suddenly, world temperatures fell about 2-10° C (5-14° F), polar ice spread, more than one-third of the land area lay under a blanket of ice 2.1 km (7,000 ft) thick, ocean level dropped about 60-120 m (200-400 ft), and the coastline moved 160 km (100 mi) or more seaward. The last glacial advance ended about 10,000 years ago (Elsom, 1992, p. 98). Among the first scientists to advance theories to account for these periodic climatic changes were
James Croll (1864) and Milutin Milankovitch (1920, 1941). Their theories which utilize such orbital parameters as obliquity, eccentricity, and precession will be discussed later.

King (1975, p. 272, 273) provided carbon 14 and other data that indicated several advances and retreats of sea level during Quaternary time. Based upon evidence from pollen sequences, molluscan faunal changes, bog development, and basic glacial fluctuations, one can envision a eustatic regression of the sea about 2,150 years before present (B.P.), that correlates with a climatic deterioration between 2,000 and 2,200 yrs B.P., and a climatic amelioration prior to that. King also reported that a large transgression, which occurred about 8,800-9,300 yrs B.P., was probably related to an earlier abrupt climatic amelioration that took place 8,600-9,000 years B. P. She realized that glacial advances generally indicate greater ice accumulation accompanied by eustatic lowering of sea-level; glacial melting results in ice retreat which provides much water to the sea and results, therefore, in a eustatic rise of sea-level. By using dating methods involving measurements of Thorium$^{230}$/Uranium$^{233}$ and Uranium$^{234}$/Uranium$^{238}$ ratios, King was able to show that combinations of eustatic and isostatic changes, variously recorded as sea level advances at 90,000±20,000 to 160,000±40,000 yrs B.P and 80,000±50,000 to 180,000±60,000 yrs B.P, actually
reflected periods of decline in glaciation (King, 1975, p. 273). Watney and others (1989, p. 89) lend credence to King's belief by stating that glacial eustasy is strongly supported as the cause of the relatively short-term (possibly 250 to 400 yr) but high amplitude (perhaps 90± m; 300± ft) fluctuations in sea level. Evidence for eustatic change includes the ability to correlate individual marine inundations among basins and continents (Ross and Ross, 1987; Boardman and Heckel, 1989a). These late Pleistocene glacial advances and retreats produced high-frequency sea-level changes with magnitudes on the order of 100-150 m (330-500 ft), with periodicities of around 100,000 yrs, and with rates of sea-level change at about 10 m (33 ft) per ten thousand yrs (Donovan and Jones, 1979).

Recent Stage (Pleistocene Series)

The youngest sedimentary unit in Wilson County is alluvial material that fills valleys cut into the Pennsylvanian strata. These sediments fall mainly into the realm of alluvium, a category that the U.S. Geological Survey has placed in the Recent Series (Wilmarth, 1938, p. 1781); the Kansas Geological Survey places these sediments in the Recent Stage of the Pleistocene Series (Zeller, 1968, p. 60, 63).

Stream Valley Alluvium. Thick deposits of alluvium of Recent age occur in the major stream valleys of Wilson County and constitute the most important fresh-
water-bearing formation in the county. Thin alluvial deposits occur locally in nearly all stream beds of the county, but only the important occurrences in the valleys of the larger streams were mapped. Water-well drilling shows that the thicker alluvial deposits extend to depths as great as 15 m (50 ft) below flood plain level (Fig. 3) and consist of poorly sorted gravel, sand, silt, and clay. Local sorting, characteristic of most flood-plain deposits, was noted in many low-lying areas in the county, and sand, silt, or clay are found laterally at the same stratigraphic position. The alluvial material is generally clay and silt in the upper part and grades downward through sandy silt to gravelly sand. Cobbles about 5 to 13 cm (2 to 5 inches) in diameter occur in a few places in the gravelly sand near the base of the alluvium. Local concentrations of chert pebbles amid these cobbles suggest reworked material from older chert gravel deposits of Pleistocene and Pliocene age.

**Pleistocene and Pliocene Series**

Sedimentary deposits of early to middle Pleistocene and late Pliocene age occur as terrace deposits at several levels along hill slopes and as cappings of hilltops above major drainage systems such as the Verdigris and Fall Rivers in Wilson County. The origin of these deposits is presumably related to increased fluvial activity following the growth of glaciers and ice caps in the
northern United States. The largest of these ice sheets reached into Kansas within 145 km (90 mi) of Wilson County (Frye and Leonard, 1952, p. 194); the present drainage systems that now enter the county were probably within 80 km (50 mi) of the ice front at the beginning of, or even before, Pleistocene time. Moore (1958, p. 522-23) stated that C14 dating indicated that the Wisconsinan (late Pleistocene) glaciation occurred within the last 30,000 years, and that the Pleistocene Epoch embraces at least 300,000 years; an estimate that Pleistocene time amounted to one million years may not be too great. Elsom (1992, p. 15) puts the beginning of Pleistocene time at two million years. Pliocene glaciations would add an additional two to five million years to the latest ice age.

Chert gravel deposits. Remnants of chert gravel accumulations that occur about 5 to 80 m (15-260 ft) above the present flood plains of the Verdigris, Fall, and Neosho Rivers are preserved in Wilson County. These remnants fall into four general groups lying 5 to 12 m (15-40 ft) above flood-plain level, 15 to 37 m (50-120 ft) above, 49 to 64 m (160-210 ft) above, and 79 m (260 ft) or more above. The deposits of chert gravel, shown on the geologic map (Plate 1), were located during detailed mapping of rocks of Pennsylvanian age and are believed to be representative of the influence and distribution of Quaternary and Tertiary ice-age deposits. One must keep
in mind, however, that (1) the chert gravel remnants may represent merely the thicker or more concentrated gravel accumulations of former streams and not former drainage systems as a whole, (2) the local variations in depth of erosion and in thickness of gravel deposits filling the channels must have affected their chances of preservation, and (3) that many of the evidences of these erosional and depositional activities are not immediately available for interpretation inasmuch as the bottoms of the deposits are rarely exposed, and the upper parts have been partially removed by erosion.

The origin of these gravel deposits in Kansas has been the subject of speculation since E. P. West (1885) attributed them to a marine invasion of Kansas in post-Permian time. He postulated that the pebbles were rounded, distributed, and concentrated by wave and current action in a vast arm of an epicontinental sea. He believed that stream action could not account for the very wide distribution of the deposits. In 1896 Haworth advanced the theory that the pebbles were residual products concentrated along the lines of outcrop of practically every chert-bearing limestone bed in the Carboniferous sequence as the less resistant materials were removed. He believed that the rounding of pebbles and the large size of some deposits were due to a certain amount of downslope movement, transportation by streams, and abrasion by winds (Haworth, 1896a, p. 254, 255).
Wooster (1915, p. 58) believed that the chert gravels were the resistant debris left behind in an 80- to 97-km (50- to 60-mi) wide north-south belt as a result of the continual lowering of a vast peneplain surface in eastern Kansas since the close of the Paleozoic Era. Concomitant with the lowering of the surface was a shifting of the outcrops of cherty Lower Permian limestones 80 km (50 mi) westward to their present outcrops in the Flint Hills. More recently, authors have suggested that the chert gravels are remnants of former streams that flowed eastward and southward from an ancestral Flint Hills (Todd, 1918, p. 37; Moore and others, 1951, p. 17; Frye and Leonard, 1952, p. 184, and O'Connor, 1953, p. 7; Frye, 1955, p. 83; Seevers and Jungman, 1963, p. 394; and Aber, 1992, p. 115).

The youngest group of chert gravel terrace deposits in Wilson County lies approximately 5-12 m (15-40 ft) above the present flood plains of the Verdigris and Fall Rivers (Figure 4). These deposits occur only near the present courses of the rivers and seemingly are related to a former base level of the drainage system. The distribution of the deposits indicates that the earlier stream valleys were probably broader than the present ones, and that the direction of flow perpendicular to the strike of the strata was already well established (see Frye and Leonard, 1952, Figs. 12-15, p. 194, 195).
Figure 4. Reconstruction of Quaternary and late Tertiary drainage systems in Wilson County as interpreted from chert gravel deposits.
Deposits of the 5-12 m (15-40 ft) group are generally less than 1.5 m (5 ft) thick, but locally they are as much as 5 m (15 ft) in thickness. They consist of abundant subangular grayish-orange chert pebbles in a light-brown matrix of clay and silt. Some chert pebbles contain fusulinids and brachiopods. Subrounded to rounded pebbles of sandstone of local origin, as much as 12 cm (0.4 ft) in diameter, occur with the chert pebbles that range in size from 0.6 to 5 cm (.02-.17 ft) and average 1.2 to 1.8 cm (.04-.06 ft). The sandstone pebbles are light brown and very fine grained. Grains of fine- to medium-grained quartz sand are scattered throughout the matrix and locally form cemented pods. Although generally abundant, the chert pebbles in some places occur only in thin lenses 2.4-12 cm (.08-.4 ft) thick, or are widely scattered through the deposit which then consists of a light-brown, pebbly, clayey sandy siltstone. The deposits of the 5 to 12 m (15-40 ft) sequence are tentatively assigned to the Illinoian Stage of the Pleistocene Epoch based on their topographic position relative to the present flood plain, on their position relative to other chert gravel deposits, and on the greater percentage of pebbles of local derivation in these deposits as compared to those at higher levels.

A somewhat higher sequence of chert gravel deposits, which locally cuts downward into the 5 to 12 m (15-40 ft) group, lies 15 to 37 m (50-120 ft) above the flood plains.
of the Verdigris and Fall Rivers. The remnants of this sequence comprise the thickest and economically most important deposits in the county and occur only within the present drainage basins of the Verdigris and Fall Rivers except in the northeastern corner of the county where a small group of deposits lies northeast of and 12 m (40 ft or more) below the drainage divide between the Verdigris and Neosho Rivers. This relation to the present topography precludes a past connection with the Verdigris River and indicates that the group must have accumulated in a meander of an ancient drainage system of the Neosho River. The deposits are 1 to 6 m (3-20 ft) thick and are lithologically similar to the lower chert gravels except that they contain very little locally derived material. The chert pebbles are fairly well polished and subangular to subround. These deposits are believed to be Nebraskan in age.

It seems probable that the drainage system represented by these deposits was established early in Pleistocene time, and that the altitudes of the divide areas have since then confined all later drainage to essentially the same paths as those followed by the present rivers. The downward cutting through more than 33 m (100 ft) of strata in a terrain made up of resistant limestone and sandstone units and at the presumed low stream gradient of about 60 cm per km (4 ft per mi) would conceivably have taken many thousands of years. Later
alluviation and development of a fossil soil zone in the deposits, as reported by Davis (1957, p. 249, 250), would have taken additional time. This fossil soil zone, developed on deposits that comprise his 18 to 24 m (60-80 ft) terrace in Montgomery and Wilson counties, is compared by Davis (1957, p. 250) to a similar soil zone in the Emporia terrace in Lyon County. That specific terrace has been dated as Kansan in age on the basis of identification of teeth and other vertebrate remains as well as on the presence of a 1 to 1.3 m (3-4 ft) lentil of Pearlette volcanic ash (O'Connor, 1953, p. 7). If Davis' statement (1957, p. 250): "The soil color, texture, and composition are similar in both deposits and seem to be a valid basis for correlation" is warranted, the terrace deposit 20 to 25 m (60-80 ft) above flood plain in Montgomery and Wilson counties is also Kansan in age. Where thickest, however, part of the gravel in the 15 to 37 m (50-120 ft) terrace deposits in Wilson County may include gravel left behind during an earlier stage, the Nebraskan Stage of the Pleistocene Epoch (Figure 5).

The chert-gravel deposits that lie 49 to 64 m (160-210 ft) and 79 m (260 ft) or more above the present flood plains of the Verdigris and Fall Rivers are believed to correlate with similarly situated deposits in Elk County which are judged to be Nebraskan or Late Tertiary in age (Frye and Leonard, 1952, p. 61). They are similar in lithology to the lower deposits, except that they lack
Figure 5. Chert gravel deposit lying about 20 m (60 ft) above the flood plain of the Verdigris River near the center of sec. 19, T 28 S, R 15 E. (A) View of pit face; about 2 m (6 ft) exposed. (B) Closeup of same face showing chert and locally derived sandstone pebbles.
locally derived material. The deposits between 49 and 64 m (160 and 210 ft) above flood plain are as much as 1.5 m (5 ft) thick and consist of subround to subangular, grayish-orange chert pebbles in a matrix of light-brown clay or silt in which are scattered many fine- to medium-size sand grains. These deposits generally lie upon the upper surface of the resistant Stanton Limestone that forms the major cuesta across the center of Wilson County, and their areal pattern bears little if any relationship to the present drainage system. The positions of the gravel on the tops of the hills and their general northsouth trend in the central and eastern parts of the county suggest that the ancient river that transported them followed a meandering path along a strike valley between the resistant limestone beds of the Stanton Limestone of the Lansing Group and the thick sandstone beds of the Douglas Group. The small deposit in the northeastern part of T 28 S, R 16 E, and several deposits in the southern part of T 26 S, R 17 E in the southeastern corner of Woodson County, less than 1.6 km (1.0 mi) north of the Woodson County line (Wagner, 1961), suggest the presence at that time of a parallel drainage system in what is now the Neosho River Valley.

Jamkhindikar (1967), in an ancillary study of Pleistocene gravel deposits, chose two deposits along the Neosho River Valley about 16 km (10 mi) southeast of the
corner of Wilson County for examination. These deposits were studied to determine the clay mineralogy, sedimentary parameters, and heavy mineral content of the gravels. The upper deposit was believed to be a terrace deposit of Nebraskan age; the lower deposit represented a flood-plain deposit of Wisconsinan age. Both deposits had chert gravels of varying abundance laterally; vertically, the gravels were generally concentrated in the lower parts. The clay minerals, determined by X-ray diffraction intensity (D.I.) patterns, were montmorillonite, illite, kaolinite, and a 14 Angstrom mixed-layer clay mineral. Montmorillonite was the most abundant clay mineral in both deposits; the flood plain deposit showed a greater abundance of illite than was present in the alluvial terrace deposit; but the terrace deposit had a greater abundance of kaolinite than the flood-plain deposit. Differential thermal analysis (D.T.A.) values showed that montmorillonite was dominant in the (Nebraskan) alluvial terrace deposit, and that illite and kaolinite were variable; in the (Wisconsinan) flood-plain deposit, the order of relative diffraction intensity and the order of abundance were (1) montmorillonite, (2) illite, and (3) kaolinite. Results of a grain-size analysis showed that silt and clay constituted 86 percent of the flood-plain deposit and 84 percent of the alluvial terrace deposit. Sand made up the remainder except for one alluvial terrace sample at 5.5 to 6.1 m (18-20 ft) depth which contained
11 percent gravel. In the flood plain deposit, sand made up 14 percent of the total except in 2 samples that contained about 3 percent gravel each. Heavy mineral analysis showed the presence of zircon, tourmaline, and staurolite in all samples, garnet in all except one sample, topaz in all except two samples, magnetite in all except three samples, epidote in one-half the samples, and kyanite was found in only two samples. Practically all heavy minerals of the flood-plain deposit are present in the alluvial terrace deposit except epidote and kyanite, which are either rare or absent from the terrace deposit (Jainkhindikar, 1967, p. 4-11).

The group of chert gravel deposits that lies on the Oread Limestone near the western edge of Wilson County at the same relative position above flood plain as the deposits along the Neosho River at the eastern edge of the county, suggests that other northeast-trending drainage systems shown by Frye and Leonard (1952, p. 194) were operative concurrently. The oldest chert gravels in Wilson County are only 5.6 to 10 cm (.17-.33 ft) thick and about 80 m (260 ft) above flood plain; they lie above the Verdigris and Fall Rivers at an altitude of 339 m (1,080 ft) in sec. 10, T 29 S, R 15 E. Inasmuch as no fossils have been found in the matrix of the upper chert gravels, an age assignment must be based upon other evidence. The pebbles of the higher gravels in eastern Kansas, with which these gravels are believed to correlate, consist
only of chert of types that are characteristic of the Herington and stratigraphically lower Permian limestones (Frye and Leonard, 1952, p. 184) and must either have been transported eastward 80 to 129 km (50-80 mi) or have been subjected to lowering by erosion while 46 to 61 m (150-200 ft) of underlying strata were removed.

In a study of high-level stream-terrace chert-gravel deposits of east central Kansas, Law (1986, p. 24) concluded that the upland chert gravels are remnants of an immense east-trending preglacial river system that was termed the "Old Osage River." He believed that the chert pebbles and cobbles were rounded during eastward transport of approximately 130 km (80 mi) from the Flint Hills of Kansas during flood stages. Stream piracy during headward erosion by the Verdigris and Neosho rivers funneled gravels southeastward to the Wilson County area in late Tertiary to early Pleistocene time. The presence of quartzite pebbles scattered throughout the gravels suggests that the "Old Osage River" had access to the Equus Beds and/or the Pliocene Delmore Formation even farther to the west (Law, 1986, p. 22). Frye and Leonard (1952, p. 60) point out that the chert pebbles in the gravel deposits characteristically have well-rounded corners, and that the sand grains in the reddish clay matrix are well rounded, implying transportation over a considerable distance or abrasion for a long period of time. Further evidence of their antiquity is provided by
the red clay matrix which fills the interstices of the gravels and by the absence of limestone pebbles. This combination of evidence demonstrates that the gravels have been subjected to prolonged weathering. In most exposures examined, the red clay matrix persists through the entire thickness of gravel (Frye and Leonard, 1952, p. 60).

The relationship of the higher chert gravels in several eastern Kansas counties to the topography and to the outcrop area of the Herington and lower limestones in the Flint Hills region of Kansas is well stated by O'Connor who observed (1953, p. 7) that “the high-level chert gravels near their source beds in the Flint Hills occur in high relative positions of topography, but considerably lower than the highest elements of topography. As they are traced eastward, their position in lower topography becomes higher and higher. Easternmost chert gravel deposits in Anderson County, Kansas, occur on the highest topographic position of the area.” The Anderson County gravels occur about 19 km (12 mi) northeast of those lying 49 m (160 ft) or more above flood plain in Wilson County. The latter are atop the highest topographic prominences in the central and western parts of the county. Because of their topographic position, the highest chert gravels in Wilson County seem certainly to be related to similarly situated deposits in Allen, Anderson, Coffey, and Greenwood counties.
As noted by Frye (1955, p. 83, 84) the probability of a Tertiary age assignment for these higher chert gravels in Eastern Kansas on the basis of topographic position can be fixed only by the sequence of younger terraces. The low Wiggam terrace is tentatively assigned an Illinoian age and the extensive Emporia terrace is securely dated as Kansan in age by its contained Pearlette volcanic ash, vertebrate fossils, and sequence of buried soils and loesses on the surface. Reconnaissance of the east-central Kansas region indicates that the three terrace levels at approximately 23 m (75 ft), 29 m (95 ft), and 47 m (150 ft) above adjacent flood plains have persistence well beyond Chase and Lyon counties, and that a fourth level at 76 to 91 m (250-300 ft) above adjacent flood plains is to be correlated with the gravels of the highest divides farther west. From these data, Frye reasoned (1955, p. 84) that there are two or perhaps three cycles of Tertiary erosion and alluviation, and since the bedrock involved is all Pennsylvanian and Permian in age, he believed that it was permissable to contrast 12 m (40 ft) of post-Kansan bedrock incision against approximately 76 m (250 ft) of pre-Kansan post-highest chert gravel bedrock incision. He concluded that the erosional history of the present topography probably started early during the Tertiary (or earlier) and records three and perhaps four cycles of erosion and alluviation during Tertiary time as well as three and perhaps four
during Pleistocene time. Thus, although the upper gravels in Wilson County lack fossils, a probable Tertiary age is suggested by the roundness of the pebbles and sand grains, their deeply weathered matrix, and their topographic position.

This discussion of the chert gravel deposits and alluvial materials in Wilson County requires speculation not only on the source of the gravels, but also on their origin. The former existence of continental glaciation in the Alpine area of Europe was proposed in 1837 by the Swiss geologist Louis Agassiz in a paper read before the Helvetic Society. Inspired by statements describing glacially striated boulders in northeastern America [published by Benjamin Silliman in 1821, Peter Dobson in 1826, Timothy Conrad in 1839, and Edward Hitchcock in 1841], Agassiz traveled to North America in 1846 in order to verify the presence of the glaciated boulders and to debate their significance. Following his visit and subsequent mapping of the deposits, the drift border in America was defined and a tentative sequence established; a map was then prepared and published in 1874 by J.S. Newberry that showed the drift border as far south as Kansas (Wright and Frey, 1965, p. 3-5).

A correlation chart by R. C. Moore (1958, p. 505) has equated the major Pleistocene ice sheets of northern Europe with those of North America. Thus, the Würm Stage of Europe includes both the Wisconsinan and Iowan Stages
of America, the Riss is equivalent to the Illinoisan, the Mindel is equal to the Kansan, and the Günz is Nebraskan (Moore (1958, p. 505). The southern extent of the Pleistocene ice sheet was established by Newberry's (1874) and later maps to be within a hundred miles of Wilson County and less than 80 km (50 mi) from the headwaters of rivers that drain through Wilson County.

Milankovitch Theory and Isotopic Variations

The relationship of the several Kansas chert deposits to Pleistocene climatic variations seemed possibly to be accounted for by the multiple glaciation theories of James Croll (1875) and Milutin Milankovitch (1924, 1941). The Croll and Milankovitch hypotheses required that the orbit and axial-rotation vectors of the Earth varied during geologic time such that seasonal and latitudinal distributions of terrestrial insolation would have been modified over time intervals of tens of thousands of years. According to the data utilized in their theories, the eccentricity of the Earth's orbit has an approximate maximum insolation variation of 20% over a period of approximately 96,000 years, the precession of the equinoxes completes a cycle about every 21,000 years, and the obliquity of the ecliptic varies from the present 23.5° almost as much as 2.5° over a period of about 41,000 years. Observations in five deep sea cores show the $^{18}$O main periods of precession at 19,000 years and 23,000 years, and obliquity at 41,000 years; data from these
deep-sea cores also indicate a 100,000-year eccentricity band (Imbrie and others, 1984, p. 269). This statistical evidence of a close relationship between the time-varying amplitudes of the orbital forcing and the time-varying amplitudes of the isotopic response implies that orbital variations are some of the main external causes of the succession of late Pleistocene ice ages (Fischer and Bottjer, 1991, p. 1065).

Since the pioneer work of Croll and Milankovitch, a meaningful evaluation of their astronomical theories of the Pleistocene ice ages has been needed. Imbrie and others (1984, p. 270-296), and Fischer and Bottjer (1991, p. 1063-1069) provide data based on measurements of the ratio of $^{18}O$ to $^{16}O$ from five open-ocean cores and on cycles recorded in varves in ancient lake beds. In the cores, radiometric control was determined for the entire length of each core. The Brunhes-Matuyama boundary was dated radiometrically for different cores at 730±11 thousand years (KY), 728 KY, 738 KY, and 790KY. Insolation curves for particular latitudes and seasons were plotted against curves showing variations not only in obliquity, but in the precession index, and in the longitude of perihelion. The climate systems respond to insolation changes driven by variations in obliquity at periods of 41 KY and orbital precession at 100 KY, modified by other factors at 19 KY and 23 KY. Little agreement was noted with these data and with climatic
oscillations around 100 KY that dominate the isotopic record. Imbrie and others (1984) believe that as much as 85 percent of the isotopic variance in each of four narrow frequency bands (centered on periods of 19 KY, 23 KY, 41 KY, and 100 KY) is forced in some way by orbital variation. Changes in the global volume of glacial ice are the dominant influence on oscillations in five $\delta^{18}O$ records over the past 780,000 years. Coherencies between orbital and isotopic signals at each of the main orbital periods of 19 KY, 23 KY, 41 KY and 100 KY exceed only 0.9 and are statistically significant. Therefore, they believe that variations in the geometry of the Earth's orbit are the main cause of the succession of late Pleistocene ice ages (Imbrie and others, 1984, p. 301-302). Elsom (1992, p. 98, 99) summarizes much of present knowledge diagrammatically and in a short text for the last 850,000 to 1,000,000 years.

Oxygen isotope ratios in foraminifers from deep-sea cores should also reflect the water temperature (climate) in which their tests were deposited. The mean $\delta^{18}O$ varies with the quantity of isotopically light ice stored on the continents so that the record from foraminifers is a blend of global ice volume and local temperature components. Furthermore, data from foraminifers in deep-sea cores are related to coral reef terrace ages using a time scale obtained from deep-sea cores and coral terraces (Chappell and Shackleton, 1986, p. 137). The final time-
scale was developed by tuning the original record on the basis of its relationship to orbital precession, obliquity, and eccentricity functions. The results show that ocean water was 1.5°C (2.7°F) cooler than present about 40,000 yrs before present (B.P.) in the deep Pacific Ocean with sea level about 40 m (130 ft) lower and $\delta^{18}O$ at 4.50. An interglacial is suggested at about 125,000 years B.P. with ocean water the same as present height or possibly 6 m (20 ft) higher with $\delta^{18}O$ at 3.40 (Chappell and Shackelton, 1986, p.139).

By using oceanic current action as a means to control and to modify ice growth during an ice age and to control melting during an interglacial, Ruddiman and McIntyre (1981, p. 617-626) were also able to utilize the $\delta^{18}O$ and $\delta^{16}O$ content in shells of benthic foraminifers to determine the temperature variations in sea water. Summer insolation in the northern hemisphere is at a minimum because summer occurs at the most distant pass (aphelion) in the Earth's slightly eccentric orbit around the sun. The tilt in the Earth's axis decreases summer insolation in high northern latitudes, such that north of 65°N the summer insolation is at a minimum; south of 65°N, the precessional position at aphelion is dominant. The ratio of the two stable isotopes of oxygen, $\delta^{18}O$ and $\delta^{16}O$, in shells of benthic foraminifers reflects the growth and decay of continental ice. Heavier isotopic values indicate larger ice volumes and suggest changes at 75,000
to 72,000 years B.P., 115,000 years B.P., 185,000 to 190,000
years B.P. and 230,000 years B.P. Summer insolation at the
latitudes of major ice sheets in the northern hemisphere
varies with dominant frequencies of 41,000 years north of
about 65°N and 23,000 years south of 65°N. Imbrie and
Imbrie (1980, p. 943) demonstrated that the summer
insolation curves at 65°N and 45°N can reproduce ice-
volume records for growth and decay of ice sheets along
the Milankovitch insolation retardation effect. They also
explored the nonlinear response arising from a faster time
constant for ice decay than for ice growth as shown by the
100,000-year ice volume ($\delta^{18}O$) cycle, and they concluded
that the nonlinearities involved in rapid ice decay can
create 100,000-year power by transferring power from the
23,000-year precessional cycle (Imbrie and Imbrie, 1980,
p. 951).

Fractionation during ocean-atmosphere transfer
preferentially removes $\delta^{16}O$ and stores it in the ice caps.
The $\delta^{18}O$-enrichment of ocean waters is recorded in the
shells of benthic foraminifers living on the sea floor.
The southward spreading of melt water at maximum rates
during the high-insolation season tends to suppress
productivity most in the warm season. Therefore, the
strong 23,000-year signal represents a systematic surface-
water response to precessional forcing (Ruddiman and
In order to relate the Pleistocene data of pages 52 through 56 to Paleozoic time, we must realize that because of the great mass of the oceans, rapid changes of \( \delta^18 \)W (\( \delta^18 \)W is \( \delta^18 \)O of water on the SMOW {Standard Mean Ocean Water} scale (see Anderson and Arthur, 1983) are apparently not possible by any means other than by the process of glaciation. If the assumption is made that temperatures may have been generally higher at times in the Paleozoic than those experienced since, and that \( \delta^18 \)W might have fluctuated slowly by only a few mils, then it is possible to suggest that a characteristic \( \delta^{13} \)C of -3(±1%), a \( \delta^18 \)W of -1(±1%), and a water temperature in degrees centigrade of 25°(±5) for late Carboniferous shallow marine shelves (Hudson and Anderson, 1989, p. 190) may have been similar to the \( \delta^{13} \)C, the \( \delta^18 \)W, and to the water temperature present in the Wilson County area in late Pennsylvanian time. Finally, we may conclude that it is likely that the oxygen isotope method of paleotemperature determination will contribute not only to paleothermometry but will contribute also to resolving the isotopic history of seawater (Hudson and Anderson, 1989, p. 190).

**Summary Statement.** The preceding data indicate that more than adequate time was available for the erosion and lowering of chert gravel deposits 91 m (300 ft) or more in Kansas. However, any attempt at correlation of
glacial deposits of northeastern North America and specific chert gravel deposits of Kansas is very hazardous, but is also very tempting in view of Moore's statement that "In the great interior plains region south of the glaciated country, the chief sedimentary record during the Pleistocene Epoch consists of deposits made by streams...The various formations...form terraces along stream valleys, the highest terraces being the oldest...Deepering of valleys in the plains region seems to correspond to times of ice sheet expansion, and aggradation was most pronounced during ice recession and in the early part of interglacial ages" (Moore, 1958, p. 504).

A certain degree of cyclicity is evident in the relation of glacial and interglacial sediments in the Pleistocene of Kansas. Similarities in the physical appearances of the deposits within the sequence may have made differentiation of most packets of sediment one from another practically impossible without some diagnostic feature. However, such a geologic feature as the presence of the Pearlette volcanic ash bed seemingly ties the enclosing sequence to the end of Kansan till accumulation or to the start of the Yarmouthian interglacial sedimentation since the Pearlette is stated to be the only ash bed in the Pleistocene sequence of the area and thus establishes the only ash bed time line (Frye and others, 1948, p. 513). Volcanic ash beds of the Pliocene have
different color, refractive index, shape of the shards, $\text{Fe}_2\text{O}_3$ content, and specific gravity, and therefore are distinguishable from the Pearlette (Frye and Leonard, 1952, p. 43). Also, a distinctive molluscan (snail) faunal assemblage is commonly associated with each of the major cycles of Pleistocene deposition in Kansas, and in the complex Wisconsinan cycles, a stratigraphic sequence of faunal zones was determined (Frye and Leonard, 1952, p. 44). Such molluscan faunal zones have been identified with other units in the Pleistocene glacial sequence, and in conjunction with lithologic character, weathering profile, and topographic form, have made possible the recognition of different Pleistocene deposits in many parts of Kansas (Frye and Leonard, 1952, p. 42-46).

SECTION 38: THE MESOZOIC ERA

Includes medium-grained intrusive rocks of Cretaceous age, and metamorphic effects seen in intruded Paleozoic (Pennsylvanian) sedimentary rocks.

Cretaceous System

Intrusive Rocks

As noted earlier in this dissertation, the geologic mapping of Wilson County was begun along the common boundary between Elk County (to the west) and Wilson County so that I could learn the details of the stratigraphy from George Verville who was in his third
year of mapping the geology of Elk County in order to satisfy a requirement for his Ph.D. degree at the University of Wisconsin. Together we mapped the geology of a strip 3 km (2 mi) wide, and then I turned east and began mapping along the boundary between Wilson County and Woodson County. I had mapped about 13 km (8 mi) along that boundary when I observed gray-green quartzite blocks along the hillside. These I mapped and then, in order to account for their occurrence in such an unexpected location, I followed a farm road up the hill on which they had been stacked in windrows. At the end of the road was a farmhouse where I encountered George Hill, Jr., who explained that many years earlier (during the Great Depression of the 1930's) his father had allowed the local Works Progress Administration (WPA) advisory board in Fredonia to set up a project on his property where the board members envisioned the development of a public park and recreation area as a means of providing work for local unemployed men. Near a spring on Hill's property a pond was dug in the micaceous soil, the greenish quartzite rocks were moved into windrows, and picnic tables were built and positioned around the pond, which was then stocked with fish and became known as Hills Pond. At first, people flocked to the pond, but eventually the area was overgrown with blackberry vines and sumac, cattle found the pond, and the area reverted back to nature. Micaceous golden soil, however, could still be seen
clearly in the banks of the pond. The history of the discovery of these micaceous rocks began in 1879, some 70 years earlier (see Appendix B for details of the discovery).

I collected samples of these greenish quartzite blocks and associated hard black micaceous igneous rocks which I examined in thin sections shortly thereafter when I arrived in Lawrence. I determined from a study of thin sections that the mineral content of the black igneous rock was principally phlogopite mica, serpentine, and tremolite-actinolite; smaller amounts of biotite mica, olivine, hypersthene, augite, apatite, magnetite, and titanite; the clay minerals nontronite and illite were also present. The rock was medium-grained and the term mica-peridotite seemed best to fit the mineralogy. Perusal of the records on file at the Kansas Geological Survey revealed that other geologists had determined the mineralogy of these igneous rocks. I discovered that K. K. Landes had sent a specimen of the black rock from the Silver City Dome to E. W. Heinrich who had in February 1948 sent a letter to Landes stating that the rock was a fine- to medium-grained peridotite. Another opinion was obtained by W. W. Hambleton who gave a sample to P. C. Franks for study. The response from Franks in June 1953 affirmed that the rock was a fine- to medium-grained peridotite. Meantime, I had sent a sample to Charles Milton of the U.S. Geological Survey in Washington, D.C.
Milton also classed the rock as a peridotite that "was composed originally of olivine, biotite, diopsidic-augite and relatively abundant sphene; but most of the olivine has been altered to serpentine and phlogopite, the biotite to phlogopite and vermiculite, and the diopsidic-augite to green chlorite. Weathering resulted in the formation of mixed-layer clay minerals, limonite, and magnesite(?)" (Charles Milton, written communication, July, 1956).

When writing my report (Wagner, 1954), I thought I would name the peridotite after the Silver City Dome but found that name had been preempted for use as the Silver City Granite (Kerocher and others, 1966, p. 3603). I therefore decided on the name "Hills Pond Peridotite" because of the good exposures in the bank of the recreation area pond.

The type locality of the Hills Pond Peridotite was designated as 152 m (500 ft) east and 30 m (100 ft) south of the center of the north line of Sec. 32, T 26 S, R 15 E. The extent of the main outcrop of the deeply weathered igneous body is shown in Figure 1 of my report (Wagner, 1954) which indicates that the peridotite is bounded on the north by a fault, has several sill-like bodies that extend southward as determined by their being intersected in several wells. Hambleton's interest in the Silver City Dome continued and during the winter of 1953-1954, he and Merriam performed a magnetometer survey of the Rose Dome-Silver City Dome area. Their vertical
intensity magnetic map shows strong negative anomalies over both the Rose and Silver City dome areas (Hambleton and Merriam, 1954, p. 127-128). Twenty-two diamond drill holes were put down by the Geological Survey of Kansas in 1955 in order to establish the dimensions of the intrusive body and to provide fresh samples of both the igneous body and the metamorphic rocks. Two additional areas of outcrop of the peridotite were mapped, as well as eight areas of metamorphosed sediments, one of which is in roadcuts along the north line of the NE 1/4 of Sec. 6, T 27 S, R 15 E in Wilson County. The metamorphic effects at this location are an increase of porosity and slight silicification in the South Bend Limestone Member of the Stanton Limestone. The porosity increase is apparently the result of alteration of limonitic oolites to a more soluble form of iron and subsequent removal of the oolites and enlargement of the cavities thus formed. Chemical analyses performed by the Geological Survey of Kansas show a 13 percent increase in silica and magnesia from the intrusive rocks, and a compensating loss in calcium and water in the metamorphosed strata.

Other metamorphic effects were noted in the halo that surrounds small areas of golden mica rock in the NE 1/4 NW1/4, Sec. 32, T 26 S, R 15 E and in road cuts along the common north-south line between sections 31 and 32, T 26 S, R 15 E (Wagner, 1954). Metamorphic effects in the South Bend Limestone Member of the Stanton Limestone
consist locally of the complete disintegration of the oolitic limestone facies into a white calcareous clay containing small (1 mm) black spheres that are attracted to a magnet. Other effects are silicification and the addition of greenish crystals of epidote and tremolite-actinolite. In places, the thin dark-gray Haskell Limestone Member of the Lawrence Formation has been invaded along the joint system by dark-colored hydroxyl-apatite and jasperoid. Locally, the entire 36 cm (14 in) of the Haskell has been replaced by the apatite and jasperoid. The Vinland Shale Member of the Stranger Formation is similarly phosphatized locally; generally, however, the clay portions of the shale are unaltered even in areas where the more silty portions have been completely silicified and chloritized as have the coarser grained rocks, such as the Ireland Sandstone Member of the Lawrence Formation and the Tonganoxie Sandstone Member of the Stranger Formation along the margins of the main intrusive (Wagner, 1954, Fig. 1). Acid hydrothermal solutions or vapors charged with silica, magnesia, alumina, and locally phosphate apparently accompanied intrusion, filled the voids of the sandstones and siltstones with silica, and combined with indigenous iron and carbonate of the affected strata to form chlorite, sericite, epidote, and other metamorphic minerals. The presence of quartz veinlets cutting the intrusive body
indicates that some action of silica-rich solutions occurred after crystallization of the peridotite.

The lateral extent of the peridotite intrusives to the south into the subsurface of Wilson County can be approximated by use of descriptions written by oil men who drilled the wells in the general area. An experienced driller familiar with the section of rocks being drilled could tell the type of material (limestone, sandstone or shale) in which he was drilling by the action of the cable which he gripped loosely with his hand and by the cuttings that circulated out of the well head. Unusual materials were recognized and recorded in the drillers logs of several wells in northern Wilson County. These I interpreted as sills of mica-peridotite intruded into the sedimentary sequence (Figure 6); each log recorded hard black rock or mica rock at several depths. The Puckett and Honor Lodge wells, located about 1.6 km (1 mi) south of the Silver City Dome, have no such rocks and show the normal stratigraphic section of the area. The log of the No. 1 Hase Well (NW cor. Sec. 6, T 27 S, R 15 E) recorded black rock and black mica rock from about 280 to 340 m (915-1105 ft) depth; the log of the No. 1 Bentley well (SE cor. NW1/4 NW1/4 Sec. 6, T 27 S, R 15 E) recorded mica rock from 280 to 325 m (910-1060 ft) and from 348 to 352 m (1142-1155 ft); the log of the No. 1 Young well (SE cor. NE1/4 NE1/4 Sec. 5, T 27 S, R 15 E) shows mica rock from
Figure 6. Correlated drillers logs in the area of the Silver City Dome, showing intrusive rocks (datum is mean sea level)
91 to 107 m (300-350 ft), 189 to 200 m (620-650 ft), 245 to 250 m (805-820 ft) and 317 to 322 m (1040-1055 ft). The log of the No. 1 Young well also recorded granite (?) from 107 to 115 m (350-375 ft) and black rock from 250 to 253 m (820-830 ft). It seemed very likely that these anomalous rocks represented altered and unaltered igneous rock similar to the grayish-yellow very micaceous clay that crops out less than 1.6 km (1 mi) to the north or similar to the dark blackish-green micaceous rock cut in core-drill holes at shallow depth where the Geological Survey of Kansas had drilled directly down into the intrusive. By removing the 50 m (165 ft) or so of these unusual rocks from the logs of the wells shown in Figure 6, the uparched beds became a nearly normal sequence (Figure 7).

Following publication of my report in 1954 (GQ49) and my transfer to Washington, D.C., in 1955, other geologists became increasingly interested in the Silver City Dome and have written some 16 reports concerning the geology. A short report by Winchell (1959a) that dealt with the Stranger Formation revealed that the Silver City Dome had a closure of 15 m (50 ft). Age determinations, using thermoluminescence methods on six samples allowed Pearn (1959) to show that the Haskell Limestone Member of the Lawrence Formation at the Silver City Dome was metamorphosed only 60 million years ago. However, this age was based upon somewhat questionable alpha counts,
Figure 7. Correlated drillers logs in the area of the Silver City Dome; intrusive rocks removed (datum is base of Stanton Limestone)
and must be considered a minimum age. A third report, by Franks (1959), described in detail the results of thin section and X-ray diffraction studies of samples of dark gray micaceous rock taken from 19 core holes drilled by the Kansas Geological Survey and from a single core sample taken between 233 and 242 m (765-793 ft) from a well on the Silver City Dome. Franks reported that the rock is a serpentinized mica peridotite containing about 25% phlogopite, and about 10% each of phenocrysts of olivine, diopsidic augite, and a light-reddish-brown pleochroic amphibole in a serpentine grandmass with apatite, magnetite, perovskite, and nontronite.

Merriam (1963) provided an age for the granite at Rose Dome. His source was apparently a written communication from E. G. Lidiak who gave an age of 1220 million years (Merriam, 1963, p. 154 footnote). Merriam surmised that the granite was carried upward as blocks incorporated in the peridotite intrusive. Snyder and Gerdemann (1965), p. 409) also subscribed to the theory that the granite reached its present position by being carried upward during emplacement of the basic rocks. Franks (1965, p. 66) in an abstract for a talk to the Geological Society of America wrote that emplacement of the granite was probably as young as Cretaceous or even early Tertiary. Zartman and others (1967, p. 852, 856, 858) provided a reliable age date for three samples of the mica peridotite by potassium/argon methods; they were
91±5, 90±5 and 88±4 million years. These dates are Late Cretaceous and give an average age of 90 million years.

The next reference to the Wilson and Woodson County intrusive rocks was by Hayes (1967), who believed that dickite crystals that he collected while participating in a Geological Society of America field trip to study algal limestones in the Lansing Group of southeast Kansas in 1965 were of hydrothermal origin. Hayes writes that the dickite-filled pores range in size from a fraction of a millimeter to a centimeter across, and that the dickite appears as discrete, exceptionally well crystallized, pseudo-hexagonal plates whose infrared and DTA patterns conform to previously published data for dickite (Hayes, 1967, p. 893, 894). He believed that the relationship of dickite to igneous intrusions suggests a hydrothermal origin for the dickite and could reflect cooling of magmatic water or heated ground water below the temperature of dickite formation away from the proposed igneous source; the highly porous limestones of the Lansing Group could have conducted significant volumes of water rapidly for miles to give the widespread distribution of the dickite (Hayes, 1967, p. 895).

Isotopic and mineralogic studies reported on by Bickford, Franks, Rose, Wagner and Wetherill (1971, p. 2863-2867) showed that eight samples from three granitic rock types at Rose Dome (coarse-grained plutonic type, recrystallized granitic breccia, and flow-aligned quartz-
feldspar granitic breccia) all provided an age that averaged 1190±100 m.y. Although the results of the 8 samples do not plot on the whole rock isochron, they yielded a calculated Rb/Sr age which is Precambrian. Studies of mineral separations of three whole rock samples of K-feldspar and plagioclase yielded an 1176±50 m.y. isochron. A Rb/Sr isotopic age of 1200 m.y. is consistent with the Precambrian basement rocks of the area. Franks, Bickford and Wagner (1971, p. 2869-2877) were responsible for the mineralogic part of the studies. Their results suggest that the alkaline ultramafic magma probably intruded at temperatures greater than 800°C if fluid pressures were in the range from 200 to 300 bars. Such temperatures would have led to partial melting of the granitic inclusions and resulted in the formation of high sanidine and high albite from original microcline and albite.

In 1977, Merrill, Bickford and Irving (1977, p. 130) reported the presence of potassic richterite in the Hills Pond Peridotite. The results of such a determination were of unanticipated consequence. The basic igneous rocks at Hills Pond immediately were classed as lamproites, not peridotites. Three reports in 1985 all discussed the Hills Pond Lamproite. Mitchell (1985) in a review of the mineralogy of lamproites included data on the Hills Pond occurrence; Berendsen (1985) pointed out that the intrusives in Woodson and Wilson counties are alkalic and
ultrapotassic; Cullers and others (1985), regrettably, used the term Silver City Lamproite in their description rather than Hills Pond Lamproite (Silver City having been used earlier for a different rock unit, was not an available term). Erroneous statements are made throughout the Cullers and others (1985) report; Bergman (1987) uses the proper designation Hills Pond lamproite and credits P. Berendsen in a personal communication dated 1984 with correctly noting that the mica peridotite at Hills Pond is actually a madupitic lamproite (Bergman, 1987, p. 114). Berendsen (1988) discusses, among other characteristics, the industrial uses of the Hills Pond Lamproite. (For a more detailed treatment concerning the petrography and chemistry of these interesting intrusive rocks, see Appendix B).

SECTION 3C: THE PALEozoIC ERA

This section concerns the Paleozoic Era and includes detailed descriptions of strata of the Pennsylvanian, Mississippian, Devonian, Ordovician, and Cambrian Systems.

Pennsylvanian System

General Statement

Strata of the Pennsylvanian System in Wilson County are typical of those found throughout Kansas. They are characterized by features of sedimentation of stable platform areas in the Midcontinent region. Stratigraphic units are commonly even-surfaced and relatively flat-lying
with nearly constant dips to the west of about 30 to 38 m per km (20-25 ft per mi). The strata crop out in a north-northeast-trending belt completely across the county (and state) and have been traced down-dip more than 483 km (300 mi). The thickness of the Pennsylvanian sequence is relatively constant at about 366 m (1,200 ft), although thicknesses within formations may vary by 15 m (50 ft) or more.

The Pennsylvanian System in Kansas has been divided into three major series, Upper, Middle and Lower. The Upper Pennsylvanian Series in Wilson County contains strata of the Virgilian and Missourian Stages; the Middle Pennsylvanian Series has strata of the Desmoinesian and Atokan Stages of which only those of the Desmoinesian Stage are found in the county (the Atokan Stage is not represented); and the Lower Pennsylvanian Series, which has only the Morrowan Stage, is not found in Wilson County.

Watney, French and Franseen (1989, p. 23) have provided a short synopsis of the events that occurred in the Midcontinent region when the supercontinent Pangaea was the only landmass of the Earth and all the former continents had joined together. They proposed (1989, p. 23) that even though the Permian and Pennsylvanian Systems are represented by sediments covering only 23% of Paleozoic time, thicknesses of these strata account for 45-75% of the Paleozoic sedimentary column on the shelf.
area in Kansas. Overall, the Pennsylvanian was a period of significant subsidence, and the burial of sediments on the shelf had produced a high-fidelity sedimentary record. During Missourian time the large supercontinent was in the final stages of formation (Watney, French and Franseen, 1989, p. 23).

The Ouachita Mountains bordering the Midcontinent on the southeast formed along the suture zone created by the collision of Laurasia with Gondwana (Rascoe and Adler, 1983). Broad, active patterns of subsidence, accompanied by more restricted uplifts, occurred on the craton during this collision creating very favorable sediment-accumulation potential during the Pennsylvanian (Houseknecht and Kacena, 1983; Kluth and Coney, 1981a, 1981b; Thomas, 1985). "The areal variation of average subsidence rates on the shelf during the Missourian conforms to basin development in the southern Midcontinent" (Kluth, 1986).

Cyclic Sedimentation

The portions of the Pennsylvanian System that crop out in Wilson County contain strata of two stage divisions, four groups, and 12 formations (Table 1). The system is characterized by sequences of shale, limestone, and sandstone that represent alternating marine and nonmarine depositional environments during successive advances and retreats of the Pennsylvanian sea. Each complete sequence represents a cycle of sedimentation, or
cyclothem (Wanless and Weller, 1932, p. 1003). Some of the limestone units in Wilson County reflect a marine transgression and regression within themselves and, together with other units, form larger cyclic sequences termed megacyclothem (Moore, 1936, p. 29). The cyclic deposits of Late Pennsylvanian age in Kansas were thoroughly discussed by Moore (1936, 1949), who presented typical schemes of cyclic deposition for beds in different parts of the Kansas Pennsylvanian and Permian sequences. A relatively complete sequence of cyclic deposits is described for Upper Pennsylvanian strata by Moore (1949, p. 145) who diagrams typical groupings of the upper Lansing and lower Shawnee units (upward) starting with (1) sandstone, then (2) thin shale, (3) coal, (4) thin shale, (5) brown limestone, (6) light-colored shale, (7) dark gray, thin, vertically jointed limestone, (8) black platy shale, (9) light-colored shale, (10) thick wavy-bedded limestone, and (11) light-colored shale.

Cyclothem in deposits of Middle Pennsylvanian age in Kansas, where fully developed, contain in ascending order, the following types of sedimentary deposits: (1) non-marine sandstone, (2) sandy to clayey shale containing land plant remains, (3) underclay, (4) coal (5) black shale, (6) gray shale, (7) limestone and (8) calcareous shale containing marine fossils (Moore, 1949, p. 42, 43, 51). Another cyclothem had (upward) an additional sandstone and/or shale unit, a thick algal limestone, and
a thick shale which represent a retreat of marine waters (Moore, 1949, p. 82). Although the sequence revealed in the Pennsylvanian strata of Wilson County did not fit Moore's cyclic scheme exactly, many of the essential characteristics could be recognized. Wagner (1964) therefore, following the prior work by Moore (1936, 1949), indicated that in the six megacyclothemets that were represented in the outcropping rocks of Wilson County, the deepest depositional environments of the cyclic units were the fusulinid-rich limestones. He placed the units with brecciated-appearing angular areas of light brownish-gray limestone in a matrix of yellowish gray limestone in his "normal transgressive-regressive marine reeflike areas" (Wagner, 1964, p. 584).

Work by John Harbaugh in 1959 to 1962, and later by Philip Heckel in 1968 to 1985, clarified the environmental habitats of the Plattsburg and Stanton Formations. Harbaugh (1959, 1960, 1962), for example, correctly recognized the true significance of thickened limestone deposition with brecciated-appearing angular fragments as great algal banks that expanded locally in thickness from about 3 m (10 ft) to 30 m (100 ft) or more and in area from about 150 m (500 ft) by 180 m (600 ft) to 8 km (5 mi) by 40 km (25 mi). These algal buildups were recognized during my mapping of Wilson County, but their true nature and great extent was not suspected. Harbaugh and Heckel traced them through 12 counties along their outcrops from
Oklahoma to northern Kansas and Missouri, a distance of over 320 km (200 mi), thus establishing their importance to an understanding of the geologic history and of strand line shifts during late Pennsylvanian time (Figure 8). In a study of cyclic-sediment environments that covered the states of Oklahoma, Kansas, Missouri, Nebraska and Iowa, Heckel (1968, 1969, 1972, 1975, 1979, 1985) concluded that the deepest-water sedimentation occurred during deposition of black shale that was preceded and followed by light-gray shale and lime-rich sediment accumulation that terminated in the development of great algal banks. Heckel thus had modified the depositional environment scheme that had been developed in 1936 by R. C. Moore (1936, p. 30-32; 1949, p. 43-47; 1962, p. 97) and had been accepted and used for more than 25 years. In Moore's scheme (1959, p. 47) the deepest water (farthest transgression) phase was during deposition of the fusulinid-rich limestone unit (Figure 9). Concerning black fissile shale Moore (1950) considered it to have been deposited in a shallow marine marsh rather than in deep water as later proposed by Heckel (1969). However, this is not to say that black shale deposition is confined to either deep-water or shallow-water deposition. Neither is it to say that phosphatic nodules, as noted by Heckel (1975) in association with Pennsylvanian black shales, occur only in a deep-water environment. As pointed out by
Figure 8. Phylloid algal limestone buildups in eastern Kansas (Extracted from Heckel, 1969, p. 1059, 1060).
A. Stratigraphic positions of buildups; B. Strike-line positions of buildups.
Figure 9. Basic cyclothems showing transgressive and regressive patterns of cyclic sedimentation in Pennsylvanian time. (Modified slightly from Moore, 1959, p. 47)
Miller and Swineford (1957) some of these nodules contain casts or molds of shallow-water marine fossils that served as nuclei around which phosphate was concentrated. Nevertheless, the water chemistry of Pennsylvanian black shales could have been similar than some present-day coal swamps. Shallow-water origins are still acceptable for such black shale units as the Genesee and Middlesex Formations of the Devonian of New York as described by Hard (1931) and for certain black shales in Illinois which are believed by Zangerland Richardson (1963) to have originated in environments similar to the present Louisiana bayous. There are also those in the inland lakes and coastal swamps (Dismal Swamp, Okefenokee Swamp, Florida Everglades) which influenced Moore (1959) in his belief that different black shales of the Pennsylvanian occurred in a shallow-water environment.

Meanwhile, Heckel had also developed a typical cyclothem to which he could add extraneous beds as needed. Heckel chose an almost indispensable middle unit above and below which he arranged other stratal types. This unit he called the “core shale” (Figure 10). His scheme included (upward): (1) a sandy (outside) shale, (2) a thin dark gray (middle) limestone (3) a black (core) shale, (4) a thick (upper) limestone, and (5) a sandy (outside) shale (Heckel, 1975, p. 8, 9, 39; 1988, p. 45). To this he could add a “super” limestone, a “fifth” limestone, and a
### Basic Cyclothem

(Kansas-type)

in Kansas-Iowa outcrop belt

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Depositional Environment</th>
<th>Phase of Deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OUTSIDE SHALE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1.</strong> Gray to green, locally red Soil;</td>
<td>Nearshore Nonmarine</td>
<td>Detrital influx after carbonate shoal formed</td>
</tr>
<tr>
<td><strong>2.</strong> Sandy shale w. siltstone sparse fossils</td>
<td></td>
<td>Detrital influx before shoal conditions reached</td>
</tr>
<tr>
<td>Laminated unfoss. bird's-eye calcisiltite te siltite</td>
<td>Offshore</td>
<td>Stillstand</td>
</tr>
<tr>
<td>loc. cross-bedded</td>
<td></td>
<td>Subaerial sedimentation</td>
</tr>
<tr>
<td>Skel. calcarenite w. marine biota</td>
<td></td>
<td>Detrital influx</td>
</tr>
<tr>
<td><strong>UPPER LIMESTONE</strong></td>
<td>Stillstand</td>
<td>Stillstand</td>
</tr>
<tr>
<td><strong>Gray shaly</strong></td>
<td></td>
<td>Stillstand</td>
</tr>
<tr>
<td><strong>Upper Limestone</strong></td>
<td>Regressive</td>
<td>Regressive</td>
</tr>
<tr>
<td><strong>Skel. calcitrite w. abundant marine biota</strong></td>
<td>Eustatic lowering of sea level</td>
<td>Eustatic lowering of sea level</td>
</tr>
<tr>
<td><strong>CORE SHALE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gray-brown Shale w. loc. invert, calcarenite ~ top</strong></td>
<td>Maximum Transgression</td>
<td>Maximum Transgression</td>
</tr>
<tr>
<td><strong>Black fissile Shale</strong></td>
<td>Stillsstand</td>
<td>Stillsstand</td>
</tr>
<tr>
<td><strong>w. PON, pelagic fauna</strong></td>
<td></td>
<td>Still stand</td>
</tr>
<tr>
<td><strong>MIDDLE LIMESTONE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dense, dark</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Skel. calcitrite w. marine biota; loc. calcarenite at base</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>OUTSIDE SHALE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sandy shale w. marine biota</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gray to brown</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sandy shale w. loc. Coal, Sandstone</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 10.** Basic transgressive-regressive depositional cycle of Heckel (1975, p. 39; 1988, p. 45).
"lower" limestone that appeared in only the most complete megacyclothemes (Heckel, 1977, p. 1046). Merriam (1989, p. 20) as a result of his geologic mapping of Chautauqua County (adjacent to Wilson County on the southwest) discusses a grouping of shales and limestones to which he assigns depositional characteristics. His fundamental units are a transgressive limestone (Leavenworth type), a black fissile pivotal shale (Heebner type), and a regressive wavy bedded, mixed fauna limestone (Platts mouth type). This triad commonly is overlain and underlain by a nonmarine or marginal marine shale with or without a coal and contains sheet or channel sandstones or siltstones. These marginal marine units contain abundant evidence of subaerial exposure including subaerial limy crusts, paleosols, and desiccation and solution features. In general, the lithologies of transgressive limestones are 'condensed'; that is, these limestones are compact, hard, dense, even bedded, and thin with a fauna that has a low diversity and a low abundance. On the contrary, regressive limestone lithologies are 'spaced-out,' with floating grains, thick and irregular bedding (usually wavy or slabby) and a fauna that has a high diversity and a high abundance. It is in this facies that the algal banks occur along with shallow-water pelletites, oolites, osagites, and fusulinites (Merriam, 1989, p. 20).
Also to be mentioned in this discussion of rhythmicity is the cyclic forcing scheme of Milutin Milankovitch (1920, 1941). This scheme seems to be particularly applicable to the Kansas Paleozoic sequence in which the sedimentation record reveals a decided rhythmic arrangement of the stratigraphy. Furthermore, ice ages were a well-known climatic ingredient in Paleozoic time (Crowell and Frakes, 1975; Crowell, 1978). Also, orbital cyclostratigraphy has become an important concept in recent years such that it warrants some elaboration. Many sequence stratigraphers, for example, report much higher numbers of sequence boundaries than had been previously observed in the rock columns of the Cenozoic and Paleozoic Eras. Van Wagoner and others (1990, p. 52), estimate that many major unconformities are spaced at intervals of 100,000 to 150,000 years; global curves such as those by Haq and others (1988) apparently refer to many sets of sequences (Schlager, 1992, p. 22). The carbonate record confirms this notion in many instances (e.g. Fischer, 1964; Goldhammer, Oswald, and Dunn, 1991). These observations imply that the frequency bands of orbital cycles and stratigraphic sequences overlap, and thus the two approaches complement each other. Under most circumstances depositional systems respond rhythmically to linear forcings; that is, they fall behind, then catch up, overshoot, and fall behind again.
As an additional contribution to cyclicity, Heckel (1985, 1986) constructed a sealevel curve for a part of the Pennsylvanian of the Midcontinent. He estimated that the main cycles (megacyclothem) may have had durations of 235,000 to 400,000 years which may coincide approximately with one of the Earth’s eccentricity cycles of 413,000 years. Intermediate cycles would have lasted 120,000 to 220,000 years and have been related to the other eccentricity cycles of 95,000 to 135,000 years. Minor cycles may correspond to the 44,000 to 120,000 year climatic cycles (Heckel, 1985, p. 12). These values are within the time range estimated by other methods, and Heckel (1986, p. 330) believed that the range for all cycles corresponded to the range of periods of Earth’s orbital parameters that constitute the Milankovitch insolation theory for the Pleistocene ice ages, and that it further supports the Gondwanan glacial control for the Pennsylvanian cycles. Heckel’s careful and detailed work probably has resulted finally in determining the mechanism of formation of the Kansas Pennsylvanian cyclic sedimentation and the megacyclothem.

A geochemical, mineralogical and petrological study of the Upper Pennsylvanian and Permian shales of eastern Kansas was done by Cubitt (1979) using X-ray diffraction, emission spectrometric analysis, electron spin resonance, Fourier analysis, and a multivariate statistical analysis methodology. His results were surprising in that he
concluded that the cyclicity of the sequence was more
dependent upon local structural movement than upon
eustacy, and that the cyclic arrangement was at
approximately 21 m (70 ft) intervals rather than on
transgressive-regressive criteria (Cubitt, 1979, p. 92-
93). He conjectured that the cyclicity of the shale
deposits was related to tectonic uplifts within the
Ouachita foldbelt resulting from cyclic movement along
subduction zones due to stress diffusion from plate
boundaries as postulated by Bott and Dean (1973, p. 339-
341). Interestingly, Cubitt records that the black
shales studied were enriched in the metallic and trace
elements Be, Cd, Cr, Cu, Mn, Ni, Pb, V, and Zn by the
chemical action of organic matter; the gray shales had
high contents of calcite, CaO, MnO, Sr, Sn, Ge, and Bi
(Cubitt, 1979, p. 92). From this study of late Paleozoic
shales, Cubitt (1979, p. 93) also concluded that a three-
component cycle, represented by (1) calcareous marine
inside shales, (2) restricted-marine black shales, and (3)
deltaic and prodeltaic outside shales, best reflects the
depositional sequence he investigated. The concentration
of manganese in shales may be related to an increase in
\( \text{Mn}^{2+} \) ions (substituting for \( \text{Ca}^{2+} \) in calcite) under
reducing conditions. It seems likely that aragonite forms
in shallow-water environments (Cloud, 1962) with minor
manganese substitution for calcium (Thompson, 1972).
Calcite, however, predominates in deep-water carbonate
sediments and in some shales may reflect early diagenetic effects, rather than deposition under highly reducing conditions.


Dolomitization

The origin of dolomite has been a source of speculation since Sorby (1856, p. 77) first pointed out some 138 years ago the existence of ancient dolomites with great numbers of “minute fluid cavities” containing solutions of a “briny character”, thus indicating a probable secondary porosity and late origin of the
dolomitizing fluid. It is beyond the realm of this dissertation to reconstruct the history of the studies of dolomitization; suffice it to say that a great number of theories have been promulgated over the years, most of which have been noted in such reports as those of Steidtmann (1911) and Van Tuyl (1916). With the discovery of Recent (Holocene) dolomite in modern calcareous sediments in the late 1950’s and early 1960’s, dolomite literature has expanded markedly (see Fairbridge, 1957; Morrow, 1982a, 1982b, 1990). In 1960, Adams and Rhodes presented a good state of the art description of the current (at that time) theory of the conditions necessary for effective dolomite production in a natural setting. Major dolomite deposits of both normal marine and restricted environments are limited to, or closely associated with, shallow epicontinental shelves similar to those of Paleozoic age in the Midcontinent region. Thus, all adequately explored major sequences of sedimentary dolomite are known to include or interfinger with calcitic limestones characterized by abundant shallow-water fossils (Adams and Rhodes, 1960, p. 1912). Highly concentrated brines necessary for dolomitic deposition needed to be deposited in heated waters (35°C or above), under highly alkaline conditions (pH 9.0 or higher), and nearly neutral redox potentials. Concentrations of Mg, K, Na, Br, F and a few other elements would have had to be excessively high, and CO₂, Ca, O₂ and S₂ contents abnormally low.
Mg-Ca ratio would have been many times greater than in normal sea water. This brine would seep downward through the shelf floor and displace the connate water by its greater density. The brine would follow bedding planes where vertical migration paths were unavailable. The rocks through which the brine seeped would be composed of metastable aragonite and high-magnesian calcite which would be readily dolomitized by the potent hypersaline brines. The seeping brines would migrate mainly through the more porous zones and bypass the denser limestones. Coarse-grained porous dolomites are generally limited to beds previously composed of coarse-grained porous limestones. Where constantly renewed supplies of brine continued to pour through the carbonates for appreciable spans of geologic time, a thick dolomite sequence could develop (Adams and Rhodes, 1960, p. 1912, 1916, 1917).

Fisher and Rodda (1967) judged dolomite to be a product of metasomatic replacement of calcium carbonate under conditions of elevated pH and salinity resulting from contact with magnesium-enriched brine waters. Replacement was thought to be chiefly at the depositional surface, though some probably occurred in nonlithified sediments below that surface by downward and outward seepage of brines, or by seepage refluxion of brines in permeable grainstones. From their viewpoint dolomitization was a secondary process ranging from pre- to post-lithification; however, they thought that it was
doubtless contemporaneous with and directly associated with the evaporitic facies (Fisher and Rodda, 1967, p. 52, 53). The common association of dolomite and chert in many Lower Paleozoic strata may be the result of a combination of magnesium-rich carbonate solutions and those charged with opaline silica, as reported by von der Borch and Jones (1976, p. 587-591).

In the lower Midcontinent region massive transfer processes seem to have played a decisive role in the dolomitization. For extensive dolomitization, such as in Ordovician rocks, it seems likely that the Mg must have been brought in from an external source. An early origin for Arbuckle dolomite may have resulted from having a large volume of seawater readily available to provide a magnesium source (Gao, Land, and Folk, 1992, p. 1658). Cathodoluminescence procedures show that these early dolomites are either nonluminescent or only dully luminescent and appear to be extremely depleted in $\delta^{18}O$ ($\delta^{18}O$ values of -5.1 to -10.0% PDB). Low $\delta^{18}O$ values (and $^{87}Sr$ values of 0.7085 to 0.7089) could be due to $^{18}O$-depletion in ocean water, or even to post-depositional alteration; these values commonly characterize early Paleozoic carbonates (Gao, Land, and Folk, 1992, p. 1658). Meteoric water is believed to have been responsible, at least in part, for the alteration of nonluminescent to dully luminescent (early) dolomite. The differences in chemical compositions between nonluminescent to dully
luminescent (early) dolomite and brightly luminescent (late) dolomite indicate that the late dolomite originated from different fluids than did the early dolomite. More importantly, the radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (as high as 0.7097) of most brightly luminescent (late) dolomite suggest that the late dolomite formed from $^{87}\text{Sr}$-enriched externally derived fluids. Studies also show that the late dolomite has $\delta^{18}O$ values of $-2.5$ to $+5.9\%$ (Gao, Land, and Folk, 1992, p. 1660-1661).

Groundwater flow patterns or selective utilization by algal growths on platform banks of epicontinental seas could have resulted in the magnesian calcite and dolomite of the late Pennsylvanian limestones of Wilson County. Laboratory experiments by Gebelein and Hoffman (1973) support the algal hypothesis. The sheath material in the Holocene stromatolite-forming blue-green algae *Schizothrix calicola* shows a three- to four-fold increase in Mg/Ca ratio relative to that in the sea-water medium. Sufficient magnesium is complexed in a single 2 mm-thick algal mat layer to produce a layer of dolomite 1 mm thick. The Mg ion is a necessary component of the photosynthetic pigment (chlorophyll) found in the blue-green algae. High-magnesian calcite can be produced experimentally at low temperature and pressure in the presence of certain organic compounds capable of complexing Ca ions. The high concentration of magnesium in algal sheaths may represent a reserve for the
production of chlorophyll. Some of the magnesium in the sheaths may have been derived from preexisting chlorophyll molecules (Gebelein and Hoffman, 1973, p. 612).

As pointed out by Hardie (1987, p. 166) the flood of papers interpreting ancient dolomites to be of supratidal origin was stemmed only by the rise of a new idea that brackish ground water in the “mixing zone” between coastal fresh-water lenses and the underlying seawater column might be an effective dolomitizing fluid. This theory seems to have replaced the idea of evaporite brine reflux postulated by Adams and Rhodes (1960). These notions helped to result in many new theories and modifications of older theories, none of which, in the opinion of Hardie, overcomes the testing of variability in dolomitization inherent in the multitude of environmental conditions under which dolomites apparently formed. Hardie stated (in 1987) that “the two principal models in vogue today for massive dolomitization of platform carbonates are the hypersaline brine model for those ancient dolomites associated with evaporites, and the brackish-water mixing-zone model for dolomites, not obviously related to evaporites” (Hardie, 1987, p. 166). The phenomenon of cation order-disorder in dolomite means simply that there is not one single dolomite mineral but many dolomites, each with different thermochemical properties depending on degree of order and nonstoichiometry. Completely disordered phases are the most soluble (the least stable)
in the spectrum but are also the easiest to precipitate at 25°C in the laboratory. Ordered stoichiometric dolomite is the least soluble (the most stable) dolomite phase but has defied all experimental attempts at synthesis below 100°C. For ordered dolomite to form, it appears to be necessary to let the reactions run much longer (more than several thousands of years, apparently), or to raise the reaction temperature [Baron in 1960 converted calcite to ordered dolomite in 12 days at 100°C] (Hardie, 1987, p. 168). Most recently, a very high volume of sea water is postulated as being the source for the magnesium needed in dolomite (Gao, Land and Folk, 1992, p. 1658).

In summary, dolomitization in Wilson County is interpreted to have been controlled in part by algal bank development that caused a refluxion of magnesium-rich waters downward and laterally through the porous ooid sands into the algal bank. Thus, the coralline algae with high magnesium contents were possibly the major contributors to dolomitization. A change from an intertidal or supratidal environment to one below low-tide level is proposed for the growth of the phylloid algae. After the end of ooid formation, the algal bank could grow upward and restrict the waters shoreward of the bank. Because of restricted conditions, evaporation may have caused an increase in salinity thus increasing the magnesium/calcium ratio, which later aided in dolomitizing portions of the algal bank. It has been determined that
the Recent (Holocene) alga Lithophyllum has an average magnesium carbonate content of about 15 mole percent with a range between 5 and 25 mole percent (Johnson, 1961, p. 18). Closely related Archaeolithophyllum probably had a similar composition. High-magnesium calcite is chemically unstable when removed from the marine environment and readily alters to low-magnesium calcite. Original textures are preserved when the unstable form changes from high- to low-magnesium calcite (Friedman, 1964, p. 811). A later diagenetic alteration may result in complete solution of the algal structures. Drusy calcite fills the algal voids and is replaced by normal dolomite or more commonly by ferroan dolomite (Frost, 1968, p. 80).

**Virgilian Stage**

The Virgilian Stage is the uppermost large time-stratigraphic unit in the Pennsylvanian rocks of Kansas. The name Virgilian was taken from the town of Virgil, Greenwood County, about 32 km (20 mi) to the northwest of Wilson County and was first used in a chart by Moore in 1931. Actual publication was in a later chart (Moore, 1932, p. 88) in which all strata between the unconformity at the base of the Americus Limestone in the Admire Group of Permian age and the base of the Stranger Formation in the Douglas Group of Pennsylvanian age were included in the Virgilian Stage. Moore redefined the upper boundary in 1936 (Moore, 1936, p. 50, 142, 143) and placed it at
the unconformity at the base of the Towle Shale (Admire Group, Gearyan Stage); the lower boundary remains as originally defined, but the Towle Shale is now considered to be the basal member of the Onaga Shale (Admire Group, Gearyan Stage, Lower Permian Series) (Zeller, 1968, p. 44, Plate 1). Although no profound unconformity or distinct faunal break occurs in the stratigraphic sequence between strata of the Admire Group, Gearyan Stage and of the Wabaunsee Group, Virgilian Stage, the boundary is placed at the unconformity at the base of the Towle Shale Member of the Onaga Shale because: (a) this unconformity is the most widespread and represents the deepest erosion of any in that section of strata, (b) this unconformity lies only slightly below the lowest strata containing *Pseudoschwagerina*, and (c) the lithologic characteristics of the beds above the unconformity are similar to each other and are very different from those below (Moore, 1940b, p. 303).

Evidence for a time break at the base of the Virgilian Stage, Douglas Group and the top of the Missourian Stage, Lansing Group, is based upon both faunal and diastemic criteria at or near the base of the Virgilian. For example, a pronounced evolutionary break occurs among the *Triticites* of Kansas, approximately at the contact between the Virgilian and Missourian Stages (Moore and Thompson, 1949, p. 675-676); and deep cutting and filling of channels shows that considerable erosion
and sedimentation occurred in Kansas during this time period (Zeller, 1968, plate 1). Unconformities record this time break throughout much of the Midcontinent region. An angular unconformity separates Virgilian and Missourian rocks in the Ardmore basin; thick conglomerates and prevalent red-beds characterize the Virgilian-Missourian break in central Oklahoma; and erosional channels, cut as deep as 30 m (100 ft) into Missourian strata, are filled with basal Virgilian sandstone in north central Texas, southern Oklahoma, and eastern Kansas (Moore, 1932, p. 88; Dott, 1941, p.1662-1676). A locally pronounced unconformity near the base of the Virgilian Stage in eastern Kansas is represented by sandstone and locally derived conglomerate units in the Tonganoxie Sandstone Member of the Stranger Formation (Douglas Group); these units fill channels eroded locally into underlying strata as deep as the Stanton Formation of the Lansing Group (Moore, 1936, p. 149; Patterson, 1933, p. 13; Newell, 1935, p. 80; Lins, 1950, p. 130-136).

The paleogeographic setting during Virgilian time in southeastern Kansas can be reconstructed by using data obtained from the geologic mapping of Wilson County and adjacent areas. A great epicontinental sea that covered much of the Midcontinent area was being gradually filled with carbonate and terrigenous sediment in southeastern Kansas. Where such tectonically active highlands as the Ancestral Rocky Mountains on the west and the Ouachita

95
Uplift and Arbuckle and Wichita Mountains on the south bordered the sea, wedges of terrigenous sediment prograded basinward. The Ouachitas and adjacent highland areas were probably the main source of clay, silt, and sand for southeastern Kansas, as shown by a consistently larger amount of coarse detritus and greater thickness of terrigenous rock in the sequence toward the south and by clastic wedges and carbonate mounds that offlap to the north and west in Virgilian rocks. On the northern and eastern margins were lowlands of the Canadian Shield and Ozark Dome. These areas had been eroded to low levels, and rocks that cropped out were primarily Lower Paleozoic carbonates. They furnished minor quantities of debris to the southeastern Kansas area. In much of western Wilson County, the break in sedimentation between basal Virgilian sandstone and shale and the uppermost Missourian limestone and shale is obscure and may not be present (Wagner and Harris, 1953, chart). O'Connor (1963) was of a similar opinion and recommended that the name Pedee Group be abandoned and that the Weston Shale be made the basal member of the Stranger Formation. The Stranger Formation then became the basal formation of the Douglas Group and Virgilian Stage and thus was the dividing line between strata of Virgilian and Missourian age (O'Connor, 1963, p. 1877, fig. 3; Zeller, 1968, p. 34, plate 1).

In Wilson County the upper 230 m (750 ft) of strata of the Virgilian Stage are missing due to erosion, and
strata of the stage are represented by only about 130 m (420 ft) of predominantly argillaceous sediments assigned to the Oread Limestone, Lawrence Shale and Stranger Formation. The contact between rocks of the Virgilian and Missourian Stages is covered and could not be seen, or is perhaps gradational, over much of the outcrop area in the county.

Shawnee Group

The youngest (uppermost) rocks of Pennsylvanian age in Wilson County are in the lower part of the Shawnee Group which is typically exposed in Shawnee County about 145 km (90 mi) to the north. Haworth (1898, p. 93), in naming and defining the Shawnee "formation," included all strata "from the Oread limestone upward to the summit of the Osage [Scranton] shales." Moore revised the nomenclature of the Shawnee Group in 1931 and placed in it all strata between the base of the Oread Limestone and the top of the Topeka Limestone (Moore, 1931, chart). The revision shown in the chart was described by Moore as a redefinition (Moore, 1936, p. 159, 160; 1949, p. 139-145) and, as thus defined, the Shawnee Group consists of alternating thick limestone units and thick shale units that are readily distinguished from the overlying beds by the greater preponderance of limestone in the Shawnee Group and the more complex but clearly repetitive sequence of cyclical units in the group and from the underlying
beds by the greater clastic quality of lithology in the strata below (Moore, 1949, p. 139-143).

The Shawnee Group contains the following formations listed from youngest to oldest (downward): Topeka Limestone, Calhoun Shale, Deer Creek Limestone, Tecumseh Shale, Lecompton Limestone, Kanwaka Shale, and Oread Limestone. Of these, only the Oread Limestone is present in Wilson County.

Oread Limestone

Naming, Distribution, and Thickness. The Oread Limestone was named by Haworth (1894, p. 123) for exposures at Mount Oread, the site of the University of Kansas at Lawrence. Only the lower limestone, shale, and thin limestone of this report were included in the Oread "Formation" as originally defined; but subsequently, Haworth (1895a, p. 278; 1895b, p. 461), Bennett (1896, p. 114-116), and Moore (1936, p. 160) extended the formation to contain seven shale and limestone units. The Oread Limestone now contains seven members, listed in descending order: the Kereford Limestone Member, the Heumader Shale Member, the Plattsmouth Limestone Member, the Beebner Shale Member, the Leavenworth Limestone Member, the Snyderville Shale Member, and the Toronto Limestone Member (Table 1).

In Wilson County the Oread Limestone crops out only in the extreme northwestern part, where it caps high
topographic prominences because an algal buildup has increased its thickness and resistance to erosion (Fig. 8A). Its outcrop belt, however, extends more than 482 km (300 mi) northeast into Missouri, Iowa, and Nebraska and southwest 80 km (50 mi) or more into Oklahoma (Fig. 8B).

The outcrop characteristics and thicknesses of the members of the Oread Limestone are different in the northern and southern parts of the belt and in the subsurface to the northwest some 322 km (200 mi) distant. In northern Kansas, the shale members are moderately thin, and the limestone members form subordinate benches on a single prominent escarpment (Moore, 1935, p. 162). In the southern part of the state, the lower shale member is much thicker, and the outcrop is marked by two relatively prominent escarpments separated by a distance of 1.6 to 4.8 km (1-3 mi). At the type locality, the thickness is about 14 m (45 ft) (Moore, 1936, p. 161), but in Wilson County and immediately adjacent area, the entire formation is as much as 40 m (130 ft) thick (Wagner and Harris, 1953; Wagner, 1954). The limestone members of the Oread have been traced continuously from northeastern Kansas to Wilson County, and correlation with the type area has been established (Fig. 8B). The Oread Limestone can also be correlated with equivalent strata 320 to 480 km (200-300 mi) downdip into northwestern Kansas, the Plattsmouth, Heebner and Leavenworth members in particular (Stephens and Watney, 1986, p. 167). However, major changes in
lithology in the Oread Limestone and other formations may occur over long distances down dip as is shown by a chronostratigraphic cross section in western Kansas by Watney (1985c, p. 124). These changes include local lensing out laterally of thin limestones like the Leavenworth and black, fissile shales like the Heebner.

The area at the time of deposition of the Oread Limestone of the Virgilian Stage was that of an extremely broad shelf across the Midcontinent region; it apparently sloped gradually southward to the margin of the Anadarko Basin (Watney, 1985b). A reconstruction by Heckel (1977) of the environment at the time of deposition of the Oread Limestone placed Kansas within 10° of a paleoequator that was directed N45°E (Figure 11). The Pennsylvanian Sea was bounded by the Appalachian Mountains and Ozark Uplands on the east, the Ouachitas, Arbuckles and Wichitas on the south, and ancestral Rocky Mountains on the west. By noting the positions of these land masses, the geographic position of the sea, and the probable wind direction from the northeast, Heckel suggested circulation patterns, such as fresh water inflow and upwelling in the sea, and thus explained the distribution of the ecological variations recorded in the different stratigraphic units (Figs. 11A, B). Parrish (1982) also suggested a circulation model; it was based on differential heating of continents and oceans in late Pennsylvanian time.
Figure 11. Pennsylvanian circulation patterns and thermocline in the Midcontinent region that allowed the deposition of black organic-rich sediments (from Heckel, 1977, p. 1054).
Galle (1967) made a geochemical study of the Oread Limestone throughout its outcrop area in eastern Kansas. Samples of the Toronto and Plattsmouth members were taken in Wilson County, but the nearest Leavenworth and Kereford samples came from Greenwood County near the Wilson County line. Chemical analyses of these samples are given in Appendix A (Galle, 1967, p. 101, 102, 104, 105, 107). The high silica content of the Kereford is due to abundant quartz grains (sand) in samples from southeastern Kansas.

Due to the greater thickness of one of its shale members (Plate 2A), the Oread Limestone in Wilson County is not the predominantly limestone unit that occurs at the type locality, but the formation is bounded by limestone units in the Wilson County vicinity also, and therefore, the lithologic term "limestone" is retained in the name.

Lithologic Character. The upper two members of the Oread Limestone, the Kereford Limestone Member and the Heumader Shale Member, have been removed by erosion from Wilson County but are present within 2.4 km (1.5 mi) of the northwest corner of the county (Wagner, 1954). The uppermost member, named the Kereford Limestone Member by Condra (1927, p. 45), is typically exposed at the Kereford quarry near Atchison, Kansas (Moore, 1936, p. 168), about 193 km (120 mi) north of Wilson County. In the type area, the Kereford is a "dense, somewhat arenaceous, in part oolitic and quite fossiliferous" limestone (Condra, 1927, p. 45); these characteristics are also found in an
exposure immediately northwest of Wilson County, where the member consists of 2 m (6 ft) of hard, sandy, algal (oolitic?) fossiliferous limestone with a clayey limestone interbed (Wagner and Harris, 1953; Wagner, 1954). The Heumader Shale Member, which conformably underlies the Kereford, was named for the Heumader quarry near St. Joseph, Missouri (Moore, 1932, p. 94, 96), about 225 km (140 mi) north of Wilson County. Near Wilson County the Heumader is much thicker than in the type area and consists of about 15 m (50 ft) of partly fossiliferous, concretionary, silty shale (Wagner and Harris, 1953; Wagner, 1954) with several siltstone and limestone interbeds. The remaining five members of the Oread crop out in the county and are discussed (downward) in greater detail below.

**Plattsmouth Limestone Member.** First published use of the term Plattsmouth limestone was by Keyes (1898, p. 349) who gave the name to a limestone unit 9 m (30 ft) thick near Plattsmouth, Nebraska. The term has since been restricted to the main limestone unit of the Oread, and therefore includes only part of the limestone sequence near Plattsmouth (Moore, 1936, p. 167).

The only remnants of the Plattsmouth Limestone Member in Wilson County are three small separated outcrops in Secs. 23 and 26, T 27 S, R 13 E (Plate 1). The unit is well exposed to the west in Greenwood and Elk Counties, where it is the thickest limestone member of the Oread,
locally forms the caprock of the ridges and dip slopes, and ranges in thickness from 1.5 to 3 m (5-10 ft) (average about 2 m or 7 ft). Its most distinctive feature in the Wilson-Greenwood-Elk County area is a wavy-bedded appearance well displayed along cliff-like exposures (Figure 12). The wavy-bedded appearance is believed to reflect an oscillation-rippled upper surface of thin limestone beds overlain by lenticular thin gray shale units.

The uppermost part of the Plattsmouth is a mottled-appearing limestone bed about 6 cm (2.4 in) thick. It is made up of intermixed, irregularly shaped fragments of cryptocrystalline, very light-brownish-gray limestone and very finely crystalline, light-brownish-gray limestone. Thin seams 0.5 mm (1/50 inch) of olive-gray crystalline calcite separate the rock into 6 to 13 mm (0.24-0.48 in) segments. Many of these curvilinear seams resemble cross section views of brachiopod or pelecypod shells but have none of the internal or external features of such shells; other seams have very irregular shapes. The curvilinear seams were presumed to be algal in origin by Harbaugh (1959, p. 300-314) who noted similar shapes in the Plattsburg Limestone and is credited by Heckel and Cocks (1969, p. 1063) with being the first geologist to recognize that such leaf-like algal seams and encrusting algae were the principal biotic constituents of Kansas algal mounds. The seams are actually algal blades from
Figure 12. Plattsmouth Limestone Member of the Oread limestone in sec. 21, T 29 S, R 13 E. (A) Cliff-like exposure. (B) Upper surface of wavy beds. (C) Detail of wavy-bedded character.
the Codiacean alga *Eugonophyllum* and the Dasycladacean alga *Epimastopora* as reported by Wray in 1983 (see Merriam and Wolf, 1983, p. 12). *Eugonophyllum* closely resembles the Holocene Phacophycean alga *Thalassiophyllum Blathrus* (Figure 13) as shown by Konishi and Wray, (1961, p. 661). *Epimastopora* possessed a large cylindrical, unsegmented thallus from which projected numerous branches arranged in spiral fashion (Merriam and Wolf, 1983, p. 12). These features resemble the modern, *Thalassia*-bound mudbanks which trap, bind and stabilize carbonate mud in concave upward, cigar-shaped banks that nearly parallel the shoreline (Wermund, 1975, p. 27). In the Plattsmouth member the banks commonly were topped with subaerial crusts or with osagites, pelletites or fusulinites indicating agitated, shallow-water conditions (Merriam, 1985, p. 74). If less clayey materials were available, the bank would become a more rigid structure over which calcareous shales could drape. Identification of these seams as algal in origin is difficult if not impossible to determine in many deposits because of recrystallization. The western margins of the mound grew at a faster rate than other parts of the mound. This is inferred because of the presence of *Epimastopora* (Fig. 13) a green Codiacean algae that is characteristic of higher energy mound environments. The mound extended to the north until water depth restricted algal growth. Culmination of the mound began with subtle influxes of
Eugonophyllum

Archaeolithophyllum missouriense

Thalassiophyllum clathrus

Eugonophyllum

Penicillus

Udotia

Pennsylvanian algae

Modern algae

Figure 13. Reconstructions of the Pennsylvanian algal genera Eugonophyllum and Archaeolithophyllum and of the modern genus Thalassiophyllum. Mound growth habits of the Pennsylvanian Eugonophyllum and modern Penicillus and Udotia also shown. Modified from Toomey and Babcock (1983), Wray (1964), Konishi and Wray (1961), and Wermund (1975).
elastics that clouded the water, choked the algae, and eventually buried the bank (Wolf, 1984, p. 75). The only other recognizable fossils in the limestone are fusulinids, and sparse small foraminifers some of which are filled with radially oriented calcite. The rock ranges in composition from a grainstone to a packstone or a biomicrite to bioclastic. Heckel and Cocke (1969, p. 105) recommended use of the term “phylloid algal-mound complex” for carbonate features that consist largely of a distinctive suite of rock types containing abundant leafy or phylloid algae.

Immediately underlying the mottled-appearing, wavy beds of light-gray, finely crystalline, fossiliferous limestone, is a very light-gray, very finely crystalline, fossiliferous limestone bed that generally weathers almost white but is locally speckled with small orange spots of iron oxide (limonite). The bed is about 13 cm (5 in) thick and contains abundant fusulinids (N. tritici), a few exposed fusulinids, and broken valves of brachiopods are abundant. The most common and best preserved brachiopods are Enteletes plattsmouthensis Newell and Marginifera cf. M. wabashensis (Porwood and Pratten). The remaining 3 m (10 ft) of the lower part of the Plattsmouth Member consists of 5 to 10 cm (2-4 in) thick, wavy beds of light-gray, finely crystalline, fossiliferous limestone. Locally, some of the beds are medium crystalline (almost saccaroidal), and others are very finely crystalline.
light pinkish gray. Fossils in this part of the member include Enteletes, Marginifera, Neospirifer, Crurithyris, Dictyoclostus and Composita, the rugose corals Lophophillidium and Caninia, the algae Ottonosia, both ramose and encrusting bryozoans, echinoid spines, small gastropods, and the ubiquitous crinoid stems.

Farther south, near Sedan, Kansas, Wolf (1986, p. 74, 75) describes a Caninia rugose coral layer made up in part of an unbroken rugose coral colony that represents "an exotic thanatacoenosis (death assemblage)." Wolf states that the concentration and orientation of these corals indicate that the remains could not have been transported far because of their unbroken, non-abraded condition. A smaller assemblage was noted in Wilson County. Possibly they were washed into a paleotopographic low which prevented damage.

The upper surfaces of the beds in the lower 3 m (10 ft) of the member are irregular and resemble oscillation-type ripple marks (Fig. 12B). These irregular upper surfaces apparently contribute to the wavy bedding, but many of the irregularities shown on Fig. 12 (A, C) cannot be explained by an irregular upper surface alone, and may largely reflect lithologic variations at the time of sedimentation. Small concentrations of clay in the most deeply weathered beds apparently make the rock more susceptible to weathering. Strains brought about by shrinkage during diagenesis may also have played an
important part in the development of the wavy bedding for, as shrinkage during lithification took place, the rock probably adjusted along these clayey separations, and channelways were formed along which water could later diffuse and percolate. Other irregularities unrelated to clay concentration may be entirely the result of shrinkage.

In northwestern Kansas, 483 km (300 mi) away, the Plattsmouth Limestone Member is encountered at a depth of about 1190 m (3900 ft) (Stephens and Watney, 1986, p. 171) where it consists of upper and lower units also. The upper unit is mainly somewhat dolomitic mudstones in conjunction with wackestones, and packstones which are relatively clean with respect to clay. Bioclasts are composed of brachiopod fragments, crinoid columnals, fusulinids, and a few bryozoans. Sutured stylolites are somewhat common reflecting diagenetic solution and differential vertical movement under pressure. The lower unit contains a similar fauna but with burrow mottling and calcite dissolution and compaction features. Microstylolites and quartz silt are abundant, but no large sutured stylolites are present in the lower unit. Where chert nodules are found, microstylolites drape around them, indicating that the nodules formed before compaction. In both areas the Plattsmouth represents a shallowing-upward unit ranging from thick, low-energy,
sub-tidal marine, silty and argillaceous wackestone to
thin bioclastic packstone.

**Heebner Shale Member.** The Heebner Shale Member
was named for exposures on Heebner Creek and on the
Heebner farm near Neihawka, Nebraska, where the unit is
about 1.5 m (5 ft) thick. The top portion of the bed is
bluish and argillaceous; the lower portion is black,
finely bedded, and somewhat “carbonaceous” (Condra, 1927,
p. 37). The Heebner is poorly exposed in Wilson County,
where its outcrop position is generally covered by float
from the overlying Plattsmouth Limestone Member. Where
exposed, however, the Heebner conformably underlies the
Plattsmouth and consists of about 1.8 m (6 ft) of shale,
the upper two-thirds of which is light olive gray and the
remainder, grayish black. The upper part of the Heebner
is calcareous and fossiliferous near the contact with the
Plattsmouth and also in the transitional zone between the
gray and black parts. The fossils consist of the
brachiopods *Crurithyris*, *Hustedia*, *Punctospirifer*,
*Chonetes*, *Chonetina*, and *Enteletes* amid many
unidentifiable shell fragments and crinoid and bryozoan
remains. Locally a few fish teeth and fish bones remain.

The lower 0.6 to 0.9 m (2-3 ft) of the Heebner is a
nearly black, very fissile, conodont-bearing shale that
breaks upon weathering into paper-thin plates as much as
8 cm (3 in) across. Finely comminuted plant remains are
abundant on bedding planes in a few places. Small
phosphatic concretions, 2.5 to 5.1 cm (1-2 in) in diameter, are found locally in the central part; the $P_2O_5$ content of the concretions is as much as 32 percent (Runnels and others, 1953, p. 98). Conodonts identified by L. D. Harris (Wagner and Harris, 1953) from the Heebner in Wilson County and the immediately adjacent area include Cavusgnathus, Hindeodella, Lonchodus, Ozarkodina, Streptognathodus and Trichognathus. Other microfossils identified are the foraminifers Ammodiscus, Cornuspira, and Tetrataxis, and the ostracodes Bairdia and Cavellina. Unidentified small fragments of bryozoans, brachiopods, and crinoids are present also. On gamma ray-neutron well logs the Heebner Shale Member produces a pronounced "kick" because of the gamma-ray emission (Watney, 1985c, p. 109). Heckel (1977, p. 1048) believed that this fissile black shale represented a deep-water facies which he referred to as the "core" shale because it occurred in a position centered between a limestone above ("upper limestone") and another limestone below ("middle limestone"). "Outside" shales occur above and below the limestones just mentioned. Characteristics of the black "core" shale are thinness in conjunction with great lateral persistence, presence of conspicuous nonskeletal phosphorite, fineness of detrital grain size and marine fauna; those characters together point to very slow sedimentation away from a source of detrital influx (Figs. 10, 11) and far offshore in water deep enough for a thermocline to develop. Although
lack of algae suggest deposition below the effective photic zone for algal production of carbonate, depths need not have been greater than typical epicontinental depths of about 100 meters (Heckel, 1977, p. 1048). Also to be noted is that the black shale facies is rich in organic matter and the heavy metals cadmium, chromium, copper, molybdenum, nickel, lead, vanadium and zinc (Cubitt, 1975, p. 93) as well as phosphate. Heckel (1977, p. 1048) also believed that the black, fissile shale was the result of anoxic bottom conditions.

Wignall (1991, p. 167) postulated that black shales like the Heebner form when rapid sea-level rise leads to marine-sediment starvation due to sediment entrapment in flooded river valleys in epicontinental basin environments. Rapid transgression in previously shallow-water areas leads to oxygen-restricted deep water beneath a pycnocline that isolates the bottom waters from oxygen-rich surface waters by the presence of a density interface within the water column. Geochemical studies of black shales like the Heebner have revealed the presence of molybdenum and zinc in conjunction with the phosphatic nodules (Coveney, Watney and Maples, 1991, p. 148). In Pennsylvanian shales, enriched molybdenum values probably were developed mainly because of fixation of the metal in acidic pore fluids. Heckel and Hatch (1992, p. 88) made the point that the widespread offshore black shales, which are sandwiched between widespread marine limestones and
deposited below a thermocline during sea-level highstand, contain an abundant conodont fauna dominated by *Idiognathodus, Idioprioniodus* and *Gondolella*; such a fauna is not found in black shales of other environments.

A careful study of the clay mineral content throughout the entire Kansas outcrop area of the Heebner Shale Member was made by Crouch in 1971. In his study he was able to divide the Heebner into three units. The upper part of the Heebner is a light-gray calcareous shale unit that contains nodules and laminae of phosphate in the lower few inches at its outcrop in northern Oklahoma and central and northern Kansas (Crouch, 1971, p. 39). The middle part is a hard fissile black shale unit that ranges in thickness from about 0.3 to 1.5 m (1-3.5 ft). Many thin, generally discontinuous, phosphatic laminae and nodules as well as numerous conodonts make this unit distinctive. The phosphatic nodules have a fairly high phosphate content (32 percent P$_2$O$_5$); the uranium content was only 0.017 percent U$_3$O$_5$ (Runnels and others, 1953, p. 98). The lower unit is a thin gray calcareous, fossiliferous shale about 8 cm (3 in) thick. This lower shale (Crouch, 1971, p. 38) thins, however, to only 0.6 cm (0.25 in) of dark marly shale that contains an abundance of small, thin-shelled brachiopods and pelecypods forming a coquina. In the Wilson County area this very fossiliferous limy unit was included in the Leavenworth Limestone Member by Wagner and Harris (1953). Clay mineral
analyses were performed on 13 samples taken by Crouch (1971) along the outcrop in eastern Kansas about 46 cm (18 in) above the Leavenworth-Heebner contact. Illite and mixed-layer expanding clays predominate; kaolinite is significant in the southern part of the study area. The quartz content and clay mineral studies indicated that the source of the Heebner was mainly to the south with a minor northern source possible. Deposition was below wave action with no currents of significance (Crouch, 1971, p. 62).

In a study of the Heeber Shale Member, Evans (1967, p. 47-49) also separated the Heebner into three units, an upper calcareous shale unit, a black, fissile shale unit, and a lower calcareous shale unit. The upper two units correspond to the Heebner as described in Wilson County, but not the lower unit. That unit occurs as a recognizable segment of the Heebner only in northern Oklahoma, in the Chautauqua County area of southernmost Kansas, in the northernmost part of Kansas, and to the north through Missouri and Nebraska into Iowa. In Iowa and Oklahoma, this lower unit consists of as much as 20 cm (8 in) of soft, olive-colored, calcareous shale. Between these areas, the unit is only 0.6 to 2.5 cm (.25-1 in) in thickness; it is composed of dark marly shale that contains an abundance of small, largely unbroken, thin-shelled brachiopods and pelecypods (Evans, 1967, p. 48).
Evans (1967, p. 5-10) performed a series of geochemical analytical tests on the black shale as well as on the nodules and thin laminae of phosphate in the Heebner. The tests included those to provide data on the P\(_2\)O\(_5\) and CaO contents (as described by Shapiro and Brannock, 1962, p. A32 and A38), on the organic content, on the combined water in clay minerals, on the loss of weight in the form of CO\(_2\), on the amount of kerogen (in oil) as described by Cuttitta (1949), and on the amount of uranium (using auto-radiographic evaluation methods that allowed differentiation of uranium, thorium and potassium to the total radioactivity); finally, a mechanical analysis was included to provide clay and silt contents. The calcium phosphate is probably bound up as fluorapatite as shown in thin sections that were used for petrographic analysis. In thin section, some phosphate nodules appear to be diagenetic in origin, as shown by the arching upward and bowing downward of the planes of stratification parallel to the upper and lower boundaries of the nodules. Cubitt (1979), too, studied thin sections of black shales. His studies also showed that black shales contain abundant phosphorite bands and nodules in a black organic-rich matrix. The phosphorite laminae rarely exceed one millimeter (.04 in) in thickness but may extend up to several centimeters (10 in) in length. Phosphorite nodules also vary considerably in size and may contain fossils such as radiolaria and spicules. Both laminae and
nodules lie along planes of fissility. The black shale facies is inferred to have been a marine deposit resulting from slow deposition in an oxygen-depleted sea. During high sea-level stands, a quasi-estuarine cell below an established thermocline may have existed in which upwelling cold phosphate-rich water depleted the epicontinental sea of oxygen, resulting in anoxic water conditions and deposition of black, organic and phosphate-rich muds (Cubitt, 1979, p. 84) (see Fig. 11B).

**Leavenworth Limestone Member.** The Leavenworth Limestone Member was named for a roadcut exposure northwest of the Federal Penitentiary at Leavenworth, Kansas (Condra, 1927, p. 38). At the type locality, the Leavenworth is a dark-gray, dense, vertically jointed, fossiliferous limestone whose thickness averages about 61 cm (24 in). In Wilson County the Leavenworth ranges from 43 to 56 cm, (17-22 in) in thickness and is a medium dark-gray, very finely crystalline, fossiliferous, vertically jointed limestone (Figure 14A). The fresh rock characteristically breaks with a musical ring. It would be considered a wackestone in the Dunham (1962) classification and a "middle limestone" by Heckel (1983). Fossil remains of small orbiculoid brachiopods and thin-shelled pelecypods occur locally at the top of the Leavenworth in a thin poorly consolidated bed 0.6 to 1.3 cm (0.24-0.5 in) thick. This fossiliferous unit where it thickens laterally and contains more clay could be
Figure 14. Leavenworth Limestone Member of the Oread Limestone in sec. 21, T 29 S, R 13 E. (A) Effects of vertical joint system. (B) Weathered surface with algal bodies and crinoid remains.
considered a basal bed of the overlying Heebner Shale Member, but where so thin and fossiliferous, it appears to belong with the limestone. Other fossil remains occur throughout much of the Leavenworth member. These etch out in relief on the pale yellowish-brown weathered surface, and in many exposures the most distinctive feature of this surface is the presence of numerous dark, oval-shaped algal bodies (oncolites?) that range in length from 13 to 38 mm (0.5-1.5 in) and in width from 10 to 16 mm (0.4 to 0.6 in) (Figure 14B). The algae consist of irregular concentric layers around brachiopod shell fragments, crinoid columnals, horn corals or other shell fragments. Small unbroken shells of fusulinids and fragments of larger shells have been enclosed in the outer algal layers in some bodies. Many fossil fragments are not encased in algal growths, however.

In respect to the fossil content of the Leavenworth, it is pertinent to point out that in his doctoral dissertation concerning the Leavenworth Limestone Member, Toomey (1964, p. 33) relates that Maxim K. Elias suggested, in 1937, that it was possible to estimate the depth of deposition of marine limestones by comparing the invertebrate fauna within a Paleozoic stratum to its counterparts in present marine waters and observing the depth of optimum life conditions for the modern forms. Thus, Elias utilized the old maxim of uniformitarianism that the “present is the key to the past.” This led Elias
to assign sea depths ranging from less than 6 m (20 ft) for the pelecypod-bearing dark shale phase of the cyclothem to about 61 m (200 ft) for the fusulinid-rich phase of the cyclothem. Toomey (1964, p. 33-40) then proceeds to provide reasons why the process of uniformitarianism is impossible to accept. Toomey's reasoning is clever, fairly complete, but not convincing.

In thin section, the finely-crystalline matrix is seen to be composed of a mixture of 0.02 mm crystalline calcite in which are enclosed small foraminifers (1 to 2 mm), oolites (0.5 to 2 mm), and small rounded shell fragments (1 to 2 mm). The larger shell fragments are mainly coarsely crystalline calcite; algal growths are composed of crenulated, roughly parallel dark and light layers of finely crystalline calcite. The algae encase shell fragments as much as 2.5 cm (1 in) in length and resemble most closely Johnson's descriptions and figures of Osagia colonies (Johnson, 1946, p. 1103 and pl. 5, Figure 5) but have been called Cryptozoon and Ottonosia. Other fossil remains in the Leavenworth consist of lophophyllidid corals, echinoid spines and plates, crinoid columnals, pelecypods, gastropods, small Triticites, and brachiopods represented by the genera Marginifera, Derbyia, Composita, Juresania and Linoproductus. Insoluble residues contain many fragments of arenaceous foraminifers. A study by Hutter (1972) revealed the presence of several genera of chitinozoans in the
Leavenworth Limestone Member along the 320 km (200 mi) outcrop trend in eastern Kansas; he also found specimens of the three chitinozoan genera *Euconochitina*, *Lagenochitina*, and *Virgilochitina* in samples from eastern Greenwood County within 6 km (4 mi) of the Wilson County line.

Toomey (1969a, 1969b, 1972) discussed in three reports the biota of the Leavenworth throughout its outcrop range. The first report covered the biota in general, and the second and third reports discussed the algal content and foraminiferal content, respectively. None of the samples was from Wilson County but five were from eastern Elk and Greenwood counties and therefore, given the constancy of Leavenworth lithology over its outcrop range of 480 km (300 mi), most of the data in Toomey's report can surely be extended eastward across the common county line and be applied to Wilson County. Toomey (1969a, p. 1001) indicated that the Leavenworth was deposited essentially parallel to what must have been the eastern shoreline of a Late Pennsylvanian epicontinental sea. The limestone formed on a broad, shallow, slowly subsiding, sedimentary platform that existed in the area of Kansas, Oklahoma and Nebraska and extended into adjacent states (Toomey, 1969a, p. 1010, 1013). Results of point counts of thin sections from 32 localities, indicated that the overall volumetric composition of the Leavenworth was 26 percent skeletal grains and 74 percent
pelletoids, mud and spar; it would be classified as a mud-supported wackestone of Dunham (1962). Concentrated organism burrowing disrupted the Leavenworth from top to bottom over the outcrop area, thus precluding any internal detailed correlations of very fine biotic zones. Water depth was inconclusive; deposition could have occurred in water depths of 3, 9, 18 or 30 m (10, 30, 60 or 100 ft). The algal content of the Leavenworth was stated by Toomey (1969b, p. 1313) as representing three major algal groups (red, green and blue-green). He reported that the bulk of the flora consisted of algae of uncertain affinities and algal-related structures, algal-coated grains and algal? or algal/fungal? borings. Species of *Epimastopora* of the Dasycladaceae and *Eugonophyllum* of the Codiaecae were both listed as possibly from the southeastern Kansas area (Toomey, 1969b, fig. 1). The calcareous foraminifers recognized in samples from the outcrop belt included five fusulinid families and 13 non-fusulinid smaller foraminifers. The most abundant fusulinids were of the *Kansanella/Triticites* group, whereas, the most abundant smaller foraminifer was a species of *Globivalvulina*; all were typical of a shallow-water platform environment (Toomey, 1972, p. 287).

A fossiliferous very fine pebble or granule conglomerate bed 2.5 cm (1 in) thick occurs at the base of the Leavenworth in many exposures. At the base also are unbroken shells of brachiopods and large pelecypods
enclosed in a light brownish-gray matrix of subangular to rounded granules (2-4 mm) of limestone. *Orthomyalina* and *Juresania* are abundant in the matrix and are generally oriented concave side down.

The Leavenworth is essentially unchanged from the composition in Wilson County and in the subsurface 483 km (300 mi) to the northwest. The unit represents a deepening of the marine environment ranging from shoal-water, energetic conditions to a quiet open-marine state typical of transgression which characterizes the “middle” limestone of Heckel (1983). Transgression must have been rapid in order to have covered such a large area of the shelf as indicated by the thin, widespread uniform nature of the unit (Stephens and Watney, 1986, p. 170).

*Snyderville Shale Member.* The Snyderville Shale Member was named by Condra (1927, p. 38) for exposures just east of the Snyderville quarry near Nehawka, Nebraska. In the type area, it consists of about 3.7 m (12 ft) of argillaceous shale; the upper part is bluish gray, the lower part is reddish brown. The Snyderville is much thicker in Wilson County than near Nehawka and averages about 15 m (50 ft) (Plate 2A).

The uppermost 0.3 m (1 ft) of the member is light olive-gray calcareous shale in which fossils are abundant at a few localities. The fauna indicates a marine environment and includes the brachiopods *Chonetes* and *Dictyoclostus*, the mollusks *Astartella* and unidentified
gastropods, the ostracodes *Amphissites, Bairdia, Cavelina* and *Hollinella*, the foraminifers *Tetrataxis* and *Triticites*, the algae *Osagia*, as well as echinoid spines, crinoid columnals and plates, ramose bryozoan fragments, and unidentified conodont remains. Fossils were not observed in the remainder of the Snyderville, and this, in conjunction with its reddish-brown color, is suggestive of nonmarine deposition for all except the uppermost 30 cm (12 in).

The next older 4.6 m (15 ft) of the Snyderville is predominantly dark reddish-brown slightly silty claystone with lenticular interbeds of pale greenish-gray silty claystone. Irregular-shaped limonitic calcareous nodules, which are commonly stained reddish brown on their outer surfaces and are brown, red, green, or white within, are locally abundant in the reddish-brown phase. A bed of light greenish-gray calcareous siltstone, 30 cm (1 ft) in thickness occurs about 3 m (10 ft) below the top of the unit; its upper surface has markings that resemble mud cracks.

The middle 6 m (20 ft) of the Snyderville consists predominantly of pale greenish-gray silty claystone in which discontinuous dark reddish-brown areas are locally abundant. The reddish-brown coloration has no bedded arrangement but appears as large irregular masses. Dark yellowish-orange ironstone concretions, 13 to 19 mm (0.5-0.75 in) in diameter, are locally common. This
irregularly colored unit is generally bounded above and below by locally calcareous, pale greenish-gray to yellowish-gray very fine grained, silty sandstone and siltstone. The upper of these beds is 1.5 to 2.1 m (5-7 ft) thick and is composed of well-sorted, very fine grained sand to silt-size subangular quartz grains that are locally cemented with calcium carbonate. Two, and locally three, lenticular sandstone beds occur at or near the base of the middle claystone unit. The beds are yellowish gray, locally finely micaceous and calcareous, 15 to 25 cm (6-10 in) thick, and are composed mainly of well-sorted, very fine quartz grains. Ripple marks and worm tracks (?) are locally common, and plant fragments were noted at one locality.

The lower 4.6 m (15 ft) of the Snyderville consists predominantly of pale greenish-gray silty claystone in the upper one-third and dark reddish-brown claystone in the lower two-thirds. Thin discontinuous lenses of reddish-brown claystone occur in the upper one-third, and large irregular greenish-gray areas occur in the lower two-thirds.

Toronto Limestone Member. The Toronto Limestone Member was named by Haworth and Piatt (1894, p. 117) from exposures near the town of Toronto, Woodson County about 8 km (5 mi) north of the Wilson County line. The Toronto ranges from 0.3 to 2.1 m (1-7 ft) in thickness and averages about 0.9 m (3 ft). It would be classed as a
wackestone in the Dunham (1962) classification, and the "lower" limestone of Heckel (1975). It underlies the Snyderville Shale Member with apparent conformity where the contact is well exposed (Plate 2A).

The Toronto varies considerably in lithology and fauna. A few outcrops show the uppermost 13 cm (5 in) of the Toronto to consist of a light orange-gray fine-grained limestone with sinuous channels 7.6 to 13 cm (3-5 in) wide and 1.3 to 2.5 cm (0.5-1 in) deep filled with grayish-brown medium-grained calcareous sandstone. Elsewhere, the upper half of the member is commonly very light olive-gray or very pale yellowish-brown limestone that is very finely crystalline and weathers olive gray or moderate yellowish brown. This upper part generally contains abundant crinoid stems and less abundant crinoid pinnules and calyx parts. Also present are ramose and fenestrate bryozoans, broken valves of Neospirifer and Derbyia, other brachiopod fragments, productid spines, and sparse lophophyllid corals; fusulinids are locally abundant (Figure 15A). In a few places, the upper 2.5 cm (1 ft) has a brecciated appearance in which angular fragments of dark yellowish-orange argillaceous limestone (possibly, broken algal fronds of Eugonophyllum; see Wray, 1977) occur in a groundmass of very pale-orange limestone. In this same unit, many irregular, sinuous, dark-gray areas (probably the algae Ottonosis or Cryptosoon or Eugonophyllum) are conspicuous on weathered surfaces. The
Figure 15. Toronto Limestone Member of the Gread Limestone at the center of the west line of sec. 36, T 27 S, R 13 E. (A) Upper fusulinid-rich limestone. (B) Lower fusulinid-rich clayey limestone.
algae coatings occur as irregular layers formed around crinoid columns, horn corals, and other fossil fragments 1.3 to 5.1 cm (0.5-2 in) across or in length. In a few exposures, the uppermost part of the Toronto is a light-brown sandy, sparingly fossiliferous limestone that weathers to nodular masses.

The lower half of the Toronto is principally a yellowish-gray to very pale yellowish-brown fine- to medium-grained very fossiliferous limestone that weathers yellowish gray to dark yellowish brown. The wavy-bedded character of this part of the member is emphasized by weathering. Fossils occur throughout, but the fossil content varies in type and abundance both horizontally and vertically. Locally, as in sec. 36, T 27 S, R 13 E, single beds in the lower part of the member are made up almost entirely of fusulinids (Fig. 15 B), and in sec. 23, T 27 S, R 13 E, the rock is largely made up of coralline growths. The fauna of the lower part of the Toronto contains many fusulinids as well as pelecypods such as Myalina, Aviculopecten, and Aviculopinna; brachiopods such as Chonetes, Composita, Crurithyris, Derbyia, Dictyoclostus, Hustedia, Juresania, Meekella, Neospirifer, Punctospirifer, and Rhipidomella(?); ostracodes such as Amphissites, Bairdia, and Hollinella; a lophophyllid coral and the coral Syringopora; high- and low-spired gastropods; fenestrate, ramose, and encrusting bryozoans; and the ubiquitous crinoid stems. The
fusulinids were identified as being predominantly *Triticites secalicus* (Say) but include also a form which appears to be intermediate between *Tricites secalicus oryziformis* Newell and *Triticites secalicus* (Say) (D.A. Myers, written communication December 16, 1959).

In a few places, the lowermost part of the Toronto is a wavy-bedded, light-gray, very fine grained, sparsely fossiliferous limestone, 0.6 m (2 ft) thick, whose lower surface is a plane and whose contact with the underlying shale is abrupt. In most places, however, the basal part is argillaceous, contains profuse fusulinids (Figure 15B) and grades downward through 7.6 to 12.7 cm (3-5 in) of calcareous, fossiliferous, nodular shale into contact with the underlying Lawrence Formation.

**Stratigraphic and Structural Implications.** The lithologies, faunas, and thicknesses of the different members of the Oread Limestone can be used to reconstruct in a general way the environment of deposition of each member, and to interpret local vertical movements of the land surface or sea bottom as well as regional (eustatic) changes in sea level during Oread time. Use of this information will also make possible a resume of the geologic history of the entire sequence of Paleozoic and younger rocks of Wilson County, although in reverse order, before concluding this report.

The sparry algal calcilutite in the upper part of the Plattsmouth Limestone Member contains the remains of an
algal colony that grew slightly below sea level and formed a mound complex. The algal bank growth may have begun on an exotic thanatocoenosis of other biota. This death assemblage may have afforded the light-sensitive plants a slight photic advantage. Once established, the algal community would have grown above the level of the surrounding sea floor because of the combined influence of a high growth rate and effective sediment baffling (Wolf, 1984). Changing environmental conditions could have brought the colony to an end or have caused it to move laterally. The Caninia coral growth confirms the shallow-water environment, and the broken nature of much of the coral remnants suggest intermittent but strong wave action (possibly during storms). Deeper water at times is suggested by other constituents of the fauna which consists of fusulinids, calcareous brachiopods, corals, and bryozoans. They indicate that the member was deposited in marine water ranging in depth from less than 15 m (50 ft) to possibly 61 m (200 ft) or more. The oscillation-type ripple marks in the upper part suggest that the Plattsmouth formed only slightly below active current movement but in the zone of bottom agitation; and the shaly zones that contribute to the development of wavy bedding suggest that a small amount of fine terrigenous material was contributed to the oscillation-ripple environment from time to time. The echinoid spines, small gastropods, and abundant crinoid stems in the lower part
indicate that, at the beginning of deposition of the member, the water was shallower than 15 to 30 m (50 to 100 ft) and that the currents were strong enough at times to move debris of granule or larger size.

The greater amount of clay relative to calcareous fragmental material in the upper calcareous gray shale part of the Heebner member suggests relatively shallow water near to shore. The underlying black, platy shale part, with profuse conodonts and a few ostracodes, suggests a poorly circulating organic-rich, partly anoxic deep-water environment. Prolific growths of algae or seaweed possibly provided this organic matter and produced a dampening effect on wave action and water circulation (Weller, 1957, p. 351; Heckel, 1972b, p. 262), or a spate of green Codiaecean algae may have proliferated in shallow water and been carried seaward to become a thanatocoenosis in deeper water. Also possible is the development of a thermocline that provided a dampening effect. Phosphate, which formed as laminae or migrated to nuclei during diagenesis to form concretions, may have accumulated as a result of bacterial decomposition of organic debris (Barnes, 1957, p. 304, 305). A concise statement outlining the geographic and climatic circumstances that prevailed at the time of deposition of the Heebner and other Pennsylvanian black shales in Kansas is provided by Heckel (1977, p. 1045, 1065) in which he writes that during Pennsylvanian time the position of
Midcontinent North America lay in the trade-wind belt north of the paleoequator along the Appalachians; this allowed establishment of large-scale quasi-estuarine circulation in the Midcontinent epicontinental sea (Fig.11). A hint concerning the origin of the remarkable thinness and extent of each bed of the platy black shale is given by Evans (1967, p. 105) where he says that "the relative purity exhibited by many laminations and the high level of radioactivity in the phosphate compared to the shale, seem to indicate that accumulations of phosphate took place slowly and in the absence of appreciable clastic deposition." If this is a correct interpretation, the numerous phosphatic laminae may be thought of as minor diastems, which would imply that the slowness of accumulation generally associated with black shales may be supplemented, in this instance, by the existence of many gaps in the sedimentation record. It appears probable, therefore, that the black muds were laid down slowly and over a considerable period of time. A hypothesis of this nature would enable the evolution of restricted conditions to spread gradually, and does not require the rapid supply of large amounts of organic material to the site of deposition. The suggestion of numerous diastems in a poorly oxygenated environment has appeal because otherwise the carbonaceous debris, which fell continuously to the bottom, would form a single thick bed rather than a
relatively thick sequence of platy paper-thin black laminae.

The thin, algal, fusulinid-bearing Leavenworth Limestone Member indicates a rapid transgression of the sea over a very large area. The presence of abundant algae and fusulinids in the upper and middle parts indicates that a water depth of no more than 61 m (200 ft) was reached; the heavy-shelled pelecypods in the granule conglomerate bed at the base indicate probable shallow-water conditions at the beginning of the cycle.

The presence of red and green shales that lack marine fossils in all except the uppermost part and the local occurrence of calcareous siltstone and ripple-marked sandstone lenses that contain a few plant fragments suggest that the lower two thirds of the Snyderville Shale Member accumulated during a transgressive phase at tide level or slightly above sea level much of the time. At no time was the altitude of the land surface in Wilson County sufficient to allow the development of deep scour channels. The variation in thickness of the Snyderville member probably reflects local warping of the land surface during accumulation of this thick argillaceous unit.

The basal member of the Oread reflects transgressive to regressive marine conditions. The upper sandy facies of the Toronto is interpreted as indicative of a shallow sea and a nearby land area. The sinuous interchanneling appearance of the uppermost part in a few places is
thought to reflect local but strong shoreline current action causing intermixing of calcareous sand and limy mud. The lithology of some beds suggests that currents moved algal fronds and fragments into local pockets. Generally, beds in the upper part of the member are indicative of near-shore marine conditions in a receding sea where evaporation allowed hypersaline waters to form; these waters supported a population of marine plants (algae) and invertebrate animals. The lower part of the Toronto member in most places in the county is composed almost entirely of fusulinid remains, but locally, the fauna includes broken parts of all the constituents of a normal transgressive succession (ostracodes, pelecypods, gastropods, bryozoans, brachiopods, corals, and fusulinids). An apparent equivalent of this fauna is found in the uppermost calcareous shale of the Wathena Shale Member of the Lawrence Formation but more commonly a lithologic break occurs at this contact. A continuation of the fauna during the addition of large quantities of calcareous material to the environment resulted in an apparent concentration of calcium carbonate sufficient to form limestone during the early stages of transgression; argillaceous material then became a minor constituent in western Wilson County. Nevertheless, Troell (1965, p. 20-21) considered the upper part of the Wathena Shale Member of the Lawrence Formation to be a part, at least locally, of the transgressive phase of the cyclothem that includes
the lower part of the Toronto Limestone Member of the Oread Limestone.

Thus, the Oread Limestone reflects the deposition of two cyclic units, a complete megacyclothem in the upper part and a relatively incomplete cyclothem in the lower part. According to Heckel (1975, p. 8), the bulk of each particular vertical sequence in eastern Kansas is characterized by an alternation of laterally persistent, 3 to 30 m (10-100 ft) thick, generally sandy shale formations with equally persistent 3 to 15 m (10-50 ft) thick limestone formations containing thin shale members. Heckel (1975, p. 8) states further: "Moore (1936, 1949) regarded couplets of successive limestone and shale members as cyclothems, and most significantly, he recognized that particular distinctive limestone-shale-member couplets were repeated upward in the same sequence in several different limestone-shale formations to produce repeating cycles of cyclothems that he termed 'megacyclothems'". Inasmuch as the middle of the megacyclothem usually corresponds to a limestone formation, this formation name is applied to the corresponding megacyclothem. The upper and lower limits of a megacyclothem lie within the adjacent shale formations, which are termed "outside" shales because they lie outside the limestone-shale bundles that constitute the main part of the megacyclothem (Heckel, 1975, p. 8).
Two to five more or less distinctive limestone members characterize lower Virgilian and Missourian megacyclothems in eastern Kansas. These limestone members are designated "lower", "middle", "upper", "super", and "fifth" from their relative positions in the most complete megacyclothem. Only the middle and upper limestone members are present in nearly all these megacyclothems. The other limestone members are present in less than half the megacyclothems, and Heckel and Baesemann (1975, p. 506-507) regard the other limestone units as little more than "fortuitous occurrences"; in the case of some "super" limestones, parts of the upper limestone member are separated by a "fortuitous" shale (Heckel, 1975, p. 8).

"Significantly, the middle and upper limestone members are separated by the most distinctive of the shale members, the one that typically contains a black fissile-to-platy facies, which commonly carries phosphorite laminae and nodules and lacks benthonic fossils. This member is commonly referred to as the 'black shale member' even though the black platy facies is not always present. (This absence gave rise to the concept of 'phantom black shales' of Moore, 1950, because the only position in which the black facies does occur in the Upper Pennsylvanian in eastern Kansas is between the middle and upper limestone members.)" (Heckel, 1975, p. 8).

The basic pattern that emerges to characterize a single transgressive-regressive sequence (cyclothem) in
the Upper Pennsylvanian, then, is (in ascending order)s
outside

(nearshore)

limestone member— core

shale--middle
(offshore)

(transgressive)

shale member— upper

(regressive) limestone member— outside (nearshore) shale
member (Heckel,


The core shale is the

black shale member in the Heckel system,

because it forms

the core of the 5-part sequence between "outside" shales.

The "Douglas Formation" was named for Douglas County,
Kansas

(Haworth,

1898, p.

93),

where

it is typically

exposed; it was defined to include all strata between the
top of the Oread Limestone and the top of the Stanton
[Garnett] Limestone.

Elevation of the unit to group

status and redefinition of its boundaries was initiated by
Moore

(1931, chart), who placed in the group only the

strata bounded above by the base of the Oread Limestone
and bounded below by the unconformity at the base of the
Stranger Formation.
contact

of

the

In 1963, O'Connor moved the lower

Douglas

Group

to

include

the

latan

Limestone and the Weston Shale of the Pedee Group.
latan and Weston were

reduced

The

from formation rank to

member status and became the latan Limestone Member and
the Weston Shale Member of the Stranger Formation; the
name Pedee Group was abandoned. The Missourian-Virgilian
Stage boundary is placed at the base of the redefined
Douglas Group (O'Connor, 1963, p. 1876,

137

1877).

In the


same paper, O'Connor changed the name Lawrence Shale to Lawrence Formation and moved the base of the formation down to include the Haskell as a limestone member of the Lawrence Formation. Thus, the Lawrence would contain, downward, an unnamed shale member, the Amazonia Limestone Member, the Ireland Sandstone Member, the Robbins Shale Member and the Haskell Limestone Member. The Stranger Formation would contain (downward) the Vinland Shale Member, the Westphalia Limestone Member, the Tonganoxie Sandstone Member, the Iatan Limestone Member and the Weston Shale Member. As thus defined, the Douglas Group consists chiefly of clastic rocks. The Douglas Group in Wilson County now averages about 61 m (200 ft) in thickness and consists of alternating sandstone, siltstone, shale, and thin limestone units. The principal source terrane of terrigenous detritus for the Douglas Group is believed to have been the northern flank of the Arbuckle and Wichita Mountains; the Ozark Dome and its western periphery were of secondary importance as a source area (Ball, 1964, p. 317).

**Lawrence Formation**

**Naming, Distribution and Thickness.** This formation was originally named the Lawrence shale for exposures at Lawrence, Douglas County, Kansas, by Haworth (1894, p. 122) who assigned to it 64 m (210 ft) of shale and interbedded sandstone and limestone. Later, the
Lawrence was restricted to strata above a regional unconformity near the middle of the formation (Moore, 1936, p. 155). As thus restricted, the formation consisted of 30 to 46 m (100-150 ft) of shale with a thin limestone member, the Amazonia, near its top and a thick sandstone member, the Ireland, at its base (Moore, 1936, p. 156-157).

When the name was changed to the Lawrence Formation and the strata redefined to include the Haskell as the basal limestone unit by O'Connor (1963, p. 1877), the Lawrence Formation consisted (downward) of an unnamed shale unit, the Amazonia Limestone Member, the Ireland Sandstone Member with an unnamed coal bed, the Robbins Shale Member, and the Haskell Limestone Member. The unnamed shale unit in the uppermost part was designated the Wathena Shale Member by Stanton M. Ball (1964, p. 158) giving the Lawrence Formation a total of five named members (downward) (Table 1). The Lawrence Formation in Wilson County averages around 21 m (70 ft) thick; the thickness ranges from about 18 m (60 ft) near the northwestern corner of the county to more than 30 m (100 ft) in the southwestern part (Plate 3A, 3B).

Lithologic Character. The Lawrence Formation is almost entirely shale in the northwestern corner of the county but becomes predominantly massive sandstone in the southwestern part. The upper part of the formation presumably maintains its shaly character; the difference in
lithology results from the addition of a thick sandstone body in the lower part (Plate 3A).

*Wathena Shale Member.* The name Wathena for the upper part of the Lawrence Formation was proposed in 1964 by Stanton M. Ball in his doctoral dissertation at the University of Kansas. The name was taken from the town of Wathena, Doniphan County, Kansas. The proposed type section is an abandoned quarry along the Missouri River bluffs about 1 km (0.6 mi) south of the town of Wathena. The type locality is in the NE 1/4, Sec. 33, T 3 S, R 22 E (Ball, 1964, p. 158).

In Wilson County the Wathena Shale Member consists of about 8 m (25 ft) of gray and varicolored nodular shale. The uppermost 0.6 to 0.9 m (2-3 ft) is medium light-gray to light olive-gray very calcareous, fossiliferous, nodular claystone that locally grades upward into the Toronto Limestone Member of the Oread Limestone (Figure 16A). Fusulinids are extremely abundant in most exposures of this uppermost part, together with a few foraminifers of the genus *Tetrataxis.* Also present are the brachiopods *Chonetes* and *Dictyoclostus,* the ostracodes *Bairdia* and *Amphissites,* and the unidentified broken remains of ramose bryozoans, brachiopods, crinoids, corals, and echinoid spines and plates. The lower one-half of this member is only sparingly fossiliferous, but concentrations of pelecypods occur locally.
Figure 16. Uppermost and lowermost parts of the Lawrence Formation in Wilson County. (A) Williamsburg coal (at pick) separated from the basal limestone of the Oread by calcareous shale of the Wathena Shale Member near the center NE 1/4 sec. 23, T 27 S, R 13 E. (B) Cross bedding in the Ireland Sandstone Member near the center NW 1/4 sec. 25, T 27 S, R 13 E.
A thin coal bed conformably underlies the fossiliferous claystone (Fig. 16A) and where exposed is found consistently about 0.9 m (3 ft) below the top of the Wathena Shale Member (Plate 3A-12, 15, 16, 17, 18). The coal is correlated with a minable coal, the Williamsburg coal, that occurs at essentially the same stratigraphic position near Williamsburg, Franklin County, Kansas. The coal is 5 to 10 cm (2-4 in) thick in Wilson County and generally contains argillaceous layers at the middle and near the top. About one-third of the coal bed is vitrain and fusain, about one-third is argillaceous (bony) coal. Approximately 30 cm (12 in) of dusky-blue plastic claystone (underclay) immediately underlies the coal bed.

Mottled light-gray and moderate reddish-orange claystone, 2.4 to 3 m (8-10 ft) thick, occurs below the underclay and is underlain by 0.6 to 1.5 m (2-5 ft) of dark reddish-brown claystone which contains large blotches of pale-olive slightly silty claystone. Reddish-brown and nearly white calcareous nodules 1.3 to 15 cm (0.5-6 in) in length, as well as small euhedral gypsum crystals, are common in this claystone unit. The lower 2 m (6 ft) of the Wathena Shale Member consists of dark reddish-brown and moderate olive-gray slightly silty claystone from which many small ironstone concretions weather.

Amazonia Limestone Member. The Amazonia Limestone Member was named for exposures near Amazonia, Andrew County, Missouri (Hinds and Greene, 1915, p. 31,
where it consists of gray, even-bedded, sparsely fossiliferous, fine-grained limestone 1.2 to 2.7 m (4-9 ft) thick near the type locality; it lies about 7.3 m (24 ft) below the top of the Lawrence Formation.

Limestone beds correlated with the Amazonia Limestone Member crop out about 7.6 m (25 ft) below the top of the Lawrence Formation at six localities in Wilson County and adjacent area. In the SW1/4 SE1/4 Sec. 26, T 27 S, R 13 E, the Amazonia is 13 cm (5 in) thick and consists of yellowish-gray, medium-grained, sparsely fossiliferous, sandy limestone. The sand grains are mostly fine-grained quartz, are moderately well sorted, and are subangular and nearly equant. Fossils include crinoid stems, productid spines, fenestrate bryozoans, brachiopod shell fragments and Osagia(?). Somewhat over 1.6 km (1 mi) farther north in the SE1/4 NW1/4 Sec. 23, T 27 S, R 13 E, the limestone bed is 20 to 25 cm (8-10 in) thick and is very light gray, porous, and very fossiliferous. It is made up almost entirely of small brachiopods (Juresania) and pelecypods (Aviculopecten), plus productid spines, crinoid stems, ramose bryozoans, and many unidentified shell fragments. Nearby, in two exposures along the north line NW1/4 Sec. 23, T 27 S, R 13 E, the Amazonia is an iron-stained, very light olive-gray to very pale yellowish-brown fossiliferous limestone (Plate 3A-15). The bed is about 0.5 m (1.5 ft) thick and consists of well bedded, sandy, finely micaceous
limestone. In the upper part, crinoid stem segments with star-shaped centers are particularly conspicuous, and abundant *Aviculopecten* occur near the middle of the bed in conjunction with *Nucula(?)*. Other fossils include the brachiopods *Juresania, Derbyia, and Chonetes*; encrusting, ramose, and fenestrate bryozoans; productid and echinoid spines; crinoid calyx parts; and small horn corals. Near the SW cor. Sec. 13, T 27 S, R 13 E, the Amazonia is a light brownish-gray, medium-crystalline, slightly fossiliferous limestone. It contains unbroken remains of the brachiopod *Chonetes*, fragments of other brachiopods, and crinoid columnals. A unit of impure, poorly bedded, finely micaceous limestone represents the Amazonia near the center of the west line SE 1/4, Sec. 14, T 27 S, R 13 E. It is ripple marked and has only a few fossils (mostly crinoid stems and brachiopod fragments) that occur in small pockets. The sixth exposure consists of about 0.5 m (1.5 ft) of light-gray to mottled grayish-orange limestone at the SW corner SE 1/4 Sec. 14, T 27 S, R 13 E. The limestone is very fossiliferous, contains abundant crinoid stem segments and brachiopods that weather out of many thin-bedded limestone fragments.

*Ireland Sandstone Member.* The Ireland Sandstone Member was named by Moore (1932, p. 93) for exposures on the Ireland Farm, 8 km (5 mi) southwest of Yates Center, Woodson County, Kansas. The type locality is only 10 km (6 mi) north of Wilson County, and the member there is
lithologically the same as in Wilson County. According to Verville and others (1958, p. 26) "In this part of Kansas, the Ireland Sandstone is regarded as including beds that lie next below the Amazonia Limestone." Ball (1964, p. 142) in his study of the Douglas Group accepted Verville's statement and redefined the Ireland to include all strata between the Amazonia Limestone Member (above) and the Robbins Shale Member (below). As thus defined, the Ireland member in Wilson County ranges in thickness from 4.6 to 34 m (15-110 ft) and comprises 1 to 3 sandstone beds separated by silty or sandy shale units. The shale units thin and thicken laterally and in many places are missing. Where the shale units are absent, the sandstone beds form a sandstone unit as much as 43 m (140 ft) thick (Plate 3A). This sandstone is formed of several thick beds similar to the thick rippled sandstone lithotype of Rutan (1980, p. 27, fig. 6). In fresh exposures, the shale units range from light gray to light olive gray; they weather to yellowish gray and moderate yellowish brown. The shale units generally are silty but may be very silty or sandy. The beds that form the upper sandstone unit are each 1.5 to 3 m (5-10 ft) thick and form breaks in slope or prominent escarpments. They are commonly grayish orange to moderate brown and have well-developed ripple marks; worm(?) tracks are locally abundant on bedding planes. The sand grains are predominantly quartz of very fine size, well-sorted, subrounded, and are in part
cemented by small concentrations of limonite which give a speckled appearance to the rock; mica flakes are sparse and restricted to certain beds in a few areas. In addition to the quartz and mica flakes, Sanders (1959, p. 147) reported a few tourmaline and chlorite grains in his samples. Permeability, measured with both an air permeameter and a water permeameter varied from 65 to 132 Meinzer units in samples taken near the center of the channel studied. Casts of crinoid stems, low-spire gastropods such as Worthenia(?) and others, the pelecypods Allorisma, Nuculana, Schizodus(?), and Aviculopecten, and the brachiopods Crurithyris and other unidentified genera were found in a few places in the upper sandstone unit and in the upper part of the lower sandstone bed.

The lower sandstone bed averages about 6.1 m (20 ft) in thickness, is locally cross bedded (Fig. 16B), and fills channels some of which were apparently cut at least 30 m (100 ft) into the underlying rocks (Plate 3A, 3B). The base of the Ireland is poorly exposed in most places, but is well shown in a roadcut on State Highway 96 about 10 km (6 mi) northwest of Fredonia (SE 1/4 SE 1/4 Sec. 8, T 28 S, R 14 E) (see Figure 17). The bedding in the upper 3.7 m (12 ft) of this exposure is both lenticular and truncated. The sandstone beds are composed almost entirely of subrounded, well-sorted, nearly equant, fine to very fine quartz grains; few to several angular fragments of
Figure 17. Roadcut exposure of the lower part of the Ireland Sandstone Member of the Lawrence Formation. State Highway 96 near the SE cor. sec. 8, T 28 S, R 14 E.
carbonized wood occur on bedding planes in the lower 0.3 m (1 ft). Elongate bodies of siltstone and sandstone containing much broken carbonaceous matter occur in the lower 0.6 m (2 ft) of sandstone in the roadcut, and fragments of light olive-gray shale are abundant in the basal 5 cm (2 in) of the sandstone. Bower (1961, p. 7, 8) discussed and pictured the same outcrop shown in Fig. 17. He, too, noted the numerous rounded clay bodies derived from the underlying shale. Fragments of Calamites are common locally as noted also by Henning (1984, p. 72).

The Ireland forms the capping of several ridges and dip slopes, supports a relatively dense growth of oak trees, has many perennial springs and, next to gravels in the Fall and Verdigris River valleys, is the best source of potable water in Wilson County.

**Robbins Shale Member.** The Robbins Shale Member of the Lawrence Formation was originally the uppermost member of the Stranger Formation. It was redefined as a member of the Stranger Formation. It was redefined as a member of the Lawrence Formation by O'Connor (1963, p. 1877). The Robbins was named by Moore and Newell (Moore, 1936, p. 153, 154) for exposures about 8 km (5 mi) north of Wilson County on the Robbins farm in sec. 11, T 26 S, R 15 E. At the type locality, the member is a marine argillaceous shale of variable thickness (Moore, 1936, p. 153). In Wilson County, it is predominantly a light olive-gray slightly silty, locally fossiliferous shale that is
characterized by beds and lenses of small ironstone concretions. It averages about 24 m (80 ft) in thickness in the county but ranges from 15 m (50 ft) in the northern part to as much as 37 m (120 ft) in the southern part (Plate 3,B). The change in thickness was apparently caused by erosion, which removed the upper 15 to 21 m (50-70 ft).

The upper 6 to 15 m (20-50 ft) of the Robbins is light olive-gray to moderate olive-brown silty to sandy shale that characteristically contains abundant moderate yellowish-brown to dark yellowish-orange oval ironstone concretions. In the northern part of the outcrop belt, 1.5 to 4.6 m (5-15 ft) below the overlying Ireland, is a thin sandy concretionary bed that lies above two thin beds of moderate yellowish-brown sandstone or sandy siltstone that occur in the middle 6.1 to 9.1 m (20-30 ft) of the Robbins.

At three localities, fossiliferous zones consisting of two or three thin beds of limestone or a 1.5 m (5 ft) unit of very fossiliferous clay shale occur in the member. In a road-cut at the center of the west line of Sec. 12, T 29 S, R 13 E, the Robbins Shale Member contains well-preserved fossils in a bed about 17 m (55 ft) below the top. Included are the brachiopods *Chonetes, Chonetina, Composita, Crurithyris, Derbyia, Dictyoclostus, Hustedia, Marginifera, Punctospirifer*, the gastropod *Worthenia*, and another that closely resembles *Hypselentoma*, a pelecypod.
close to *Nuculopsis*, a horn coral, ramose bryozoans, ostracodes, arenaceous foraminifers, and many crinoid stem segments. Three thin fossiliferous limestone beds separated by shale and siltstone occur about 6.1 m (20 ft) below the top of the Robbins in the railroad cut under the bridge at the SW corner Sec. 11, T 30 S, R 13 E. The beds are medium gray where fresh, and light brown and friable where deeply weathered. They are generally slightly silty to sandy and micaceous, and contain such fossils as *Chonetes*, *Condrrathyra(?), Crurithyris, Derbyia, Dictyoclostus, Linoproductus, Marginifera, Neospirifer, Nuculopsis(?), unidentified gastropods, crinoid stem segments, fusulinids, and *Osagia(?). Coalified organic fragments occur locally in the sandy phase of the limestone. In the northwest corner Sec. 25, T 29 S, R 13 E, the Robbins contains *Chonetes* and several productid brachiopods about 14 m (45 ft) below the top. The contemporaneity of these three fossil zones is doubtful, but they establish a marine environment during at least part of Robbins time. They could possibly represent extensions of the Amazonia Limestone Member, but appear to be too low stratigraphically.

The shale in the lower 9 to 12 m (30-40 ft) of the Robbins is moderate greenish gray to yellowish gray and slightly silty. Ironstone concretions are fairly common in the upper part of this portion of the member, but are less abundant toward the base where the shale becomes dark.
gray to black and fissile and contains small phosphatic concretions in the lower 8 to 30 cm (3-12 in) in many outcrops. Miller and Swineford report a unique assemblage of clay minerals, casts of fish brains, and phosphatic and goethite nodules at the base of the Robbins (Miller and Swineford, 1957). A 5 cm (2 in) bed of dark yellowish-orange very fine-grained sandstone forms the basal bed of the Robbins Shale Member locally in the SE1/4 sec. 5, T 27 S, R 14 E.

**Haskell Limestone Member.** The Haskell Limestone Member was named by Moore for exposures near the Haskell Institute at Lawrence, Kansas (Moore, 1932, p. 93) where it was mapped as the upper limestone member of the Stranger Formation. The Haskell was later redefined and placed as the basal member of the Lawrence Formation (O’Connor, 1963, p. 1877). The Haskell Limestone Member was described by Moore (1936, p. 153) as a single ledge of hard, bluish-gray, fine-grained limestone without shale partings. In Wilson County, the Haskell is generally a single hard limestone bed 0.3 to 0.5 m (1-2 ft) thick; locally, in the NW 1/4 SW 1/4, sec. 19, T 28 S, R 14 E, it has a brecciated-appearing, shaly limestone unit in the middle and lower parts and is as much as 2.4 m (8 ft) thick. Where thick and with a brecciated appearance, the Haskell may have developed a small phylloid algal bank as shown diagrammatically by Heckel and Cocke (1969, p. 1059, fig. 1). The Haskell conformably underlies the Robbin
Shale Member throughout Wilson County and was noted by Ball (1964, p. 313) as being the most widespread of the limestones in the area he studied.

In the northern and southern parts of the county, the Haskell is generally less than 0.6 m (2 ft) thick and is chiefly a hard, medium-gray limestone that weathers light olive gray and is vertically jointed (Figure 18A). Petrographically, the matrix appears as cryptocrystalline calcite in which minute fossil fragments are concentrated locally in pockets. Larger fossil fragments, many of which are surrounded by algal coatings, are common throughout. The coatings are a sequence of irregular, crenulated layers that surround the fossil fragment and maintain the general shape of the fragment. They resemble closely the *Osagia* pictured by Johnson (1946, pl. 4, Figure 4) and, as in his illustration, are associated with *Nubecularia*. Small oolites are present in the matrix, but are rare. Fibrous calcium carbonate composes the outer rinds of a few of the oolites and the middle parts of some shell fragments. The outer parts of the shell fragments are crystalline calcite; the long directions of the crystals are oriented perpendicular both to the shell edge and to the fibrous coating of calcium carbonate. The most common fossils are crinoid stems and large *Osagia* or oncites; less abundant are long slender fusulinids (most commonly near the top), lophophyllidid corals, ramose bryozoans, fenestrate bryozoans, the brachiopods *Hustedia*,...
Figure 18. Haskell Limestone Member of the Lawrence Formation. (A) Typical exposure of Haskell showing vertical jointing. Myalina near hammer is from the uppermost part of the Vinland Shale Member of the Stranger Formation or base of the Haskell. SW cor. Sec. 34, T 26 S, R 14 E. (B) Weathered surface showing brecciated facies in NW 1/4 Sec. 12, T 29 S, R 13 E. (C) Weathered surface showing crenulated algal bodies in SW 1/4 Sec. 23, T 29 S, R 13 E.
Crurithyris, Chonetes, and Composita, and productid spines. Insoluble residues contain the arenaceous foraminifers Tolypammina and Ammovertella, and a few fine- to medium-size quartz grains that are regenerated; some show etched and pitted surfaces.

The Haskell thickens markedly in the west-central part of the county, in an area 4 km (2.5 mi) north to 5 km (3 mi) south of New Albany. The additional thickness, from 0.7 to 1.3 m (2-4 ft), consists primarily of platy or shaly limestones that in most places appear to overlie the single hard bed; in other areas that lack exposures, they seem to underlie the position of the hard limestone bed. The shaly limestone crops out as thin, wavy-surfaced limestone plates that are light gray and yellowish gray. The weathered surface of the thickened Haskell has a brecciated appearance (Fig. 18B) produced by 1.3 to 2.5 cm (0.5-1.0 in) angular areas of pale yellowish-orange limestone in a matrix of very pale orange limestone. Thin veinlets (broken algal plates?), 0.3 cm (0.12 in) wide, of olive-gray calcite generally separate the cryptocrystalline fragments from the matrix. In thin section, the matrix appears as very finely crystalline, limonitic calcite containing scattered crenulated Osagia (Cryptozoan?) and small fragments of brachiopod(?) shells and coarsely crystalline calcite (crinoid stem fragments?), as well as a few small oolites with radial structure in the outer part and concentric structure.
throughout. Enclosed in this matrix are cryptocrystalline limestone fragments in which are found the shells of small Foraminifera, large Osagia or oncolites, brachiopod shell fragments, and crinoid remains (Fig. 18C). A few small spheres of iron oxide were noted in the matrix, but most of the iron is now dispersed as limonite stain. The veinlets of calcite resemble cross-section views of brachiopod shells, but their pattern is too complex for that origin, and they are probably broken fronds of phylloid algae (Fig. 13).

The portion of the Haskell Limestone Member described in the previous paragraph is almost identical to the algal banks discussed by Van Buskirk (1986, p. 31-36) in Chautauqua County immediately to the southwest. The thickened Haskell in Wilson County appears to be an algal bank comparable in size and content to those in Chautauqua County. The brecciated appearance and thin veinlets of calcite that resemble cross-section views of brachiopod shells are also similar to those shown by Harbaugh (1961, plates 2, 4, 9, 10). These photos are of specimens of leaf-like algal fragments from Kansas and New Mexico which Harbaugh believes resemble the alga Eugonophyllum (Konishi and Wray, 1961, p. 660, 663). Heckel and Cooke (1969, p. 1073-1074) also noted that locally the Haskell thickens to 1.8 m (6 ft) and contains zones of algal calcilutite, which the thickened areas I mapped must represent.
In a few places, the basal 5 cm (2 in) of the Haskell is a hard, medium-crystalline limestone that is sandy and micaceous and contains a pelecypod fauna composed of large *Myalina* (*Orthomyalina?*) (Fig. 18A). Small oolites and fragments of brachiopods, fenestrate bryozoans, and crinoids are also present in the basal 5 cm (2 in).

**Stratigraphic and Structural Implications.** The fusulinid-bearing, fossiliferous, calcareous, clay shale of the Wathena Shale Member that overlies the thin coal bed in the uppermost part of the Lawrence Formation indicates a complete regressive pulse to shoreline swamp conditions followed shortly by transgression to a relatively deep-water marine environment of the basal member of the Oread Limestone. The presence of pelecypods above the coal, and of ostracodes and thin-shelled brachiopods as well as the remains of thick-shelled brachiopods, bryozoans, crinoids, corals, and echinoids, supply good evidence of marine transgression. Prior to this transgression, debris of land plants, some in large fragments (vitrain) but mostly as finely comminuted matter (attrital coal) and interlaminated with carbon-rich clay (bony coal), attests to coal swamp conditions.

The red and gray claystones with calcareous nodules and small gypsum crystals in the lower part of the Wathena Shale Member suggest that alternating near-shore marine and brackish water or inland lake environments preceded the coal-forming stage. The several lithologic types and
faunas of the Amazonia Limestone Member indicate that a brief, shallow encroachment of the sea filled separated local basins and allowed the development of different marine organisms in these basins and the deposition of different calcareous materials in each. The lenticular shales and sandstones below the Amazonia suggest that the shoreline of the sea had remained in the Wilson County area for a time sufficient to allow channels as deep as 30 m (100 ft) to be cut. The fluvial channels had been filled with sand and silt derived from a vegetation-covered land area that supplied a quantity of carbonaceous fragments among which were large pieces of *Calamites*. The vegetation had presumably been drowned when the sea swept far into the area for a short period and laid down a blanket of sand in which were engulfed the remains of gastropods, pelecypods, small brachiopods, and crinoid stem fragments. Local influxes of clay-size and sand-size debris led to the accumulation of interfingering deposits of sand and shale of variable thicknesses. Such areas of shoreline erosion and sand deposition are important to the accumulation of petroleum.

Lack of fossils in the upper shale of the Robbins indicates that the sea water was not amenable to abundant marine life or its preservation during deposition of clay-size material. Ironstone concretions in the upper part of the member possibly reflect local concentrations of ferrous oxide that collected in lagoonal or restricted bay
environments. Sandy limestone beds, one of which contains abundant fusulinids, indicate that a fairly deep-water marine environment was present in Wilson County during part of Robbins time, or that a distant fauna was carried into the area. The small areal extent of these calcareous beds suggests the possibility that the limestone-forming environment may have been confined to local bays or arms of the sea. The presence of sand in the limestone suggests that currents strong enough to carry sand grains entered the area intermittently, possibly as a result of storm conditions. The black, fissile, conodont-bearing shale near the base of the Robbins indicates that a quiet, relatively stagnant water environment, in which plant growth and phosphate were concentrated, was in effect near the start of Robbins time. This sort of environment was also envisioned by Moore (1929, p. 465) for black shales when he suggested that they were deposited in a nearshore area controlled by "stagnation not unlike that of the coal swamps and quiet, undisturbed sedimentation of a humus muck. Extremely shallow water, with sunlight promoting abundant plant growth and aiding in partial decay, with too little depth for circulation and effective wave or tidal agitation, seem to offer the environment required." Ball (1964, p. 281) pointed out that Miller and Swineford (1957, p. 2012) described an almost identical depositional environment for nearshore, shallow-water phosphatic nodule formation. Thus the two hypotheses would seem to
substantiate each other. However, Heckel (1977, p. 1065) has more recently become a proponent of a deeper water environment for deposition of phosphate-rich black shales. He believed that the equator during Pennsylvanian time nearly paralleled the trend of the Appalachian Mountains (Fig. 11), and that the opening for the introduction of sea water into the nearly flat Midcontinent epicontinental sea was probably through west Texas. This opening must have faced westward into the ocean along the equatorial margin of the southwest-directed winds of the trade-wind belt where many factors combined to promote upwelling of deeper ocean water. As the epicontinental sea became deeper, a thermocline is presumed to have developed during transgression. The thermocline would have prohibited sea-bottom oxygenation by use of shallow-depth small cells of wind-driven vertical circulation (Fig. 11A, B) such that a large cell of quasi-estuarine circulation would have developed and brought the deeper, cold, oxygen-poor, phosphate-rich water in along the bottom of the epicontinental sea to upwell and cause phytoplankton blooms. Settling and decay of organic matter from the phytoplankton, as it was carried outward by surface circulation into the deep incoming water, would have depleted all the available deep oxygen and continually enriched the phosphate content in a circulatory trap. This eventually would have produced an anoxic bottom environment in which phosphate became sufficiently
concentrated to foster deposition together with substantial amounts of undecomposed organic matter and thus to form the thin widespread phosphatic black-shale facies. Each major transgressive-regressive sequence, therefore, represents one complete eustatic rise and fall of sea level starting with deposition of an outside shale followed by a middle limestone, a core (black) shale, an upper limestone, and an outside shale; in other words, a nearshore rapid coarse detrital influx, rapid transgressive carbonate production, settling of fine organic- and phosphatic-rich detritus in a deeper water offshore environment, followed by slow regressive carbonate production and nearshore detrital influx (Heckel, 1977, p. 1064, 1065).

The local presence of basal sandstone shows that sand was introduced into certain small areas at the beginning of Robbins time. The variable thickness of the Robbins Shale Member is presumably due principally to beveling by erosion following uplift of the land surface in the northern part of the county and withdrawal of the sea in early Lawrence time.

The lithology and fauna of the Haskell Limestone Member indicate a depositional sequence much like that of the Leavenworth Limestone Member of the Oread. The faunal change from oolites, corals, bryozoans, and brachiopods, to fusulinids and then to algae indicates that the environment changed from shallow water to relatively deep
water and then to shallower supersaline water. The breccia in the member may be the result of the exposure, desiccation, and redeposition of the lime muds, or it may reflect the deposition of angular fragmental blade-like material resulting from the destruction of phylloid algal growths. The basal part of the Haskell indicates the modification of a near-shore muddy environment to one of relatively clear water in which calcareous material predominated.

Algal banks are composed of leaflike phylloid algae that J. L. Wray describes in a personal communication (1983) to D. F. Merriam as belonging to the genera Eugonophyllum and Epimastopora. Eugonophyllum belongs to the Family Codiaceae, whose members are green calcareous algae in which the thallus consists of a calcified blade of variable shape (Fig. 13). The cortex is divided into an inner and outer layer. This genus generally occurs in the interior of the algal bank. The other genus, Epimastopora, belongs to the Family Dasycladaceae. It, too, is a green calcareous algae whose thallus is generally large, cylindrical and unsegmented. It has numerous long branches arranged in spiral rows around a primary stem and is considered to be indicative of bank margins. All algal banks, including that of the Haskell Limestone Member of the Lawrence Formation, are thought to have been of shallow-water marine origin and to have developed along old shorelines under moderate energy
conditions; they probably preferred areas of topographic irregularity, such as an uneven seafloor (Merriam, 1986, p. 14). Most phylloid algae grew as erect plants that reached a height of about 13 cm (5 in), consisted of relatively broad, potato-chip-like “leaves”, and utilized a “holdfast”, composed of an outer cortical layer and a central medullary core (Fig. 13), to anchor themselves to the seafloor. The leaves of the algal plants were brittle and fragile and needed a quiet, warm, oxygenated environment below the effective wave base but within the clear water (photic) zone in order to grow by photosynthesis. The shape of the basin was important because if a thermocline developed, the water might become cool and anoxic (Van Buskirk, 1986a, p. 57). Salinity and especially nutrients had to be in balance to create a proper environment (Wray, 1977). Once established, the algae could flourish and produce a new generation every few weeks (Toomey, 1981); thus, they dominated the area almost to the exclusion of any other forms of life (Toomey and Babcock, 1983). As the leaves fell to the sea floor, new plants grew on top and produced a semihorizontal stacking pattern evident in the algal-mound complex. The aragonite presumably was altered to calcite after burial. Neomorphication subsequently occurred, and areas of sheltered porosity under the umbrella-like leaves were filled with sparite.
Data regarding local structural movement during Lawrence time are scant. Channels 30 m (100 ft) deep were cut into the underlying shale; uplift of the land or regression of the sea that brought about the erosion could have been either local or regional, or both.

**Stranger Formation**

**Naming, Distribution and Thickness.** The Stranger Formation was named for exposures in bluffs on the east side of Stranger Creek in Sec. 3, T 12 S, R 21 E, Leavenworth County, Kansas about 200 km (125 mi) north of Wilson County. The name appeared in a chart by Moore (1931), but the unit was first formally described by Newell (1935, p. 79-82) who included in it only about 21 m (70 ft) of strata below the persistent gray Haskell Limestone Member. Moore (1936, p. 147) pointed out that "a more desirable boundary for the top of the formation is the marked hiatus at the base of the...Lawrence shale" and revised it to include those strata. In 1963 the limits of the Stranger Formation were again revised, this time by O'Connor who removed the Haskell Limestone Member and Robbins Shale Member from the upper part and added the Iatan Limestone and Weston Shale to the lower part (O'Connor, 1963, p. 1876, 1877). As modified, the Stranger Formation contains five members, in descending order the Vinland Shale Member, the Westphalia Limestone Member, the Tonganoxie Sandstone Member, the Iatan
Limestone Member, and the Weston Shale Member (Table 1; Plate 3B). Only four of the five members are present in Wilson County, the Iatan Limestone Member not being represented. The Stranger Formation has an aggregate thickness of about 60 m (200 ft) and occupies an outcrop belt as much as 8 km (5 mi) wide that extends from the southwestern corner of the county to the middle of the north line (Plate 1). The formation is bounded above and below by limestone units of the overlying and underlying formations.

**Lithologic Character.** The Stranger Formation is predominantly clastic rocks; the upper half is chiefly shale and the lower half is mainly sandstone and siltstone. Geologic mapping of the Stranger Formation is dependent upon mapping the Haskell Limestone Member of the Lawrence Formation because only in combination with the Haskell can the Vinland and Westphalia members form a good stratigraphic marker at the outcrop in Wilson County. In combination the three units form a distinctive sequence as follows: a thin, compact, gray limestone with dark, irregular, elongate bodies throughout (the Haskell) underlain by a yellowish-gray shale that contains well-preserved large *Myalina* valves at the top (the Vinland) below which is a brown, *Osagia*-bearing impure limestone (the Westphalia).

**Vinland Shale Member.** The Vinland Shale Member as originally named by Patterson (1933, p. 17) included
strata now placed in the underlying Westphalia Limestone Member (Newell, 1935, p. 82). In the type area near Vinland, Douglas County, Kansas, the Vinland consists of about 4.3 m (14 ft) of gray, calcareous, and sandy marine shale that conformably underlies the Haskell Limestone Member of the Lawrence Formation. In Wilson County the Vinland is a light olive-gray partly calcareous claystone that averages about 2.7 m (9 ft) in thickness but ranges from 1.2 to 5.5 m (4-18 ft). It underlies the Haskell with abrupt contact and is very fossiliferous in the uppermost 8 to 30 cm (3-12 in). Almost characteristically, this upper part of the Vinland contains many unbroken valves of the large pelecypod Myalina in conjunction with Chonetes and fragments of other small brachiopods, ramose bryozoans, corals, echinoid spines, and crinoid columnals. The ostracodes, Bairdia, Hollinella, and Cytherella(?) and the foraminifer Ammodiscus (Wagner and Harris, 1953) occur in association with the Myalina. About 5 km (3 mi) north of Buxton, the uppermost part of the member is sandy.

The uppermost calcareous unit is underlain by 0.6 to 4.6 m (2-15 ft) of light olive-gray to yellowish-gray very slightly silty claystone that breaks, upon exposure, into 0.6 cm (0.25 in) squarish fragments. The only fossils observed in this part of the member are a few plant remains on bedding surfaces, but the next underlying 30 cm (12 in) is generally fossiliferous and grades downward into the Westphalia Limestone Member. This lower 30 cm
(12 in) of the Vinland is light olive-gray to yellowish-gray slightly silty claystone that locally contains either abundant brachiopods or Osagia and fusulinids. In the SE1/4 Sec. 5, T 27 S, R 14 E, the faunal assemblage includes abundant algae (Osagia), the fusulinids Pseudostaffella(?) and Ozawainella(?) and the foraminifer Tetrataxis intermixed with small gastropods, brachiopod fragments, echinoid spines, bryozoans, and ostracodes (Wagner and Harris, 1953).

Westphalia Limestone Member. The Westphalia Limestone Member was named by Moore and Newell (Moore, 1936, p. 150-151) for outcrops about 5 km (3 mi) north and east of Westphalia, Anderson County, Kansas. In the type area, the Westphalia is a thin, brown, fusulinid-bearing limestone characterized by abundant Triticites secalicus oryziformis (Newell, 1934, p. 425; Moore, 1936, p. 150). In Wilson County, the Westphalia averages about 0.9 m (3 ft) in thickness, is brown, and contains the same fusulinids; but in this area, it is more characteristically an algal (Osagia) limestone (Figure 19). In the middle part of the outcrop area in Wilson County it has a 15 to 30 cm (6-12 in) limestone rubble zone near the center, is sandy at the base, and is as much as 1.8 m (6 ft) thick (Plate 38 14, 16).

The upper 0.6 to 0.9 m (2-3 ft) of the member, which is areally the most widespread part, consists of moderate
Figure 19. Westphalia Limestone Member of the Stranger Formation. (A) Weathered surface showing abundant algae (Osagia) and fusulinids (Triticites) near the SE cor. sec. 23, T 28 S, R 13 E. (B) Thin section showing Osagia and fusulinids in a very fine grained silt and calcite matrix, ordinary light (X 10).
yellowish-brown to pale yellowish-brown impure fossiliferous limestone. Small 0.25-0.5 cm (0.1-0.2 in) bean-shaped algae (Osagia) and sparsely interspersed slender fusulinids (Fig. 19A) show in relief on the moderate yellowish-orange to pale-brown weathered surfaces. In an exposure along the north side of State Highway 96 in the SE1/4 sec. 9, T 28 S, R 14 E, this upper part of the member is a mass of flattish, oval Osagia in a finely crystalline matrix. Staining with Alizarine Red S, as outlined by Friedman (1959), reveals that the matrix in a thin section from this locality is dolomitic, and that many of the fossils have been somewhat selectively dolomitized. Most of the algae have a core of crystalline dolomite covered by several successive crenulated, wrinkled layers of cryptocrystalline calcite. Algal layers have also formed around the calcium carbonate of fusulinids, echinoid spines and plates, ramose bryozoans, and small shell fragments. Angular silt-size quartz grains are sparsely scattered throughout the rock. Some are held between the algal layers; others lie within the outer row of chambers of fusulinids, and others are found only in the matrix. Insoluble residue from this part of the member contains arenaceous foraminifers in about the same abundance as quartz grains and also a few flakes of muscovite mica. The foraminiferal genera Ammodiscus, Ammoverella, Glomospira, and Tolypammina are represented. The quartz grains are etched and pitted.
The lower 0.3 to 0.9 m (1-3 ft) of the Westphalia Limestone Member is generally pale yellowish brown and weathers grayish orange. The lower part is much more impure than the upper part and contains an appreciable amount of terrigenous material in the calcareous matrix. Impurities of clay size are most common in outcrops in the northern part of the county; impurities of silt and sand size are most abundant in outcrops in the southern part. In some localities, the argillaceous and arenaceous constituents predominate, and the rock is an algal mudstone or sandstone. At the northern border of the county (Secs. 2, 5, and 6, T 27 S, R 14 E), the algae (Osagia?) in the upper part of the Westphalia are smaller than those in the lower part where they are 1.3 to 2.5 cm (0.5-1 in) in length. These algae form multiple coatings of 2 to 20 irregularly crenulated layers around fusulinids, echinoid spines, oolites, elongate iron-oxide cores, and shell fragments (Fig. 19B). Staining and petrographic study show no dolomite in the Westphalia in this area; the matrix is cryptocrystalline calcite and clay. Angular silt-size grains of quartz are abundant throughout the matrix and within the algal growths and outer chambers of fusulinids. The shell fragments are largely unidentified; most are calcite, but a few seem to be aragonite (2V = 20° ± 5°) optically negative, high birefringence, fibrous). Insoluble residues of samples from the northern edge of the county contain numerous
Tolypammina and Ammovertella amid limonite-cemented siltstone fragments, tabular crystals of barite(?) coated with limonite, pitted and regenerated grains of clear and cloudy quartz, and flakes of muscovite mica. Near the base of the member in this area, fusulinids are very abundant, and a large alga, provisionally identified as Collinia, occurs locally. In the central part of the outcrop area in the county, the lower part of the Westphalia ranges from grayish red to dark yellowish orange and weathers pale grayish red to moderate yellowish brown. Ironstone concretions are common, and a more varied fauna occurs near the base. The brachiopods Composita, Crurithyris, Hustedia, Neospirifer, Punctospirifer, and Juresania; the pelecypods Astartella, Aviculopecten, and Nuculana; the gastropods Bellerophon and Worthenia; and fragments of fenestrate and ramose bryozoans, crinoid columnals, and unidentified small shell fragments are abundant locally in the southwestern part of the county where the Westphalia is sandy and locally thin or missing. Limonitic clay and etched fine-grained quartz in approximately equal amounts compose about 95 percent of the insoluble residue of a specimen from sec. 24, T 29 S, R 13 E. The remainder consists of a few flakes of muscovite mica, several granules of siltstone, a few grains of pyrite, and the broken tests of the foraminifers Ammovertella and Hyperammina. A thin section from near the base of the Westphalia in Sec. 25, T 29 S, R 13 E, is
of a granule or sandy limestone. About one-fourth of the rock is abraded fossil fragments, and about one-third is reworked granules of siltstone and limestone, about one-third is subangular fine-grained quartz, and the remainder is fine-grained, crystalline calcite matrix. The fossil fragments include parts of echinoid spines and plates, ramose bryozoans, fusulinids, Osagia, high-spire gastropods, and brachiopod(?) shells. Granules of cemented siltstone consist mainly of fairly well rounded angular silt-size quartz in a limonitic, argillaceous, calcareous matrix. Granules of limestone, also fairly well rounded, are less abundant. Some are fossiliferous limestone; others are unfossiliferous, argillaceous limestone. The quartz grains range from angular to round (average subangular). Most of them have sharp extinction; however, a few have wavy extinction in polarized light.

Where the Westphalia is 1.5 to 1.8 m (5-6 ft) thick south of New Albany, 0.3 m (1 ft) of sparsely fossiliferous limestone rubble (possibly deeply weathered, calcareous nodules or concretions) in a clayey limestone matrix occurs between the upper and lower parts of the member. This rubble unit is generally very pale orange except where excessive iron staining has changed it to pale yellowish orange or dark yellowish orange.

Tonganoxie Sandstone Member. The first use of the term Tonganoxie was in a stratigraphic diagram (Moore and others, 1934, chart) in which Moore used this name for
the basal member of the Stranger Formation. Moore (1936, p. 147) later designated the type locality as the area east of Tonganoxie and described the sequence as including heavy, cross-bedded, micaceous, channel sandstone, micaceous sandy shale, and several coal beds. He considered the formation to represent nonmarine fluviatile deposition upon broad coastal plains. The member fills channels or grades laterally into shale and ranges in thickness from nearly 30 m (100 ft) in northeastern Kansas to only 0.9 to 1.2 m (3-4 ft) locally in the southeastern part of the State (Moore, 1936, p. 148-150).

In Wilson County, the Tonganoxie lies conformably beneath the Westphalia Limestone Member and contains contemporaneous facies represented by massive locally cross-bedded channel sandstone and thin-bedded shaly sandstone and sandy shale. Where the Tonganoxie has the greatest amount of sandstone, as in the west-central part of the county, it grades upward and laterally through unfossiliferous calcareous sandstone into the sandy Osagia-bearing limestone of the Westphalia; in areas where the Tonganoxie is primarily siltstone and claystone, as in the northern and southern parts of the county, the upper contact is relatively abrupt but conformable. The Upper and Lower Sibley coals found locally elsewhere in the uppermost part of the Tonganoxie in eastern Kansas (Moore, 1936, p. 149; Lins, 1950, p. 114; Sanders, 1959, p. 137) were not found as such in Wilson County, although small
fragments of carbonaceous debris were found along bedding planes in sandstone a few inches below the top of the Tonganoxie.

The upper part of the Tonganoxie is principally interbedded yellowish-gray micaceous siltstone and light olive-gray silty claystone with thin yellowish-gray very fine grained, micaceous sandstone interlaminations. Siltstone and claystone occur in about equal amounts in this upper part, but in the lower part, siltstone and sandstone predominate, and the section consists of (a) alternating 3.8 cm (1.5 in) beds of yellowish gray to pale orange micaceous siltstone and 1.3 cm (0.5 in) beds of very slightly silty pale yellowish-brown claystone, or (b) grayish-orange, massive, fine- to medium-grained sandstone. Ripple marks are well developed in the siltstone beds of the upper part at many places, and where they occur the average thickness of the siltstone beds increases to about 5 cm (2 in) (Figure 20A). Interbedded claystone fills the ripple troughs and usually covers the crests with a 1.3 cm (0.5 in) layer. Where ripples are lacking, the bedding is regular and smooth (Fig. 20B). Small flakes of muscovite are concentrated on the upper surfaces of the siltstone layers. In thin sections, the siltstone is a mesh of well-sorted interlocking quartz grains. Other minerals make up less than 5 percent of the rock and consist of muscovite, magnetite(?), chert, topaz, biotite, and plagioclase, in order of abundance. The mica
Figure 20. Upper part of the Tonganoxie Sandstone Member of the Stranger Formation. (A) ripple-marked siltstone facies at south line SE 1/4 sec. 30, T 26 S, R 15 E. (B) Well-bedded siltstone facies near SW cor. sec. 6, T 27 S, R 15 E. (C) Concretion in sandstone in SW 1/4 sec. 17, T. 27 S, R 14 E.
flakes are oriented parallel to the bedding and are concentrated along bedding planes. A thin section of the interlaminated, well-bedded, argillaceous siltstone has about 15 percent clay that fills the interstices between the angular quartz grains and apparently forms a coating around most of the grains. About 80 percent of the rock is quartz and chert. A few quartz grains have wavy extinction, and some contain inclusions. Locally, the well-bedded siltstone near the top of the member contains a few beds of concretionary, very fine-grained sandstone (Fig. 20c). The beds, which are as much as 0.8 m (2.5 ft) thick, are grayish orange, very micaceous and composed almost entirely of very fine-grained, well-sorted, subangular quartz grains.

Where the channel-filling facies of the Tonganoxie is not well developed in the county, the lithologies described above extend down to the top of the Weston Shale Member, and the contact with the Weston is gradational. Elsewhere, coarser grained rocks occur in the lower part of the Tonganoxie, and the contact with the Weston is abrupt.

The channel-filling facies of the Tonganoxie is as much as 18 m (60 ft) thick but averages only about 9 m (30 ft). It is best displayed as the cap-rock on South Mound (Figure 21a) and West Mound, the erosional remnants at Fredonia, and in the oak-covered hills about 5 km (3 mi) southwest of Fredonia and about 3 km (2 mi) northeast
Figure 21. Basal part of the Tonganoxie Sandstone Member of the Stranger Formation. (A) Erosional remnant at South Mound, Fredonia, Kansas. (B) Thin section of specimen from South Mound showing sharp, interpenetrating contacts between quartz grains; crossed nicols (X 200).
of Coyville. Where thickest, the sandstone is silty and clayey near the top. It lies with sharp contact on the Weston Shale Member and generally has a zone of angular claystone fragments or a boxwork of limonite at the base. Thin-section studies of sandstone collected from South Mound at Fredonia indicate a coarsening of grain size and an increase in angularity of the grains downward through the 3 m (10 ft) of poorly sorted sandstone. In the upper and middle parts of the unit, the sandstone ranges from very fine to medium grained but averages fine grained in the upper part and medium grained in the middle part. In the lower part, it ranges from very fine to coarse grained and averages medium grained. Quartz is the predominant mineral throughout the unit and makes up nearly 90 percent of the grains. About one-third of these grains have embayed contacts; some are interpenetrating and stylolitic (Fig. 21B). Many grains have fine inclusions, and a few have undulatory extinction. Chert grains are the next most abundant constituent of the sandstone and range from less than 5 percent in the upper part of the sandstone at South Mound to about 10 percent in the lower part. Other constituents, which make up considerably less than one percent of the rock, include magnetite, muscovite mica, hypersthene, zircon, topaz (?) and plagioclase feldspar. Limonite and clay commonly fill the interstices between grains and are more prevalent in the middle and lower parts. Small spots of limonite give a speckled appearance.
to the rock. The Tonganoxie is essentially monomineralic but unlike most monomineralic sandstones, which have well-rounded grains due to much transport and reworking, many of the quartz grains in the Tonganoxie are tabular, angular fragments indicating that regrowth or solution has modified previously rounded corners to sharp angles. On the other hand, the features that are attributed to regrowth or solution may have been authigenic in origin and may have been subjected to almost no abrasive action.

Weston Shale Member. The Weston Shale Member was named for exposures near Weston, Platte County, Missouri (Keyes, 1899, p. 306) and formerly included the shale unit between the Iatan and Stanton Limestones. The Iatan member is now classed as a member of the Stranger Formation but is not present in Wilson County; the Weston Shale Member comprises the lowermost strata of the Stranger Formation. Where the base of the overlying Tonganoxie Sandstone Member of the Stranger Formation is conglomeratic, the top of the Weston is sharply marked by a local erosional unconformity. Elsewhere in the county, the Weston grades upward through a silty facies into the Tonganoxie without any apparent break in sedimentation. Accurate measurement of the thickness of the Weston in the county is difficult because of the poor exposures, lack of marker beds, and breadth of the outcrop belt. The thickness of the Weston Shale Member apparently ranges from about 36 to 43 m (120-140 ft) (Plate 3B).
The uppermost 9 m (30 ft) of the Weston is composed of interbedded medium olive-gray and moderate yellowish-brown silty shale in which are incorporated beds of grayish-orange, micaceous, very fine grained, thin-bedded sandstone, 0.3 to 15 cm (0.125-6.0 in) thick. The sandstone beds commonly contain carbonaceous remains on bedding planes. A 6 m (20 ft) unit of alternating medium olive-gray and moderate yellowish-brown slightly silty shale separates the silty shale and micaceous sandstone from an underlying clay shale about 27 m (90 ft) thick. Thin, silty shale beds show as thin bands in weathered exposures of this unit (Figure 22A).

The 27 m (90 ft) unit is the part of the Weston used for ceramic products. It consists of medium olive-gray clay shale that is vertically jointed and fissile so that it breaks readily into rectangular fragments (Fig. 22B). Ironstone concretions occur in lenticular beds and as separate oval bodies in the upper part of this lower unit. The concretions are dark yellowish orange to moderate red, and one from the South Mound at Fredonia contained a gastropod. In a study of the conodonts of the Stanton Limestone, Wood (1977, p. 30) collected one sample from the base of the overlying Weston Shale Member of the Stranger Formation. In the sample he noted frequent (10-30) specimens of Idiognathodus sp. A and rare (1-9) specimens of Anchignathodus minutus and Stepanovites conflexa.
Figure 22. Middle Part of the Weston Shale Member of the Stranger Formation at West Mound, Fredonia, Kans. (A) Weathered outcrop in brick plant pit showing thin silty beds. (B) Exposure showing well-developed bedding and jointing.
Stratigraphic and Structural Implications. The large pelecypods, ostracodes, small foraminifers, brachiopods, bryozoans, echinoids, and solitary corals in the fauna of the calcareous shale deposited in late Vinland time indicate a muddy marine environment. The plant debris and silt of the lower part of the Vinland show a considerably less calcareous and a nearer shore habitat with vegetation along the shoreline or along streams that reached the sea.

The presence of fusulinids and algae from base to top of the Westphalia seems to indicate that throughout Westphalia time the water depth was possibly only slightly less than 30 m (100 ft), thus fulfilling the relatively deep-water requirement of the fusulinids and the photosynthetic requirement of the algae. The local limestone rubble may reflect storm-wave action leading to the formation and concentration of limestone cobbles in mid-Westphalia time; or they may merely represent nodules that formed later. The restriction of basal sandy limestone to the southern part of the county implies introduction of sand-size material from a southerly direction at the start of Westphalia time and, in conjunction with the local occurrence of pelecypods and gastropods, may indicate the approximate position of the Westphalia shoreline.

Prior to this limestone deposition, the county was the site of shoreline or continental deposition of clastic
rocks of the Tonganoxie. Vegetation supplied organic fragments to the sand, and much fine-grained muscovite was introduced. The basal sand was deposited in local channels cut deeply into the near-shore muds, and the wide range in size of clastic debris and winnowing action of currents led to the deposition of sand in some areas and of silt and clay in others. Well-developed ripple marks indicate shallow-water deposition. Winchell (1951a, p. 38) states that some of the streams that carried non-marine sands into and filled channels in northeastern Kansas probably reached southeastern Kansas and deposited sand in the deeper valleys of the “Tonganoxie River” system which they subsequently filled. The marine phase which later blanketed the southeast Kansas area probably carried sandy material northward from the flanks of the rising Arbuckle and Ouachita systems and covered the lowlying area of Wilson County and the adjacent region.

The small carbonaceous fragments incorporated in sand and silt debris at the end of Weston time in the northern part of Wilson County indicate that deposition was near a shoreline along which vegetation was present. The greater amount of sand and silt in the upper beds in the northern part of the county may reflect a sediment supply from the north or a source area in the southern part of the county whose product was later removed by uplift and erosion. The coarser fraction from the upper part of the Weston near Fredonia could have been reworked and concentrated
into beds in the northern part of the county. The marine origin of the middle part of the Weston is suggested by the presence of an unabraded marine gastropod as the nucleus of one of the ironstone concretions. The nearly pure clay and its accumulation into thin even beds that lack ripple marks or other sedimentary structures suggest that the environment of deposition in middle and early Weston time was one of quiet, marine waters far from shore and lacking strong current action.

\[\text{Pedee Group}\]

[Term abandoned. See O'Connor, 1963, p. 1877]

[Iatan Limestone and Weston Shale made members of Stranger Formation]

The term Pedee was introduced by Moore (1932, p. 93, 97) for the dominantly argillaceous strata at the base of the Virgilian Stage and overlying the dominantly calcareous strata of the Lansing Group of the Missourian Stage. The term was taken from Pedee Branch in the vicinity of Weston, Missouri, about 190 km (120 mi) northeast of Wilson County, and was first clearly defined in its former usage in 1936 (Moore, 1936, p. 137, 138). At that time the Pedee Group consisted of two formations, the Iatan Limestone at the top and the Weston Shale below. The Iatan does not occur in Wilson County, but where present in Kansas it is now called the Iatan Limestone Member of the Stranger Formation. The Weston, also, is now a member of the Stranger Formation; it has been placed in
the Douglas Group and is the Weston Shale Member of the Stranger Formation (O'Connor, 1963, p. 1876, 1877).

**Missourian Stage**

First application of the term Missouri in geological literature was by Keyes (1893, p. 85), who used "Missouri terrane" in a geographic sense to replace the "Upper Coal Measures" of Broadhead (1866, p. 311, 313; 1873, p. 6). The type locality was defined by Keyes (1893, p. 85) as the northwestern part of the State of Missouri. The name Missouri received broad sanction, and in 1947 was adopted formally by the State Geological Surveys of Iowa, Kansas, Missouri, Nebraska, and Oklahoma as the Missourian Series (Moore, 1948, p. 2020, 2021, 1949, p. 66; Moore and others, 1951, p. 78). By definition, it included all strata from the unconformity at the base of the Douglas Group, or its equivalent, to the base of the Pleasanton Group, or its equivalent (Moore, 1949, p. 66-72; Greene and Searight, 1949, p. 9; Condra and Reed, 1943, p. 50; Dott, 1941, p. 1659, 1670). As noted by Moore (1949, p. 15), he and M. L. Thompson (Moore and Thompson, 1949) had proposed in an article published in the American Association of Petroleum Geologists Bulletin (p. 275-302) that the Pennsylvanian System be divided into three divisions (downward) the Kawvian Series, the Oklan Series, and the Ardian Series (Moore, 1949, p. 15, 24). These names were never adopted, but the Pennsylvanian System was
later subdivided into the Upper, Middle, and Lower Pennsylvanian Series, which resulted in reduction of the Missourian and comparable units to the stage category, e.g., Missourian Stage.

The upper limit of the Missourian Stage is placed at the base of the Stranger Formation (Douglas Group). This contact was discussed under the Virgilian Stage. The character of the unconformity at the lower limit of the Missourian Stage is well shown by outcrop sections prepared as a result of field work in Kansas by Jewett (1941, pl. 1; 1945, pl. 4), in Missouri and Iowa by Cline (1941, figure 2), and in Oklahoma by Oakes (Oakes and Jewett, 1943, figure 1). Further justification for a stage break at this stratigraphic position is furnished by the presence of a distinct faunal break at approximately this horizon as stated by Hinds and Greene (1915, p. 6) and Moore (1936, p. 52, 69-70). Furthermore, Jewett (1941, p. 299) noted that the upper limit of the occurrence of the brachiopod *Mesolobus* is about one meter (3 ft) below the base of the Hepler Sandstone, the basal formation of the Pleasanton Group of the Missourian Stage. Verification is also provided by Dott (1941, p. 1661, 1663, 1666-1668, 1672, 1673) who also noted that division between the Missourian and Desmoinesian in the Midcontinent region is based on the disappearance of the brachiopod genus *Mesolobus*; he noted further that the bryozoan genus *Prismopora*, certain important fusulinids,
and other fossils were also missing. Moore (Moore and others, 1944, p. 671, 672) stated that the boundary between the Missourian and Desmoinesian Stages is the most sharply defined and easily located datum surface in the Pennsylvanian System and listed the ranges of the different fusulinids and other faunas showing that the base of the Missourian is the upper limit of the fusulinids *Fusulina* and *Fusulinella*, the coral *Chaetetes*, the bryozoan *Prismopora*, and the brachiopod *Mesolobus*. Additional work on the fusulinids by Thompson was reported by Moore (1948, p. 2020), Thompson (1948, p. 22-24), and Moore and Thompson (1949, p. 291-296) who showed in text and diagrams the distinct faunal break in fusulinid genera at the base of the Missourian and also indicated the ranges of American fusulinid genera.

The outcropping rocks in Wilson County that are included in the Missourian Stage are in the Lansing and Kansas City Groups. In surface exposures in the county, these groups comprise the following formations listed in descending order: Stanton Limestone, Vilas Shale, Plattsburg Limestone, Lane-Bonner Springs Shale, Iola Limestone, Chanute Shale, Drum Limestone, Cherryvale Shale, and Dennis Limestone (Table 1).

**Lansing Group**

The term Lansing was introduced by Hinds (1912, p. 7) to include all strata between the base of the Weston Shale
and the top of the Iola Limestone. The limestone unit termed Iola is now known to be the combined Frisbie and Argentine Limestone Members of the Wyandotte Limestone (Moore, 1949, p. 111, 113). The type locality of the Lansing Group is Lansing, Leavenworth County, Kansas (Hinds and Greene, 1915, p. 155). After several periods of modification, the upper limit of the group was again placed at the base of the Weston Shale (which is now the Weston Shale Member of the Stranger Formation) and the lower limit at the top of the Bonner Springs Shale (Moore and Condra, 1932, chart). As thus defined, the Lansing Group is characterized by dominance of limestone and consists of two limestone formations, the Stanton Limestone above and the Plattsburg Limestone below, separated by a shale unit, the Vilas Shale (Table 1). This definition of the group was unanimously adopted by the State Geological Surveys of Iowa, Kansas, Missouri, and Nebraska in 1947 (Moore, 1948, p. 2031, 2033, 2034). All three formations of the Lansing Group are present in Wilson County where the group averages about 46 m (150 ft) in thickness.

A depositional cycle comparable to the depositional pattern suggested by several workers for eastern Kansas cyclic sedimentation was proposed by Watney (1980, p. 10-31) for strata of the Lansing and Kansas City groups in western Kansas. According to Watney the land area from which terrigenous clastic sediment came was to the north;
deeper water was to the south. In northwestern Kansas, Watney’s typical cycle is characterized by a thick “upper carbonate” zone and a thinner “lower carbonate” zone separated by a shale (“lower shale”) of variable thickness. The “upper carbonate” zone is overlain by another shale (“upper shale”). Each unit of the cycle has its unique characteristics, which allow recognition of the cycles throughout the Lansing-Kansas City section (Watney, 1980, p. 14).

Stanton Limestone

Naming, Distribution, and Thickness. The name Stanton was applied by Swallow (Swallow and Hawn, 1865, p. 6; and Swallow, 1866, p. 74) to the limestone sequence exposed near Stanton, Miami County, Kansas. Workers in nearby areas believed this sequence to be the limestone next above the Vilas Shale, but later mapping (Newell, 1935, p. 74, 76) showed that the limestone of Swallow and Hawn correlated with the lower limestone of the group, the Flattsburg Limestone, rather than with the upper limestone. By that time, however, the name Stanton had for many years been employed for the upper limestone and was well established through usage in geologic reports on the Pennsylvanian strata of Kansas, Missouri, and Nebraska (Haworth and Bennett), 1908, p. 101, 104; Hinds and Greene, 1915, p. 156; Condra, 1930, p. 32-34, 36; Moore, 1936, p. 131, 132). Its use for the upper limestone of
the group was approved at the Interstate Conference in 1947 (Moore, 1948, p. 2031, 2033) and is so used herein.

Outcrops of the Stanton Limestone are located in three different facies belts (Figure 23) designated by Heckel (1975a), from north to south, the Open-marine Facies Belt, the Algal-mound Facies Belt, and the Terrigenous-detrital Facies Belt (Heckel, 1975a, 1975b, 1977). The major transgressive-regressive (cyclothemic) sequences of the Stanton Limestone include one complete cyclothem (Captain Creek-Eudora-Stoner) and the beginning of another cycle (South Bend) according to Heckel (1975a, 1975b).

Paleontologic studies of the Stanton Limestone in Wilson County, in addition to those by Harris and the author (1953), have been done by Newell (1933), Wray (1964, 1968, 1977), Cocke (1970), Baeseemann (1973), Senich (1975, 1978), Brondos (1974, 1983) and Wood (1977). Stratigraphic studies include those by Wagner and Harris (1953), Wagner (1954, 1961), Davis (1955), Wilson (1957, 1971), Harbaugh (1960, 1962), Heckel (1966, 1975a, 1975b, 1977), and others. Along its outcrop in eastern Kansas, the Stanton ranges from 6 m (20 ft) to more than 30 m (100 ft) in thickness (Moore, 1936, p. 132). In Wilson County, it is 5 to 20 m (15-65 ft) thick (Plate 2B). The Stanton is the major escarpment-forming unit in the county and crops out diagonally from the northeast corner to the center of the south boundary (Figure 23, Plate 1). The
Figure 23. Outcrop pattern of Stanton Limestone in eastern Kansas showing positions of major facies belts (Modified from Heckel, 1975a, p. 3).
Stanton Limestone controls to a marked degree the topography of its outcrop area because of its considerable thickness and resistance to erosion. The configuration of the upper surface of the formation cannot be used as a reliable datum to analyze deeper structure as it appears merely to reflect a greater amount of limestone deposition in Stanton time. Some areas of high topography in the Stanton outcrop area are sites of structural upwarp.

The Stanton Limestone commonly lies with general conformity upon the Vilas Shale; but elsewhere algal bank limestone deposits of the Stanton and shale beds of the Vilas may form an intertonguing relationship, or the Stanton may fill shallow scours that have been cut into the top of the Vilas.

The Stanton is subdivided into three limestone and two shale members named (downward): the South Bend Limestone Member, the Rock Lake Shale Member, the Stoner Limestone Member, the Budora Shale Member, and the Captain Creek Limestone Member (Table 1). During several years with the Kansas Geological Survey and later at the University of Iowa, P. H. Heckel made exhaustive studies of phylloid algal mounds in Wilson and nearby counties in eastern Kansas (Heckel, 1966, 1968, 1971, 1972a, 1972b, 1974, 1975a, 1975b, 1975c, 1984, Heckel and Cocke, 1969). Heckel observed that a line of outcrops trended about N30°E from Fredonia to Buffalo; another set trended generally eastward from Fredonia for about 10 km (6 mi).
About 1.6 km (1 mi) north of Altoona, the latter trend changed to N70°E and continued another 16 km (10 mi) into Neosho County. Heckel designated the trend between Fredonia and Buffalo as the Northwestern Rim of his Algal Mound Tract; the trend generally eastward from Fredonia he called the Wilson County Channel (Figure 24). A subsidiary trend in the extreme southeastern part of Woodson County goes in a S70°E direction from about 5 km (3 mi) north of Buffalo essentially through the common point that bounds Woodson, Wilson, Neosho and Allen counties. This trend Heckel designated his County Line Channel. An extension to the northeast (N40°E) in Woodson County, he called the Woodson County Channel (Heckel, 1975c, p. 45; 1978, p. 28).

Each of the limestone members of the Stanton has a phylloid algal-mound phase as determined by detailed mapping of these units from southern to northern Kansas along the outcrop (Fig. 8). Doctoral dissertations and Masters theses have been written by graduate students at the University of Kansas, the University of Iowa, Rice University, and other Midcontinent universities and colleges in the process of determining the locations and extents of these algal buildups from Illinois to New Mexico. Heckel has been most instrumental in encouraging these studies and has summarized the early research on facies and distribution of such mounds (Heckel, 1974).
Figure 24. Algal mound tracts of Wilson and adjacent counties (Modified from Heckel, 1978, p. 23).
This summary and the results of recent research clearly demonstrated that calcareous algae ranged from shoal-water environments where they built small mounds, to abandoned delta lobes and shelf edges, where they constructed massive banks (Harbaugh, 1959, 1962; Frost, 1975, Wermund, 1975; Heckel, 1975b, 1975c, 1978; Toomey, Wilson and Rezek, 1977; and Welch, 1977).

**Lithologic Character.** The Stanton is predominantly a limestone unit in Wilson County. The more prominent limestone types represented in its members include oolitic sandy limestone, wavy- and thin-bedded limestone, brecciated-appearing limestone, massive, cavernous-weathering limestone, and hard, gray algal or oolitic limestone. Progressive, but periodically accelerated, uplift and nondeposition or erosion (or both) during seawater regression apparently characterized much of late Stanton time, having occurred during the deposition of the Stoner and Rock Lake Members. The time of greatest water depth was during accumulation of the black shale of the Eudora. Fluffy dickite fills cavities in algal mound limestones of the Stanton and Plattsburg formations as discrete pseudohexagonal plates. Fluffy kaolinite exhibits similar properties. X-ray diffraction patterns of dickite and kaolinite look similar as do differential thermogram analysis (DTA) patterns in these two formations. Infrared (IR) patterns have similar but diagnostic peaks according to Schroeder (1967, p. 70-72)
who states that dickite, being more sensitive to external conditions than kaolinite, forms in a more restricted environment. He concluded that the dickite from Wilson County was precipitated from meteoric waters that were heated by and mixed with magmatic solutions derived from the peridotite intrusions in Woodson and Wilson Counties. Dickite and kaolinite were also recognized in Wilson County algal mounds by Moussavi-Harami (1980, p. 108).

All limestone members of the Stanton in Wilson County are fossiliferous, but some are more so than others. The shale members are thin and locally are so calcareous that their separation from the limestone members is arbitrary. Well-preserved specimens of leaf-like and encrusting coralline red algae from algal mound complexes in the Stanton and Plattsburg limestones have been identified by Wray (1964) as two species of the genus Archaeolithophyllum: A. missouriense Johnson, and A. lamellosum Wray (Heckel and Cocke, 1969, p. 1063). In addition, green algae are also represented in the algal-mound facies chiefly by two Codiaeacean genera which were erect plants with large blades. Wray has identified them as Anchicodium and the related genus Eugonophyllum from the Captain Creek and Stoner mounds, respectively (Fig. 13). Representing another family of green algae is the Dasycladacean genus Epimastopora which was observed in the Stanton Limestone (Heckel and Cocke, 1969, p. 1064).
The observed stacking of many mound complexes suggest the possibility that great compaction in the thicker shale around an underlying mound complex produced a general topographic high that provided an environment sufficiently favorable to have triggered algal proliferation (Heckel and Cocke, 1969, p. 1067). Once, initiated, mound development continued because of the feedback effect described by Harbaugh (1964, p. 201). Shallowness of water over the mound, in conjunction with the baffling effect of the algal thicket, reduced water movement over the mound surface and gave rise to a quiet environment that allowed lime mud accumulation. This environment explains the calcilutite matrix of the mound (Heckel and Cocke, 1969, p. 1067). The algal mound sequences in the Stanton Limestone consist of buildups of phylloid algal calcilutite with a “rim” along the northwest side composed of calcarenite. The buildups are cut by contemporaneous channels filled with skeletal calcarenite and calcilutite, black shale, gray shale conglomerate, and sandstone. About 25 m (80 ft) of relief occurs between channel bases and mound tops.

Factors controlling conodont distribution in the mound complex were light penetration, temperature, oxygenation and salinity that vary with water depth (Heckel and Baesemann, 1975, p. 504-505). A study of the vertical pattern of conodont distribution in the Stanton Limestone shows that abundance and diversity increase
upward from the Captain Creek Limestone Member into the Rudora Shale Member; they then decrease upward through the Stoner Limestone Member to the Rock Lake Shale Member, and finally show a secondary slight increase upward in the South Bend Limestone Member. The greatest abundance and diversity are present in the core shale and adjacent portions of the limestone units which represent the maximum transgression and deepest water in the cyclic phase (Wood, 1977, p. 66).

Brondos (1983) collected and analyzed the results of a study of ostracodes and foraminifers in 31 samples collected from members of the Stanton Limestone and immediately adjacent strata in Wilson County. His efforts record the presence of more than 30 genera and species of ostracodes and 12 genera of foraminifers (Brondos, 1983, p. 38-60). He notes (p. 50) that because of the lack of direct evidence regarding important factors such as temperature, light penetration, or salinity in ancient depositional environments, controlling mechanisms for ostracode communities such as those from the Stanton Limestone remain open to conjecture. The apparent correlation between higher diversity, finer grain size, and distance from shoreline, however, and evidence from studies of Holocene ostracodes suggest that these physical factors also played an important role in the development
of fossil ostracode assemblages. In his study of the ostracodes of the Stanton Limestone, Brondos (1983) found that the best faunas occurred in the Stoner Limestone Member, although some were found in the Eudora and Rock Lake members. He was able to differentiate assemblages by habitat, and relegated the different genera and species to environmental occurrences by biotopes. Biotope is used in the sense of Von Bitter (1972) to mean a body of sediment representative of relatively uniform environmental conditions and characterized by a particular fauna adapted to those conditions. Brondos (1983) indicated that his offmound biotope contained *Geisina gregoria, Bairdia beedei, Regelites dattonensis,* and *Cryptobairdia hooverae*; the intramound biotope was represented by *Acratina menardensis* and *Roundyella simplissima*; the quiet water offmound environment was inhabited by *Moorites minutus, Cryptobairdia seminalis, Bairdia beedei,* and *Orthobairdia* sp.; the quiet water marine assemblage included *Paraparchites humerosus, Moorites minutus, Amphioites centronotus,* and *Hollinella* sp.; the nearshore marine or deeper biotope forms were *Amphissites centronotus, Fabalicypris acetalata, Bairdia acuminata, Orthobairdia texana, Kelletina robusta, Kirkbya firma,* and *Cyathus striatus*; the shoaling delta biotope contained *Cavellina fittsi, Pseudobythocypris pediformis, Healdi simplex, Basslerella firma, Moorites minutus,* and *Corniyella* sp.; and the marginal mound biotope consisted of *Roundyella*
simplicissima, Kegellites dattonensis, Kirkbya firma, Kelletina robusta, Monoceratina lewisi, Orthobairdia texana, and Healdi simplex; other forms were Microcheilinella unispinosa, Bairdia crassa and Schleesha pinguis (Brondos, 1983, p. 38-44). The foraminifers included the encrusting forms Tetrataxis and Tubertina, the mobile form Globivalvulina and the agglutinated form Ammodiscus (Brondos, 1983, p. 56). Throughout the area of the algal-mound complex, including also the channel and rim areas, he reported the foraminiferal genera Tubertina, Tetrataxis, Hyperammina, Apterinella, Ammoverella, Endothyra, Triticites, Ammobaculites, Orthovertella and Earlandia. The environment was entirely marine and within the photic zone, with good circulation but not high energy. An abundance of plant life provided places for attachment for those genera that preferred to live an attached life (Brondos, 1983, p. 56-64). These foraminifers have a tendency to occur in channels within the mounds or near the mound rim. Concerning foraminifers in general, Brondos (1983, p. 67-68) wrote that the high diversity of genera in the algal mound complex showed a preference for an environment with abundant places for attachment or within loose sediment depending upon their choice. Food supply, turbidity and water depth were also significant requirements.

Senich made an exhaustive study of the brachiopods, gastropods and pelecypods of the Stoner and Captain Creek
limestone members of the Stanton Limestone in Wilson County. In his study he followed Heckel’s tripartite areal breakdown of the Stanton Formation into (1) central mound, (2) channel, and (3) rim biofacies (Senich, 1975, p. 1). These three biofacies can be related to basinal calcilutite, channel and basin-rim calcarenite, and buildup calcilutite. The buildup calcilutite is generally dominated by phylloid algal blades, with local encrusting red algae and occasional stromatolitic laminations. Invertebrates consist of rare gastropods, ostracodes, bryozoans, brachiopods, and echinoderms. Channel and rim calcarenites are composed chiefly of fragments of pelmatozoan echinoderms, algae, bivalves, gastropods, bryozoans and foraminifers. Basinal calcilutite is dominated by fenestellid bryozoan fronds, brachiopods, calcisponges, crinoid remains, echinoid spines and rare phylloid algae. The algal carbonate buildups extend 8 to 24 km (5-15 mi) along the outcrop where they may fringe a basin or be transected by contemporaneous channels.

Abrupt thickening of individual members of the Stanton Limestone and lateral facies changes associated with algal-mound complexes characterize Stanton units in southeastern Kansas. Each facies is represented by a major lithology. The mound lithofacies is dominantly an algal calcilutite; the channel lithofacies and the westward-dipping rim facies are dominantly calcarenites. Abundant and diverse invertebrate biotas are closely
associated with each of these lithofacies. The mound lithofacies is dominated by phylloid algae, the channel lithofacies is dominated by echinoderm (pelmatozoan) debris, and the rim lithofacies is dominated by brachiopods. The general picture during early Stanton deposition involves a complex association of shallow, normal marine environments. Broad mud mounds rich in algae dominated most of the interior region and reflect very shallow water with strong sunlight penetration but relatively poor circulation and nutrient replenishment. Contemporaneous with the mounds was a long, linear, skeletal sand-filled algal-poor channel that was rich in several suspension-feeding invertebrate groups (echinoderms, brachiopods, bryozoa). Trending parallel to the depositional strike of the mounds was a wide, rimming drape of skeletal sands, small muddy banks and local oolite shoals. Major invertebrate groups were extremely abundant and diverse, especially brachiopods, echinoderms, bryozoa, and pockets of bivalves. Varying densities of these organisms reflect several environments with different degrees of water agitation and generally good overall circulation and nutrient replenishment along the edge of the regional mound (Senich, 1975, p. 141, 152, 153).

South Bend Limestone Member. The name South Bend, taken from the town of South Bend, Cass County, Nebraska, was applied by Condra and Bengtson (1915, p. 23)
to a limestone that was later found to correlate with the Iatan Limestone (Condra, 1930, p. 11). The name was then transferred to the limestone unit next lower in the section, the uppermost member of the Stanton. In the type area, at the Burlington quarries 3 km (2 mi) northwest of South Bend, the member is nearly 3m (10 ft) thick and consists of gray, massive, fossiliferous (fusulinid-bearing) limestone that is cherty in the upper part and oolitic in the middle part. In Wilson County also, the upper limestone unit of the Stanton is a fusulinid-bearing oolitic limestone. The South Bend apparently underlies the Weston Shale Member of the Stranger Formation conformably; however, the contact with the Weston is locally accentuated by the weathering process. Where exposed in quarry faces or on the floors of quarries, the uppermost 3 to 8 cm (1-3 in) of the South Bend is very argillaceous, and the vertical transition from shale to limestone is more gradational than is apparent. Argillaceous laminae are in places abundant at the top of the South Bend (Ball, 1964, p. 243). The South Bend generally rests unconformably upon the underlying strata of the Rock Lake Shale Member and locally even lies on the upper part of the Stoner Limestone Member (Plate 2B).

During engineering geology investigations in Wilson and Montgomery Counties, Frank Wilson (1957) noted anomalously great thicknesses of limestone in the South Bend and other limestone members of the Stanton. He
concluded that they were formed as parts of large carbonate masses of organic, possibly algal, origin. Algal material was also noted by Wilson a short distance both above and below this zone in the South Bend member (Wilson, 1957, p. 432).

In Wilson County the South Bend is 1.5 to 6 m (5-20 ft) thick, and where thickest the upper part is an oolitic, fragmental limestone in which the oolites and shell fragments are incorporated into a microcrystalline calcite matrix. Thin sections show that many of the oolites are composed of radially oriented calcite, a few have concentric rings, and many are largely limonite. The oolites commonly range from about 0.2 to 0.5 mm in diameter, but in some areas, they reach 1.0 mm. The limestone contains medium-size quartz grains, both as centers of oolites and individually within the limestone matrix (Figure 25A, B). Locally, the quartz grains are etched, of fine-grain size, and scattered. About 10 percent of the oolites have quartz grains at their centers. The majority of these quartz grains are euhedral, but they have been dissolved and replaced at their margins by dolomite or calcite, or both (Fig. 25A, B). A few of the quartz grains in the matrix are well-rounded with little embayment. Others are deeply dissolved and appear as elongate angular grains with a well-developed rim of dolomite and calcite. As noted by Ball (1963, p. 241), the basal contact of the South Bend
Figure 25. South Bend Limestone Member of the Stanton Limestone. (A) Thin section showing euhedral regrowth on original rounded quartz grain in the limestone matrix and later replacement by calcite, crossed nicols (X 240). (B) Partly euhedral quartz grain at center of oolite. Inner ring of oolite is largely limonite; outer ring is coarsely crystalline calcite. Very finely crystalline calcite has partly replaced the limonite and quartz; crossed nicols (X 160).
Limestone Member is relatively sharp and locally overlies a disconformity. Cross-stratification or conglomerate in the basal bed and an irregular base overlying a scoured or channeled surface are not uncommon. The erosional contact may appear gradational because of reworking. Blatt and others (1972) suggested that pH and temperature are the most important controlling parameters in the replacement of quartz by calcite. As both pH and temperature increase, solubility of silica tends to increase while solubility of calcite decreases. This condition probably was the cause of silica replacement by calcite in the South Bend. It is likely that pH rather than temperature was the major controlling factor in replacement of quartz by calcite in the South Bend, because these rocks are located in a tectonically inactive area and were not deeply buried. Therefore, they were not subjected to high temperature. Dapples (1967) suggested that replacement of quartz by calcite in certain sandstones is related to pH changes which are controlled by carbon dioxide changes near the outcrop. At slow rates, silica solution takes place contemporaneously with calcite cementation (Dapples, 1971). Undulatory extinction in the quartz grains is uncommon. Ball (1964, p. 62) also noted the presence of quartz and other terrigenous grains in the South Bend. He used Dunham's (1962) classification and termed the South Bend a mixed fossil-lime wackestone and a quartzose molluscan-lime
wackestone. Oolith or pellet lime packstone (rarely grainstone) or limestone clay-pebble conglomerate are developed locally in the lower part of the South Bend in Johnson, Franklin, Anderson, Woodson, and Wilson counties (Ball, 1964, p. 62, 66). Zircon and chert form a very small percentage of the grains.

Fragments of brachiopod, pelecypod, and gastropod shells are scattered throughout the unit in conjunction with fusulinid remains and a few pebbles of finely oolitic limestone. The insoluble residue of the more oolitic facies contains several genera of arenaceous foraminifers including Ammolitovertella, Tolypammina, Glomospira, and Hyperammina(?). Other constituents of the residue are euhedral, pitted or broken quartz grains, muscovite mica, and a few siltstone granules (Wagner and Harris, 1953). The South Bend also displays an oolitic character along the county line between Wilson and Woodson counties, in the area of the Silver City Dome. The oolites occur in the upper part in conjunction with relatively abundant fusulinids and crinoid stems as well as the fragmental remains of brachiopods, pelecypods, bryozoans, and corals. In this area the oolites are commonly replaced by limonite and are orange gray in color. Where the oolitic South Bend is adjacent to or directly overlying the intrusive body at the Silver City Domes (center of north line of NE1/4 NE1/4 sec. 6, T 27 S, R 15 E, along the north line NE1/4 NE1/4 NE1/4 sec. 6, T 27 S, R 15 E, and center of
SEL/4 sec. 32, T 26 S, R 15 E), the oolites are black in color and magnetic. The limonite has been altered here, presumably by heat and gaseous emanations during intrusion of the Hills Pond Lamproite (peridotite), to magnetite and specular hematite.

The South Bend locally is a sandy limestone that contains lenticular sandstone units (NE cor. Sec. 24, T 29 S, R 14 E) and is locally strongly cross-beded. Inclination of the strata in sec. 24 (Figure 26A) may in part represent initial dip of beds and may in part reflect draping over an algal buildup or folding associated with the Fredonia Dome. The abrupt contacts between sandy limestone and sandstone (Figure 26B) seemingly represent both current scouring and contemporaneous deposition of sandstone and sandy limestone. About 3 km (2 mi) west of Altoona, the upper surfaces of some beds have asymmetric ripple marks and abundant tracks and traces of marine invertebrates (Brondos, 1983, p. 21).

Pebbles and fragments of limestone and shale are common in the basal part of the South Bend. The unit is even more sandy in this part, and locally consists of as much as 4.6 m (15 ft) of sandy limestone and sandstone. Irregular interruption of bedding by sandstone lenses probably reflects an interbedded relationship with a sandy phase of the Rock Lake Shale Member. Some sandy limestone beds contain large angular fragments of claystone, 6 to 8 cm (2.5-3 in) in length, in a medium-grained matrix of
Figure 26. South Bend Limestone Member of the Stanton at the NE cor. Sec. 24, T 29 S, R 14 E. (A) Outcrop showing strong east dip of beds. (B) Detail of contact relations between sandstone (dark) and sandy limestone (light).
crystalline calcite and detrital quartz. In the Wilson County Channel of Heckel (1975c, p. 45, 46), the South Bend is as much as 5 m (15 ft) thick, and is part of a phylloid algal mound tract. The lower part is mainly conglomeratic or oolitic quartz sandstone; the upper 0.6 to 1.2 m (2-4 ft) is predominantly skeletal algal calcilutite (Moussavi-Harami, 1980, p. 62). Thin sections show that claystone interbeds contain a few small mica flakes and quartz grains in a flocculent appearing clay matrix. Fragments of fossiliferous limestone and of brachiopod shells are locally present. Quartz is by far the most abundant detrital mineral in limestone of the lower part of the South Bend. The grains are all deeply embayed, and most are rimmed by dolomite. Inclusions occur in most of the quartz grains, and wavy extinction is present, but uncommon. Other mineral grains, composing about 10 percent of the detrital minerals, include chert, muscovite, biotite, zircon, quartzite, and plagioclase feldspar. Mudstone or claystone fragments and small grains of muscovite, biotite, hematite(?), and feldspar compose the remainder of the residue. The quartz grains are angular, fairly well sorted, and many are pitted and have a frosted appearance.

The fauna of the South Bend is sparse in most exposures. Fusulinids (Triticites) are generally present, but scattered; small pelecypods and gastropods (bellerophontids and archaeogastropods) occur locally.
Newell (1933, pl. 1 and p. 140) listed the following forms as being more or less common in the South Bend member in the cement plant quarry at Fredonia. The only coral noted was *Syringopora* *cf.* *multattenuata*; brachiopods included *Rhipidomella carbonaria*, *Punctospirifer kentuckiensis*, *Hustedia* sp., *Meekella striatocostata*, *Derbyia* sp., *Streptorhynchus affine*, *Dielasma bovidens*, and one pelecypod, *Strebloptera* (?) *herzleri*. He later recorded (Newell, 1937, p. 53) the presence of the paratype of *Aviculopecten gradicosta* in the cross-bedded, sandy, oolite facies of the South Bend near Fredonia. A sample from the cement plant quarry at Fredonia was examined for its rhomboporoid bryozoan content by Jean Squires. She recorded the presence of *Rhombocladia delicata* Rogers and *Rhombopora lepidendroides* Meek in her sample (Squires, 1952, p. 11, Fig. 3).

Wood (1977, p. 29) reports 7 genera of conodonts from the South Bend. Samples from the upper part contained *Idiognathodus* sp. A, *Anchignathodus minutus* and *Stepanovites conflexa* with rare specimens of *Adetognathus* spp., and *Anchignathodus* sp. A. The lower part of the South Bend has rare specimens of *Adetognathus* spp., *Idiognathodus* sp. A, *Idiognathodus delicatus*, and *Idiognathodus elegantulus*. Remains of crinoids were collected and studied by Pabian and Strimple from Oklahoma to Nebraska. Pabian (1979, p. 75) recorded that he and Strimple had recognized two distinct types of crinoid
assemblages in many stratigraphic units in this part of the Midcontinent region. The assemblages were called simply Types I and II (Pabian and Strimple, 1979, p. 425). Type I contained large, ornate crinoid genera which were interpreted as warm-water forms; Type II assemblages contained small, inornate genera which were interpreted as cold-water forms. The warm-water assemblages came from stratigraphic units that represent nearshore deposits that formed near the end of a regressive phase of a transgressive-regressive cycle (e.g., the upper part of the South Bend Limestone Member of the Stanton Limestone and the Spring Hill Limestone Member of the Plattsburg Limestone). The cold water transgressive crinoidal assemblages occurred in the Leavenworth Limestone Member of the Oread Limestone, the Captain Creek Limestone Member of the Stanton Limestone, and the Hickory Creek Shale Member of the Plattsburg Limestone (Pabian, 1979, p. 75).

Rock Lake Shale Member. Original use of the name Rock Lake was by Condra (1927, p. 59) for a shale bed exposed in the vicinity of Rock Lake, Sarpy County, Nebraska. At that time, this shale was thought to be much higher in the section. In a later publication, however, Condra (1930, p. 11, 27) stated correctly that the Rock Lake is the upper shale member of the Stanton Limestone. At the type locality the member is about 1.8 m (6 ft) thick and consists (downward) of 61 cm (24 in) of bluish argillaceous shale, 30 cm (12 in) of dark maroon shale, 15
cm (6 in) of greenish sandy shale, 8 inches of maroon shale, and about 61 cm (24 in) of calcareous shale (Condra, 1927, p. 157). In reconnaissance studies, Wilson (1957a, 1957b), Kenny (1958), and Heckel (1975a, 1975b, 1977, 1978) suggested that the Rock Lake Shale Member can be related to a deltaic regime, particularly where it has many sandstone lenses as in Montgomery County to the south of Wilson County (Moussavi-Harami, 1980, p. 13).

In Wilson County a period of erosion seems to have immediately preceded deposition of the Rock Lake Shale Member, for it apparently lies unconformably upon the Stoner Limestone Member (Plate 2B). The Rock Lake itself was apparently removed over much of Wilson County by erosion prior to deposition of the South Bend Limestone Member. Possibly, the interbedded sandy limestone and sandstone, here placed in the basal part of the South Bend Limestone Member, is a facies of the Rock Lake and not of erosional significance; but because these beds are predominantly limestone, they are placed in the South Bend Limestone Member in this report.

The Rock Lake Shale Member is poorly exposed in Wilson County. At only a few places is a shale bed observed at the stratigraphic position occupied elsewhere by the Rock Lake. At the northeast corner of the town of Fredonia, a thin shale unit lies below the basal reddish calcareous sandstone of the South Bend Limestone Member. It consists of about 30 cm (12 in) of very light olive-
gray clay shale underlain by 30 cm (12 in) of dark yellowish-orange clay shale. About 2.4 km (1.5 mi) north of this exposure, the conglomeritic phase of the overlying South Bend contains clay fragments that were probably derived from shale of the Rock Lake. A very calcareous, fossiliferous shale at this stratigraphic position in the NW 1/4 sec. 6, T 27 S, R 15 E, and SW 1/4 sec. 31, T 26 S, R 15 E, is correlated with the Rock Lake. A microfauna collected from these exposures by Harris (Wagner and Harris, 1953), included the foraminifers *Endothyra*, *Climacocammina*, *Textularia*, *Tetrataxis*, *Glyphostomella*, undetermined fusulinids, and the ostracodes *Bairdia* and *Amphissites*. Megafossils included crinoid columnals, ramose bryozoans, echinoid spines and plates, and brachiopod(?) shell fragments. Newell (1933, p. 138, 139) recorded abundant large echinoid spines and plates, which he referred to *Echinocrinus* cf. *trudifer* in the Rock Lake [Wolf Creek] Shale Member in the central and northern parts of Wilson County. Moussavi-Harami (1980, p. 177, 223), while studying the facies of the Rock Lake in Montgomery County adjacent to Wilson County on the south, determined that the Rock Lake Shale Member was mainly sandstone. He included a small area in Wilson County in his study the results of which showed that the northward prograding fluvially dominated deltas that operated in southern Montgomery County were different from those in the Wilson County part of his area where pre-existing
channels in the carbonate shelf were filled with quartz sands that apparently were derived by reworking of material from a source to the north, south or east. He also noted that a channel sandstone in the Rock Lake Shale Member cut into flat-lying beds of the Stoner Limestone Member in a road-cut exposure along Hwy 47 about 4 km (2.5 mi) east of Fredonia (Houssavi-Harami, 1980, p. 40, 41). About 6 km (4 mi) farther east (3 km west of Altoona), a cross section by Heckel (1975c, p. 46) shows the relations between the Rock Lake and other members of the Stanton Limestone in a different road cut along State Highway 47. There, the Rock Lake is apparently a quartz-rich sandstone about 2.4 m (8 ft) thick that is underlain by calcarenite of the Stoner Limestone Member (Heckel, 1975c, p. 46). Following an investigation of channels along the Persian Gulf, Heckel (1975c, p. 68) concluded that the dominantly carbonate mud that is developing along the Persian Gulf today is occupying a very similar environment to that in which the Stanton was deposited in Pennsylvanian time.

In his conodont study, Wood (1977, p. 28, 29) reports that specimens are rare throughout the Rock Lake. He identified only Idiognathodus delicatus, Adetognathus spp., and Idiognathodus, sp. A. In a study of the ostracode fauna of the Stanton, Brondos (1983, p. 190, 192) listed Bairdia crassa, Kegellites sp., Microcheilinella sp., Roundyella sp., and Bairdiacypris sp. from the Rock Lake.


*Stoner Limestone Member.* Condra (1930, p. 11-12) proposed the name Stoner for the middle limestone member of the Stanton Limestone from the Stoner farm in Nebraska. The type locality was designated as the area extending from the Old Burlington Railroad quarries, about 3 km (2 mi) northwest of South Bend, Nebraska, southeastward through the Stoner farm (Condra, 1930, p. 36). At the type locality, the Stoner is about 5 m (15 ft) thick and consists of an upper light-gray to bluish-gray, somewhat argillaceous, wavy-bedded limestone about 0.6 m (2 ft) thick below which is about 3 m (9.5 ft) of bluish-gray, dense, massive, fossiliferous limestone with considerable crystalline fine calcite. This limestone is underlain by a thin, bluish-gray shale 0.7 m (2.5 ft) thick, and 0.5 m (1.5 ft) of bluish-gray, dense fossiliferous limestone at the base. The Stoner Limestone in Wilson County has many of these characteristics. Parts of it are wavy-bedded, parts are of finely crystalline calcite, and most of it is light gray to medium gray and fossiliferous.

The Stoner in Wilson County is 1.5 to 9 m (5 to 30 ft) thick, and where thickest it has at the top a light-gray, irregularly bedded, sparsely oolitic, finely crystalline limestone unit 1.5 to 4.5 m (5-15 ft) thick. Fusulinids occur only locally. A fauna collected by Newell (1933, p. 110) from this unit at the cement plant quarry at Fredonia contained many specimens unknown elsewhere, and a few genera not previously recorded from the Midcontinent.
region. Concerning these forms, Newell (1933, p. 110) wrote: "This novel fauna may represent an assemblage that had developed in some other faunal province, possibly in west Texas or the Cordilleran region, and except for a temporary invasion, was prevented from reaching the northern Midcontinent by a faunal barrier, either of inhospitable environment or of land." Newell, in listing the fauna, also pointed out (1933, p. 136): "The outstanding features of this fauna are the exotic orthoids and the peculiar assemblage of gastropods." The fauna is as follows: Michelinia sp., Composita cf. trilobata, Dielasma bovidens, Parenteletes cooperi?, Schizophoria cf. texana, Echinoconchus semipunctatus, Juresania ovalis, Heekella striatocostata cf. ventricosa, Derbyia cf. deercreekensis, Pleurophorus cf. subcostatus, Pleurophorus n. sp., Pseudomonotis cf. kansasensis, Pteria longa, Conocardium n. sp., Myalina kansasensis, Myalina cuneiformis, Euconospira cf. planibasalis, Lepetopsis? peregrina n. sp., Lepetopsis parrishi, Helictostylus girtyi n. sp., Ptychomphalus cf. persimplex and Pithodea broadheadi?.

In his detailed study of the macropaleontology of the Stoner and Captain Creek Limestone Members of the Stanton, Senich (1975, p. 21) indicated that the fauna and lithology of the algal mound facies were considerably different from those of the channel and rim facies which were similar in many respects. In listing his faunas for comparison of
similarities, the faunas of the mound and rim facies are placed under the Captain Creek heading; the channel fauna is listed under the Stoner for comparison with the "Fredonia" facies of Newell (1933) which Senich noted is most comparable with his channel facies because his first collections for his channel facies study came from the Fredonia quarry, the source of Newell's "Fredonia" facies, (Senich, 1975, p. 44).

Wood (1977, p. 25-27) reported that the Stoner conodont population increased in abundance and diversity downward, particularly in the phylloid-algal mound facies belt. *Adetognathus* spp., *Adetognathus minutus*, and *Idiognathodus delicatus* are generally present in low numbers scattered throughout the Stoner. *Gondolella bella* occurs stratigraphically higher in the Stoner than anywhere else; *Idiognathodus* sp. A is present but rare in the upper and middle parts; *Aethotaxis advena* is present but rare in the middle and basal parts; *Idiognathodus elegantulus*, *Gondolella bella* and *Idiognathodus typus* are found mainly near the base but tend to increase in numbers from rare to abundant toward the Wilson County Channel where they occur in maximum numbers. *Stepanovites conflexa*, *Anchignathodus minutus*, and *Anchignathodus? sp. A* are present near the base; *Idiognathodus delicatus* is frequent in the basal part.

The lower and more widely distributed part of the Stoner (Plate 2B) consists principally of blotchy-
appearing, medium-gray and yellowish-gray thin-bedded, wavy-bedded, and locally cross-bedded, fossiliferous limestone (Figure 27A), that averages about 4.6 m (15 ft) in thickness. In many places, thin beds within the Stoner are medium- to coarse-crystalline coquinaid limestone made up entirely of crinoid columnals and plates (Figure 27B), echinoid spines, fenestrate bryozoans, and pelecypod and brachiopod fragments. Identifiable fossils include such genera as *Meekoporella*, *Composita*, *Juresania*, *Neospirifer*, *Schizophoria*, and *Syringopora*. In many places, relatively unfossiliferous, very finely crystalline limestone predominates, and much of the Stoner is a brecciated-appearing unit of angular areas of light brownish-gray limestone in a matrix of yellowish-gray limestone typical of phylloid algal mound occurrences.

In the NE 1/4, Sec. 18, T 29 S, R 16 E, the Stanton and Plattsburg Limestones are both exposed in a roadcut along Hwy 47 about 2.4 km (1.5 mi) west of Altoona. A channel deposit 11 to 12 m (35-40 ft) thick and consisting mainly of skeletal calcarenite (Captain Creek or Stoner) was sampled. The strata are extensively cross-bedded and are composed of skeletal grains of crinoid-stem fragments, fenestrate bryozoans, brachiopods, phylloid algal remains, and sponges. Recognizable specimens of the bryozoan *Glyptopora* sp. and the brachiopod *Schizophoria* sp. as well as abraded specimens of *Neokinckophyllum heckeli*, *Dibunophyllum valeriae*, *Caninia torquia* and
Figure 27. Stoner Limestone Member of the Stanton Limestone. (A) Exposure in State Highway 47 roadcut 3 km (2 mi) west of Altoona showing even bedding (top), cross bedding (middle), and wavy bedding (bottom) on weathered vertical-joint face. (B) Crinoid-fragment coquina in the Stoner near the center of the south line, Sec. 14, T 29 S, R 14 E.
Fusulinids occur locally near the top of this part of the member, and sinuous areas of coarsely crystalline calcite that closely resemble in form the algae Cryptozoon are abundant in some areas. Vugs and fractures filled with clear calcite are also conspicuous at many places. The oolitic facies appears to have accumulated in depressions bordering the Fredonia Dome (Plate 2B). An abandoned quarry south of the railroad tracks less than 1.6 km (1 mi) south of Benedict has about 10 m (33 ft) of the Stoner Limestone Member exposed. Four units were differentiated: (1) a basal 7 m (22 ft) of algal-rich calcilutite, (2) 0.3 m (1 ft) of fossiliferous calcareous shale, (3) 2.1 m (7 ft) of algal invertebrate-rich calcilutite and calcarenite and (4) a unit consisting of 1.1 m (3.5 ft) of fusulinid- and bryozoan-rich skeletal calcarenite that produced moderately abundant poorly preserved abraded specimens of *Caninia torquia* and *Dibunophyllum parvum* (Cocks, 1970, p. 62). The basal part of the Stoner and upper part of the Captain Creek also contained specimens of the cold-water crinoid genera *Apographiocrinus, Cibolocrinus, Contocrinus, Delocrinus, Eriscrinus, Isoallagecrinus, Lecythiocrinus, Plaxocrinus,* and *Stenopecrinus* (Fabian, 1979, p. 75-77).

**Eudora Shale Member.** This member of the Stanton Limestone was named by Condra (1930, p. 12) "from good exposures east of Eudora, Kansas" about 137 km (85 mi) north of Wilson County. Near the type locality, the
Eudora member is about 1.8 m (6 ft) thick and consists of 0.9 m (3 ft) of gray argillaceous shale underlain by about 0.45 m (1.5 ft) of black fissile shale and about 0.45 m (1.5 ft) of greenish-gray argillaceous shale at the base. In Wilson County the Eudora consists generally of greenish-gray shale, but locally it is partly black platy shale. In most places, it is made up of 0.6-1.5 m (2-5 ft) of light-greenish-gray very slightly silty calcareous shale that grades laterally into clayey limestone. A nodule-bearing sample of the Eudora was obtained from a relatively new quarry east of Buffalo (NE 1/4 NE 1/4 Sec. 22, T 27 S, R 16 E). Nodules in the shale range in size from about 0.6 to 1.9 cm (0.25-0.75 in). Many of the nodules show in thin section that they are made up largely of phosphorite micronodules (peloids) packed together in rows and separated in some samples by thin bands of phosphorite. X-ray analyses (Runnels and others, 1953; Mitchell, 1981) show that the phosphorite in the nodules is a carbonate fluorapatite; average P$_2$O$_5$ content is about 30% (Kidder, 1982, p. 34, 35). In an exposure 3 km (2 mi) west of Altoona and another near the northeastern corner of the county, 0.3 to 1.0 m (1-3 ft) of almost black, fissile, platy shale with phosphatic nodules occurs near the center of the Eudora. The black shale breaks into paper-thin plates on whose surfaces flattened orbiculoid brachiopods are locally abundant. Pelagic organisms in this anoxic black shale include conodonts of the genera
Gondolella, Idioprioniodus, and an unnamed species of Anchignathodus? (formerly Ozarkodina) according to thesis data collected by R.H. Wood, Jr. (see Heckel, 1977, p. 1050). The conodont fauna, on the basis of the Gondolella is interpreted by Heckel and Baesemann (1975) as occupying the deepest water in Midcontinent seas (Brondos, 1983, p. 17).

Wray (1968, p. 116) identified the phylloid algae Eugonophyllum and Archaeolithophyllum from the Wilson County area (Fig. 13). In a few places the lower 15 to 30 cm (6-12 in) of the Eudora is a thin-bedded, very argillaceous limestone that contains the remains of large pelecypods. Other fossils, most abundant in the lower and upper parts of the Eudora, include crinoid columnals, horn corals, encrusting bryozoans, echinoid spines, and brachiopod and mollusk fragments. Identifiable specimens include Neospirifer, Composita, Hustedia, Dielasma, and Syringopora. Newell (1933, p. 133) reported that between T 22 S and the middle of T 32 S, the calcareous, nearly white, nodular phase of the Eudora is characterized by a distinct fossil assemblage. A few of the species are otherwise unknown in the Midcontinent region, or are rare, so that this faunule represents a novel facies. The fauna at one locality may be considerably different from that at another place, but each fauna would be characterized by most of the following forms (Newell, 1933, p. 133, 134): Lophophyllum profundum, Lophophyllum westi, Dibunophyllum

Jeffords (1947, p. 34, 52, 54) recorded two additional corals from the Eudora Shale Member in Wilson County; *Lophophyllidium coniforme* from Sec. 21, T 29 S, R 15 E and *Stereostylus milichus* from the Santa Fe railroad cut near Vilas (Jeffords, 1947, p. 34, 52, 54).

According to Wood (1977, p. 24, 25) the conodont *Idiognathodus delicatus* extends to the top of the Eudora Shale Member at some localities, particularly in the phylloid-algal mound facies belt where the maximum diversity and highest concentration of conodonts occur. Also present are *Idioprioniodus typus, Idiognathodus elegantulus, Anchignathodus? sp. A., Stepanovites conflexa, Idiognathodus spp., Adetognathus spp.* and *Gondolella bellai*. These conodonts lie mainly below the black shale facies, but some genera are present in low numbers in the dark gray to black shale samples that lack phosphate. However, many genera do not occur in the fissile phosphatic black shale. Brondos (1983, p. 190,
192) lists four ostracodes that are most characteristic of the Eudora. They are: Cryptobairdia folger, Bairdia crassa, Bairdia pompilioides, and Ammoverella sp.

Captain Creek Limestone Member. The basal part of the Stanton Limestone was named the Captain Creek Limestone Member by Newell (1935, p. 76) for outcrops along Captain Creek, near Eudora, Douglas County. This member name was adopted in 1947 by the State Geological Surveys of Iowa, Kansas, Missouri, and Nebraska (Moore, 1948, p. 2031). Near the type locality, the Captain Creek is about 1.5 m (5 ft) thick and is a gray to dark-gray, massive, evenly bedded limestone with sugary to dense texture. Individual limestone beds are ordinarily more than 20 cm (8 in) thick. The member generally has a mottled blue and pink brecciated appearance at the upper surface and characteristically contains Enteletes pugnoides in the upper part (Newell, 1935, p. 77).

Both the Stanton and Plattsburg Limestones are present in the 9 m (31 ft) of limestone exposed in the north end of the quarry at the southern edge of the town of Fredonia. The Captain Creek Limestone Member of the Stanton makes up most of the quarry wall; a transition zone that would normally be Vilas Shale seems to be present but very little shale is recorded. Laterally, the upper part represents the transition between the Stanton algal complex at the south and a Stanton channel deposit to the north. The lower 0.6 m (2 ft) consist of algal
calcilutite to calcarenite and calcareous shale interbeds. The limestone bed contains abundant fusulinids, echinoid spines, fenestrate bryozoans, Punctospirifer, Composita and Rhipidomella. The algae Neokoninckophyllum variabile and N. acolumnatum are found abundantly in growth position along the upper surfaces of the calcilutite. Algal and sponge content increases upward in the overlying 9 m (30 ft) in the quarry wall (Cocke, 1970, p. 60). Cocke reports on six other localities in Wilson County at which he sampled the Captain Creek Member. At locality (1), approximately 1.6 to 2.4 km (1-1.5 mi) south and 1.6 km (1 mi) west of Fredonia, he obtained a sample from the lower Stanton in the Wilson County Channel of Heckel (1975c, p. 45). Cocke (1970, p. 61) reported that the 0.9 m (3 ft) of skeletal calcarenite at that location was particularly rich in crinoid and bryozoan debris along with the corals Caninia torquia, Neokoninckophyllum heckeli, Dibunophyllum valeriae, and Geyerophyllum cylindricum. (2) On an E-W county road, 7 km (4.5 mi) west and 1.6 km (1 mi) south of Altoona, corals were collected from a flat area in the road ditch. Neokoninckophyllum heckeli and Dibunophyllum parva were found in algal calcilutite. (3) In the NE 1/4 SE 1/4 Sec. 2, T 28 S, R 15 E, at an abandoned quarry site, approximately 8 m (27 ft) of Captain Creek limestone is exposed in which Neokoninckophyllum heckeli and Dibunophyllum parva were collected from the uppermost
surface. (4) About 11 km (7 mi) northwest of Neodesha, in an abandoned quarry where 6 m (20 ft) of Captain Creek algal calcilutite is exposed, specimens of the corals *Neokoninckophyllum heckeli*, *Dibunophyllum parva*, and *Geyerophyllum cylindricum* were collected. (5) In a pasture exposure on the Odell farm about 2.4 km (1.5 mi) south and 1.9 km (1.2 mi) west of Fredonia, specimens containing abundant *Caninia torguia* as well as *Neokoninckophyllum heckeli* and *Geyerophyllum cylindricum* were obtained. (6) On Hwy 96, 5 km (3 mi) west of Neodesha in an algal calcilutite to sparry algal calcilutite approximately 3 m (10 ft) thick, *Neokoninckophyllum heckeli* occurs in a zone about 1.2 m (4 ft) from the base of the exposure (Cocks, 1970, p. 61, 62).

Where measured by me in Wilson County, the Captain Creek is chiefly a medium-gray massive- to thick-bedded, cavernous limestone 3 to 5 m (10-15 ft) thick (Figure 28A). This cavernous limestone unit generally forms escarpments, weathers almost white, and is deeply pitted with holes 1.3 to 5 cm (0.5-2 in) in diameter. A conspicuous vertical joint system separates the rock into a series of large blocks 0.9 to 6.1 m (3-20 ft) across. Crystalline calcite veinlets 1.6 to 9.7 mm (.062-.38 in) in width cut the medium-grained matrix. The unit locally has, at or near the top, a 20 cm (8 in) thick zone of thin-bedded, somewhat argillaceous, red-blotched limestone that contains large (5 cm; 2 in) pelecypods. The most
Figure 28. Captain Creek Limestone Member of the Stanton Limestone. (A) Typical pitted, cavernous exposure near center of Sec. 27, T 29 S, R 15 E. (B) Large nautiloid cephalopod from the Captain Creek east of Fredonia.
abundant fossils in the cavernous limestone are crinoid columns, fenestrate bryozoan fronds, and the remains of such brachiopods as *Enteletes*, *Hustedia*, and *Neothespirifer*. Corals and fusulinids are locally common. Newell, in his study of the stratigraphy and paleontology of the upper part of the "Missouri Series" in eastern Kansas, reported (1933, p. 131) that at any good exposure between T 10 S and T 32 S, the Captain Creek member is characterized by the following fauna: most abundant are *Enteletes pugnoides*, *Marginifera wabashensis*, *Triticites neglectus*, *Composita ovata*, *Cancrinella boonensis*, and *Acanthopecten cf. A. carboniferus*; less common are *Hyalina kansasensis?*, *Juresania nebrascensis*, *Enteletes hemiplicatus var. plattsburgensis*, and *Dictyoclostus portlockianus var. crassicostatus*. At the cement plant quarry at Fredonia, *Enteletes pugnoides*, *Cancrinella boonensis*, and *Triticites neglectus* are locally abundant.

The brachiopod, gastropod and pelecypod faunas that are representative of the mound biofacies are listed by Senich (1975, p. 26, 27) for both the Captain Creek and Stoner members. The faunas also include the alga *Archaeolithophyllum* and the echinoderm *Erisocrinus*. The brachiopods are *Composita "subtilita"*, *Phricodothyris perplexa*, *Punctospirifer kentuckiensis*, *Dielasma bovidens*, *Enteletes "pugnoides"*, *Hystriculina wabashensis*, *Antiquatonia crassicostata*, *Reticulatia americana*, *Echinaria semipunctata*, *Puleratia cf. P. symmetrica*; the
Coelenterates consist of Dibunophyllum valeriae, Neokoninckophyllum cf. N. heckeli, Lophoanplexus sp., Stereostylus sp. Geyerophyllum cf. G. cylindricum, Lophophyllidium sp., and Syringapora multattenuata; the bivalves noted were Cypricardella sp., Astartella sp.; the gastropods Euconospira turbiniformis, Gosseletina cf. G. spironema; and indeterminate bryozoans and myalinids.

The rim biofacies has no echinoderms in common with the mound facies; the brachiopods have a few forms in common as can be seen in the following listing starting with Composita "subtilita", Punctospirifer kentuckyensis, Hustedia mormoni, Neospirifer "dunbari", Phricodothyris perplexa, Derbyia cf. D, deercreekensis, Derbyia sp., Dielasma bovidens, Schizophoria cf. S. texana, Hystriculina wabashensis, Antiquatonia crassicostata, Reticulatia americana, Linoproductus cf. L. prattenianus, Linoproductus cf. L. platyumbonus, Pulchratia symmetrica, Neochonetes transversalis, Enteletes "pugnoides"; bryozoans are Fenestella sp., Polypora sp., Rhombopora sp., and Meekoporella dehiscens; only two bivalves are listed, Septimyalina sp. and Septimyalina burmai; the gastropods include Gosseletina sp., Glabrocingulum sp., Euconospira turbiniformis, Meekospira sp., Pseudozygopleura sp., Pharkidonotus sp. and Retispire sp.; coelenterates have the following forms, Caninia torquia, Dibunophyllum sp., Dibunophyllum cf. D. valeriae,
Neokoninciphyllum heckeli, Geyerophyllum sp., and Syringopora multattenuata; red and green algae include the rhodophytan Archaeolithophyllum sp., and the solenoporacean Parachaetetes sp.

Algal stromatolites comprise the lowest form of carbonate deposition in the Captain Creek member along the rear of the reef in Wilson County (Wilson, 1971, p. 5). The external shape of stromatolites may vary from simple encrustations to massive cauliflower-shaped heads. Well-developed stromatolites occur at the bases of both the Captain Creek and South Bend members of the Stanton Limestone. Nearly every type of stromatolite has been noted in Wilson County. They range from simple saucer-like cups to large and complex toadstool shapes several feet in diameter (Wilson, 1971, p. 7).

The lower 0.6 to 1.5 m (2-5 ft) of the Captain Creek member consists of yellowish-gray, finely crystalline, algal and oolitic (?) limestone. Locally, in the central part of the outcrop belt, this unit is apparently missing. Where thin, this basal part of the Captain Creek is a single vertically jointed massive bed; elsewhere, it is made up of 2 to 3 thin, vertically jointed beds. Thin sections of this unit show that it consists of a mass of small (0.25 to 0.5 mm) spheres most of which are flattened and have dark centers. None shows radial structure and all appear to be small algae (Osagia). Fossils occur in local concentrations; the most spectacular are large
nautiloid cephalopods (Fig. 28B), possibly *Domatoceras*, from the basal part of the member east of Fredonia. Several crystal-filled casts of these cephalopods were seen in the State Highway 47 roadcut, about 3.2 km (2 mi) west of Altoona. At outcrops in Sec. 34, T 28 S, R 15 E and secs. 23 and 33, T 30 S, R 15 E, the lower part of the Captain Creek member contains beds of hard, brittle, medium-gray to grayish-orange, partly argillaceous limestone in which thin, dark veinlets (?) of calcite are abundant. Limestone beds containing similar veinlets occur locally in the upper part of the Vilas Shale.

In the phylloid-algal mound facies belt, the conodonts *Adetognathus* spp., *Anchignathodus minutus*, and *Idiognathodus elegantulus* are generally scattered throughout the samples of the Captain Creek member. *Idiognathodus delicatus*, *Gondolella bella*, and *Idioprioniodus typus* occur only at the top. *Idiognathodus* sp. A, *Anchignathodus*? sp. A, and *Stepanovites conflexa* are rare and present only at the top at one locality each. In general, conodonts tend to increase in number and diversity upward in the Captain Creek Limestone Member; maximum numbers and diversity occur in the phylloid-algal mound facies belt where a phosphatic shale directly overlies it.

The lower part of the Captain Creek Limestone Member near the towns of Altoona and Benedict in Wilson County consists of 0.8 to 0.9 m (2.5-3 ft) of yellow-gray, finely
crystalline algal and oolitic (?) limestone with a humpy irregular surface. The exposures show this basal bed to occur generally as a single vertically jointed bed, although it locally has shaly intervals that appear to be intercalations of Vilas Shale. The upper surface has the appearance of small flattened domes which may be heads of crudely formed stromatolites. Heckel (1975c, p. 21) distinguished this unit by informally designating it the Benedict bed. The Benedict bed and thin overlying shale provided rare conodont specimens including *Adetognathus* spp., *Stepanovites conflexa*, and *Anchignathodus minutus*; some are from the position of the stromatolite heads (Wood, 1977, p. 22, 23).

In most places in Wilson County, the Captain Creek member of the Stanton Limestone lies conformably upon the Vilas Shale, and the bedding in the Stanton above the contact and in the Vilas below the contact is roughly parallel to the contact (Figure 29A). Where the contact between the two units is unconformable, however, the calcareous marine sediments of the Captain Creek fill irregular, steep-walled scour channels cut 1.6 m (5 ft) or more into the underlying Vilas Shale (Fig. 29B).

**Stratigraphic and Structural Implications.** The stratigraphy and structure of the Stanton Limestone and other formations of the Lansing Group in Wilson County and adjacent areas are the subject of papers by Chelikowsky and Burgat (1947), Wagner (1953, 1954, 1961), Wilson
Figure 29. Contact between the Stanton Limestone and the Vilas Shale. (A) Relatively even-surfaced contact with thin, algal limestone, at pick (circled), in upper part of the Vilas Shale at west line NE 1/4 Sec 26, T 28 S, R 15 E. (B) Irregular contact; basal Stanton Limestone that fills scour channels cut into the top of the Vilas Shale, NE 1/4 Sec. 18, T 29 S, R 16 E.
(1957), Davis (1959), Harbaugh (1959, 1961) and Heckel (1972a, 1975a, 1975b, 1975c, 1978, 1983, 1988). Chelikowsky and Burgat (1947, p. 95) attributed the changes in thickness of the Stanton Limestone and Vilas Shale between Fredonia and Altoona to variations in sedimentation and subsequent differential compaction. An abnormal thickness of sandstone in the Vilas Shale was required by their interpretation. Wagner (1954, 1961) assumed that both sedimentologic and structural factors controlled their accumulation. A more realistic exposition of the depositional characteristics of Captain Creek time would have been to interpret the brecciated-appearing parts of the limestone as algal buildups as was done by Wilson, Harbaugh and Heckel. Calcareous algae are assumed to have proliferated as turbidity decreased, and mounds developed as the algal fronds trapped and bound carbonate mud that contained debris consisting of fragments of brachiopods, crinoids, bryozoans, etc., and tests of foraminifers and fusulinids. Wilson (1957) considered the Stanton Limestone deposits in Wilson and Montgomery Counties as representing a barrier-reef development during Stanton time. He recognized similar reefs in each limestone member of the Stanton Limestone, and stated (1957, p. 433): "The three reefs overlap slightly so that the total average width of the reefy sediments in the Stanton Formation is probably less than five miles." He admits (Wilson, 1957, p. 435) that "The
reef-building organisms could not be definitely identified by the writer. Algal deposits were present in much of the strata and were believed to represent the major frame-building organisms although individual forms could not be identified. Wilson also believed (1957, p. 435) that the thinning and local absence of the formation was caused by wedging out of the talus sediment at the reef front. Davis (1959) considered the thickness variations as representing reef-development during Plattsburg and Vilas times. Harbaugh (1959, p. 326-327) interpreted the thickness variations as due in part to local structural warping and in part to deposition of an extensive lens-shaped calcareous marine bank. Heckel (1972) espoused a phylloid algal bank origin.

In the 1950-1953 study of Wilson County by the writer, distinctive algal-mound facies were not observed as such in the South Bend Limestone Member, and the absence of a solid reef core in any of the members of the Stanton, as well as the coincidence of the thinning of the members of the Stanton directly over the Fredonia Dome (Plate 2B), suggested that the thinning and absence of reef or mound formation were related to structural uplift and erosion rather than to wedging out of reef talus or other mechanism. However, the sedimentary facies represented in the Stanton Limestone cannot be accounted for simply by deposition during transgressions and regressions of the sea accompanied by local structural
uplift on the Fredonia Dome and development of bordering structural sags as originally postulated. Evidence that the large thicknesses of limestone in the members of the Stanton Limestone are the result of great accumulations of phylloid algal remains in calcareous banks is overwhelming. The identification of the remains of both red *(Archaeolithophyllum)* and blue-green *(Eugonophyllum)* algae as was done by Eastwood (1958) and Wray (1964, 1965, 1968) leaves no doubt as to the algal origin of the thick depositional features just described.

The fusulinid-bearing, poorly bedded, sandy, oolitic South Bend Limestone Member probably reflects a nearshore calcareous marine environment in which sand grains and other small objects from a low-lying maturely weathered nearby land area were continually being agitated and coated with calcium carbonate during oscillation by wave action. Quartz sand was probably transported along the shore by currents and was deposited into inclined strata in sand-lime bars at the shoreline and in the foreset beds of local delta fronts at the seaward ends of channels (Fig. 26A). Potholes and irregular scours were cut locally into these bars and deltas by currents during periods of excessive activity and were soon again filled with sand (Fig. 26B). The position of these inclined strata of the South Bend member in relation to the Fredonia Dome suggests that a part of the inclination may have resulted from local upward movement on the dome. The
presence of abundant fusulinids in a few places suggests that large quantities of these small animals were locally swept from a nearby deeper water habitat into Wilson County to be eventually entrapped in the sandy calcareous sediments as they accumulated. The clay fragments in the basal sandy limestone of the South Bend suggest that in earliest South Bend time, the marine-shale environment of the Rock Lake was brought slightly above sea level, and the marine clay, which was exposed and desiccated to form a mud-cracked surface, furnished the fragments.

The ostracodes, echinoids, and fusulinids of the fauna of the Rock Lake Shale Member suggest either that fusulinids could tolerate the same environment as the other elements of the fauna or that the fusulinids were brought into this muddy environment to die. The variation in thickness and absence of the member throughout much of the county suggests that a general lowering of sea level or considerable local uplift and attendant erosion and influx of sand immediately followed Rock Lake deposition.

The lithology of the Stoner Limestone Member indicates that it accumulated in a marine environment well suited to the deposition of nearly pure algal limestone. The oolites and algal fragments in the upper part of the Stoner reflect a well-agitated, shallow-water environment. The absence of the oolitic facies atop the Fredonia Dome and maximum thickness both north and south of the dome suggest that the oolites and fossil fragments, which may
have originated in shallow water over the dome, were carried by current action to lower areas of peripheral sag adjacent to the uplifted area. Remnants of the oolitic facies atop the dome were presumably removed by erosion prior to the deposition of the Rock Lake Shale Member. The local concentration of certain fossil types, to the exclusion of all others, in the lower part of the Stoner Limestone Member suggests that the sea floor at that time was a series of local depressions separated by barriers that made possible the development of environments especially suited to certain life forms. Locally, only the remains of crinoids furnished the material that accumulated to become thin beds of limestone; elsewhere, only fenestrate bryozoan remains were supplied; and in other places, brachiopods flourished, or pelecypods, or echinoids. The locally large concentrations of brecciated-appearing limestone are most likely the remnants of moderate-sized phylloid algal banks.

The greenish-gray calcareous shale of the upper part of the Eudora Shale Member represents a muddy transition from the anoxic black shale environment of the middle part of the Eudora to the carbonate-rich environment of deposition of the Stoner Limestone Member. The close similarity between the black shales with phosphorites and modern phosphorites suggests that the Pennsylvanian phosphorites and enclosing shales probably formed very slowly (a few millimeters of growth per thousand years) in
an offshore sediment-starved regime. Non-skeletal phosphorite occurred principally as nodules and laminae. The nodules occurred at distinct horizons probably representing periods when conditions favored phosphorite formation. The shale that surrounds the nodules has been displaced probably as a result of compaction. Generally horizontal laminations of phosphorite alternate with wispy stringers of shale. Phosphate nodules are composed of peloids, cements, (apatite, calcite, silica, pyrite), microfossils and megafossils. X-ray analyses (Runnels and others, 1953; Mitchell, 1981) show that the phosphorite in the nodules is a carbonate fluorapatite. The nodules generally average about 30% P\textsubscript{2}O\textsubscript{5} (Runnels and others, 1953). Peloids are sub-spheroidal, are composed of collophane (cryptocrystalline apatite), and are generally about 100 to 150 microns in long dimension. According to Robbins and Porter (1980) the main source of phosphorus was from fecal pellets of ostracodes. Laminae of phosphorite consist of discontinuous layers composed of tiny micronodules; laminae are entirely collophane. Radiolarians (first reported by Berendsen and Hodine-Zeller, 1978) are the dominant skeletal-grain type found in Midcontinent Pennsylvanian phosphorite nodules. The diagenetic sequence for the nodules is (1) apatite cement as thin radiating rims, (2) silicification, (3) calcification, (4) pyritization. All cements are void-filling in origin (Kidder, 1982, p. 31, 41, 48).
Cook (1975) and Bentor (1980) provided excellent summaries concerning the origin of marine phosphorites. They believed that phosphorites formed on the sea floor of pericontinental shelves at depths of 60 to 450 m (200-1500 ft) in areas of slow clastic influx in conjunction with upwelling and high organic productivity at low paleolatitudes. Bentor (1980) gives this sequence of events in their growth as starting with upwelling of currents that were driven by prevailing winds; thus began the supply of nutrients necessary to support high productivity of pelagic organisms. Upon death, the organisms sank to the bottom and released the phosphorus in their systems as free apatite for precipitation in the sediment as decay proceeded. Phosphorites were formed primarily by direct precipitation of apatite at or below the sediment/water interface, and not as a replacement of calcite. Upwelling promoted the development of a circulatory nutrient trap for production of pelagic organisms (Brongersma-Sanders, 1971). Moore, in 1929, had proposed a nearshore swamp environment for the accumulation of debris for fissile black shales. Zangerl and Richardson (1963) and Merrill (1975) expanded on the nearshore environment by invoking a flotant of seaweed to generate anoxic conditions necessary for black shale deposition (Kidder, 1982, p. 51-57).

Bottom-dwelling pelecypods as well as horn corals, bryozoans, echinoids, and brachiopods formed the fauna
supplied to the calcareous shale that generally overlies the black shale. Orbiculoid brachiopods apparently flourished in the local quiet-water environment now represented by the fissile black shales of the middle part of the Eudora. Petrographic examination reveals abundant and diverse radiolarians preserved in the phosphorite nodules of the black shales. The calcareous gray shale at the base of the Eudora indicates that a short period of less restricted argillaceous sedimentation preceded the quiet, stagnant environment of middle Eudora time.

The Captain Creek lithology reflects a carbonate-rich marine environment. The porous, cavernous sparingly fossiliferous limestone of the upper part of the member records a general, but shallow invasion of the sea. The waters presumably were highly charged with carbonate and formed flocculating masses of calcium carbonate on the sea floor; these masses were incorporated into the growth of phylloid algal mounds whose remains lithified to form an open-textured calcareous rock. The locally fossiliferous, brecciated-appearing parts of the Captain Creek suggest that periodically, local storms may have brought in large quantities of shell fragments and have swept them into the algal leaves to form a brecciated slightly lithified mass. Reduction in water agitation allowed these materials to settle into a thick phylloid algal bank deposit. The abundant Osagite algae and oolites in the lower part of the Captain Creek reflect shallow, relatively well-lit,
highly charged saline waters. The irregular surface at
the top of the underlying Vilas Shale may have formed
through the action of tidal currents which operated
between high and low tides and cut scour channels that
were filled by the algal-oolitic limestone at the base of
the Captain Creek as the sea encroached upon the land.

The local absence of the Captain Creek Limestone
Member is due either to local uplift and nondeposition
along the crest of the Fredonia Dome during transgression
in Captain Creek time or to uplift, deep erosion, and
channel filling toward the end of Captain Creek time.

**Vilas Shale**

**Naming, Distribution, and Thickness.** Haworth
(1898, p. 51) credited G. I. Adams with the suggestion
that the shale sequence well represented in the
northeastern part of Wilson County around the town of
Vilas be designated the Vilas shale. The Vilas is an
“outside shale” that caps the underlying Plattsburg
cyclothem (Watney, French and Franseen, 1989, p. 89). The
formation crops out across the county from the northeast
corner to the center of the south line (Plate 1) and is as
much as 33.4 m (110 ft) thick in the triangular area
between Vilas, Benedict, and Altoona (Plate 3C). It thins
rapidly both west and east of Altoona; about 6 km (4 mi)
to the west, it is only 2.4 m (8 ft) thick, and about 10
km (6 mi) to the east, it is only 1.5 m (5 ft) thick.
It appears to be missing south of Fredonia but thickens again markedly at the boundary between Wilson and Montgomery Counties.

Lithologic Character. The most nearly complete exposure of the Vilas Shale in Wilson County is in roadcuts along the east lines of the SE 1/4 sec. 11 and NE 1/4, sec. 14, T 28 S, R 16 E, about 6 km (3.5 mi) southwest of Vilas. At that locality, the Vilas lies conformably below the Stanton Limestone and is about 34 m (110 ft) thick. The uppermost 0.9 m (3 ft) is light grayish-orange, fossiliferous, calcareous shale that locally contains an abundant microfaunal assemblage intermixed with the remains of crinoids, echinoids, gastropods, pelecypods, bryozoans, and brachiopods. The microfauna consists of the ostracodes Bairdia and Kirkbya(?), and the foraminifers Polytaxis, Tetrataxis, and unidentified fusulinids (Wagner and Harris, 1953). A medium gray algal limestone bed, 15 to 30 cm (6-12 in) thick, occurs at the base of the uppermost 0.9 m (3 ft) thick shale unit; the bed is made up in some places of disconnected, flattish, algal nodules or concretions; in other places, the bed is as much as 1.5 m (5 ft) thick and is irregularly bedded. In most of the outcrop area, the bed is a mass of algae (Osagia) and oolites. Thin sections show the algae to range in length from 1 to 20 mm and to form coatings around shell and rock fragments ranging in length from 0.25 mm to 15 mm. The algal
coatings on small objects (0.25-2 mm) are smooth-surfaced and thin; the coatings on larger objects (2-15 mm) are thicker and are commonly composed of many thin, encrusting, irregularly crenulated layers (Figure 30A). The centers of many of the small algae are detrital grains of crystalline calcite; other centers are recognizable as shell fragments. The small algae are mainly flattened spheres or discs; the large algae generally conform to the shapes of the shell fragments around which they formed. Both of these types apparently fall within the genus Osagia as pictured by Johnson (1946, Figure 3, pl. 10; and Figure 4, pl. 4), but the larger forms closely resemble Cryptozoon from other beds. The oolites associated with the algae are spherical and average 0.25 mm in diameter. Unlike the algae, they show a prominent radial structure that extends all the way to the center in many oolites; but in most specimens only the outer part is radial (Fig. 30B). Many oolites formed around subround fragments of very finely crystalline or microcrystalline limestone.

The limestone bed at the base of the uppermost 0.9 m (3 ft) of the Vilas Shale may correlate laterally with a bed containing algal limestone concretions. Newell (1933, p. 62) suggested that these concretions were colonies of calcareous algae of the sort described by Georges Gurich (1906, p. 48) as Malacostroma. Newell also pointed out that most of the algal "heads" are concavo-convex slabs 7.5 to 10 cm (3-4 in) thick and 0.3 to 0.6 m (1-2 ft)
Figure 30. Limestone beds near the top of the Vilas Shale. (A) Thin section of algal, oolitic limestone bed in Sec. 27, T 29 S, R 15 E, showing small algae in upper left, large algae in center, and radial oolites in matrix, ordinary light (X 30). (B) Same showing detail of radial oolites, crossed nicols (X 300). (C) Weathered surface of different bed in Sec. 33, T 30 S, R 15 E, showing sinuous paths of dark calcite veinlets.
across, that they lie isolated from each other in shale, and that in a few instances a reef-like structure or bed is formed 0.3 m (1 ft) thick and about 1.5 m (5 ft) across. He stated: “These masses weather out as buff impure limestone. Fresh fractures occasionally show layers of dense, bluish limestone which shows delicate lamination. In rare instances a development of irregular, ragged stolons appears at the upper surface as in the alga Somphospongia Beede. The algal limestone is generally crusted over or overlain by a dark colored oolitic limestone which locally bears a few poorly preserved mollusks and particularly the brachiopod Punctospirifer kentuckiensis. The oolitic limestone is possibly also of algal origin since the contained fossils are commonly coated over with a lamellar limy deposit of probable organic origin” (Newell, 1933, p. 62-63).

Locally, as in Secs. 27 and 31, T 29 S, R 15 E and Secs. 33 and 34, T 30 S, R 15 E, the limestone unit containing the algal concretions incorporates grayish-orange limestone fragments in its lower part. Many of the fragments have an algal or accretionary coating around them; elsewhere, the fragments are closely associated with thin olive-gray, irregularly shaped seams or blades 0.1 cm (0.04 in) thick, that may be of algal origin (Fig. 30C). In Sec. 36, T 28 S, R 15 E, a limestone bed at the same stratigraphic position is made up almost entirely of small brachiopod shells, probably Punctospirifer, all coated
with algal encrustations and enclosed in a silty calcareous matrix. Crinoid stems, pelecypods, gastropods, and sparse fusulinids are also associated with limestone at this stratigraphic position. It is tempting to include the uppermost fossiliferous 1.5 m (5 ft) of shale of the Vilas in the overlying Stanton Limestone. However, since the fossiliferous unit is very discontinuous and where exposed can be traced laterally almost into unfossiliferous shale that underlies the Stanton with a sharp contact, the decision was made to place the unit in the Vilas Shale as was done by Newell (1933, p. 61-63).

The next underlying 5.5 m (18 ft) of shale is dark bluish gray to light olive gray, non-silty, and unfossiliferous. Near the center of this 5.5 m (18 ft) of shale are several thin beds of calcareous clayey concretions, some of which are seamed with veinlets of dark gray to black calcite (algal fronds?).

In the southern part of Wilson County the lower 26 m (85 ft) of the Vilas rests conformably on the Plattsburg Limestone and consists of light olive-gray, unfossiliferous, slightly silty, locally micaceous shale that contains several thin beds of ironstone concretions in its upper and lower parts. Near the center of Wilson County, a unit of very dark-gray shale about 1.5 m (5 ft) thick occurs locally in the Vilas Shale about 9 m (30 ft) above the base. It is overlain by 17 m (55 ft) of yellowish-gray shale and underlain by 9 m (30 ft) of light
olive-gray, slightly silty shale. A lateral transition of
the Spring Hill Limestone Member of the Plattsburg
Limestone into the Vilas Shale in the so-called marine
bank development of the Plattsburg Limestone was
postulated by Harbaugh (1959, p. 312, 314, 318-319, 323-
324; 1962, p. 15), and by Heckel and Cooke (1969, p. 1073)
thus allowing the Captain Creek Limestone Member of the
Stanton Limestone to rest directly upon the Plattsburg
Limestone.

Jeffords (1947, p. 30) recorded the occurrence of the
solitary coral *Lophophyllidium coniforme* in the Vilas
Shale at a locality 10 km (6 mi) east and 0.8 km (0.5 mi)
south of Fredonia on State Highway 47.

A study of the clay mineralogy of the Vilas Shale was
performed by Kinell (1964) who sampled the Vilas at five
good exposures in Wilson and Montgomery counties. His
figure 3 shows the presence of kaolinite (7.13Å°, 3.56Å°),
illite (10.04Å°, 4.98Å°, 3.35Å°, 1.99Å°), and chlorite
(14.02Å°) in each of the sampled areas. Several factors
were taken into account in order to determine the
significance of the diffraction patterns given by each set
of samples. These factors included the (1) source area
(marine or terrestrial); (2) climate (kaolinite needs good
drainage, a pH of 6.0-7.4, and precipitation greater than
evaporation; montmorillonite prefers evaporation greater
than precipitation; kaolinite indicates non-marine and
near-shore environments; illite and chlorite result from
marine conditions; chlorite is characteristic of continental slope); and (3) diagenetic modification (saline water causes adsorption of potassium by illite and chlorite; montmorillonite exchanges calcium cations for potassium and magnesium; kaolinite changes to illite in a marine environment). Kinell (1964, p. 31) concluded that illite was the principal clay mineral in the Vilas Shale; that chlorite content increased downward in the Vilas whereas kaolinite increased upward, particularly when chlorite was not present; and that diagenetic effects, if present in the Vilas Shale, were not convincingly discernible.

Stratigraphic and Structural Implications. The changes in thickness of the Vilas Shale are apparently the result both of lateral variations in sedimentation and of structural downwarp or uplift. However, delta lobes of large size were a prominent depositional feature in latest Vilas time in northern Montgomery County just south of the Wilson County line. As the sea transgressed northward at the beginning of Stanton time, the delta lobes were abandoned and the seafloor was rapidly colonized by brachiopods, crinoids, bryozoans, ostracodes and foraminifers. The main Vilas lobes were subject to compaction and subsidence so as to nearly pinch out to the north in Wilson County. The wide distribution of thin limestone beds near the top of the Vilas seems to preclude extensive erosion at the end of Vilas time as the cause of
the thickness variations. Rather, they seem to indicate several impulses directed toward the generation of algal colonies which were unsuccessful. Pre-Stanton erosion at the top of the Vilas did occur locally, however, and is well shown in roadcuts 3 km (2 mi) west of Altoona along State Highway 47, where surge channels with rounded bottoms and nearly vertical sides were cut 0.6 m (2 ft) or more deep into the Vilas (Fig. 29B). The channels are separated by intervening areas with tops smoothly convex upward and closely resemble present-day bay muds that have been cut to similar depths and kept fairly smooth and clean of clay debris by tidal action. Vilas time may therefore have ended with the argillaceous marine sediments locally exposed to surge channel erosion. The thin, algal, oolitic limestone bed below the fossiliferous uppermost 0.9 m (3 ft) of the Vilas indicates a change from a widespread nearshore, supersaline environment to one reflecting an abundant supply of clay-size debris. The fossils in the uppermost part of the Vilas suggest that occasional strong waves and currents brought fragments of crinoids and bryozoans (and a few fusulinids) into the biozone of a nearshore marine fauna that included abundant algae, small gastropods, pelecypods, and brachiopods. Locally, thin, platy algal bodies tried to develop colonies at this approximate time and the remains formed a brecciated-appearing limestone bed. The presence of limestone beds with the platy calcite bodies in the
lower part of the Captain Creek Limestone Member indicates that these particular environmental conditions continued into Stanton time.

The more than 30 m (100 ft) of shale that underlies the thin oolitic limestone bed between Vilas, Altoona, and Benedict indicates a relatively long period of concentrated argillaceous deposition in that area. On the Fredonia Dome, however, slight uplift apparently reduced shale deposition and preservation to only about 3 m (10 ft), and farther south in Wilson County, a facies of the Plattsburg Limestone apparently replaced argillaceous sedimentation of Vilas Shale.

**Plattsburg Limestone**

**Naming, Distribution, and Thickness.** The Plattsburg Limestone was named by Broadhead (1865, p. 317) for exposures at Plattsburg, Clinton County, Missouri. According to Moore (1936, p. 128), the Plattsburg has been traced from northwestern Missouri to a point near the Oklahoma boundary where it disappears; but it apparently reappears farther south in Oklahoma. Along the outcrop belt in Kansas, the thickness of the Plattsburg ranges from less than 1.5 m (5 ft) to more than 30 m (100 ft). In Wilson County the Plattsburg crops out in a northeasterly trending belt generally near the bottom of the escarpment capped by the Stanton Limestone. In the northeastern part of the county, it is only 0.3 to 3 m (1-
10 ft) thick, but in the south-central part of the county, it is as much as 35 m (115 ft) thick (Plate 2C) and forms the major part of the escarpment capped by the Stanton Limestone. Most of the mounds south and east of the Stanton escarpment are capped by the Plattsburg Limestone.

Lithologic Character. The Plattsburg Limestone at the type locality is a gray and ashy-blue coarse limestone 4 to 7 m (13-23 ft) thick (Broadhead, 1865, p. 317, 327). In the outcrop area in northeastern Kansas and adjacent parts of Missouri, the Plattsburg is strikingly constant in its distinguishing features and shows little variation in lithologic and faunal characters (Newell, 1935, p. 71; Moore, 1936, p. 128). It is nearly everywhere divisible into 3 parts: a relatively thick, upper limestone (the Spring Hill Limestone Member), a thin shale parting (the Hickory Creek Shale Member), and a basal, thin, blocky limestone (the Herriam Limestone Member).

In Wilson County all three members are readily distinguished where the formation is thick. Each member contains the sponges Girtyocoelia and Heliospongia, and where the formation is thickest, a poorly bedded, sparingly fossiliferous, oolitic algal limestone occurs above the sponge-bearing beds. Where the formation is very thin, it appears that the upper two members are missing, but exposures in that area are not continuous, and correlation between members could not be made with certainty. However, the lithology and bedding of the
limestone where it is thin are more nearly like those of the Merriam Limestone Member than like those of the Spring Hill Limestone Member, and correlation is made on that basis.

Spring Hill Limestone Member. The Spring Hill Limestone Member was named by Newell in 1932 (Moore, 1936, p. 129) for exposures near the town of Spring Hill in southern Johnson County, Kansas. At the type locality in a railroad cut at Spring Hill (SE. cor. sec. 14, T 15 S, R 23 E), the member is about 4 m (12 ft) thick and consists (downward) of: (a) 2 m (7 ft) of drab to buff, granular limestone composed largely of minute fossil fragments and thin, wavy streaks of carbonaceous limestone with a Composita zone 0.3 m (1 ft) above the middle; (b) 0.4 m (1.3 ft) of drab, massive, oolitic, limestone; and (c) about 1.2 m (4 ft) of drab, dense, hard, massive limestone with a shaly streak at the top and a zone of Enteletes hemiplicatus var. plattsburgensis and Marginifera wabashensis in the lower part (Newell, 1935, p. 102).

In Wilson County the Spring Hill Member ranges in thickness from less than 0.3 m (1 ft) to more than 27.4 m (90 ft) but averages only about 7.6 m (25 ft). Where of average thickness, it is characterized by the sponges Girtyocelia and Heliospongia (Figure 31A, B, C, 32A). Where thickest it has at its top a unit of oolitic and algal limestone that is locally more than 20 m (65 ft)
Figure 31. Sponges of the Spring Hill Limestone Member of the Plattsburg Limestone at quarry in Sec. 22, T 29 S, R 15 E. (A) Heliospongia in typical crinoidal coquina matrix (X 2/3); (B, C) Girtyocoelia in coquinoid matrix, (X 1).
Figure 32. Spring Hill Limestone Member of the Plattsburg Limestone. (A) Girtyocoelid in lower part of member at quarry in Sec. 33, T 29 S, R 15 E. (B) Algal (?) plates in upper part of member at quarry in Sec. 6, T 29 S, R 15 E (X 1). (C) Thin section of oolitic facies in Sec. 26, T 28 S, R 15 E, crossed nicols (X 30). (D) Breccia facies in upper part of member at quarry in Sec. 6, T 27 S, R 15 E (X 2/3).
thick (Plate 2C). This unit is best developed in the south-central part of the county where it is characterized by the phylloid algae Archaeolithophyllum and Eugonophyllum; it thins rapidly northward and southward and is possibly missing locally a short distance northwest of Altoona and south of Vilas.

The uppermost 0.9 m (3 ft) of the Spring Hill Member consists principally of oolites or Osagia(?) that have diameters generally less than 3 mm (0.125 in) but locally as much as 6 mm (0.25 in). This oolitic part is well exposed in a few roadcuts just south of the Verdigris River in the NE1/4 Sec. 26, T 28 S, R 15 E, and north of the river in the NW1/4 Sec. 30, T 28 S, R 16 E. Staining with Alizarine Red S shows the rock to be calcite with but a small amount of clay and limonite and no dolomite. The oolites, which are concentrically banded, are commonly in contact with one another (Fig. 32C); they were concentrated into depressions and were enclosed in very finely crystalline limestone. Thin section studies show that the rock has been moderately and somewhat selectively recrystallized by calcite (Figure 33A, B). The crystal size in the oolites and in most of the calcite matrix is 0.1 to 0.2 mm, but in parts of the thin sections, the matrix consists of calcite crystals as small as 0.02 mm. Crystal boundaries, either in matrix or in oolite, generally stop abruptly at the oolite boundary (Figs. 32C,
Figure 33. Spring Hill Limestone Member of the Plattsburg Limestone. (A) Thin section of concentric oolite, ordinary light (X 80). (B) Thin section of concentric oolite, crossed nicols (X 80). Note that crystal boundaries cross concentric bands. Note also perpendicularly oriented crystals at oolite boundary in upper right.
of calcite in which the long directions of a few of the
crystals are oriented perpendicularly to the oolite
surface (Fig. 33B). However, distinct internal radial
structure, characteristic of many oolites is lacking.
Recrystallized calcite in the oolites forms crystals
irregularly elongated parallel to the direction of the
concentric bands, but the crystals cross the bands and
commonly include 2 to 5 bands (Figs. 32C; 33B). Some of
the concentric bands extend to the center of the oolite,
but more commonly either crinoid stem segments, or small
shell fragments, or subangular microcrystalline limestone
fragments form the centers (Fig. 32C). Many of the nuclei
seem to have been unaffected by recrystallization,
possibly because they were primary calcite, not aragonite.

Diekite was recognized in the Plattsburg Limestone in
10 samples from the NW1/4 Sec.26, T 30 S,R 15 E in Wilson
County. There seems to be a thermal relationship between
kaolinite and dickite, the dickite being high temperature.
Whether this is due to heat from depth of burial or a
magmatic (hydrothermal) source is still open to question.
The igneous intrusions in Wilson and Woodson Counties
could produce a source for hydrothermal solutions. These
heated waters, under pressure, could have moved up-dip and
along the strike of the gently westward-dipping
Pennsylvanian strata. Dickite would have been deposited
as the warm waters moved away from the vicinity of the
intrusions; it could then have formed crystals and crystalline (fluffy) masses in porous and permeable algal-mound limestones, stylolites, joints, veins and fractures (Schroeder, 1967, p. 66-68).

Where the Spring Hill is thickest, the upper 18 m (60 ft) below the oolitic part consists of irregularly bedded, sparsely fossiliferous, phylloid algal, locally oolitic limestone. Small cavities and vugs lined with clear calcite crystals are common. In places, crystalline calcite occurs abundantly in short plate-like or vein-like bodies (broken algal fronds) that lie generally parallel to the bedding (Fig. 32B). Many have very irregular shapes, suggesting their biologic origin; they may have been crenulated and fractured while in a semiplastic condition during compaction of the enclosing sediments (Fig. 32 B, D). Crinoid stem fragments and other algal growths, some resembling Cryptozoon, are abundant in a light olive-gray limestone matrix in some exposures. Characteristically, much of the unit is a brecciated-appearing, poorly bedded limestone in which medium dark-gray, irregularly shaped, very finely crystalline phylloid algal fragments, 1.3 to 5 cm (0.5-2 in) in length, occur in a matrix of light olive-gray, finely crystalline limestone. The ends of many of the fragments are serrated as though they have been violently pulled apart while semilithified and immediately enclosed in a gel-like...
carbonate matrix (Fig. 32D). In thin section, the fragments are seen to be composed in part of a foraminiferal microfauna and minute particles of fossil debris. The matrix appears to have been predominantly silt-size grains of dolomite and calcite in which were enclosed a few very small oolites and numerous small segments of crinoid stems and fragments of shells. The weathered surface of this upper part of the Spring Hill Limestone Member is generally gray and irregular. Discussions with D. F. Merriam convinced J. W. Harbaugh to embark upon a study of the anomalous thickenings of limestone and shale described above. Five reports were written by Harbaugh (1959, 1960, 1961, 1962, 1964); he proposed that the broken, platy edges of dark-colored fragments in the thick limestone accumulations of the Plattsburg Limestone were algal in origin (Harbaugh, 1959). In 1960, (p. 194) Harbaugh expanded his study to include the Stanton Limestone and was able to relate the leaf-like broken fragments in the Stanton to the algae Anchicodium and Spongiostromata. He also discussed the similarity of origin of those algae to that of the modern algal form Halimeda described by Johnson (1957, p. 178) off Saipan (Harbaugh, 1960, p. 225-227). In his 1961 report (Harbaugh, 1961, p. 120) related the leaf-like form to the alga Eugonophyllum of Konishi and Wray (1961, p. 659-666). Harbaugh was, thus, the first geologist to
recognize that leaf-like and encrusting algae form the principal biotic constituent of the anomalously thickened limestone deposits of Wilson County and eastern Kansas in general. He termed them algal banks as opposed to reefs because they were made up mainly of fragmental material and had no apparent attachment to a solid substrate.

Based on acetate peels made from the etched surfaces of samples of limestone from the Spring Hill Limestone Member, Harbaugh (1959, p. 300-314) differentiated three subdivisions in the member (downward): (a) a calcarenite subdivision as much as 11 m (35 ft) thick, (b) a crystalline limestone subdivision as much as 14 m (45 ft) thick, and (c) a fragment-pellet limestone subdivision that ranges from 0.9 to 11 m (3-35 ft) thick. Harbaugh's calcarenite and crystalline limestone subdivisions apparently correlate with the part of the Spring Hill described by me in the first part of the previous paragraph. The lower part of my Spring Hill coincides generally with his fragment-pellet limestone subdivision.

P. H. Heckel also became interested in the algal mound complex that occurs in the Spring Hill Limestone Member in Wilson County. He determined that the Spring Hill is 18 to 24 m (60-80 ft) thick and consists of algal to sparry algal calcilutite, algal sparite with ferroan dolomite and non-algal calcilutite (Heckel and Cocke, 1969, p. 1072-1073). Hummocks 1.2 to 1.5 m (4-5 ft) high
were observed within the mound facies; thin beds of fossiliferous calcarenite outline the hummocks. Commonly, a thick, skeletal calcarenite with fusulinids and stromatoporoids overlies the mound facies. Elsewhere, oolitic calcarenite with brachiopod-shell accumulations, and thin algal calcilutite interbedded with shale locally cap the mound complex. A pisolitic calcarenite forms the cap at the northeast end of the mound facies and extends northeastward for several miles. Beyond there a myalinid-bearing skeletal calcarenite occurs at the top of the thin non-mound Plattsburg. The mound complex is underlain by 1.2 to 1.5 m (4-5 ft) of sponge-rich calcilutite and calcareous shale, which persists for about 6 km (4 mi) south of the mound and also extends northward composing most of the thinned formation. The Vilas Shale thins over the mound complex and locally pinches out. The Vilas reaches a maximum thickness of 27 to 30 m (90-100 ft) to the north and south of the complex (Heckel and Cocke, 1969, p. 1073).

D. L. Nelson (1978) studied in detail the Spring Hill algal mound near Neodesha in Wilson County as a master's thesis with Heckel as his supervisor. In his excellent 181-page report, Nelson recognized and described petrographically four subdivisions of the Spring Hill and included sections on depositional environment and diagenesis for each subdivision. His subdivisions
were a skeletal to oolitic calcarenite (unit 4), a spar-spot skeletal calcilutite (unit 3), a skeletal-algal sparry calcilutite to sparite (unit 2), and a skeletal-sponge calcilutite (unit 1). Nelson's unit 4 would equate with my oolitic-Osagia part. Dolomite is moderately abundant as a cement between casts of mollusks or as replacements of molluscan shells in this unit. Gastropods are typically composed of dolomite; it appears that dolomite is preferentially localized in former aragonitic molluscan shell layers (Nelson, 1978, p. 157). Nelson's units 2 and 3 presumably correspond to Harbaugh's crystalline limestone subdivision and to my irregularly bedded, fragment-rich finely crystalline central part. The fragments may correspond in part to Nelson's highly irregular patches of ferroan dolomite (1978, p. 113, 116).

Nelson's unit 2 was apparently partly filled first with a layer of botryoidal calcite or an irregular mosaic of fairly equant crystals. Ferroan calcite is the common late stage cement in conjunction with ferroan dolomite, both of which presumably replaced botryoidal aragonite-needle cement (Nelson, 1978, p. 84, 88, 89). His unit 1 has radiating fans of botryoidal calcite, similar to primary aragonite cements described by Ginsburg and James (1976) and Sandberg (1981), as early void-filling cement. Ferroan calcite void fill is always a later stage than non-ferroan cement and could possibly be related to a
high-magnesian calcite precursor. Dolomite and celestite occur as late-stage void fills following ferroan and non-ferroan blocky mosaics and acicular rim cements (Nelson, 1978, p. 43, 44).

The Spring Hill is the most widespread member of the Plattsburg. This member averages about 8 m (25 ft) in thickness over most of the outcrop area in the county. The upper part of the Spring Hill is apparently missing northeast of Vilas where the entire Plattsburg Limestone is only about 15 cm (6 in) thick. Where of average thickness, most of the Spring Hill consists of light olive-gray, hard, clayey, very thin-bedded and irregularly bedded, fossiliferous limestone. It characteristically has abundant Heliospongia and Girtyocoelia, but also contains many crinoid fragments and less abundant Neospirifer, Derbyia, Marginifera, Crurithyris, Echinoconchus, Composita, horn corals, and encrusting and fenestrate bryozoans. Much of the Spring Hill is a detrital limestone in which many small fossil fragments are enclosed in a silt-size, argillaceous, calcareous matrix. Weathered surfaces of the rock are stained grayish orange to dark yellowish orange by iron oxide. The Heliospongia occur both in clusters (Fig. 31A) or as fragments. The Girtyocoelia are separated pellet-size spheres (Fig. 31B) or, more commonly, chains of spheres (Fig. 31C, D; 32A). Newell (1933, p. 129) listed Heliospongia ramosa,
Heterocoelia (now Girtyocoelia) beedei, Girtyocoelia benjamini, Maeandrostia kansasensis, and Coelocladia spinosa from this general area. Winchell (1957a, p. 10; 1957b, p. 131) reported a large nautiloid cephalopod from the Spring Hill Member in Sec. 8, T 28 S, R 17 E in Wilson County. Squires (1952) reported the presence of the rhomboporoid bryozoans Rhombopora lepidodendroides Meek and Rhombopora favata Moore from the NE corner of the NW1/4, Sec. 26, T 30 S, R 15 E in Wilson County (Squires, 1952, p. 10, fig. 3). In the NW 1/4 Sec. 18, T 30 S, R 15 E at the Carr Quarry, less than 1.6 km (1 mi) northwest of Neodesha, Cocke (1970, p. 60) records that algal limestone of the Plattsburg, approximately 9 m (30 ft) thick, is exposed in the quarry wall. The upper 0.9 to 1.2 m (3-4 ft) consists of oolitic skeletal calcarenite with abundant fragments of the algae Archaeolithophyllum at the base along with the corals Neokoninckophyllum variabile and Dibunophyllum valeriae.

Cocke (1970) collected algal specimens from several Spring Hill localities in Wilson County. At the locality (1) in the main quarry just south of Fredonia the Spring Hill comprises the lower 1.2 to 1.5 m (4-5 ft) of limestone exposed in the southwest one-fourth of the quarry wall; there it consists of algal calcilutite to calcarenite with calcareous shale interbeds. The calcareous shale is presumed to be an equivalent of the
Vilas Shale. The lower limestone bed contains abundant fusulinids, echinoid spines, fenestrate bryozoans, *Punctospirifer*, *Composita* and *Rhipidomella*. *Neokoninckophyllum variabile* and *N. acolumnatus* are found abundantly in growth position, particularly on the upper surfaces of the calcilutite. Other localities include (2) the northeast side of the St. Louis & San Francisco railroad cut along Fall River about 6 km (4 mi) southeast of Fredonia where the Plattsburg is 12 m (38 ft) thick and underlies about 2 m (6 ft) of Vilas Shale. A 0.6 m (2 ft) thickness of oolitic calcarenite that contains the stromatoporoid *Parallelopora*, some fusulinids, the pelecypod *Aviculopecten* and the brachiopod *Meekella* occurs at the top of the Spring Hill at this locality. Next below is about 3.3 m (11 ft) of crinoid-rich skeletal calcarenite, which has the remains of a few *Neokoninckophyllum variabile* and *Dibunophyllum valeriae* along the upper undulating surface. The lower 8 m (25 ft) of the Spring Hill consist of massive algal limestone that contains a few bryozoan and crinoid fragments. (3) In the Carr quarry, less than 1.6 km (1 mi) northwest of Neodesha, a cap of oolitic skeletal calcarenite, 0.9 to 1.2 m (3-4 ft) in thickness, that contains abundant fragments of the algae *Archaeolithophyllum* sp. overlies a thin shale unit in which the corals *Neokoninckophyllum variabile* and *Dibunophyllum valeriae* occur in growth
position. The oolitic calcarenite unit is followed downward by approximately 8 m (25 ft) of algal Plattsburg Limestone in which algal remains are only moderately abundant. (4) On Kansas Hwy 96, 5 km (3 mi) west of Neodesha where the Plattsburg Limestone is 35 m (115 ft) thick; the Spring Hill Limestone Member of the Plattsburg is separated from the overlying Captain Creek Limestone Member of the Stanton by a 3 m (9 ft) interval of Vilas Shale; about 4 m (13 ft) of skeletal to oolitic calcarenite of the Spring Hill overlies a 13 m (42 ft) thick algal-rich calcilutite in which dissepimental corals in growth position are associated with the rugose coral *Neokoninckophyllum variabile* on a hummock 1.2 (4 ft) high and approximately 5 m (15 ft) below the top; the hummock is underlain by 6.7 m (22 ft) of pelletal calcilutite; the lower 12 m (38 ft) is interbedded calcilutite and calcareous shale. At the locality (5) 1.6 km (1 mi) north and 8 km (5 mi) east of Fredonia on the west side of a southeast-flowing stream, as much as 6 m (20 ft) of oolitic calcarenite is present. There, the beds dip eastward, as opposed to the normally westward gentle dip of the Pennsylvanian strata; interestingly, a single specimen of *Neokoninckophyllum variabile* was found at this locality; it was accompanied by lophophyllidid corals, bryozoans, the brachiopods *Dielasma* and *Composita*,
the pelecypod Myalina, and crinoid cups representing several crinoid genera (Cocke, 1970, p. 60, 61).

Hickory Creek Shale Member. The Hickory Creek Shale Member was named by Newell in 1932 (Moore, 1936, p. 129) from a stream near Peoria, Franklin County, Kansas. In the general area of the type locality, the Hickory Creek Shale Member is about 0.3 m (1 ft) thick and is commonly gray or yellowish-gray calcareous shale, but in some nearby areas, it is a black, carbonaceous, platy shale (Newell, 1933, p. 47-48).

Where measured in Wilson County, the Hickory Creek is from 0.9 to 9.1 m (3-30 ft) thick (Plate 2C) and is consistently very finely micaceous, slightly silty, very calcareous and fossiliferous, and varies from medium light gray or light olive gray to yellowish gray. Thin, silty laminae locally contain plant fragments. The most common fossils are crinoid columnals and the sponges Girtyocoelia and Heliospongia. The fossils weather readily from the clayey matrix, and unbroken specimens are abundant. The Girtyocoelia weather out as chains of small spherical-shaped bodies or separated spheres 0.6 cm (0.25 in) in diameter (Fig. 31B, C). The Hickory Creek member grades laterally from very thin-bedded, fossiliferous shale to poorly bedded, very calcareous shale and clayey limestone. Concerning the fauna of the Hickory Creek, Newell (1933, p. 129) stated that the sponges Girtyocoelia benjami,
Maeandrostia kansasensis, Heliospongia ramosa, and especially Coelocladia spinosa and Heterocoelia (now Girotocoelia) beedei are particularly abundant in the Hickory Creek Shale Member south of the Neosho River. He stated also (Newell, 1933, p. 130) that, "In central Wilson County, a number of mollusks, definitely of the geosynclinal facies, are introduced into the sponge fauna. Of particular note is the occurrence together in the southern facies of the Hickory Creek of Leiorhynchus rockymontanus and Enteletes hemiplicatus var. plattsburgensis."

Moore (1940a, p. 34, 39, 41, 53) reported the collection of the holotype specimen of the crinoid Elibatocrinus notabilis and paratype specimens of Elibatocrinus leptocalyx from the Hickory Creek at a locality 4 km (2.5 mi) west of Neodesha on State Highway 96. Jeffords (1947, p. 30) reported specimens of Lophophyllidium coniforme from the Hickory Creek Member at several localities in Wilson County. Squires (1952, p. 9, fig. 3) recorded the rhomboporoid bryozoans Rhabdomeson decorum Moore, and Rhombopora paenecalva n. sp. from the Hickory Creek Shale Member at the center of the west side of sec. 8, T 27 S, R 17 E. The conodont fauna in the Hickory Creek is dominated by abundant Idiognathodus (Heckel and others, 1985, p. 34).
Jacques (1964) made a study of the microfossil content of the Hickory Creek Shale Member. By sieving through 3 sieves (no. 35, no. 60, no. 120), he was able to make his microscopic counts without continual refocusing of the binocular microscope. The locality in Wilson County at which the Hickory Creek Shale Member was sampled was a good roadcut exposure along Highway 47 about 2 km (1.25 mi) west of Altoona. Ostracodes identified in Wilson County samples were Bairdia (abundance decreases downward, species not identifiable); *Amphissites* (second most abundant genus with specimens most common in the upper foot) includes species *A. centronotus, A. roundyi, A. carinotus,* and *A. dattonensis*; *Bythocypris* (most abundant in the upper 0.6 m (2 ft), poor preservation); *Healdia* (few specimens); *Cavellina* (most abundant in the upper 0.3 m (1 ft)); *Selenites* (rare, large size specimens); *Hollinella* (very rare, very large, disarticulated valves); *Monoceratina* (small, rare, recognized by distinctive caudal process and spine, disarticulated); *Ulrichia* (rare, complete carapaces); and *Kirkbya* (very rare, complete carapaces). Foraminifera outnumbered all other microfossils; the maximum in one sample was 1,289 specimens near the base of the Hickory Creek, and included *Ammodiscus* (increase in number toward base, granular surface texture, discoidal shape, siliceous test); *Cornuspira* (glossy surface, discoidal shape,
calcareous test); Nodosinella (abundant, coarsely granular siliceous test); Nodosaria (abundant, glossy, calcareous test); Ammobaculites (uniserial, slightly conical test); Spiroplectammina (coiled, biserial, granular texture, many broken tests abundant near top of member); Endothyra (amber-colored, semi-glossy test); Tetrataxis (cream color, very finely granular surface texture, most abundant near top of Hickory Creek). The only trilobite represented was Ditomopyge (fragments of free cheeks, genal spines, and brims of 28 individuals near base of member). Sponge spicule fragments were found in only four samples (Jacques, 1964, p. 12-26). Holothurian ossicles (sclerites, shaped like spoked wheels) were rare, Protocaudina hannai (eight perforations in outer rim), Protocaudina kansasensis (ten perforations in outer rim), Ancistrum (hooklike or hook-shaped with an eyelet), and Thurolia (perforated plates). Conodonts included Hindeodella (amber colored) and Streptognathodus (dark gray), both with either single blade-like portion or denticulated bar. Gastropods consisted only of abundant juvenile forms of Pseudozygopleura (high spired) and planispiral bellerophonid unornamented low spired forms; abundance increased downward. Pelecypods were not identified generically because juvenile shells were unornamented; both pectinids and myalinids were represented (4 specimens). Brachiopods included immature
forms of *Rhipidomella, Dictyoclostus, Juresania, Neospirifer, Punctospirifer, Composita, Hustedia,* and *Neochonetes*. Jacques concluded, from the above listing and abundance curves, that ecological factors such as salinity, depth of water and temperature were important symbiotic controls. He stated that the assemblages also reflected commensalism (Jacques, 1964, p. 27-39).

**Merriam Limestone Member.** The Merriam Limestone Member was named by Newell in 1932 (Moore, 1936, p. 128) for exposures in a quarry at Merriam, Johnson County, Kansas (NW corner Sec. 7, T 12 S, R 25 E). These quarry exposures are no longer available, having been covered by a housing project (Merriam and Merriam, 1991, p. 161).

In 1956, McNanus (1956, p. 3) proposed that the roadcut exposure on the west side of U.S. Highways 50 and 169, just south of the highway interchange at Merriam, be considered as the type section. Later, O'Connor (1971) remapped Johnson County and set up a reference section in the SE 1/4 SW 1/4 Sec. 12, T 12 S, R 24 E along Hwy I 35.

Recent interstate highway construction destroyed O'Connor's reference section and Merriam & Merriam proposed a new reference section at the intersection of Interstate Highway I 35 and U. S. Highway 56 (Exit 228BC at the center of SW 1/4 SE 1/4 Sec. 12, T 12, R 24 E) (Merriam and Merriam, 1991, p. 161-163). The Merriam Limestone Member there is 0.7 m (28 in) thick and consists
of two thin limestone beds separated by about 8 cm (3 in) of shale. The upper limestone bed is 23 cm (9 in) thick, is light gray (weathers brownish), is hard, stylolitic, has some Osagia and algal fragments, and also contains crinoid columnals, brachiopods, and tiny fusulinids. The intervening shale is gray in color, is clayey, and is 10 cm (4 in) thick. The lower limestone bed is 37 cm (15 in) thick, is light gray (weathers gray), is very fine grained, hard, nodular, has Osagia (especially in the lower part), and also contains brachiopods and fenestrate bryozoans (Merriam and Merriam, 1991, p. 165).

In Wilson County, the Merriam is a single bed that generally is massive, vertically jointed, very fossiliferous, and is consistently slightly more than 0.3 m (1 ft) thick except in the southwestern part of T 28 S, R 17 E where the Plattsburg Limestone as a whole thins to less than 15 cm (6 in). McManus (1956, pl. 2) correlated this bed in Wilson County with the lower limestone unit of the Merriam elsewhere to the north. In Wilson County the Merriam is light gray to light olive gray and weathers grayish orange. It has a very finely crystalline limestone matrix in which the remains of crinoids, sponges, brachiopods, horn corals, and bryozoans are interspersed. In thin sections the matrix of the Merriam is seen as a mass of almost cryptocrystalline calcite and clay-size calcareous debris that contains broken and worn
shell fragments and a few angular silt-size quartz grains. Enclosed in this matrix are larger fragments of brachiopods, crinoid stems, echinoid spines, small foraminifers, and small and large algae.

Crinoid columnals are by far the most abundant fossils in the Merriam, but the sponges *Girtyocoelia* and *Heliospongia* are the most distinctive. Also present are the brachiopods *Meekella, Hustedia, Composita, Derbyia,* and *Marginifera.* Small subcircular oolites or flattened algae (*Osagia*) are locally abundant in the lower part of the member. Newell (1933, p. 130) reported *Enteletes hemiplicatus var. plattsburgensis* from the Merriam in this general area. Heckel and others (1985, p. 34) reported that the lower part of the Merriam to the north contained a moderate assemblage of conodonts. The most abundant were *Adetognathus* in the upper 0.3 m (1 ft) with *Idiognathodus* also present lower down. The basal part of the Merriam contains *Adetognathus* accompanied by both *Anchignathodus* and *Idiognathodus.*

**Stratigraphic and Structural Implications.** The oolitic limestone at the top of the Spring Hill member reflects a shallow-water marine environment in which small oolites or *Osagia* were being oscillated back and forth in carbonate-rich water by current or wave action along the shoreline of the sea, or of an island in the sea, or on the bottom of a bordering shallow lagoon. The thinness
and wide distribution of the oolitic unit suggests a flat or gently undulating surface whose highest point was near Vilas. The algal, brecciated-appearing, sparsely oolitic limestone that is 18 m (60 ft) thick south of the Fredonia Dome and 3 m (10 ft) or less in thickness to the north of the anticline suggests accumulation of lime-mud in conjunction with growth of phylloid algae to form an algal bank in a shallow marine environment. Extremely strong wave action at times apparently forced water between layers of algal fronds that formed a major constituent in a partly lithified lime-mud; the force of the water presumably disrupted these algal mound beds, and pulled the algae violently apart. The fragments were then carried into deeper water where they were immediately incorporated in a partly crinoidal, almost cryptocrystalline matrix before most of their serrated ends could be abraded. The purity of this limestone (lack of argillaceous material) and its limited extent but greater thickness south of the Fredonia Dome suggest that limy debris from an isolated calcareous environment was transported southward by predominantly south-moving submarine currents to the center of a subsiding area where the calcareous materials encountered and intertongued with argillaceous sediment supplied from the south. The concurrent sedimentation of these two rock types presumably continued until Spring Hill time ended with the
widespread deposition of the oolite unit. Following this oolite deposition, the subsidence south of the dome apparently ceased, and the argillaceous sediment formed more than 30 m (100 ft) of Vilas Shale north and east of the dome.

The thinness of the combined Vilas Shale and Plattsburg Limestone on the crest of the Fredonia Dome, as compared with the thicknesses of these two units adjacent to the dome, is a measure of the amount of local downwarping that took place west of the dome during Plattsburg time and both east and west of the dome during Vilas time (Plates 2C, 3C). The lack of evidence of a solid framework built by algae, corals, or other organisms anywhere along the outcrop of the Spring Hill Limestone Member in Wilson County suggests that the brecciated-appearing limestone deposits may represent debris that was disrupted and supplied from calcareous phylloid algal mounds and lime-mud deposits along the top and southwest flank of the Fredonia Dome. The greater thickness of the Spring Hill Limestone Member and Hickory Creek Shale Member south and west of the Fredonia Dome indicates that subsidence in that area began as early as Hickory Creek time. The relatively constant thickness of the Merriam Limestone Member suggests that the area was stable during Merriam time. The abundance of sponges, crinoids, horn corals, and heavy-shelled and thin-shelled brachiopods in
the argillaceous facies of the Spring Hill and Merriam, as well as in the shale of the Hickory Creek, indicates that either these life forms could tolerate both slightly muddy and very muddy environments or that they were carried to those areas to die. The yellowish-brown weathered color of the sponge-bearing beds indicates a higher iron content in the argillaceous sediments than was present in the deposits formed in late Spring Hill time. Locally abundant algae and oolites in the Merriam Limestone Member indicate high salinity and shallow water at the beginning of Plattsburg time.

Kansas City Group

The Kansas City Group was named the Kansas City Formation by Hinds (1912, p. 7) from exposures in the bluffs of the Missouri River and its tributaries at Kansas City, Missouri. He classed these strata as a single formation whose upper limit was the top of the Iola Limestone and whose lower limit was the base of the Hertha Limestone (top of the Pleasanton Formation). The three formations (Lansing, Kansas City, Pleasanton) have been elevated to group status, and the Kansas City Group has been subdivided into three subgroups (Zarah, Linn, Bronson) which are further subdivided into formations and members. Although the boundaries of the Kansas City Group have been modified, those used in this report are nearly
the same as those originally set up by Hinds, the difference being that the Lane and Bonner Springs Shales are now included in the Kansas City Group. This regrouping is more appropriate in Wilson County because the Lane and Bonner Springs Shales are inseparable due to the absence of the intervening Wyandotte Limestone, and because it makes the Lansing Group a dominantly limestone unit. This usage also conforms to that agreed upon by the State Geological Surveys of Iowa, Kansas, Missouri, and Nebraska in 1947 (Moore, 1948, p. 2028-2033). More complete treatments of boundary modifications and establishment of current boundaries of the Kansas City Group are given by Moore (1936, p. 96, 97; 1948, p. 1018-1033; 1949, p. 74, 75), Wilmarth (1938, p. 1070, 1147), Greene and Searight (1949, p. 10-14) and Condra (1949, p. 34-42).

In Wilson County, parts of six formational units of the Kansas City Group are exposed in the southeastern one-fourth of the county and comprise as much as 53 m (175 ft) of strata. In the subsurface, the lower formations of the group are also present, and the group averages about 120 m (400 ft) in thickness.

The three subgroups (downward), Zarah, Linn, and Bronson (Table 1) were established in the Kansas City Group on the basis of dominant lithologic characteristics.
in northeastern Kansas and adjacent parts of Nebraska, Iowa, and Missouri (Moore, 1948, p. 1019). In Wilson County, the thick limestone formation (Wyandotte) in the middle of the upper (Zarah) subgroup is missing, and the shale units of that subgroup thicken markedly. Consequently, the Zarah Subgroup is not dominantly calcareous in Wilson County, and both it and the middle (Linn) subgroup are dominantly clastic rocks. The lower (Bronson) subgroup is dominantly limestone and is a good marker in the subsurface of the county.

Zarah Subgroup

The Zarah Subgroup was named from the village of Zarah, in western Johnson County, at the Atchison, Topeka, and Santa Fe Railroad crossing on State Highway 10 (Moore, 1948, p. 2033; 1949, p. 107). In the type area, the Zarah Subgroup includes mainly limestone beds between the base of the Plattsburg Limestone and the top of the Iola Limestone; it includes (downward) the thin Bonner Springs Shale, the thick Wyandotte Limestone, and the thick Lane Shale. In Wilson County, the Wyandotte Limestone is missing and the Zarah Subgroup is predominantly shale consisting of the combined Lane-Bonner Springs Shale (Table 1).
Lane-Bonner Springs Shale

Naming, Distribution, and Thickness. In northeastern Kansas, the stratigraphic interval between the Plattsburg Limestone and the Iola Limestone contains the Bonner Springs Shale, Wyandotte Limestone, and Lane Shale. The Wyandotte lenses out to the south, so that in Wilson County, the two shale units are inseparable. Use of the stratigraphic name, Lane-Bonner Springs Shale, for the unit between the Plattsburg Limestone and the Iola Limestone was suggested by Newell (1935, p. 56), who stated that it seems preferable to indicate the combined Lane and Bonner Springs shales by the hyphenated term Lane-Bonner Springs Shale, thus avoiding the necessity of using a new geographic name that gives no indication of its stratigraphic relation to correlative units. Moore agreed with this suggestion and pointed out (1936, p. 117) that "disappearance of the Wyandotte Limestone a short distance south of Lane makes it impossible to recognize the upper boundary of the Lane Shale. Accordingly in this region, the Lane is combined with the overlying shale under the designation Lane-Bonner Springs Shale."

The upper part of the shale unit below the Plattsburg Limestone in Wilson County correlates with the Bonner Springs Shale to the north at the Lone Star Cement Plant quarry northeast of Bonner Springs, Wyandotte County,
Kansas; this exposure is considered to be the type locality of the Bonner Springs Shale (Moore, 1936, p. 123; Wilmarth, 1938, p. 235). At the type locality, the Bonner Springs Shale is 8 m (25 ft) thick and consists (downward) of green shale 0.1 m (0.3 ft) thick, a "marlite" bed 0.9 m (2.7 ft) thick and 7 m (22 ft) of gray to dark-gray shale that is arenaceous in the middle one-third (Jewett and Newell, 1935, p. 200). The lower part of the shale unit below the Plattsburg Limestone in Wilson County is correlated with the Lane Shale, which was named by Haworth (1895a, p. 277) for exposures in the river bluffs near Lane, Franklin County, Kansas. The unit there is as much as 46 m (150 ft) thick and contains locally thick beds of sandstone in the shales. The Bonner Springs and Lane shales in northeastern Kansas are separated by a thick limestone unit named the Wyandotte Limestone for exposures in Wyandotte County, Kansas (Newell, 1935, p. 59; Moore, 1936, p. 119). As pointed out by Moore (1936), this limestone unit lenses out to the south. It is possible, however, that thin limestone beds in the upper and middle parts of the shale unit in Wilson County represent a southern extension of the Wyandotte Limestone (Plate 3D).

The Lane-Bonner Springs Shale in Wilson County occupies low topographic positions northeast and southwest of Altoona, but east of Neodesha it forms a thin cap on high prominences. The thickness of the Lane-Bonner
Springs Shale ranges from 12 to 30 m (40-100 ft) in Wilson County (Plate 3D). Heckel and Cooke (1969, p. 1072) report that the Lane-Bonner Springs Shale is about 15 m (50 ft) thick over the Raytown mound in Neosho County to the east but thickens south of the mound to about 30 m (100 ft), which is the same thickness as in parts of Wilson County. The Lane-Bonner Springs is thinnest 5 km (3 mi) north of Altoona.

**Lithologic Character.** The Lane-Bonner Springs Shale consists predominantly of medium olive-gray to light olive-gray, unfossiliferous, silty to slightly silty shale that weathers pale yellowish brown to yellowish gray and breaks to small 1.9 cm (0.75 in) rectangular fragments. Locally, the uppermost 0.3 m (1 ft) of shale is grayish orange, calcareous, and slightly fossiliferous. A thin limestone bed 1.5 to 3 m (5-10 ft) below the top of the formation about 3.2 km (2 mi) north of Altoona contains abundant crinoid stems and brachiopod fragments. An unfossiliferous limestone-concretion zone that occurs elsewhere in the county at this same stratigraphic position may be the equivalent of the fossiliferous bed, or it may correlate with one or two beds of limestone concretions 13 to 25 cm (5-10 in) thick that occur near the middle of the formation (Plate 3D). About 5 km (3 mi) west of Neodesha near the middle of the formation, the concretions occur in two beds, are unfossiliferous, pale
yellowish brown, and weather yellowish orange. They underlie shale beds that locally contain small, moderately abundant ironstone concretions. A bed of pale yellowish-brown, septarian-limestone concretions, 15 cm (6 in) thick and near the middle of the formation about 6 km (4 mi) east of Altoona, probably correlates with one of the beds west of Neodesha. The septarian concretions are slightly argillaceous, cryptocrystalline calcite with 0.3 to 0.6 cm (0.12-0.25 in) seams of dark-colored calcite irregularly radiating outward from their centers.

Two siltstone layers, each about 2.5 cm (1 in) thick, occur locally in the upper 6 m (20 ft) of the shale. Both are finely micaceous, and the upper layer contains plant fragments. Small ironstone concretions generally occur abundantly above the siltstone beds. About 5 km (3 mi) northeast of Altoona, several thin layers of ironstone concretions occur in the lower half of the formation. The concretions are 0.6 to 1.3 cm (0.25-0.5 in) in diameter and are grayish yellow to pale yellowish orange.

Stratigraphic and Structural Implications. The fossils in the upper 0.3 m (1 ft) of shale and in the limestone bed near the top indicate an environment in Wilson County or nearby that was suitable to marine life for that part of Lane-Bonner Springs time. The remainder of the shale is lithologically much like that of the Vilas Shale, which is also primarily of marine origin. The
paleoenvironment of the Lane-Bonner Springs Shale in Wilson County was probably marine also but was generally inhospitable to marine plant or invertebrate animal life. The zones of unfossiliferous limestone concretions in the upper and middle parts of the formation may have formed through migration of calcium carbonate to nuclei during diagenesis or may represent times of local concentration of calcium carbonate in an absence of marine life at the time of clay deposition. The siltstone beds with plant fragments in the upper 6 m (20 ft) of the shale suggest concentrated inflow of silt-size debris from a nearby vegetation-covered land area.

The fossiliferous limestone bed north of Altoona, which is about 1.5 m (5 ft) below the top and 11 m (35 ft) above the base of the Lane-Bonner Springs Shale cannot be correlated definitely with any other limestone beds in the sequence in Wilson County because the limestone beds west of Neodesha and east of Altoona are unfossiliferous and occur either 2.4 to 4 m (8-12 ft) below the top or 11 to 18 m (35-60 ft) above the base of the Lane-Bonner Springs Shale. The variation in thickness of the formation from 12 to 30 m (40-100 ft) may reflect local structural movement; the time of its occurrence could have been either early or late in Lane-Bonner Springs time.
Linn Subgroup

The Linn Subgroup was named from Linn County, Kansas, where there are excellent exposures of all constituent units (Moore, 1948, p. 2030). The Linn Subgroup is chiefly shale, but also includes a persistent thin limestone bed, and two or more locally thick sandstone beds. The Linn subgroup includes the Iola Limestone, Chanute Shale, Drum Limestone, and Cherryvale Shale.

Iola Limestone

Naming, Distribution, and Thickness. The Iola Limestone was named by Haworth and Kirk (1894, p. 109) for exposures at the town of Iola, Allen County, Kansas, about 24 km (15 mi) northeast of Wilson County. At the type locality, the Iola Limestone is about 9 m (30 ft) thick and is composed chiefly of light bluish-gray, irregularly bedded, thin-bedded, fine-grained limestone that is separated by 8 cm (3 in) of shale from a basal, dark bluish-gray massive limestone unit 0.6 m (2 ft) thick (Moore, 1936, p. 113). Throughout its outcrop area in Kansas, the Iola consistently is made up of three units, listed (downward), the Raytown Limestone Member, the Muncie Creek Shale Member, and the Paola Limestone Member (Moore, 1949, p. 102, 103).
In Wilson County, the Iola Limestone is well exposed only in a few stream banks and roadcuts where all three members are present, and the thickness ranges from 1.8 to 3 m (6-10 ft), with an average of about 2.4 m (8 ft). More commonly, the formation is seen only as rounded limestone rubble. Over a large part of the presumed outcrop area, the formation does not crop out, either because it is absent or because it is covered by downhill-float from the overlying shale. The presumed position of the Iola in these latter areas is shown on the geologic map by a single dashed line.

The Iola apparently underlies the Lane-Bonner Springs Shale conformably but overlies the Chanute Shale unconformably. In the east wall of the Dunbar strip mine (SW cor. Sec. 21, T 29 S, R 17 E), the basal member of the Iola lies upon siltstone beds of the Chanute Shale with a discordance of about 10° (Figure 34). The discordance was seen only in this man-made exposure.

Lithologic Character. Where well exposed in Wilson County, the Iola Limestone can be readily divided lithologically into three members (Plate 2D). These include the Raytown, a relatively thick limestone bed at the top; the Muncie Creek, a gray to black shale in the middle; and the Paola, a thin, hard limestone at the base.

Raytown Limestone Member. The Raytown Limestone Member was named for exposures near the village of
Figure 34. Angular discordance between bedding of the Iola Limestone and the Chanute Shale in the Dunbar Strip Mine, SW cor. Sec. 21, T. T 29 S, R 17 E. Exposure is about 5 m (15 ft) in height.
Raytown, Jackson County, Missouri by Hinds and Greene (1915, p. 27). They placed it in the upper part of the Chanute Shale and described it as a gray, thin-bedded limestone unit 1 to 2 m (3-6 ft) thick that overlay a black shale. Newell, in tracing the Iola Limestone northward from the type locality, found that only the upper part of the limestone at Iola correlated with the bed at Raytown (Newell, 1935, p. 51). The name has since been restricted to use for the upper limestone member of the Iola.

Where measured southwest and southeast of Altoona in Wilson County, the Raytown ranges in thickness from 1.2 to 2.7 m (4-9 ft) and averages nearly about 1.5 m (5 ft) (Figure 35A). It changes laterally from 1.7 m (5.6 ft) of predominantly clayey, fossiliferous limestone to about 1.2 m (4 ft) of slightly calcareous, unfossiliferous sandstone. Locally, where clay becomes a dominant constituent, the Raytown is largely a calcareous, fossiliferous shale (Plate 2D).

In the eastern and southern parts of the outcrop area, the Raytown is a grayish-orange, medium- to thin-bedded, very finely crystalline limestone that weathers to blocky plates. It contains the brachiopods *Chonetes, Juresania, Neospirifer, Hustedia,* and *Composita,* horn corals, and fragments of crinoid stems and ramose and fenestrate bryozoans. In places, much of the member is
Figure 35. Iola Limestone and Chanute Shale in Wilson County. (A) Iola Limestone and upper part of Chanute Shale at Mill Street Bridge, Neodesha. (B) Debris reef in Raytown Limestone Member west of Barnhill Bridge in W 1/2 Sec. 6, T 29 S, R 16 E. Note that the thin limestone bed above reef top is not curved.
made up of medium light-gray very finely crystalline, irregularly shaped fragments of limestone in a matrix of grayish-yellow, very finely crystalline Osagia-bearing limestone. The fragments range in size from 0.3 to 5.1 cm (0.125-2 in), and many have serrated ends similar to the phylloid algal fragments in the Spring Hill Limestone Member of the Plattsburg Limestone (Fig. 32D). Local concentrations of clay and very fine-grained dolomite, identified by staining with Alizarine Red S, occur in the matrix material. Fenestrate bryozoans, crinoid columnals, and other fossil fragments are abundant in this matrix. In several exposures, the upper 8 cm (3 in) of the member weathers to small flakes of algal(?) limestone; in a few others, the upper part is oolitic. To the east in northwestern Neosho County, Heckel and Cocke (1969, p. 1072) record that the Raytown Limestone Member is an algal-mound complex 11 m (36 ft) thick. Zones of algal sparite with common ferroan dolomite and zones of sparsely algal calcilutite are present locally. About 1.5 m (5 ft) of crinoid-rich limestone and calcareous shale caps the algal mound.

A light-gray limestone, located about 90 m (300 ft) west of Barnhill Bridge (W 1/2 Sec. 6, T 29 S, R 16 E) at the approximate stratigraphic position of the Raytown, is a stream-bottom outcrop that apparently represents a debris reef or bank that developed during Raytown time.
The limestone is thin bedded, argillaceous, and weathers to vertically jointed, uneven, arched surfaces (Fig. 35B). The exposed arched beds are about 6 m (20 ft) across and are composed of the remains of bryozoans, crinoids, productids and other brachiopods, sparse mollusks, and many thin unidentified shell fragments in a fine-grained clastic limestone matrix. These beds are possibly the uppermost part of a bioherm and may be draped over a central, as yet unexposed core. Thin, very calcareous shale beds are interbedded with the arched limestone; laterally, the shales are less calcareous, and the unit is a clay shale with intercalated zones of fossil fragments. Inasmuch as a thin, continuous, medium-gray limestone bed lies horizontally above both the bioherm(?) and the adjacent shale (Fig. 35B), the effects of differential compaction are seemingly negligible, and the vertical dimension of the bioherm(?) is assumed to be relatively small.

The Raytown Limestone Member, as described by Heckel (1988, p. 48), is the regressive limestone of the Iola cyclothem. The limestone is a lenticular, skeletal calcarenite at the top and becomes a skeletal calcilutite downward with abundant conodonts of the genera Anchignathodus and Adetognathus. In Neosho County it contains conspicuous phylloid algae in the lower half. These phylloid algae may be equivalent to the unidentified
shell fragments in the bioherm(?) described in the paragraph above. Lower in the Raytown the conodonts *Idiognathodus* and *Prioprioniodus* occur in abundance above the Muncie Creek Shale Member (Heckel, 1988, p. 49-50). A conodont fauna is listed by Mitchell (1981, p. 331-336) for three locations in the members of the Iola Limestone in Wilson County. He found that *Idiognathodus* dominated the faunas of all three members in every locality, that *Idioprioniodus* was also present in all three members at every locality sampled, but in smaller numbers, and that *Adetognathus* occurred at only one locality where it was confined to the Raytown Limestone Member. The ratio of *Idiognathodus* to *Idioprioniodus* ranged from 8/1 to 100/1; the ratio was highest in the Muncie Creek Shale Member.

The sandy facies of the Raytown consists of very pale yellowish-brown sandy limestone that contains very fine angular quartz grains and much fine-grained muscovite mica. A thin fossiliferous limestone bed containing many small unidentified brachiopods occurs in the upper 8 cm (3 in) of the sandy limestone. Outcrops of dark yellowish-orange sandstone of the underlying Cottage Grove Sandstone Member of the Chanute Shale occur in Secs. 14 and 15, T 29 S, R 16 E at approximately the same altitude as nearly contiguous pale yellowish-brown fossiliferous, sandy limestone beds of the Iola.
Muncie Creek Shale Member. The Muncie Creek Shale Member was named by Newell (Moore, 1936, p. 114) after a stream in southern Wyandotte County, east of Muncie (Newell, 1935, p. 52). In Sec. 12, T 11 S, R 24 E, near the type locality, the Muncie Creek consists of 0.9 m (3 ft) of shale that is mostly black and platy. The shale is gray near the top and bottom (Jewett and Newell, 1935, p. 196).

Where well exposed in Wilson County, as beneath the Mill Street Bridge at Neodesha, or at the Dunbar Strip mine (SW 1/4 Sec. 21, T 29 S, R 17 E), or at the top of the bank above Chetopa Creek (center Sec. 19, T 29 S, R 17 E), the Muncie Creek Shale Member is 0.5 to 1.5 m (1.5-5 ft) thick and has a grayish-black platy shale in the lower part (Fig. 35A). The upper 0.5 to 0.8 m (1.5-2.5 ft) of the Muncie Creek consists generally of yellowish-gray to pale yellowish-orange silty to non-silty shale that is locally very silty at the base. The lower 0.4 to 0.8 m (1.25-2.5 ft) of the member is composed predominantly of grayish-black very fissile, platy shale, the "core shale" of Heckel (1975a, p. 9), that breaks into paper-thin laminae upon weathering. The black shale commonly contains small, flattish, oval, phosphatic concretions or phosphorite nodules, 0.6 to 2.5 cm (0.25-1.0 in) in diameter, that are brownish gray to olive gray (Heckel, 1977, p. 1048). A sample obtained from the NE1/4
SW1/4 of Sec. 19, T 30 S, R 16 E about 1.2 km (0.75 mi) west of the southern part of Neodesha in southern Wilson County shows that nodules in the Muncie Creek member are commonly formed of peloids composed of collophane (cryptocrystalline apatite). They form a microcrystalline texture of oval-shaped to nearly round, closely packed grains in a bedded arrangement parallel to the long dimension of the nodule. Apatite and calcite constitute the dominant cements in the phosphorite nodules. Petrographic examination shows that the phosphorite laminae are composed of discontinuous layers of tiny micronodules of collophane. Radiolarians in the nodules, first reported by Berendsen and Nodine-Zeller (1978), are the dominant skeletal grain type (Nodine-Zeller and others, 1979). Apatite cement commonly nucleates around the skeleton as well as around individual spines and spicules (Kidder, 1982, p. 41). The concretions occur in layers about halfway between the top and bottom of the black shale. They contain radioactive material (Runnels and others, 1953, p. 97, 99) but in amounts too small (0.007 percent) to be of economic importance. About 5 to 15 cm (2-6 in) of light-gray slightly silty shale locally underlies the platy shale.

The black shale facies in the middle of the Muncie Creek records anoxic, phosphate-rich bottom conditions that developed under quasi-estuarine circulation and
upwelling associated with a thermocline during maximum transgression (Heckel, 1987, p. 120). The gray shales above and below the core shale reflect low oxygen (dysaerobic) conditions, which developed as the thermocline was forming and as it was breaking up. Conodont abundance (100 specimens per kilogram) is higher in the core shale, than elsewhere in the Iola cyclothem, due to slow sedimentation in the deep offshore shelf environment. The conodont fauna is strongly dominated by *Idiognathodus*; also present are *Prioprioniodus* and *Gondolella* (Heckel, 1988, p. 48).

Paola Limestone Member. The Paola Limestone Member was named by Newell (Moore, 1936, p. 114) from the county seat of Miami County, Kansas, where it consists of about 0.5 m (1.5 ft) of dark-bluish-gray, dense, brittle, blocky limestone with "worm-borings" at the top and numerous "marklets" below (Newell, 1935, p. 125).

In Wilson County the Paola is generally about 0.3 m (1 ft) thick but locally thins to less than 0.15 m (0.5 ft) (Figure 35A) and thickens to nearly 0.8 m (2.5 ft). Commonly, it is a medium-gray, hard, very finely crystalline, fossiliferous limestone in which the most abundant fossils are crinoid stems and brachiopod fragments. In the southwestern part of the outcrop area, the upper part contains *Cryptozoon* or *Ottonosia* (possibly oncolites), but farther north and east *Cryptozoon* (?) are
rare, and fusulinids are abundant in the upper part. Fenestrate bryozoans and horn corals are prominent locally. The Paola Limestone Member contains a large conodont fauna whose generic identifications are credited to Mitchell (1981) by Heckel and others (1985, p. 28) as being dominated by *Idiognathodus* with lesser *Anchignathodus*, *Adetognathus* and *Idioprioniodus*. The Paola weathers grayish orange, is vertically jointed, and where it surrounds dark yellowish-orange erosional remnants of the Cottage Grove Sandstone Member of the Chanute Shale, as in secs. 14 and 15, T 29 S, R 16 E, it is sandy. In a few places where it apparently fills scour channels cut into the underlying siltstone of the Chanute Shale, the Paola thickens and the lower part is silty and flaggy. Heckel (1988, p. 48) reports that the Paola can be traced with little change from Iowa to Oklahoma, a distance of about 650 km (400 mi). It is a typical transgressive limestone at the base of the Iola cyclothem and was deposited in deepening water.

Stratigraphic and Structural Implications. The abundant sand grains that are present in the limestone members of the Iola presumably are the result of erosion of sandstone beds at the top of the underlying Chanute Shale. The present distribution of sand in the Iola seemingly indicates that parts of the Chanute were exposed to erosion both east and south of Altoona, and the
outcrops of sandstone of the Chanute that are surrounded by sandy limestone of the Iola apparently represent erosional remnants that stood 3 m (10 ft) or more above the sea floor. The clayey, fossiliferous, locally algal or oolitic limestone of the Raytown away from the sandy limestone areas suggests that the environment of deposition was regressive and carbonate-rich but was modified by abundant influxes of clay, and became locally shallow, supersaline, and wave agitated. The arched beds of limestone debris and fossils on the northern flank of the Fredonia Dome near Barnhill Bridge suggest draping and compaction of a local accumulation of fossil debris around and upon a relatively solid, as yet unexposed, calcareous framework (bioherm). The presence of a horizontal (unarched) limestone bed about 1 m (3 ft) above the arched beds suggests that the amount of compaction above the bioherm is small.

The organic-rich black shale with phosphatic nodules and overlying calcareous gray shale of the Muncie Creek Shale Member suggest that deposition prior to Raytown time was in quiet, seaweed-filled or thermocline covered, phosphate-rich stagnant waters, and that as the water shallowed, an influx of clay-size debris ended the period of stagnant-water deposition. The local presence of gray shale at the base of the Muncie Creek suggests that the
deep-water environment was preceded by a short period of shallower water.

The Paola Limestone Member is similar lithologically to the Haskell Limestone Member of the Stranger Formation and the Leavenworth Limestone Member of the Oread Limestone and presumably reflects a major advance of the sea with quiet water below effective wave base in the lower two thirds. Abundant algae in the upper part near Neodesha may indicate hypersaline shallow waters in late Paola time in that area. Abundant fusulinids and a few algae in the upper part east of Altoona suggest that the deep-water transgressive phase of deposition lasted longer east of Altoona than near Neodesha and that the regressive phase, if present, was of short duration. Bryozoan, coral, crinoid and brachiopod remains in the lower part of the member indicate a marine environment well suited to invertebrate life at the beginning of the transgressive phase in early Paola time. The conodont fauna indicates a range from nearshore at the base to open shelf in the upper part (Heckel and others, 1985, p. 28).

Chanute Shale

Naming, Distribution, and Thickness. Haworth and Kirk (1894, p. 109) applied the name Chanute to shale that underlies the town of Chanute about 8 km (5 mi) east of Wilson County. At the type locality, the Chanute
consists of about 30 m (100 ft) of shale, sandstone, and thin coal beds. Northward along its outcrop belt in eastern Kansas, the Chanute thins to about 3 m (10 ft) (Moore, 1936, p. 111), but it thickens southward so that its average thickness in eastern Kansas is probably about 15 m (50 ft).

In Wilson County the Chanute crops out in the southeastern one-sixth of the county (Plate 1), where it ranges from 12 to 30 m (40-100 ft) in thickness (Plate 4). Subsurface records indicate that it averages about 23 m (75 ft) in thickness, and is 30 m (100 ft) thick in small areas southeast and northeast of Altoona. However, the Chanute is only 8 m (25 ft) thick southwest and northwest of Fredonia, west and northwest of Benedict, and northwest of Vilas (Haggiagi, 1970, Plate 1).

The Chanute Shale lies unconformably below the overlying Iola Limestone. Reddish-weathering, thick-bedded sandstone underlies the Iola in some places; in other places, a light-gray, platy siltstone immediately underlies the Iola; and elsewhere a yellowish-gray, silty sandstone approaches very near to the contact; gray shale occurs at the contact in at least two places. The variety of rocks in contact with the overlying Iola Limestone, in addition to the discordance at the strip mine, may reflect lateral facies changes or folding and erosional truncation in Chanute sediments prior to Iola time (Plate 4).
The Chanute lies conformably on the Drum Limestone in the few places where the contact is exposed in Wilson County. The relatively constant thickness of the unnamed lower shale unit of the Chanute Shale, where measured, suggests that this lower shale unit was deposited evenly throughout Wilson County. However, the Cottage Grove and/or Noxie Sandstone Members apparently occupy the position of this lower shale unit and even that of the Drum Limestone in the subsurface in some areas, suggesting that a prominent erosional unconformity occurs within and cuts through the base of the Chanute (Plate 4, sec. G-H). The Chanute is as thick as 61 m (200 ft) where the channels cut the deepest (Haggiagi, 1970, p. 7).

Lithologic Character. The Chanute Shale is divided generally into an upper coarse clastic unit, the Cottage Grove Sandstone Member, and a lower unnamed shale member that contains a local channel-filling sandstone (Noxie). In Wilson County the Chanute ranges from almost 100 percent shale and siltstone to about 70 percent sandstone and siltstone (Plate 4). The sequence of stratigraphic units described below was not directly observed in the field; it was constructed from many isolated small outcrops and measured sections. Lateral changes in facies may be more important than is indicated.

*Cottage Grove Sandstone Member.* The Cottage Grove Sandstone Member was named by Newell (Moore, 1936,
p. 111) for exposures in Cottage Grove Township, Allen County, Kansas, which adjoins the northeast corner of Wilson County. In both the type area and in Wilson County, silty arenaceous beds of the Cottage Grove member occupy roughly the upper half of the Chanute Shale.

The upper sandstone unit of the Cottage Grove Sandstone Member is as much as 14 m (45 ft) thick, but averages about 9 m (30 ft) in thickness. It is cross bedded locally, but in many exposures its bedding is irregular or obscure. This uppermost sandstone is generally grayish orange to grayish red and is thin- to thick-bedded (Figure 36A) with grains of angular to subangular, fine-grained quartz. The sandstone locally contains a few angular to well-rounded gray shale fragments, a few light-colored limestone granules, and fragments of carbonaceous matter at its base. Thickness variations suggest that the upper sandstone unit unconformably overlies the platy siltstone which ranges in thickness from about 9 m (30 ft) in the northwestern part of the outcrop area in Wilson County to only 3 to 4 m (10-12 ft) in the southeastern part of the area. At the Dunbar strip mine (SW1/4 Sec. 21, T 29 S, R 17 E), the siltstone is 2.1 to 3 m (7-10 ft) thick, very light gray, and breaks readily into plane-surfaced plates 0.6 to 3.2 cm (0.25-1.25 in) thick (Fig. 34). The 10° northwest dip of the beds may represent initial dip of foreset beds on a
Figure 36. Chanute Shale (Cottage Grove Sandstone Member) and Drum Limestone. (A) Upper reddish-weathering part of the Cottage Grove Sandstone Member in Sec. 16, T 29 S, R 16 E. (B) Thin section of oolitic Drum Limestone in Sec. 24, T 30 S, R 16 E, showing concentrically ringed oolites; crossed nicols (X20).
delta front. Many well-preserved fern leaves and *Calamites* stems occur amid abundant small carbonized plant fragments on the finely micaceous bedding planes. This unit contains ripple-marked bedding surfaces at a few localities and is crossbedded in others. The orientation of these features suggests currents moving from south to north. The siltstone overlies a poorly exposed yellowish-gray silty sandstone unit directly above the Thayer Coal.

As many as 8 thin coal beds occur in 3 groups in the Cottage Grove Sandstone Member. The two upper groups separate an overlying reddish-weathering, thick-bedded sandstone from a sandy siltstone, and the sandy siltstone from a yellowish-gray, silty sandstone (Plate 4). The group of coal beds beneath the reddish-weathering sandstone commonly consists of 2 coal beds separated by claystone partings (Figure 37A). The aggregate thickness of coal is generally less than 30 cm (1 ft), and the coal has been mined in but few places. The group of coal beds between the platy sandy siltstone and the yellowish-gray silty sandstone have been mined in a half-dozen places in the Dry Creek Mining District and extensively at the Dunbar strip mine and adjacent area in the Chetopa Mining District (Plate 4), where they total as much as 60 cm (24 in) of coal. The coal that underlies the platy sandy siltstone contains twigs and branches of dark yellowish-brown silicified wood in the northern area of outcrop in
Figure 37. Coal sections showing variations in number of coal beds in the Chanute Shale in Wilson County. Data largely from Schoewe (1944, p. 120).
Wilson County (the Chetopa Mining District, Plate 4). No silicified wood was reported from the Dry Creek Mining District. This coal group consists generally of 2 or 3 separated beds (Fig. 37).

A coal bed, termed the Thayer Coal (Newell, 1935, p. 49; Moore, 1936, p. 110-111; Whitla, 1940, p. 18, 19; Schoewe, 1944, p. 87), occurs at the base of the yellowish-gray silty sandstone. This coal has been mined extensively about 5 km (3 mi) east of Wilson County and from many small drift mines in the Chetopa Mining District in Wilson County. The Thayer Coal has an aggregate coal thickness of as much as 71 cm (28 in), and occurs generally as two beds separated by claystone (Fig. 37C). Schoewe made a detailed study of the coal resources of the Thayer bed in eastern Kansas and recorded 78 known coal localities in Wilson County (Schoewe, 1944, p. 127-129). Twenty-four localities were mine operations, mostly for local use only; the others were road and creek exposures. The Thayer coal separates the Cottage Grove Sandstone Member (above) from the Noxie Sandstone Member (below) (Moore, 1949, p. 101).

**Noxie Sandstone Member.** The Noxie Sandstone Member was named by Moore and others (1937, p. 43) for the lower sandstone unit of the Chanute Shale. The Noxie ranges in thickness from 8 to 24 m (25-80 ft) and fills channels cut into the underlying Drum Limestone in a few
places. In Wilson County the Noxie was apparently deposited contemporaneously with the unnamed shale member of the Chanute Shale as a series of bar finger sandstone bodies during deltaic sedimentation. The Noxie member is a lenticular unit that is as much as 14 m (45 ft) thick and is apparently restricted to a strip 5 km (3 mi) wide along the eastern edge of the county (Plate 4). It consists of yellowish-gray slightly micaceous, very fine grained, silty sandstone that is generally thin- and even-bedded. The sand grains are well sorted, and thin sections show that they form a remarkably tight mesh of interlocking quartz and chert grains, many of which have attenuated shapes. The contacts between grains are undoubtedly the result of secondary solution and penetration, presumably without compensating outgrowth because no well defined contact between an original grain surface and an outgrowth is apparent. Furthermore, quartz grains with undulatory extinction show no change in extinction near the grain boundary, as would be expected if outgrowth had occurred. Several of the quartz grains are in solution contact with grains of chert. Quartz composes more than half of the grains, and chert about one-third. The remainder of the grains are sodic plagioclase (andesine?) and flakes of muscovite. Limonitic clay, dispersed irregularly throughout the rock, forms about 5 percent of the sandstone.
**Unnamed Shale Member.** Throughout much of southeastern Wilson County, the lower 4.6 to 12 m (15-40 ft) of the Chanute Shale consists of gray, unfossiliferous shale. The uppermost 6 cm to 1.5 m (0.2-5 ft) of this shale is locally light olive gray, plastic when wet, and may be an underclay. Elsewhere, this part of the Chanute Shale is yellowish gray, non-silty to very slightly silty, and breaks to small angular fragments. The shale is presumed to grade laterally into the Noxie Sandstone Member.

A distinctive, thin, unfossiliferous, argillaceous limestone bed 10 to 36 cm (4-14 in) thick occurs about 1.5 m (5 ft) below the top of the unnamed shale unit in much of the area (Plate 4). The limestone is pale yellowish orange and is seamed with veinlets of moderate-yellowish-brown calcite about 0.05 cm (.02 in) wide. The bed is represented locally by a layer of nodules or concretions which, upon weathering, generally forms a series of rounded shapes and becomes very soft and porous. The bed undoubtedly corresponds to the “marlite” bed in the Chanute Shale reported by Newell to the north in Johnson and Miami Counties. Newell (1935, p. 50) described his “marlite” as a “spongy” rock that ranged from a ferruginous, argillaceous limestone to a calcareous shale. The shale that underlies the “marlite” bed is medium gray and unfossiliferous. In a few places, the
shale is dark yellowish gray to medium light gray and is slightly silty.

**Stratigraphic and Structural Implications.** Relations of the sedimentary environment to the probable paleogeography at the time of deposition indicate that the sediments were deposited in the slowly subsiding Cherokee Basin by northward- and westward-flowing streams carrying sediment toward the north from the Ouachita and Arbuckle Mountains and toward the west from the Ozark Uplift. Channel time apparently ended with marine transgression after termination of local uplift along previously active areas of upwarp, as is indicated by the thinning and absence of the reddish-weathering sandstone and the arching and truncation of the underlying platy siltstone and yellowish-gray sandstone prior to deposition of the Iola Limestone (Plate 4, Fig. 34). The Cottage Grove Sandstone Member was deposited mainly by distributaries as bar finger sands and other types of deltaic sedimentation until transgression by marine waters overwhelmed the environment and deposited the Raytown Limestone Member of the Iola. The Cottage Grove has several thin coal seams that indicate periods of decrease or cessation of subsidence during Cottage Grove deposition allowing the carbonaceous detritus to collect in back swamps and lagoonal areas between bar fingers. The reddish-weathering sandstone presumably indicates subaerial
deposition of prodeltaic clastics by streams debouching onto a subsiding coastal plain. Dips of 10° may reflect initial dip of foreset beds on a delta front. Prior to deposition of sand-size debris, land plant fragments, now in the form of coal beds, accumulated during 2 or more individual stages. The layers of impure coal or carbonaceous claystone between the beds of coal show that these stages were separated by relatively short periods of clay accumulation and/or soil development.

The well-bedded, platy siltstone apparently formed in nearshore quiet waters into which silt-size debris and small plant fragments were fed at regular intervals in order to produce a sequence of plane-surfaced beds about 1.3 cm (0.5 in) in average thickness. Coal-swamp conditions immediately preceded and followed deposition of this unit. The coal beds underlying the siltstone suggest that coal swamps formed along the coastal plain two, and locally three, times before being drowned and covered with silty clay. Silicified fragments associated with the coal indicate that large twigs and branches in the carbonaceous debris were selectively silicified by percolating silica-charged waters. The thick deposit of thin-bedded sandstone in the small area between Sec. 20, T 30 S, R 17 E, and Sec. 29, T 29 S, R 17 E, suggests that local downwarping controlled the accumulation of the silts and sands. The presence of silt, sand and coal beds in Neosho
County to the east indicate that the downwarp extended at least 9.7 km (6 mi) eastward. The coal beds possibly represent the initiation of downwarping which began with the development of a shallow, vegetation-filled swamp. Downwarping apparently continued until arenaceous material had covered the drowned trees to a local thickness of more than 15 m (50 ft). Conditions conducive to coal accumulation were then again at optimum, and the coal-forming debris accumulated, represented in beds of each overlying coal group.

The presumed uniform thickness of the slightly silty claystone that formed in earliest Chanute time appears to indicate a general period of quiet, shallowing water, undisturbed by structural uplift. Locally, however, erosion cut deep channels into the underlying sediments; these channels were filled with fine-grained sand and silt to form the Noxie Sandstone Member. Contemporaneously, the introduction of an overwhelming amount of clay-size debris into the system is presumed to have destroyed the clear-water environment of the Iola Limestone and thus to have eliminated a previously abundant marine fauna from the area and to have led to the accumulation of a thick clay-rich mud deposit. The dark-seamed "marlite" bed at the top of this claystone suggests that an iron-rich, calcareous, argillaceous (algal?) mud formed toward the end of early Chanute time during a short period of
carbonate concentration. The filling of cracks in the clayey limestone with dark-colored calcite may have occurred somewhat later during desiccation and diagenesis, or these crack-fillings may actually be the remains of algal fronds.

**Drum Limestone**

**Naming, Distribution, and Thickness.** The Drum Limestone was named by Adams for conspicuous exposures on Drum Creek, Montgomery County, about 20 km, (12 mi) south of Wilson County (Adams, Girty, and White, 1903, p. 37). In the vicinity of the type locality, the Drum is subdivided into an upper oolitic, locally conglomeratic limestone, the Corbin City Limestone Member, and a lower hard, dense, blue-gray limestone, the Dewey (Cement City) Limestone Member. As pointed out by Newell (1935, p. 44, 45) "There is a great deal of variation in the Drum of the type region, for it ranges from ... nonoolitic blue-gray limestone just north of Cherryvale ... to ...granular and oolitic limestone near Independence."

Corbin City, for which the upper limestone member was named, is about 3 km (2 mi) south of Cherryvale in Montgomery County where the thickness ranges from about 1 to 20 m (3-60 ft). The lower limestone member was named for Cement City, in Jackson County, Missouri by Hinds and Greene (1915, p. 27; see also, Moore, 1936, p. 105, 106).
The name Cement City was used for more than 30 years but has been replaced by the name Dewey which had precedence. The name Dewey, taken from a town in Oklahoma, was first used by Ohern in 1910 (p. 30). The Dewey Limestone Member was mapped northwestward from its type locality to Kansas and Missouri, and its equivalence with the Cement City was established (see Moore, 1949, p. 97-99).

In Wilson County the Drum is exposed only in the southeastern part. It is partly oolitic, and apparently both members are represented, but because it is only about 45 cm (18 in) thick, and the outcrop is discontinuous and difficult to trace, the members could be differentiated in few places. The largest exposures are in stream beds.

Lithologic Character. In Wilson County the Drum is generally a single hard, vertically jointed, medium light-gray fossiliferous, algal limestone. The lithology and fauna of the limestone vary both vertically and laterally, and correlation between widely separated outcrops is uncertain. For example, in the southeastern part of T 30 S, R 16 E, the Drum is oolitic, whereas farther east in T 30 S, R 17 E, Osagia and Cryptozoon-like algae are abundant.

The oolites, algae and invertebrate fossil remains occur in the upper part of the Drum, the Corbin City Limestone Member (Schulte, 1958, p. 22). In some localities the oolites fill scour channels or large
desiccation cracks that apparently formed in the lower part of the limestone prior to accumulation of the upper part. The oolitic facies, with its concentrically banded, locally composite and collapsed oolites (Fig. 36B), was noted in a few small outcrops only. The oolites are much larger at the top of the bed than in the lower part, and in many oolites, the outer rings are broken and stripped back or folded, possibly as a result of partial desiccation (Fig. 36B). The fossils in the Corbin City part of the Drum consist of the brachiopods Composita, Derbyia, Echinoconchus, Hustedia, Juresania, Marginifera, Neospirifer, and Punctospirifer; horn corals and Syringopora; ramose, fenestrate, and encrusting bryozoans; crinoid stem segments and calyxes; small bellerophontid and high-spire gastropods; Hyalina and small pelecypods.

In Wilson County the lower fossiliferous limestone, the Dewey Limestone Member, contains broken crinoid stems as the dominant fossils which, in conjunction with shell fragments of brachiopods, occur in a finely crystalline calcite matrix. Osagia and Cryptozoon-like algae are found locally in the "Cement City" member (Schulte, 1958, p. 23). About 5 km (3 mi) east of Neodesha in the bed of Washington Branch adjacent to State Highway 37, the Drum has two prominent joint systems that trend roughly N 10°E and N 80°E and a series of undulations that trend approximately N 45°E. Similar undulations occur in a
limestone bed exposed in tributaries to Dry Creek in Secs. 19 and 30, T 30 S, R 17 E, but that bed appears to lie stratigraphically below the projected Drum outcrop and is mapped as the underlying Dennis Limestone. The Drum and the Dennis are similar in lithology and fauna in this area, and it is difficult to distinguish one from the other.

**Stratigraphic and Structural Implications.** The lithology and fauna of the Drum Limestone record generally shallow marine waters inhabited by an abundant and varied bryozoan, brachiopod, and mollusk fauna interspersed with large and small algae. Small oolites, abundantly concentrated in pockets with shell fragments, suggest a depositional environment of local shoreline embayments in which oolites formed, and in which currents cut scour channels into which the oolites and shell fragments were deposited. Withdrawal of the sea, or local uplift, may have resulted in desiccation toward the middle of the time represented by the Drum, and cracks thus formed also served as sites of oolite and fossil-fragment concentration. The elongated and collapsed oolites suggest that temporary exposure in late Drum time may have allowed many of the later oolites to become partly desiccated prior to final incorporation into the upper part of the Drum.
Cherryvale Shale

Naming, Distribution, and Thickness. The term Cherryvale Shale was first used by Haworth (1898a, p. 47) for a shale 37 m (120 ft) thick that underlies the prominent escarpments along Drum Creek northwest of Cherryvale, Montgomery County, about 10 km (6 mi) south of Wilson County. The Cherryvale Shale has 5 members named (downward), the Quivira Shale Member, the Westerville Limestone Member, the Wea Shale Member, the Block Limestone Member, and the Fontana Shale Member (Zeller, 1968, p. 30). In Wilson County the Cherryvale Shale crops out in the Dry Creek-Washington Branch area and at the southeasternmost corner of the county. It is 11 to 14 m (35-45 ft) thick at the few localities where both top and base are exposed.

Lithologic Character. The best exposures of the Cherryvale Shale in Wilson County are in the northern parts of Sec. 25, T 30 S, R 16 E, and Sec. 30, T 30 S, R 17 E, where it is about 12 m (40 ft) thick. The upper 8 m (24 ft), the Quivira Shale Member, is a yellowish-gray finely micaceous, thin-bedded, clayey siltstone and silty shale. The next underlying 0.7 m (2 ft), consisting of several 0.64 to 1.3 cm (0.25-0.5 in) thick, platy, unfossiliferous limestone beds, possibly represent the Westerville Limestone Member. Ironstone concretions occur in the upper 1.5 m (5 ft) of the underlying shale (Wea
Shale Member), which is underlain by a light olive-gray, hard, unfossiliferous limestone bed (Block Limestone Member). The Block underlies the Wea, is only about 23 cm (9 in) thick, is micaceous and silty in the upper 8 cm (3 in), is argillaceous in the lower 8 cm (3 in), and occurs below the silty shale. The lower 8 cm (3 in) of the Block weathers dark yellowish orange, and is separated from the upper part by a thin yellowish-gray, micaceous shale bed. The lower 4 m (14 ft) of the Cherryvale is dark-yellowish-brown to medium-gray slightly silty, finely micaceous shale with a few beds of ironstone concretions (Fontana Shale Member). The lower 0.61 m (2 ft) has current ripples locally.

In the southeastern corner of the county, the upper 0.61 to 1.2 m (2-4 ft) of the Cherryvale is well-bedded, non-silty, yellowish-gray shale. Below this shale are 1 or 2 beds, 5 to 15 cm (2-6 in) thick, of hard, unfossiliferous, vertically-jointed limestone. The limestone is light gray where fresh and weathers yellowish orange or brownish orange. Light grayish-orange, silty, micaceous shale underlies the limestone.

Stratigraphic and Structural Implications. The argillaceous sediments of the Cherryvale in Wilson County suggest deposition in shallow water into which abundant clay- and silt-size material was supplied by erosion of a nearby low-lying land area for a relatively
short time. The absence of marine fossils and the lithology of the strata suggest that the sea had withdrawn from this area and a moderate thickness of terrigenous mud and silt accumulated in the southern part. Subsequent erosion carried a portion of the mud-size materials northward into local areas of downwarp that developed in Wilson County during Cherryvale time and served as catchment basins for the silts and clays. Thin beds of limestone that were deposited and later covered by more clay and silt suggest that calcium-carbonate concentration reached oversaturation near the middle of Cherryvale time.

Bronson Subgroup

The Bronson Subgroup, named the Bronson Formation by Adams (Adams, Havorth, and Crane, 1904, p. 17) is predominantly a limestone unit and is named from exposures near Bronson, Bourbon County, Kansas. It consists of five formations, listed (downward), the Dennis Limestone, Galesburg Shale, Swope Limestone, Ladore Shale, and Hertha Limestone. Only the uppermost 0.9 m (3 ft) of the Bronson Subgroup crops out in Wilson County, but the remainder is represented by about 60 m (200 ft) of dominantly limestone strata in the subsurface.

Dennis Limestone

Naming, Distribution, and Thickness. The oldest strata that crop out in Wilson County are tentatively correlated with the Dennis Limestone. The Dennis is the
uppermost formation of the Bronson Subgroup of the Kansas City Group. The Dennis was named by Adams (Adams, Girty, and White, 1903, p. 36) for exposures near Dennis in northwestern Labette County about 11 km (7 mi) southeast of Wilson County. Near Dennis, where it contains three members and is about 3 m (10 ft) thick, the formation consists of an upper thick, gray or blue, thin-bedded and in part massive, oolitic limestone (Winterset Limestone Member) that is underlain by black fissile and gray or buff shale (Stark Shale Member) and thin, blue, dense, blocky limestone (Canville Limestone Member) (Moore, 1936, p. 91).

In Wilson County only the upper limestone member crops out. The Dennis is exposed in six places in the bottom of Dry Creek and its tributaries, where it consists of 0.5 m (1.5 ft) of partly oolitic limestone that is here correlated with the Winterset Limestone Member. This member was named for exposures near the town of Winterset, Iowa (Tilton and Bain, 1897, p. 517-519) about 485 km (300 mi) to the northeast. Equivalency of the limestone at Winterset with the limestone at Dennis was regarded as established in 1912, but actual correlation of the unit at Winterset with the upper limestone at Dennis was not reported until 1932 (Wilmarth, 1938, p. 597).

Lithologic Character. In Wilson County the Dennis consists of very finely crystalline, fossiliferous, medium
light-gray limestone that weathers to thin, uneven-surfaced, yellowish-gray to grayish-orange blocks. It is generally a single, hard, vertically jointed bed, and commonly contains many small Osagia and oolites in local concentrations, as well as crinoid fragments, productid spines, ramose and fenestrate bryozoans, abundant horn corals, the pelecypod Myalina and the brachiopods Hustedia and Composita. The Winterset Limestone Member is differentiated into an algal, bryozoan boundstone in the upper 3 to 6 m (10-20 ft) underlain locally by 2.4 m (8 ft) of oolitic calcarenite that is underlain by another 3 to 6 m (10-20 ft) of algal, bryozoan boundstone (Frost, 1968, fig. 2). The Winterset is a complex, biogenic accumulation of carbonate-rich mudstone built by inplace organisms in an environment of low turbulence. The Canville is also a bank complex but on a much smaller and less complicated scale. The dominant bank-forming organism is the red alga, Archaeolithophyllum, which flourished in quiet water below active wave base. In southeastern Wilson County, a bed correlated with the Winterset is folded into a series of roughly parallel undulations in the SW1/4 NE1/4 sec. 19 and in the NW1/4 NE1/4 sec. 30, T 30 S, R 17 E. The undulations trend N 25°E. The Winterset is the regressive phase of the Dennis cyclothem (Heckel, 1987, p. 123). Exposed in adjacent Montgomery and Neosho counties but not seen in Wilson
County is a black, fissile, phosphatic shale, the Stark Shale Member below the Winterset. The Stark averages about 0.6 to 1.2 m (2-4 ft) in thickness, the upper half being a light olive-gray slightly calcareous shale that formed as the sea shallowed enough to destroy a presumed thermocline. The lower half, however, is a black fissile shale that was deposited under the presumed thermocline during maximum transgression. Below the Stark is the thin, hard Canville Limestone Member. It is mainly a skeletal calcilutite about 0.6 m (2 ft) thick, that was laid down below effective wave base during a rapid transgression of the sea at the beginning of Dennis time. Just east of Wilson County, in Neosho County, the Winterset is an algal mound complex locally 18 m (60 ft) thick.

The algal banks of the Winterset Limestone Member were mapped by Frost (1975, p. 283) updip through the subsurface from eastern Elk and Greenwood counties into the subsurface of Wilson County. The algae, mainly the red alga, Archaeolithophyllum, apparently flourished in quiet water below active wave base. Environmental factors reflected in lithologic and faunal characteristics, were good light penetration, low turbidity and turbulence, slight influx of terrigenous clastics, and moderate seafloor subsidence or rise in sea level. The Winterset thickens westward in the subsurface of Wilson County. The
skeletal calcarenite is representative of an environment intermediate between that of an algal, bryozoan boundstone and an oolitic calcarenite. The oolitic calcarenite records agitation and evaporation above a shallow-water bank. Other than lithification, dolomitization was the major diagenetic process in the Winterset Limestone Member. Dolomitization was selective, replacing first the drusy calcite in the algae, second, the carbonate matrix adjacent to the algae, and third, those fossils which were originally composed of aragonite (Frost, 1968, p. 1, 2).

In Neosho County, the Stark consists of a black, fissile shale, locally vertically jointed in the lower part. It contains phosphate concretions 5 cm (2 in) in diameter, along with small pyrite crystals. The upper part of the Stark is light olive-gray shale; its grain size is fine silt to clay; a few limonite nodules, limestone stringers, and phosphate nodules occur throughout. The Canville Limestone Member ranges in thickness from 15 cm (6 in) in northern Oklahoma to 2.4 m (8 ft) in northeastern Neosho County. The Canville is composed of skeletal mudstone and algal boundstone. The Canville is thin bedded and yellowish gray. Fossils include crinoids, brachiopods, bryozoans, Osagia, and pelecypods in the skeletal mudstone. Other fossils include phylloid algae. The algal boundstone is light gray to olive gray. Studies of Holocene dolomite deposits suggest that the presence of
abundant algal growth in conjunction with evaporation results in an increase in salinity and in a higher magnesium/calcium ratio, and thus aids in the dolomitization process. Dolomitization was the major postdepositional means of creating the abundant carbonate deposits in the bank complexes of Pennsylvanian time. The magnesium necessary for dolomitization probably was derived from several sources including mainly the phylloid algae. Specimens of the Recent Lithophyllum have an average magnesium carbonate content of about 15 mole percent (Johnson, 1961, p. 18). Closely related Archaeolithophyllum presumably had a somewhat similar composition. The Archaeolithophyllum could have easily baffled and trapped fine sediment in a manner similar to that postulated by Ginsburg and Lowenstam (1958, p. 323). Dolomitization could have been caused by concentration of magnesium ions on the shelf of the area of phylloid bank development. Downward movement into the porous parts of the algal bank by seepage refluxion (Adams and Rhodes, 1960) possibly created an environment for deposition of dolomite since the algae were formed by high-magnesian calcite which served as nuclei for initiating dolomite growth (Frost, 1975, p. 288-290).

Stratigraphic and Structural Implications. Oolites and Osagia suggest a nearshore marine environment for the Winterset Limestone Member of the Dennis Limestone
in Wilson County. Their concentration into pockets, and the presence of fossil debris of bryozoans, horn corals, crinoids, pelecypods and brachiopods indicate an abundance of life, as well as active current and wave action that effectively winnowed out any mud. This upper member, the Winterset, formed during a late regression phase when the ancient shoreline was migrating southward toward the McAlester Basin of Oklahoma. Minor post-deposition compressional folding or slumping may have formed the parallel-trending undulations. Heckel (1987, p. 123) describes the Dennis Limestone as an accumulation of storm-washed debris on a tidal flat.

Subsurface Strata of the Pennsylvanian, Mississippian, Devonian, Ordovician, and Cambrian Systems

Exploratory wells drilled in Wilson County cut rocks of Pennsylvanian to Precambrian age. The rocks of Pennsylvanian age are primarily limestone and shale in the upper part and sandstone and shale in the lower part. The rocks of Mississippian age are chiefly limestone, those of Ordovician and Cambrian age are largely dolomite, and those of Precambrian age are mainly reddish granite."

* The naming and outcrop characteristics of these and other units that occur only in the subsurface of Wilson County are described in reports by Wilmarth (1938), Moore (1936, 1949), Jewett (1949, 1954), Lee (1940c), Kercher and Kirby (1948), Merriam (1963), and Zeller (1968).
The subsurface rocks of Wilson County are known from core and ditch samples of at least 200 wells, from radioactivity and electric logs of about 1000 wells, and from drillers logs of more than 9,000 wells drilled for oil and gas (Plate 5). Core samples provide the best data for a petrographic study of subsurface formational units; however, such samples were generally taken to test or recognize only specific subsurface units. Ditch samples give general lithologic data for the entire column of strata encountered during the drilling process. Electric and radioactivity logs are also aids in the differentiation of rocks in the subsurface; but records of this kind are commonly incomplete, particularly in the upper part of the hole. Typical electric and radioactivity logs and the lithologic units and stratigraphic correlations that are interpreted from these types of logs or are recognized by use of samples are shown in Plate 6. Strip logs plotted from drillers records are also useful in correlating portions of the stratigraphic sequence and in determining the general structural configuration and the lithologic continuity of rock units. Drillers logs of the 39 wells shown on Plate 7 illustrate the lateral continuity of limestone beds and the lenticularity of sandstone and other units. The lateral continuity of such units as the Pawnee and Fort Scott Limestones makes them excellent marker beds.
Subsurface Strata of the Pennsylvanian System

The uppermost subsurface strata of Pennsylvanian age in Wilson County are in the Shawnee, Douglas, and Lansing groups. Formations of the Shawnee Group are the youngest strata that not only crop out at the surface but occur in the subsurface of Wilson County as well. They are penetrated only in the northwestern corner of the county.

Strata of the Douglas Group are cut by the drill only in the western half of the county. In the Douglas Group, the Haskell Limestone Member of the Lawrence Shale and the Westphalia Limestone Member of the Stranger Formation are recognized by many drillers. The Tonganoxie Sandstone Member is recorded in only a few wells.

Sedimentary rocks of the Lansing Group are encountered only in wells drilled by cable tools west and north of a line extending generally from 3.2 km (2 mi) west of Neodesha and Altoona toward the northeast corner of the county (Plate 1). In the Lansing Group, the Stanton Limestone is commonly the first unit to be carefully recorded in logs of wells drilled by cable tools in the county, but its usefulness in determining structure is reduced because of its rapid changes in thickness. Although recorded in some drillers logs as two beds, the Stanton is generally indicated as a single limestone unit from 1.5 to 15 m (5 to 50 ft) thick (Plate 7). The
Plattsburg Limestone of the Lansing Group also varies greatly in thickness, and where the intervening Vilas Shale is thin, as in areas south of the Silver City Dome, south of Fredonia, and west of Neodesha, the limestones of the Lansing Group may appear to occur as a single unit. The upper limestone member of the Plattsburg (Spring Hill) is recorded in logs as a gray hard limestone; the underlying calcareous and black portions of the shale member (Hickory Creek) and the thin basal limestone member (Merriam) of the Plattsburg would also be recognized and recorded in many wells.

Kansas City Group

The uppermost formation of the Kansas City Group in Wilson County is the Lane-Bonner Springs Shale. It is generally recorded in drillers' logs as light-colored shale that ranges in thickness from less than 8 m (25 ft) to about 40 m (125 ft). A subsurface limestone unit, 3 to 9 m (10-30 ft) thick near the middle of the formation, is recorded in the logs of several wells northwest of Fredonia and north of Altoona. This limestone may possibly be a southern extension of the Wyandotte Limestone. A thin sandstone is recorded at the top of the Lane-Bonner Springs Shale in the logs of a few wells.

The Iola Limestone of the Kansas City Group ranges in thickness from 3 to 20 m (10-65 ft) in the subsurface.
Near New Albany and throughout most of the northeastern part of the county the thickness averages about 15 m (50 ft), but elsewhere it is generally recorded in well logs as being about 3 m (10 ft) thick. Near the Elk County line (Plate 7), in the Jackson, Hooney, and McCray wells, the thickness increases at the expense of the overlying shale and the Iola apparently merges with the Plattsburg Limestone. However, although the Iola is generally described in logs as a single, hard, limestone unit, the middle black shale and thin limestone at the base may also be recorded locally.

The next underlying unit of the Kansas City Group, the Chanute Shale, ranges in thickness from about 15 to 45 m (50-150 ft). It is lithologically about 50% sandstone, which occurs as one or more different bodies. The upper sandstone unit, the Cottage Grove Sandstone Member ("New Albany sand"), averages less than 8 m (25 ft) thick, but in the northeastern corner of the county, the sandstone averages nearly 21 m (70 ft) in thickness, and west of Neodesha, it is as much as 46 m (150 ft) thick. In T 29 S, R 16 E, the Cottage Grove is divided into two parts by a shale unit as much as 18 m (60 ft) thick. The sandstone below the shale presumably correlates elsewhere with the Noxie Sandstone Member of the Chanute Shale. In a few areas in Wilson County three thin limestone beds are recorded about 9, 18, and 24 m (30, 60, and 80 ft) below
the top of the Chanute in the subsurface. In other areas the entire Chanute Shale thins in the subsurface, and the overlying Iola Limestone nearly merges with the underlying Drum Limestone. The shale of the Chanute is generally recorded in drillers logs as blue, white, or gray. Along a line extending southwestward from Sec. 3, T 28 S, R 17 E to Sec. 10, T 29 S, R 15 E, and south to Sec. 8, T 30 S, R 15 E, the Cottage Grove and Noxie(?) Sandstone Members extend to the base of the formation in the subsurface. In a few wells in this area, the underlying Drum Limestone is missing, and an unconformity appears to cut out the Drum and extend into the underlying Cherryvale Shale. The Drum is recorded in well logs as a thin, hard limestone; the Cherryvale Shale is generally described as a dark-colored shale about 9 m (30 ft) thick.

The next 61 m (200 ft) of strata in the subsurface of Wilson County include the lower (older) part of the Kansas City Group. Of these strata only the Winterset Limestone Member of the Dennis Limestone crops out in the county. Included in these strata are the Stark Shale Member and the Canville Limestone Member of the Dennis Limestone, the Galesburg Shale, the Swope Limestone, the Ladore Shale and the Hertha Limestone (Figure 38). The Bethany Falls Limestone Member of the Swope Limestone was believed by Payton (1966, p. 601) to have been formed in an environment identical to that of the Winterset Limestone
Figure 38. Stratigraphic classification of the Kansas City, Pleasanton, Marmaton and Cherokee Groups in Wilson County. (Modified from Zeller, 1968, plate 6).
Member of the Dennis Limestone. Payton summarized that the abrupt regional change from low-energy biomicrites in the lower parts of both the Bethany Falls and Winterset members to shallow water oosparites, biolithites, and micrites in the upper parts of these units was produced by a change from transgression to regression. The medial shale in each member thereby became a time line marker. He felt that the transgressive-facies overlap in the Middle Creek Limestone Member of the Swope Formation was consistent with this interpretation and that the framework of sedimentation for the Bethany Falls Limestone Member of the Swope Limestone and the Winterset Limestone Member of the Dennis Limestone was identical (Payton, 1966, p. 601). The shale formations can be correlated from well to well only through the relationships of the limestone units. The most persistent shale unit (Galesburg) is near the middle of the limestone sequence and in many places contains a lenticular sandstone body that produces small quantities of gas and oil locally.

Pleasanton Group

The lowermost deposits of the Missourian Stage are placed in the Pleasanton Group. The name Pleasanton "Shale" was first applied in 1895 by Erasmus Haworth to strata near the town of Pleasanton, Linn County, Kansas, about 100 km (60 mi) northeast of Wilson County. The
boundaries of the Pleasanton “formation” underwent modification several times before the term was abandoned in 1932 (see Moore, 1949, p. 69). The name Pleasanton was then replaced by the term Bourbon formation, a name credited to Moore (1932, p. 90; 1936, p. 72-73). The type locality was given as Bourbon County with the note that most of the formation is exposed in the bluffs of the Marmaton River about 1.6 km (1 mi) south of Uniontown, Bourbon County, Kansas, (Moore, 1936, p. 73). In 1949 the term Pleasanton was revived in the interest of obtaining uniform inter-state nomenclature, and the Pleasanton deposits were classed as a group with boundaries designated as the base of the Hertha Limestone (above) and the base of the Hepler Sandstone (below) (Moore, 1949, p. 72). Three formations were differentiated (downward) in the Pleasanton Group, the Knobtown Sandstone, the Checkerboard Limestone and the Hepler Sandstone (Moore, 1949, p. 73). Later, Moore and others (1952, chart) show the same three named formations in the Pleasanton Group, the Knobtown, Checkerboard and Hepler, with unnamed shale units lying above each of the named formations. Zeller (1968, p. 27, 28, and chart) indicates that the names of two of the formations have been changed to agree with those of Oklahoma, the Tacket Formation (upper) and the Seminole Formation (lower). The Seminole Formation has two members, the South Mound Shale Member
above and the Hepler Sandstone Member below. Present usage of the term Pleasanton Group, includes the strata between the base of the Hertha Limestone of the Kansas City Group at the top and the base of the Hepler Sandstone Member of the Seminole Formation at the bottom. A major unconformity separates the Hepler Sandstone Member from the underlying Holdenville Shale of the Marmaton Group. The boundary between the Missourian and Desmoinesian Stages is placed at the unconformity at the base of the Hepler Sandstone Member; the stage boundary can be recognized only locally in the subsurface. The rocks of the Pleasanton Group range in thickness from about 8 to 40 m (25-125 ft). At the top and making up more than half of the group is the Tacket Formation, a gray to yellowish-gray shale with local black shale and thin limestone beds; massive sandstone bodies occur in the upper one half of the formation in some places. Drillers logs describe the shale of the Tacket as dark gray or black. The Checkerboard Limestone in well records is shown as one or more limestone beds 0.6 to 1.5 m (2-5 ft) thick. The underlying Seminole Formation is principally light-gray to bluish-gray shale with a coal bed and an underclay lower in the section. The lower part of the Seminole Formation is composed of the Hepler Sandstone Member ("Wayside sand") which fills channels cut into the upper part of the Marmaton Group, channels from which gas
has been produced. Stratigraphic studies of the Pleasanton Group in southeastern Kansas were conducted by Hatcher (1961) and Emery (1962) and summarized by Jewett and others (1965). Underwood (1984) more recently studied the enigmatic “Bourbon flags” sequence in the Pleasanton Group, and Sutton (1985) studied the sandstones in order to determine their source and the environment of deposition. The sandstone samples studied by Sutton (1985, p. 15) were impregnated with a blue-dyed epoxy resin prior to being cut for thin sections. After cutting, the thin sections were etched and stained by the Boone and Wheeler (1968) method to determine the presence of potassium feldspar. Staining with Alizarine Red-S to distinguish dolomite from calcite and with potassium ferricyanide to distinguish ferroan calcite and dolomite from non-ferrous calcite and dolomite was done to cuts of all samples, and isolith maps were prepared. Isopachous maps were also developed by Sutton for specific formations of both the Pleasanton and Marmaton Groups. The Norfleet Limestone Member of the Lenapah Limestone has been interpreted to represent a relatively minor transgressive-regressive cycle (Parkinson, 1982). Sandstone units, such as the Hepler Sandstone Member of the Seminole Formation, fill channels cut deeply into the underlying members of the Lenapah Limestone; the channels were cut completely through the Idenbro Limestone Member. The sandstones
represent a general regression in which the sea withdrew slowly, the sediments just deposited were cut into and reworked along the coastline into a series of bars and deltas. All erosive channels were filled by cross-bedded, fine- to coarse-grained sandstone which eventually filled all the erosional lows, and transgression of the sea over the leveled plain was initiated (Sutton, 1985, p. 47-57). Sutton noted that carbonate rocks are more prevalent in southeastern than in northeastern Kansas, particularly southward from about T 27 S (Sutton, 1985, p. 57); she also recorded that the underlying fossiliferous Worland Limestone Member of the Altamont Limestone had been interpreted by Schenk (1967) as having been deposited during a regressive phase of cyclic sedimentation. The thick carbonate sequences in the subsurface may relate to the "Bourbon flags" phenomenon described by Underwood (1984), who reported that the flags grade upward, possibly into the algal Critzer Limestone Member of the Hertha Limestone. The flags are believed to have been deposited along the slope of a deltaic lobe during stillstand and early regression after minor stages of marine transgression (Sutton, 1985, p. 57). Isopach and isolith maps of the sandstone beds show that these units occupy positions within sedimentary thickness trends that suggest that the terrigenous sediments may have entered Wilson County from the northeast or southeast.
Desmoinesian Stage

The Desmoinesian Stage is separated from the overlying Missourian Stage by an inconspicuous unconformity in most places. The upper contact of the stage is designated paleontologically as the top of the Zone of *Fusulina* (Moore, 1949, p. 35). In Kansas the break occurs at the base of the Hepler Sandstone Member of the Seminole Formation, the lower formation of the Pleasanton Group. The first use of the term Des Moines was by C. R. Keyes of the Iowa Geological Survey in 1893 (Iowa Geological Survey, vol. 1, p. 100) as the Des Moines formation. In 1896, he (Keyes, 1896, p. 22) referred to these sediments as the Des Moines Series with a type locality along the Des Moines River in central Iowa. In 1932, R.C. Moore (1932, p. 89) defined the Des Moines Series as extending from the base of the Pleasanton Shale (above) to the base of the Cherokee Shale (below). In 1949, Moore called these strata the Desmoinesian Series (1949, p. 35). Zeller indicated in 1968 (p. 23) that this division of Pennsylvanian rocks had been reclassified as the Desmoinesian Stage (Figure 38). The Desmoinesian Stage includes (downward) the Marmaton Group and the Cherokee Group. The Marmaton Group contains eight formations; the Cherokee Group has only two formations.
Marmaton Group

The term Marmaton was first used as the Marmaton formation (Haworth, 1898, p. 92) with its type locality along the Marmaton River from Uniontown to Fort Scott, Bourbon County, Kansas. Shale predominates as the major rock type; the group consists (downward) of the Holdenville Shale, the Lenapah Limestone, the Nowata Shale, the Altamont Limestone, the Bandera Shale, the Pawnee Limestone, the Labette Shale, and the Fort Scott Limestone at the base. The combined average thickness of these formations is about 76 m (250 ft). Marmaton rocks crop out in Kansas in a belt ranging in width from 16 to 40 km (10-25 mi). The general strike of the belt is about 30° east of north and the dip is westerly at roughly 4 m per km (20 ft per mi) (Moore, 1949, p. 47-50). Two persistent limestones, the Lenapah and Altamont, occur in the upper part of this 76 m (250 ft) sequence (Fig. 38). The Lenapah is generally about 3 m (10 ft) thick and locally is divided into two beds by about 1.5 m (5 ft) of shale. The Lenapah is separated from the lower limestone unit, the Altamont, by light-gray shale, the Nowata Shale, which ranges from 1.5 to 11 m (5-35 ft) in thickness and is locally sandy. The Altamont, has an average thickness of about 5 m (15 ft). It is recorded in the logs of most wells and is locally divided into two separate beds. The middle part of the Marmaton Group consists of about 30 m
(100 ft) of shale, the Bandera Shale (Plate 8). Widespread sandstone beds ("Weiser sand") occur in the upper and lower parts of the Bandera. They are lenticular, 1.5 to 11 m (5-35 ft) thick, and locally produce oil and gas. The color of the Bandera Shale is recorded in drillers logs as light gray or blue.

Underlying the Bandera Shale is a readily-recognized, thick limestone unit, the Pawnee Limestone. This is the "Pink lime" of many drillers and is the "40-foot lime" of others. It consists of 9 to 14 m (30-45 ft) of brown, hard limestone. Locally, a black shale bed 1.5 m (5 ft) thick near the top separates the Pawnee into two limestone beds that are 1.5 m (5 ft) and 11 m (35 ft) thick. The Labette Shale, which averages about 9 m (30 ft) thick and is black in the upper half and light colored in the lower half, underlies the Pawnee Limestone. In a few places, the Labette contains a sandstone bed ("Peru sand") which produces gas (Plate 8).

The next lower unit in the subsurface is the Fort Scott Limestone. This limestone, the "Oswego lime" of drillers, is one of the most important units for purposes of correlation in the subsurface of Wilson County because it is the last thick limestone unit above the oil- and gas-bearing sandstones of the Cherokee Group. Lying as it does below the "Pink lime," it is recognized by most drillers, and its depth is carefully recorded in most
wells. The top of the Fort Scott Limestone "Oswego lime" was used to draw a subsurface contour map (Plate 9) which was used in constructing a profile of the top of the Fort Scott Limestone along the line of the cross section on Plate 7. The top of the Fort Scott Limestone on each well log was positioned to the dashed horizontal line (sea level) on this profile when the wells were projected to the line of the cross section (Plate 7) in order to eliminate the effects of post Fort Scott structural movements and the topography of the present land surface.

The Fort Scott Limestone averages about 10 m (30 ft) in thickness in Wilson County but is as much as 23 m (75 ft) thick in the southeastern part of the county. It generally consists of two limestone beds separated by units of dark gray and black shale. The upper limestone bed (Higginsville) is 5 to 8 m (15-25 ft) thick and overlies 1.5 to 3.0 m (5-10 ft) of dark gray or black shale (Little Oswego) which, in turn, overlies 1.5 to 3.0 m (5-10 ft) of hard limestone (Blackjack Creek). The upper limestone bed is generally called the "20-foot lime" by drillers, and the lower limestone bed is their "5-foot lime." A black shale bed beneath the "5-foot lime" commonly furnishes the largest amount of gas, but each of the black shale beds was apparently a source of the "shale gas" for which the "Oswego lime" was noted during the early 1920's. A third limestone bed about 1.5 m (5 ft)
thick is recorded in the logs of many wells, and in the logs of a few wells a fourth 1.5 m (5 ft) limestone bed is recorded beneath another 1.5 m (5 ft) of black shale.

Cherokee Group

The Cherokee Group was originally called the Cherokee shale by Haworth and Kirk (1894, p. 105) for beds reported to be about 122 (400 ft) thick in Cherokee County, Kansas, about 32 km (20 mi) southeast of Wilson County. The Cherokee Group is defined as the lower part of the Desmoinesian Stage of the Middle Pennsylvanian Series; it is equivalent to the European Upper Westphalian of the Middle Carboniferous (van Eysinga, 1978), and its upper 61 m (200 ft) or so are customarily referred to as the “Lagonda interval” in the “oil patch” in southeastern Kansas (Killen, 1986, p. 68). In 1953, the discovery was made that the name Cherokee was preempted because of prior use, and it was replaced by the Cabaniss and Krebs Groups. The name “Cherokee” was readopted to group status in 1955 due to widespread usage, and the names Cabaniss and Krebs became subgroups (Howe, 1956, p. 21). In 1959, Jewett changed the rank of the Cabaniss and Krebs to formations (Fig. 38), and as such they include all strata between the Fort Scott Limestone (above) and limestone of Mississippian age (below). These two formations now make up the Cherokee Group, the Cabaniss Formation above and
the Krebs Formation below. The boundary between these two formations is marked biostratigraphically by a readily recognized faunal change from the brachiopod Marginifera muricatina and smooth forms of Mesolobus in the Cabaniss Formation to the presence of the brachiopods Marginifera missouriensis, Spirifer rockymontanus, Spirifer occidentalis, and striated forms of Mesolobus, in the Krebs Formation (Howe, 1956, p. 20). Each formation has several members and coal beds; three limestone beds are among the members; one, the Verdigris (or Ardmore of drillers) is a good marker bed in subsurface work. Sandstone beds commonly occur as lenticular bodies in the upper part (Denesen, 1985, p. 94, 96, 107). These were classed as deltaic channel sandstones, whereas, in the lower part, the lenticular sandstones are the “shoestring sands” of drillers, and many are important oil and gas reservoirs (Bass, 1936, p. 9; Moore, 1936, p. 55, 56; 1949, p. 37-39; Zeller, 1968, p. 23, 24). The Cherokee Group contains the lowermost cyclic strata in the Pennsylvanian of the Midcontinent (Howe, 1956). Deposition of Cherokee strata occurred during a major transgression that was interrupted by many minor progradational (regressive) pulses of sedimentation (Reinholtz, 1982; Lardner, 1984; Denesen, 1985). This interpretation is supported by the successive onlap of younger rocks onto positive structural features, the
lateral continuity of thin marine and non-marine beds, and the transition from predominantly clastic sediments to carbonates during Desmoinesian time (Ham and Wilson, 1967; Visher and others, 1971; Ebanks and James, 1974; and Rascoe and Adler, 1983) as pointed out also by Staton (1987, p. 22). An attempt to map the typical “Illinois” cyclothem of Weller (1930, 1931) and/or the typical “Cherokee” cyclothem of Moore (1949, p. 42-43) would require mapping a gray, sometimes calcareous shale at the top of the Weller cyclothem and/or a diversely fossiliferous limestone at the top, if present, of the Moore Cherokee cyclothem. In each cyclothem a coal bed caps an underclay unit below and underlies a black, fissile, phosphatic shale (Boardman and others, 1984, p. 143). Early stratigraphic studies of the Cherokee Group in southeastern Kansas were based on the correlation of cyclic deposits from the top of one coal bed to the top of the next higher coal bed (Abernathy, 1936; Moore, 1949; Howe, 1956). Each cyclic sequence was designated as a formation.

The early work done on sandstones of the Cherokee Group in southeastern Kansas concentrated on several facets of geology, but mainly on stratigraphy and the origin of the oil producing sands. Rich (1923), Cheyney (1929), Bass (1934, 1936), Bass and others (1937), Leatherock (1937), and Pierce and Courtier (1937)
suggested that the shoestring sand bodies represented buried offshore bars; Rich (1926) suggested multiple origins for the sand bodies, including barrier bars, stream channels, beaches, and tidal channels; Cadman (1927), MacKenzie (1972), Murphy (1978), Hulse (1978), Reinholtz (1982), Woody (1983, 1984), Lardner (1984), Rofheart (1980), Harris (1985), Bouquet (1985), Patterson (1985), Killen (1986), and Brenner (1989) believed the sandstones were stream-channel deposits formed by migrating point bars. Hayes (1963) preferred a tidal flat or tidal channel origin; Visher and others (1971) suggested a deltaic origin; Cole (1969), Wanless and others (1970), and Ebanks and others (1977) favored a fluvio-deltaic origin. In order to correlate discontinuous sandstones from the outcrop to the subsurface, informal stratigraphic intervals were established (Ebanks and others, 1977; Hulse, 1978). In recent reports, such as those by Harris (1984), Killen (1986), and Staton (1987, p.27) radioactive dark-gray to black shales were used as marker beds to correlate stratigraphic units (Figure 39). These shales have a high uranium content and are readily recognized on gamma-ray logs; the black shales typically overlie coal beds or seatrock units where the coal bed is absent. The coals are high-volatile bituminous in rank; the seatrock or underclay commonly occurs directly below the coal bed.
Figure 39. Radioactivity log of the Cherokee Group in Wilson County showing characteristic signatures of black shales (e.g., Excello shale and V-shale) and intervals used in subsurface correlations (From Staton, 1987, p. 34).
Using a rather unique and unconventional means of defining a formation on the basis of gamma-ray well-log data, Denesen (1985) appears to have arbitrarily placed in his Banzet Formation all strata in northern Oklahoma that lie between the base of the Fort Scott Limestone and the top of the Ardmore (Verdigris) Limestone Member of the Senora Formation of Oklahoma. In southeastern Kansas the Banzet would thus include all strata between the base of the Fort Scott Limestone and the top of the Verdigris Limestone Member of the Cabaniss Formation (Fig. 38). Denesen designated the roadcut exposures along Oklahoma State Highway 10, to the south-southeast of the hamlet of Banzet, in Craig County, Oklahoma (SW1/4 SW1/4 SW1/4 Sec. 30, T 28 N, R 20 E), as the type locality of the Banzet Formation (Denesen, 1985, p. 31). He would seem to have developed a formation within a formation, the Banzet Formation within the Senora Formation. However, Denesen (1985, p. 32, 108) then recommended abandonment of the terms Krebs, Cabaniss, Senora, and Verdigris, a recommendation with which I disagree. In his conclusions regarding the Banzet Formation, Denesen (1985, p. 107-108) indicates that three major episodes of deltaic sedimentation are recorded by gamma-ray well-log signatures of the Banzet Formation in southeastern Kansas and northern Oklahoma. His data are presumed to show that deltaic lobes advanced over the Cherokee shelf after formation of the Ardmore (Verdigris) Limestone; that the Bevier and Iron
Post coal beds accumulated after these deltaic lobes had been deposited; that neither the Nemaha Uplift nor the Ozark Uplift supplied appreciable amounts of sediment to deltas of the region; that the Breezy Hill Limestone formed the cap of a delta-destructional sandstone sequence and overlay a deltaic channel sandstone ("Squirrel sand") in many wells (including those in Wilson County); and that subsequent marine transgression during late Cherokee time displaced the shoreline to the northwest (Denesen, 1985, p. 55-79). The deltaic cycles below the Bevier and Iron Post coal beds, which Denesen claimed were characterized by distributary channel deposits up to 29 m (94 ft) thick and by widespread crevasse splay sediments, were not recognized by other subsurface workers in the area (Figs. 38-40). His treatment of the stratigraphy is not used in this paper.

In a petrographic study of shoestring sands in Greenwood County, adjacent to Wilson County on the west, Evenson (1989, p. 83) concluded that compaction of the sands began as soon as other strata covered the sands in their fluvial-channel or shoestring-sand environments. The iron then selectively migrated under reducing conditions to nuclei and formed pyrite crystals. Some of the iron, however, gathered to form sideroplesite spherules and cement prior to quartz overgrowth on quartz grains and subsequent siliceous cementation. The effects of compaction then became less, and partial solution of the cement took place before calcian ankerite cementation.
Figure 40. Strata of the Cherokee group in Wilson County showing sandstone, shale, black shale and coal beds (with underclays) (from Staton, 1987, p. 30).
and partial solution occurred; this was followed by precipitation of kaolinite. Discriminant function analysis (DFA) provides a quick and relatively accurate differentiation method for classifying the sandstones as to whether they were cross-bedded or ripple-bedded using petrographic and petrophysical data (Evenson, 1989, p. 59, 83). Since sandstones are composed of a framework of mineral grains and authigenic components that occupy part of the interstitial space, these characteristics were used by Evenson (1989), Rotheart (1985), Bouquet (1984) and Woody (1984), in conjunction with grain size, sorting, porosity, and permeability, to categorize the Cherokee Group sandstones they studied. They thus relegated each sandstone sequence to a specific depositional environment and diagenetic history according to its petrophysical properties.

The interdependent variable elements just mentioned were used also by Patterson (1985, p. 16) to characterize the Cattleman sandstone. He lists mineral composition, grain size, grain shape, orientation, and packing as important characteristics. In the southeastern Kansas area the Cattleman sandstone is thought to be a distributary-mouth-bar deposit formed in the deltaic margin-fringe environment of a subaqueous delta plain (where water depths ranged from 46 to 274 m (150-900 ft)).
The sediments display a coarsening upward sequence with clean coarse sand at the top and prodelta clays in the lower part. Average mineral composition shows quartz at 33 percent, mica (including chlorite) at 8 percent, silica cement at 5 percent, opaques and miscellaneous at 15 percent, feldspar, chert, and calcite cement at 6 percent, and clay matrix at 34 percent. The grain size average for quartz is that of coarse silt (4.22 phi); the sorting is recorded as fairly well sorted; the shape of quartz grains depends on the amount of secondary overgrowth; the orientation of the quartz grains ranges from 34 to 51 degrees; and, finally, the packing reflects selective sorting and crushing of ductile grains, thus clogging the pore space. The range in porosity is from 10.2 to 20.9 percent (average 13.42±1.92 percent); the permeability range is between 0.01 and 55.0 md (average 6.78 md). Detrital mica and clay matrix material account for 48 percent of the variation in porosity and 76 percent of the variation in permeability (Patterson, 1985, p. 16, 29, 35, 63, 68, 107).

Evenson (1989, p. 81, 85-92) believed that the mud-dominated, restricted shelf facies of the Cherokee was due to confinement of the basin by topographically prominent features to the east, west, and, to a lesser extent, to the north. Wave and current action were minimal due to low relief in a shallow basin. Poor circulation in
shallow water probably resulted in abnormally high salinity, depleted nutrients, and relatively high water temperatures (Enos, 1983); a mud-supported facies landward of a higher-energy facies was thus produced. Watney (1980, p. 32) described a similar depositional setting for the Lansing and Kansas City groups in northwestern Kansas. Sedimentation of siliciclastic muddy shelf deposits was also probably controlled by the concentration of fine-grained suspended material that entered the shelf seas and by the intensity of shelf hydraulic processes as well (Johnson, 1978). Schubel and Okubo (1972) suggest that resuspension of shelf-bottom sediments may provide a major mechanism to bring muddy debris to the environment. Carbonates in essentially the same environment are typically argillaceous (Enos, 1983). Sea-bottom configuration, water circulation patterns, and other factors such as temperature, carbonate saturation, light penetration, water turbidity, salinity, and the nature of currents all affect the trends and development of carbonate units (Watney, 1980; Enos, 1983; Miall; 1984). Another important facies of the Cherokee Group involves the black shales. Their thinness in conjunction with great lateral persistence implies very slow sedimentation away from detrital influx and deposition farther offshore in deeper water underneath a thermocline (Heckel, 1984, p. 35, 36). The quasi-estuarine circulation allowed these
black, phosphatic, organic-rich shales to be deposited during high stands of sea-level across vast areas (Heckel, 1977, p. 1045; Brongersma-Sanders, 1971, p. 130).

In Wilson County the Cherokee Group averages about 122 m (400 ft) in thickness and ranges from 137 m (450 ft) to as little as 61 m (200 ft) (Plate 7). The group is thinnest in areas of uplift and thickest immediately adjacent to such areas. The most productive petroleum-bearing zones in the county are in the lenticular sandstone beds that occur in this group. The tops of the more important petroleum-bearing sandstone beds lie approximately 8, 46, 76, and 107 m (25, 150, 250, and 350 ft) below the top of the group (Plate 8).

The shale of the Cherokee Group is generally light colored in the upper 15 to 73 m (50-240 ft), but dark-gray to black shale units are interbedded locally above almost every coal bed. Where the shale is dark-gray to black, its signature on gamma ray/neutron logs is distinctive (Fig. 39). The shale in the lower 30 to 61 m (100-200 ft) of the Cherokee in well logs is recorded as light colored or blue, except above Staton's Warner B (BW) and the Riverton coal beds (Fig. 40).

Oxidation-reduction potential (Eh) and alkalinity-acidity potential (pH) are very important characteristics in coal, black shale and limestone deposition. A positive Eh value indicates an environment in which organic matter
tends to oxidize (yielding carbon dioxide); a negative value indicates a reducing environment in which organic matter is stable. Above a pH of 7.8, calcite is readily deposited; below, it tends to dissolve. Depth of water, agitation, particle size, organic content, salinity, and depth below the depositional interface are but a few of the factors which affect Eh and pH. Color intensity can be used to approximate Eh. A dark-colored (black or dark gray) shale can be interpreted as having been deposited under reducing conditions; a light-colored (white, cream, or buff) shale suggests oxidizing conditions. Eh may also vary vertically. Below the sediment/water interface, Eh tends to decrease, i.e., the environment becomes more reducing with depth. The pH may also be depth related. The surface waters may have a pH of 7.8, but the bottom waters directly overlying a black shale could be much more acidic, measuring possibly 6.6. The increased acidity is believed to result from bacterial action which reduces sulfates to sulfides. This releases hydrogen sulfide gas which tends to acidize the adjacent waters (Zobell, 1946; Elias, 1963, p. 192).

Pyrite is an important mineral because its presence indicates reducing conditions, probably due to organic matter that was metabolized by sulfate-reducing bacteria. It also presents a problem in unraveling the cementation history because siderite, the carbonate form of iron,
does not form in the presence of high concentrations of dissolved sulfur necessary for iron sulfide (such as pyrite) to precipitate (Garrels and Christ, 1963). However, siderite can precipitate if the sulfur is removed from solution during early diagenesis by precipitating primitive iron sulfide (Berner, 1980).

Shales make up 50 to 80 percent of the strata in the Cherokee Group. These shales can be broken into four main types; (1) a greenish gray-shale composed of quartz, chlorite, sericite, local concretions of siderite, minor amounts of organic matter and associated pyrite, and a small sparse marine fauna; (2) gray shale with grains of quartz, chlorite and sericite, significant amounts of organic matter, pyrite, and greater clay content and marine and plant fossils than in the greenish-gray shale; (3) black phosphatic shale containing quartz, illite, chlorite, organic matter, small phosphatic nodules and no silt; (4) olive-gray silty underclay composed of quartz and clay minerals with common pyrite crystals, ankerite veins, limestone nodules, and carbonized plant fragments (Baker, 1962, p. 1628).

The thin Verdigris Limestone, also referred to as the Ardmore limestone by drillers (Woody, 1983), is noted 24 to 30 m (80-100 ft) below the base of the Fort Scott in the logs of many wells (Fig. 40). The Verdigris and other limestones of the Cherokee Group are generally light
gray and contain gastropods, brachiopods, echinoderms, bryozoans, foraminifers, ostracodes, and green algae (Howe, 1956; Zeller, 1968; Van Dyke, 1975; Hulse, 1978). Howe (1956, p. 20-77, plate 2) describes and lists the large and diverse fauna of the Cherokee in southeastern Kansas. Of the limestones, the Verdigris is the most widely recognized marker bed in well logs; it serves to define the lower limit of a series of sandstone beds referred to as the "Squirrel sand" by drillers (Plate 8; Fig. 40). One to three sandstone bodies make up the "Squirrel sand"; they range in thickness from 0.9 to 14 m (3-45 ft) and are of restricted lateral extent.

Staton (1987, p. 26-53) used the designated surface outcrop terminology (Zeller, 1968, p. 23-25) for the Cherokee Group in his study, whereas I had used the drillers terminology because I was working with oil company personnel during my study and it predated Zeller's. The two terminologies can be readily correlated, however. Staton's Excello interval which lies directly below the Fort Scott Limestone and encompasses 30 m (100 ft) of strata with the Verdigris Limestone at the base, corresponds with the "Lagonda interval" of drillers. Within this interval, Staton has the Excello shale at the top and the Breezy Hill limestone about 3 m (10 ft) below the top (Fig. 40). Light to dark-gray shale intervenes between the Breezy Hill and the Verdigris
limestones with the Iron Post and Bevier coal beds in between along with the Squirrel sandstone about 6.1 m (20 ft) below the Fort Scott Limestone (Staton, 1987, p. 30). Denesen (1985) made an interesting observation concerning the weathered condition of feldspar grains in the Squirrel sandstone. The majority of potassium-feldspar grains are partially altered; on the other hand, the albitic-plagioclase grains are clean. The “Squirrel sand” of drillers would also occur in this interval.

On the basis of samples from 26 wells in Wilson County, Brenner (1989, p. 22, 23, 40, 41) was able to fit Wilson County into a paleogeographic reconstruction he had developed. His reconstruction agreed somewhat with an earlier one by Heckel (1977, p. 1055, 1056) in that they both had the Midcontinent region straddling the paleoequator in Pennsylvanian time, thus providing the area with warm equatorial waters that were conducive to carbonate-sediment production by biochemical processes. Siliciclastic sediments that were transported into the equatorial basin or onto the adjacent shelf, succeeded in overwhelming the carbonate-producing agents on an incredibly frequent time schedule thereby reducing the variety of the faunal assemblage recorded by Aden (1982). These eustatic fluctuations in sea level occurred about 15 times during Cherokee time (Brenner, 1989, p. 39-42).
Sandstone beds below the "Squirrel sand" are classed as "Upper Bartlesville sand" and "Lower Bartlesville sand," and many drillers include in this group the "Skinner sand," the "Stray sand," "the Burbank sand," the "Salt sand," and the "Burgess sand" as well. In some well logs, a sand body that correlates with or lies just above the "Upper Bartlesville sand" is called the "Cattleman sand." These terms for the sand bodies are used slightly differently locally. For example, Calvin (1983, p. 13) records that within the Cherokee Group in southeastern Kansas the upper sand zone is referred to as the "Squirrel sand", the middle zone as the "Cattleman sand", and the lower as the "Bartlesville sand". In this report sandstone beds lying 30 to 61 m (100-200 ft) below the base of the Fort Scott Limestone are arbitrarily classed as the "First Bartlesville sand".

In the interval 30 to 61 m (100-200 ft) below the Fort Scott, Staton shows by name only the Chelsea Sandstone, although four other sandstones (unnamed) are present (Fig. 40). The Chelsea sandstone is overlain by the Fleming, Mineral and Scammon coal beds and is underlain by the Scammon B, Tebo, and Tebo B coal beds (Staton, 1987, p. 30). Sandstones (Bluejacket; Fig. 40) lying 61 to 91 m (200-300 ft) below the Fort Scott are here referred to as the "Second Bartlesville sand," and those (Warner) lying 91 m (300 ft) or more below the Fort
Scott are classed as the "Third Bartlesville sand" (locally called the "Tucker sand"). Because of considerable thinning of the Cherokee Group over structural highs, sandstones of the "Second Bartlesville sand" may overlie Mississippian rocks in some wells. Elsewhere, those in the "Third Bartlesville sand" overlie rocks of Mississippian age except where the "Burgess sand" is present.

Between 61 and 107 m (200-350 ft) below the Fort Scott Limestone, Adams (1959), Ebanks (1979), and Staton (1987) have all mapped sandstone beds they refer to the Bluejacket and Warner Sandstones. The Bluejacket was formally named by D. W. Ohern (1914) from surface exposures about one mile west of the town of Bluejacket, Oklahoma. Adams (1959) studied the Bluejacket sandstone throughout an 11 county area in southeastern Kansas, 2 counties in Missouri, and 3 counties in Oklahoma. He found that the porosity was fairly constant (predominantly from 16 to 23 percent—average 20.2); that the permeability was variable both horizontally and vertically (predominantly from 10 to 1000 md); that the grain size averaged 0.1 to 0.2 mm; that the index of roundness was 0.28; that the geometric coefficient of sorting was 1.3; that the geometric mean diameter of grains was 1.21 mm; and that the number of grains per square millimeter averaged 103. No general relationship between porosity
and permeability was found because of the extreme variability in permeability both horizontally and vertically. Microscopic examination indicated that the fine-grained fraction was composed mainly of irregularly shaped clay-sized quartz, and that, in combination with the large particle matrix, the fine grains created a lower permeability regime in which the tortuosity of the fluid path through the Bluejacket Sandstone was quite sinuous (Adams, 1959, p. 29, 32, 33, 64).

Not satisfied with prior stratigraphic work in the lower part of the Cherokee, Ebanks (1979, p. 297-300) determined that the distribution of the sandstone bodies "has fortuitously led to miscorrelation of some of the units because of incomplete exposures in critical areas across the bordering "three-state region" of Oklahoma, Kansas, and Missouri" (Ebanks, 1979, p. 297). In a study of well logs and cores, Ebanks and others (1977) had concluded that: "Traditional stratigraphic nomenclature...does not recognize the non-continuous nature of many of the sandstones...; rather, these classifications of formations have fostered the widespread use of the same name for sandstone in about the same stratigraphic position in widely separated areas." In his study Ebanks (1979, p. 300) concluded that the "Bluejacket" sandstone of Missouri is stratigraphically lower than the Bluejacket of Oklahoma, that the "Warner"
sandstone of Missouri is stratigraphically higher than the Warner of Oklahoma and Kansas, and that two distinct sandstones have been called "Bluejacket" in Kansas outcrops. Four sandstones may be present, but two must have been previously unrecognized in the Krebs part of the lower Cherokee. Gamma ray-density and resistivity logs from drilling made possible the recognition of four sandstone bodies in the lower part of the Cherokee. The uppermost was informally called the "upper Bluejacket" and may be the updip extension of the deltaic sandstone shown by Visher and others (1971, p. 1224) to be part of a minor deltaic area east of the main "Bartlesville" delta (Ebanks, 1979, p. 300). The "upper Bluejacket" is separated from the "lower Bluejacket" by only 1 m (3 ft) of silty shale that contains a non-persistant coal bed, or a thin shaly limestone, or a sideritic mudstone bed in some areas. Only in areas of surface mining for coal are the two sandstones clearly distinguished. Two persistent coal beds, the Dry Wood and Rowe, and associated underclays and silty shales, separate the "lower Bluejacket" (which correlates with the "Bluejacket" sandstone of Missouri) from the "upper Warner" sandstone. The "upper Warner" is separated from the underlying "lower Warner" by gray shale and several thin coal beds. The "upper Warner" is probably equivalent to the "Warner" sandstone of Missouri (Ebanks, 1979, p. 300).
Staton (1987, p. 30) has also recognized the upper Bluejacket sandstone, the lower Bluejacket sandstone, the upper Warner sandstone and the lower Warner sandstone in his careful study (Fig. 40). Several coal beds, including the Bluejacket A (Abj) coal bed, Bbj coal bed, Cbj coal bed, Dbj coal bed, Dry Wood coal bed, Rowe coal bed, Neutral coal bed, Warner A (Aw) coal bed, Bw coal bed, Cw coal bed, Dw coal bed, and Riverton coal bed all occur in the Krebs Formation (Fig. 40). Twelve coal beds including the Weir-Pittsburg coal beds and above them, are in the Cabaniss Formation; those below are in the Krebs Formation. The “First (upper) Bartlesville sand” and “Cattleman sand” would appear to correlate with the Chelsea Sandstone, or beds above and below the Chelsea; the “Second (lower) Bartlesville sand” and “Stray sand” could correlate with the two Bluejacket sandstones; and the “Third Bartlesville (Stray) sand” and “Salt sand” could correlate with the upper and lower Warner sandstones. The “Burgess sand” could correlate with the lower Warner locally or be a sand body directly overlying the top of the Mississippian. The two Bluejacket and two Warner sandstones are all in the Krebs Formation (Staton, 1987, p. 30). The most widespread and thickest productive sandstone bodies are those of the “First Bartlesville sand.” In some areas the “Second Bartlesville sand” is most important; only very locally are sandstone bodies
more than 91 m (300 ft) below the Fort Scott Limestone economically important. Coal, an important economic product of the Cherokee Group at its outcrop southeast of Wilson County, was recorded in the logs of only a few cable-tool wells. One to three (or more) coal beds may be recognized in the signatures of gamma-ray/neutron logs of many wells.

Bouquet (1985, p. 1) in his study of the subsurface “Skinner sand” of the Cabaniss Formation of the Cherokee Group was charged with determining which of the geologic factors (grain size, sorting, porosity, permeability, shale beds, sedimentary structures, or environmental facies) controlled oil content in the reservoir. Other factors considered were those that could reveal the diagenetic history; they included pore geometry, types and distribution of cements, degree of dissolution, and types and distribution of authigenic clays. Correlation of stratigraphic units was based mainly on the high gamma-ray signatures of black shales and on the low neutron readings of associated coal beds. The productive “Skinner sand” lies between the Croweburg and Mineral coal beds in the upper part of the Cabaniss Formation. The Skinner is probably a distributary sand rather than a fluvial channel sand, as indicated by the relatively straight and continuous nature of the body, the presence of associated bay and marsh deposits, and the stacked, upward-fining
sequence which suggests deposition in a distributary channel that had been eroded into unconsolidated near-shore deposits. During periods of peak discharge, the channel apparently overflowed its banks resulting in the deposition of overbank natural levee and crevasse deposits. These deposits are fine-grained, coarsen upward, and consist of interlaminated sand, silt and clay that change to wavy and ripple-bedded very fine-grained sand upward and in a direction closer to the channel center. Linsen and wavy bedding as well as abundant slump structures, common mica and organic matter, sparse vertical and horizontal burrows, and lack of bidirectional-current indicators suggest deposition as a crevasse splay or as a small distributary mouth bar that formed in an interdistributary bay (Bouquet, 1985, p. 36-41). Petrographic study suggests a source to the northwest along the Nemaha Uplift with transport of materials to the southeast. Quartz and feldspar were the most abundant primary minerals observed. The diagenetic sequence started with compaction followed by formation of pyrite and precipitation of siderite cement. Precipitation of quartz overgrowth was of short duration prior to dissolution; dolomite-ankerite cementation followed and formed pore linings and fillings of dissolved detrital components. Kaolinite also filled solution cavities along with the ferroan-dolomitic-carbonate
cement. The Mg and Fe could have come from smectite-illite conversion. Of the petrophysical properties, the average porosity was 19 percent (range 10-27); permeability averaged 62 md (range 5-325); mean grain size was 1.9 phi units (range 1.2-3.6). These properties control oil migration and recovery, which encouraged Bouquet to recommend the upper sand body of the Skinner for production testing.

Strata of Mississippian age

Strata of Mississippian age occur only in the subsurface of Wilson County where they range in thickness from more than 130 m (425 ft) near the northwestern, northeastern and southeastern corners of the county to about 65 m (210 ft) atop the Fredonia Dome (Figure 41). The average thickness of Mississippian rocks in Wilson County is about 125 m (415 ft). The absence of several stratigraphic units of Mississippian age, which are recorded elsewhere in Kansas, attest to the erosional removal or nondeposition of considerable thicknesses of oolitic, cherty, and dolomitic limestones during late Mississippian (Chesteran and late Meramecian) time. Also missing are all strata of the Atokan and Morrowan Stages of the Lower Pennsylvanian.

In many wells in Wilson County, 1.5 to 10 m (5-30 ft) of angular to subrounded chert fragments occur below the
Figure 41. Isopachous map showing the thickness of Mississipian strata in Wilson County. Thickness interval, 8 m (25 ft).
argillaceous and arenaceous rocks of the Cherokee Group. These chert fragments lie upon or are part of weathered marine limestones of Mississippian age. The upper surface of these Mississippian rocks is an erosion surface upon which thick deposits of chert fragments, derived from weathering of cherty Mississippian limestones, accumulated locally or were concentrated by stream and current action. This porous material is the "Mississippi chat" or simply "chat" of the drillers and is locally productive of oil and gas. Where rounded and concentrated by stream or wave action, the chert may constitute part of the "Burgess sand." The depth to the top of these rocks is as little as 305 m (1000 ft) along the eastern border of the county and on the crest of the Fredonia Dome. It is as much as 490 m (1600 ft) to the top near the southwestern corner of the county. The upper part of the Mississippian rocks has been tested by more than 700 wells in Wilson County (Figure 42). Of these, about 100 were drilled entirely through the sequence.

Thickness and lithologic variations in the strata of Mississippian age in the subsurface of Wilson County were described by Wallace Lee (1939, 1940c, and in Moore and others, 1951), who studied cuttings of similar rocks of Mississippian age from 9 wells in this county and who tutored me in my study of well cuttings in 1952. Three of the wells, the No.1 Edwards well in Sec. 22, T 30 S, R 15 E
Figure 42. Map showing locations of wells that have tested Mississippian and older strata in Wilson County.
the No. 5 Watt well in Sec. 34, T 28 S, R 17 E, and the No. 3 Smith well in Sec. 10, T 29 S, R 15 E are shown in Figure 43. The No. 3 Smith well is located atop the Fredonia Dome; the other two wells are off the dome and are therefore probably more representative of the Mississippian strata throughout the county.

Thickness variations in stratigraphic units of Mississippian age in the wells shown in Figure 43 provide clues to the approximate times and amounts of structural uplift or downwarp that occurred during the Mississippian Period in Wilson County. Thickness changes are apparent throughout Mississippian time, and provide a means of determining times and amounts of structural movement and erosion in different areas. For example, the thinning of the Warsaw Limestone atop the Fredonia Dome indicates upward movement and erosion in late Warsaw time (or later). The thickness of the accumulations of chert fragments provides data concerning the approximate amount of erosion and areas subjected to greater or less vigorous cutting. The removal of all the limestone that enclosed the cherty fraction of the St. Genevieve, St Louis, and Salem Limestones that overlie the Warsaw probably provided a portion of the "chat" that lies upon the top of the Warsaw, but the complete removal (or nondeposition) of the oolitic St. Genevieve, St Louis, Salem, and overlying Chesteran limestones of Mississippian age and the entire sequence of Morrowan and Atokan limestones and shales of
Figure 43. Diagram showing three wells that have tested strata of Mississippian age in Wilson County. (Data from Lee, 1939, 1940c; and Moore and others, 1951).
Early Pennsylvanian age leaves a great gap in the geologic record of Wilson County. Merriam (1963, p. 223-225) indicated this gap and many others in the Kansas sequence in his graphic representations of the structural evolution and elements in Kansas geology. The base of the Cherokee Basin, among others, is shown to have moved upward and downward several times and tilted to the southeast and to the northwest. Merriam also diagrammed the times and amounts of sedimentation in Kansas as compared with thickness of the total sedimentary sequence recorded worldwide (Merriam, 1963, p. 224). The diagram shows that about 65% of the worldwide sequence is missing in Kansas. In Wilson County the stratigraphic sequence that has not been removed by erosion totals about 823 m (2700 ft), as compared to the total thickness in Kansas of about 1220 m (4000 ft). Therefore, in Wilson County only about 67% of the Kansas total is present or, roughly, only about 20% of the world total is present (80% is missing).

Mississippian strata in Wilson County range from cherty dolomitic limestone to non-cherty limestone and from calcareous, green shale to carbonaceous black shale of the Chattanooga, which is included here with the Mississippian rocks although its lower part may be Devonian (?) in age. The Mississippian rocks were described in detail by Lee (1940c) and many of the following descriptions of these rocks in the subsurface of Wilson County draw heavily on his work. Insoluble residues of the samples were also
studied by Lee; they are particularly valuable in studying Mississippian and older strata because, as stated by McQueen (1931, p. 102, 129), insoluble residues from different formations are characteristically different, and for each formation are the same over large distances.

The uppermost Mississippian unit in the subsurface of the county is the Warsaw Limestone; it is missing in some parts of the county and in other parts it is possibly as thick as 33 m (100 ft) (Fig. 43). The Warsaw is composed mainly of semi-granular limestone interlaminated with sugary dolomite and relatively large amounts of microfossiliferous chert. Insoluble residues from many of the dolomite beds are porous masses that contain abundant sponge spicules. At the base of the Warsaw in Wilson County is a characteristic silty glauconite bed about 3 to 4 m (9-12 ft) thick that rests on an irregular erosion surface at the top of Keokuk and older rocks (Lee, 1940c, p. 65-73). This bed is possibly a remnant of the controversial "Cowley facies". The presence of the glauconite of the Cowley facies at the base of the Warsaw Limestone in the Edwards and Watt wells, the absence of minor Warsaw Limestone above the glauconite in the Watt well, and the absence of the glauconite in the Smith well (Fig. 43) all suggest that deposition of the glauconite bed and the Warsaw was followed by deep erosion and concurrent uplift on the Fredonia Dome, thus reducing the thickness of strata of Mississippian age on the dome while preserving it.
elsewhere. The presence of thick deposits of subround chert clasts in several wells suggests that lag gravels accumulated locally during this period of erosion and formed cherty conglomeratic beds on the flanks of the uplift; the gravels were presumably stripped off in areas of active uplift to be deposited along the flanks. The Warsaw Limestone in Kiowa and Comanche counties, about 300 km (180 mi) to the west of Wilson County, ranges in thickness from about 27 to 52 m (90-170 ft). The lithology consists there of a slightly cherty stylolitic echinoderm-bryozoan limestone in the upper part, and an argillaceous, very cherty, dolomitized limy mudstone in the lower part. The chert is typically dark gray to white, semi-translucent, and spiculitic surrounded by crystals of ferroan dolomite enclosed by a diffuse rim of white chert. Dominant porosity types are intercrystalline, moldic, and interparticle, averaging 11.6 percent of the limestone. Average permeability is 0.13 md; horizontal permeability is typically twice as great as the vertical except where open fractures are present (Wilson, 1988, p. 33).

Where the glauconitic Cowley facies occurs at its base, the Warsaw lies by unconformable contact upon strata correlated with the dolomitic Keokuk Limestone (Lee, in Moore and others, 1951, p. 108). Keokuk strata range in thickness from less than 15 m to more than 30 m (50-100 ft) in the subsurface of Wilson County. In the southern part of the county, erosion has removed 18 m (60 ft) of
limestone above a gray, fairly extensive, oolite bed near the center of the Keokuk; this erosion apparently accounts for the difference in thickness (Fig. 43). The strata above the oolite bed are more dolomitic than those below and contain abundant chert. The chert in some zones is white or gray and even-textured, and in insoluble residues is almost everywhere accompanied by pitted, porous, siliceous rock ("cotton rock") composed of white, opaque, incompletely cemented microscopic particles of silica (Lee, 1940c, p. 17). Below the oolite bed, the Keokuk consists of gray, calcareous dolomite alternating with buff-gray, semigranular, crinoidal limestone that is less siliceous than the dolomite. Stable conditions of deposition in early Keokuk time are indicated by the presence of the oolite bed at approximately the same position above the base of the Keokuk in both the Edwards and Watt wells. The greater thickness of the Keokuk above the oolite in the Watt well suggests that the upper part was truncated by pre-Warsaw erosion in the Edwards well (Fig. 43).

Conformably below the Keokuk in Wilson County is the Burlington Limestone which maintains a relatively uniform thickness in the county, indicating stable conditions during the time of its deposition. The Burlington in each of the wells shown on Figure 43 consists of 15.8 to 16.5 m (52-54 ft) of light-colored, semigranular, crinoidal limestone. The uniform thickness of this limestone seemingly indicates widespread even deposition upon a plane
surface and rules out active structural movement or prominent erosion preceding, during, or following its accumulation. Interbedded with the crinoidal limestone are many relatively thin beds of gray dolomite and limestone that contain minute dolomite crystals. Locally, chert is abundant in the limestone and dolomite beds. The chert is characteristically even-textured, opaque, and gray, grayish white, or bluish white. Chert in dolomitic limestone beds usually has a grainy or stippled texture. Drusy quartz and minute pockets lined with fine quartz crystals are common constituents of the insoluble residues of the Burlington (Lee, 1940c, p. 58-59).

The Reeds Spring Limestone Member of the Fern Glen Limestone unconformably underlies the Burlington and consists of 23 to 37 m (75-120 ft) of gray or buff, semigranular, fine textured, dolomitic, and locally cherty limestone. The greater thickness to the south of the Fredonia Dome and less thickness atop the dome suggest slight downwarp to the south and uplift on the dome during the time of deposition of the Reeds Spring Limestone Member (Fig. 43). The chert of the insoluble residues is largely dark gray, dull, blocky, particolored, and of grainy texture. In the lower part of the formation, spongy silica as well as chert that is semitranslucent, flaky, and chalcedonic, is relatively abundant.

The thin St. Joe Limestone Member of the Fern Glen Limestone conformably underlies the Reeds Spring Limestone
Member in Wilson County (Fig. 43A). It ranges in thickness from 1.5 to 5.8 m (5-19 ft) in the three wells illustrated in Figure 43. In well cuttings the St. Joe is distinguished from the overlying limestones by only a small amount or a complete absence of chert. The limestone is semigranular in texture and is composed of crystalline fragments embedded in a fine limestone matrix. Where the St. Joe is thick, the upper part is crinoidal and the lower part contains considerable clay. An unconformity may be present at the base of the St. Joe Limestone Member of the Fern Glen Limestone and that, in conjunction with southward thinning of the Sedalia Dolomite, Northview Shale and Compton Limestone, and the absence of the Boice Shale above the Chattanooga Shale, would seem to indicate that deposition was far from continuous during Early Mississippian time.

A thin wedge of Sedalia Dolomite extends into Wilson County from the east. In the Watt well (Fig. 43), it underlies typical limestone of the St. Joe (Lee, 1940c, p. 38) and consists of 1.8 m (6 ft) of gray, coarsely sucrose dolomite. The part of the insoluble residue of the Sedalia that is characteristic of the unit consists of microscopically botryoidal aggregates or roundish granules of chert which seem to be the result of siliceous growth around impurities (Lee, 1940c, p. 37).

The Northview Shale ranges in thickness from about 2.1 to 8 m (7-25 ft) in Wilson County. In drillers logs it is
recorded as gray, green, or blue shale. In cuttings from many wells, it appears as a slightly calcareous or dolomitic shale. Insoluble residues are typically green, porous, silty aggregates (Lee, 1940c, p. 30).

The Compton Limestone consists of about 1.5 to 4.6 m (5-15 ft) of hard limestone (Fig. 43). Lee (1940c, P. 29-30) reported that in well cuttings it is typically a fine-textured, slightly greenish-gray, non-cherty limestone with waxy luster. The insoluble residues from the Compton are meager and consist of white, irregularly shaped, fragile, and spongy siliceous aggregates.

The Chattanooga Shale of Mississippian and probable Devonian age (Goebel in Zeller, 1968, p. 17) is recorded in drillers logs in Wilson County as 1.5 to 8 m (5-25 ft) of black shale underlying the Compton Limestone (Fig 43). The Boice Shale is not recognized in the county; however, an obscure disconformity separates the Chattanooga from the approximately parallel overlying deposits of definite Mississippian age. In the logs of several wells, about 2 m (6 ft) of sandstone (“Misener sand”) is shown at the base of the black shale. According to Lee (1940c, p. 21), the Chattanooga Shale is separated from the underlying beds by an angular unconformity. Locally, the Chattanooga contains abundant spores identified as Sporangites huronensis (Lee, 1940c, p 22). A northeastward increase in thickness of the St. Joe Limestone Member of the Fern Glen Limestone, of the Sedalia Dolomite and related Northview Shale, of the
Compton Limestone, and of the Chattanooga Shale (of Mississippian and Devonian age) indicate that the deeper part of the sea was probably to the north and east during that long period of sedimentation.

Pre-Mississippian Sedimentary Rocks

About 100 wells in Wilson County reached strata of the Arbuckle Group of Early Ordovician to Late Cambrian age (Figure 44). Eight of these wells penetrated sandstone correlated with the Lamotte (Reagan) Sandstone of Late Cambrian age. Studies of samples from two of the wells (the No. 1 Neodesha in Sec. 19, T 30 S, R 16 E and the No. 3 Smith well in Sec. 10, T 29 S, R 15 E) indicate the lithology of these rocks (Haworth, 1908, p. 60-64, and Stryker, 1925, p. 1212-1214). Study of insoluble residues and correlation with similar studies at the outcrop were made on samples from the No. 3 Smith well and were reported on by Kercher and Kirby (1948, p. 64, 66-67) and Lee (Moore and others, 1951, p. 120-121). Correlation of the Neodesha and Smith wells with driller logs of two other deep tests in the county, the No. 1 Morse and No. 1 McFadden, provide an approximation of the variation in thickness in the pre-Mississippian units (Figure 45).

In Wilson County, strata of Early Devonian, Silurian and Late to Middle Ordovician age are missing below the Chattanooga Shale. Those penetrated by wells in Wilson County are Early Ordovician to Late Cambrian in age attain
Figure 4.4. Map showing locations of wells that have tested "Arbuckle" and older rocks in Wilson County.
a thickness of about 300 m (980 ft), and are correlated with the Cotter Dolomite, the Jefferson City Dolomite, the Roubidoux Formation, the Gasconade Dolomite, the Bonneterre Dolomite, and the Lamotte Sandstone. The Cotter Dolomite and Jefferson City Dolomite are treated together; they average about 115 m (375 ft) and range in thickness from about 88 m (290 ft) in the McFadden well to 137 m (450 ft) in the Smith well (Fig. 45). The greater thickness of this sequence over the Fredonia Dome suggests that downwarping in Early Ordovician time may have preceded uplift of the structure in Mississippian and later time. Structural inversions of this kind are the subject of much contemporary discussion; the circumstances that bring about such inversions are not well known. The thickness of the Roubidoux Formation ranges from about 49 to 51 m (160-168 ft), of the Gasconade Dolomite from 37 to 63 m (123-206 ft), and of the Bonneterre Dolomite from about 27 to 53 m (90-174 ft). The increase in thickness of the Bonneterre Dolomite in the Neodesha well is almost offset by a compensating increase in the thickness of the Gasconade Dolomite in the other three wells (Fig. 45). These differences in thickness are seemingly attributable to facies changes or reversals in structural movement in Wilson County inasmuch as the overlying Roubidoux Formation is of essentially uniform thickness and presumably was deposited upon a relatively horizontal surface.
The Cotter and Jefferson City Dolomites are generally not separable on lithologic criteria in well cuttings (Goebel, 1968, p. 13); therefore, they are grouped into a single unit in subsurface studies in eastern Kansas. According to Lee (Moore and others, 1951, p. 119), the Cotter and Jefferson City Dolomites consist mainly of coarsely granular, cherty dolomite. The upper part of the sequence includes much oolitic chert which is brown but becomes lighter colored and less abundant downward. Near the base, white, tripolitic chert is abundant. In the Smith well (Fig. 45), this sequence is 46 to 138 m (151-452 ft) thick and cherty, except for a non-cherty unit 4.6 m (15 ft) near its center. Three arenaceous units 15 m (49 ft), 4 m (14 ft), and 11 m (36 ft) in thickness occur at the top, at the bottom of the upper two thirds, and at the base of the Cotter-Jefferson City sequence (Stryker, 1925, p. 1213).

The Roubidoux Formation consists mainly of non-cherty, coarsely crystalline, sandy dolomite, but cherty dolomite occurs in the upper one-third of the formation in some wells. In the Smith well, for example, cherty dolomite occurs 11 to 17 m (35-55 ft) below the top of the formation. The principal constituent of the insoluble residue is clean white quartz sand. The sand grains are mostly fine grained and subangular, but the larger grains are generally well rounded and pitted, frosted, or polished. Some of these larger grains, however, are
angular and show evidence of secondary enlargement; some are doubly terminated quartz crystals. The chert of the Roubidoux is white and dense, or bluish and translucent. Large, brown, translucent glassy oolites are common. The Roubidoux is characteristically very sandy at both its top and base.

The Gasconade Dolomite (Goebel, 1968, p. 13) consists mainly of coarse, granular, white to light-gray dolomite that is locally cherty in the upper and lower parts. In the Smith well (Fig. 45) chert occurs in a 15 m (50 ft) cherty dolomite in the upper 21 m (70 ft) of the sequence. The chert in this upper part is gray to dark bluish gray, dense, and glassy. About 15 m (50 ft) above the base is 4.6 m (15 ft) of cherty dolomite in which the chert is white, dense, smooth, partly porcellaneous, and quartzose.

The dolomite at the base of the Gasconade is sandy and is known as the Gunter Sandstone Member. The Gunter is distinguished from the underlying Bonneterre Dolomite by both its lithology and its insoluble residue; the latter comprises 10 to more than 50 percent of the sample. The sand grains in the residue are generally well rounded with frosted or polished surfaces. The coarse to fine, bright, angular grains result from secondary quartz enlargement and are locally common. Kercher and Kirby (1948, p. 40, 44, 65) pointed out that relatively unweathered feldspar of the Gunter in the No. 3 Smith well in Wilson County probably came from Precambrian rocks upon which the Gunter lies.
unconformably in Cowley, Sumner, and Sedgwick counties 80 to 121 km (50-75 mi) to the west. The relatively constant thickness of the Gunter, about 5 to 6 m (15-20 ft), suggests that the member may represent an effective time line and that the sandy debris probably accumulated upon a fairly level erosion surface, the top of the Bonneterre Dolomite. This surface would continue to undergo varying amounts of structural movement at the top of and adjacent to the Fredonia Dome (Figure 45). The Gunter Sandstone Member of the Gasconade overlies a dolomite sequence named the Eminence Dolomite in Missouri. In eastern Kansas, however, the Eminence is confined to a belt of only three counties in the northern part of the state (Goebel, 1968, p. 13). In Wilson County the Gunter Sandstone Member of the Gasconade Dolomite lies unconformably on the Bonneterre.

The Bonneterre Dolomite is the oldest carbonate-rich rock in the subsurface of Wilson County. In eastern Kansas it is a conspicuously glauconitic, non-cherty dolomite that is dark gray to brown and finely crystalline (Lee, in Moore and others, 1951, p. 122). Locally, it includes beds of sandy and silty dolomite and dolomitic shale near the top. Both the upper and lower 9 m (30 ft) of dolomite in the Bonneterre in the Smith well are very sandy; the size of the grains in the insoluble residue is fine to very fine sand and silt. Aggregates of silt-size grains of quartz associated with very fine-grained quartz sand and fine
glauconite grains are more abundant in the upper part than in the lower part. The aggregates are brown and porous and have a spongy texture. In the lower part, the sand grains are coarse, angular, and occur both free and in loosely cemented clusters (Keroher and Kirby, 1948, p. 28). The Bonneterre is 27-53 m (90-174 ft) thick.

The Bonneterre grades downward into the Lamotte Sandstone of Late Cambrian age. The Lamotte unconformably overlies a Precambrian surface of moderate relief (Fig. 45) and ranges in thickness from 8 to 38 m (25-125 ft) in Wilson County. The grains in the Lamotte are largely quartz, are angular to subround, and are poorly sorted, ranging from coarse to fine.

SECTION 3D: THE PROTEROZOIC ERA

Includes all pre-Paleozoic igneous, meta-igneous, and meta-sedimentary rocks that underlie sedimentary strata of Cambrian age.

Precambrian Rocks

Six wells in Wilson County bottomed in rock believed to be Precambrian in age (Figure 46). The rock was apparently granite in three of the wells, syenite in one well, and presumably metamorphic rock in the other two. The six wells are as follows:
Figure 46. Rock type and generalized structure contour map of the top of Precambrian rocks in Wilson County.
Wentworth and Glare No. 1 McFadden, NW1/4 NW1/4 SW 1/4 Sec. 26, T 27 S, R 16 E total depth 1022 m (3352 ft).

Jamison No. 1 Horse, SE1/4 SW 1/4 Sec. 13, T 29 S, R 15 E, total depth 833 m (2732 ft).

Fredonia Gas No. 3 Smith, SE1/4 SE1/4 NW1/4 Sec. 10 T 29 S, R 15 E, total depth 685 m (2246 ft).

Oil Trends No. 1 Showers NE1/4 NE1/4 NE1/4 Sec. 19, T 30 S, R 15 E, total depth 764 m (2505 ft).

Prairie No. 1 Neodesha, SW1/4 SE1/4 NE1/4 Sec. 19, T 30 S, R 16 E, total depth 735 m (2412 ft).

Finley and Henderson No. 1 Birk SE1/4 SE1/4 NW1/4 Sec. 21, T 30 S, R 17 E, total depth 704 m (2310 ft).

The top of the granite was recorded at about 705 m (2313 ft) in the No. 1 McFadden well, but most likely the sand recorded between 705 and 721 m (2313 & 2366 ft) is Lamotte, and the red rock recorded from 721 to 1009 m (2366-3310 ft) is the granite. No data are given for the interval from 1009 m (3310 ft) to the total depth of 1022 m (3352 ft), but there also the rock is presumed to be granite.

The No. 1 Horse well drilled sandy lime and sand from 682 to 721 m (2240-2367 ft) and then went into rock reported as schist. No record is given between 722 and
797 m (2370-2615 ft) at which depth red rock was recorded and then more sand. The well may have been in granite wash and weathered granite from 797 m (2615 ft) to the total depth of 833 m (2732 ft).

Samples from the No. 3 Smith well were studied mainly by Wallace Lee who reported granite cuttings from 674 m (2212 ft) to the total depth of 685 m (2246 ft) (personal communication, September 1952). Data from the No. 1 Showers well indicate that the drill went from the Lamotte [Reagan] Sandstone into Precambrian syenite at a depth of 754 m (2473 ft) (Cole and Watney, 1985, p. 137). Samples from the No. 1 Neodesha well were studied by Haworth (1908, p. 62-64) who reported that sandstone with much angular quartz and feldspar was encountered from 665 m (2182 ft) to the total depth of 735 m (2412 ft). He did not interpret the cuttings between these depths as representing granite basement because some of the grains were rounded. However, the very abundant angular grains of quartz and pink feldspar suggest that the cuttings may have come from weathered granite at 665 m (2182 ft) and that the well was in granite from that depth to the bottom. Cole and Watney (1985, p. 137), indicate that the well went from Arbuckle sand into weathered granite at 694 m (2277 ft).

The No. 1 Birk well may have bottomed in metamorphic or basic igneous rock of Precambrian age. The log shows a change from light colored sandstone, apparently the Lamotte
Sandstone of Cambrian age, to gray, hard rock at 700 m (2297 ft); only an additional 4 m (13 ft) was drilled.

The pink granite encountered in these wells is probably the "later" granite of Farquhar (1957, p. 60, 61, 81-88) who stated that much of the "later" granite is salmon pink, hypidiomorphic and granular, and varies considerably in grain size. An average mode, as given by Farquhar (1956, p. 83) and which fits well the cuttings from the Smith well, is: quartz, 25-30%; orthoclase and microcline, 40-50%; plagioclase (ca. Ab75An25), 20-25%; muscovite, 2-3%; biotite, 1-2%; accessory minerals (magnetite, zircon, sphene, hornblende tourmaline and apatite), 1%.

Topographic relief on the Precambrian surface is greater than 105 m (333 ft), ranging from 355 to 460 m (1167-1500 ft) below sea level (Fig. 46). Figure 46 thus provides a generalized map of the Precambrian surface and basement rock types encountered in the wells (modified from Cole, 1976; and Bickford and others, 1979).
CHAPTER FOUR: STRUCTURAL GEOLOGY

Being a discussion of evidence that shows the effects of tectonism, both at the present ground surface and in the subsurface, within the confines of Wilson County.
STRUCTURAL GEOLOGY

Wilson County lies in the northern part of the Cherokee Basin of southeastern Kansas (Figure 47) and northeastern Oklahoma. This structural basin is the northern part of an area of sedimentation that extended across eastern Oklahoma and into Kansas in Pennsylvanian time (Moore and Jewett, 1942, p. 487). The Cherokee Basin is bounded on the west by the Nemaha Anticline, on the east by the Ozark Uplift, on the north by the Bourbon Arch (Fig. 47), and is a northward extension of the McAlester Basin of Oklahoma (Jewett, 1951, p. 126).

During late Pennsylvanian time, a subequatorial epeiric sea covered most of Kansas and portions of adjoining states. Positive structural features that limited the areal extent of the Pennsylvanian sea and supplied clastic detritus to the basin included the Ancestral Rocky Mountains to the west, an orogenic arc comprised of the Amarillo, Wichita and Arbuckle Mountain complex to the south, and the Ozark Dome to the east (Merriam, 1986, p. 2).

Sedimentation in this structural setting was cyclic in nature, and each cycle was controlled by a series of external factors. Analysis of the probable lengths of time during which transgressive and regressive cycles took place is based on sets of assumptions (see p. 84) that Heckel (1986) made in which he estimated a range of lengths of
time from about 235,000 to 400,000 years for the major cycles; 120,000 to 220,000 years for the intermediate cycles; and 44,000 to 120,000 years for the minor cycles. The estimated ranges for all cycles fall within the range of periods of the Earth's orbital cycles that constitute the Milankovitch insolation theory for the control of the Pleistocene ice ages. These cyclic orbital parameters are: eccentricity, with two dominant periods, one about 413,000 years, and the other ranging from 95,000 to 136,000 years and averaging about 100,000 years; obliquity, with a dominant period near 41,000 years; and precession, with two dominant periods averaging 19,000 and 23,000 years (Imbrie and Imbrie, 1980).

The thin, shallowing upward depositional sequences observed within regressive cycles appear to have been punctuated aggradational cycles, as proposed by Goodwin and Anderson (1980); they occur as basic, small-scale stratigraphic units present throughout the geologic column. Goodwin and Anderson estimated the lengths of time for formation of individual punctuated aggradational cycles to be within the range of the shorter orbital periods (about 100,000 years).

The tectonic stability of shelves, platforms and basins imposed distinct geometric, vertical sequence, and areal distribution patterns on sandstone bodies. Valley-fill sandstones are the principal oil and gas and potable water reservoirs; the sands were deposited on exceedingly
stable, shallow, Midcontinent shelves where stream erosion and transgressive-regressive sea-level fluctuations removed many of the thin delta-front deposits (Brown, 1979, p. 35). The cyclic nature of Pennsylvanian deposits in the Missourian and Desmoinesian strata of the Midcontinent region are controlled in part by the paleogeography of the area as it relates to sources of sediment such as the Ouachita Mountains, Amarillo-Wichita-Arbuckle uplift, Ancestral Rockies-Apishapa uplift, and to the flooding by marine waters of the platform areas of the Midcontinent region. During much of the Pennsylvanian, most of the Midcontinent region could be described as the “Kansas shelf”. This region evolved from a low-lying source area, through a deltaic depositional province, to a mixed clastic-carbonate marine shelf. Across this shelf, the widespread continuity and cyclicity of Pennsylvanian deposition in the Midcontinent are most apparent. Early in the Pennsylvanian, marine waters transgressed across the Cherokee platform and Kansas shelf in an unending sequence of deltaic, carbonate-shelf, prograding-clastic and shallow-marine deposits. During late Virgilian time, cyclic carbonate-clastic deposition was widespread; whereas, in early Virgilian time the flood of clastics reached northward and carbonate sedimentation was of little importance. By the late Missourian, carbonate sedimentation was again in vogue; in early Missourian time mainly clastic sediment entered Kansas. The late
Desmoinesian, with sedimentation of the Kansas City and Marmaton groups, saw a predominantly carbonate regime; but earlier, the Cherokee Group in the early Desmoinesian was principally clastic continental and nearshore marine (Moore, 1979, p. 2, 8-12).

Desmoinesian and Missourian sediments onlapped a topographic surface of older Paleozoic and Precambrian rocks. The orogenic Amarillo-Wichita and Apishapa-Sierra Grande uplifts came into existence near the close of, or immediately following, Morrowan deposition. The progressive increase in carbonate content—from the predominantly shaly Morrowan strata to the thin limestones of the Cherokee Group, to the well-developed limestone formations of the Marmaton Group and succeeding rock units—indicate that a shelf-carbonate lithotope gradually evolved from Morrowan through Desmoinesian time. The shelf-carbonate environment continued to expand at the expense of the adjacent shelf area. This shelfward expansion marked the general apex of marine transgression over the Midcontinent region during Pennsylvanian time. The union of the Anadarko and McAlester basins made possible the deposition of Virgilian and Missourian blanket sandstones (Ireland, Tonganoxie, Cottage Grove, Noxie). A regressive phase began in Virgilian time and the isoliths moved progressively southward in the late Virgilian (Rascoe, 1962, p. 1369). Earlier, in Desmoinesian time the “shoestring” and other sandstones of
the Cherokee Group (Bass, 1936, p. 22-29) had been deposited.

The configuration of the area that influenced sedimentation in Wilson County is defined by a ring of positive elements that extended discontinuously from western Missouri through eastern Kansas and northern Oklahoma to the Texas Panhandle and northward through Colorado, into Wyoming and Nebraska. Wilson County lies in the Cherokee Basin of southeastern Kansas toward the northern end of the northeast Oklahoma Platform (the northern end of the McAlester Basin). The Ozark Dome lies to the east and the Nemaha Granite Ridge (anticline) to the west; the Bourbon Arch forms the northern boundary (Fig. 47). In the larger picture, the framework of this part of the Midcontinent sedimentary (depositional) basin places Wilson County in the southeastern part of a broad epicontinental sea that may have encompassed an area of nearly 500,000 km² (200,000 mi²) during Pennsylvanian time. A number of positive and negative tectonic features played a major role during the accumulation of strata of middle to late Pennsylvanian age. Three positive features, the Ozark Dome, Ouachita Uplift and Amarillo-Wichita-Arbuckle Mountain complex, all could have shed sediments that reached Wilson County. The amount of debris furnished to the area could have increased dramatically during periods of high rainfall and ameliorated climate.
The Ozark Dome, a broad structure that developed on the eastern margin of the epicontinental sea became an active tectonic feature during early Pennsylvanian time (Branson, 1962, p. 453). It was still emergent in the late Pennsylvanian, but was a broad, low-lying land area that generally supplied relatively minor amounts of detrital material to the adjacent basin of deposition. The Ouachita Uplift also contributed material to the northwest some of which may have reached the Wilson County area. However, a more likely source would have been the Amarillo-Wichita-Arbuckle Mountain chain which is thought to have been actively uplifted throughout Pennsylvanian time (Tomlinson and McBee, 1962, p. 490). Evans (1967, p. 14) states that this chain or highland area was a source for much of the coarse clastic sediment deposited in the southern part of the epicontinental sea in Virgilian time. The sediments may not have reached as far north as Wilson County, however.

The importance of the Ozark Dome and nearby contiguous areas as a source of sediment to Wilson County can be debated, since roughly 50 miles separate the eastern limit of the county from the nearest flank of the dome. Moore (1936b, p. 1795; 1958, p. 147, 153) indicates that the Ozark Dome would have had an exposed sequence of rocks of Precambrian, Cambrian, Ordovician, Silurian, Devonian, Mississippian, and early Pennsylvanian age which could have
supplied sediment to Wilson County at any time of sea withdrawal.

As noted by Evans (1967), Tomlinson and McBee (1962), and Branson (1962) the Amarillo-Wichita-Arbuckle Mountain chain was probably the primary source of terrigenous sediment and the Ozark Dome only of secondary importance. The general distribution and thickness of terrigenous material in the sandstones and siltstones in Wilson County would appear to verify this generalization.

The Prairie Plains Monocline (Prairie Plains Homocline of Merriam, 1963, p. 164, 181, 182) formed as a result of post-Permian uplift of the Ozark Dome to the east in southwest Missouri. The Permian, Pennsylvanian, and older rocks of southeastern Kansas dip to the west and slightly to the north away from the Ozark uplift. The Cretaceous rocks at the surface farther west were not affected by the uplift, but lie on the erosion surface of beveled Pennsylvanian and Permian strata. This relation places the age of the uplift to the east as post-Permian and pre-Cretaceous (Jewett, 1957). Other structural features include the Cherokee Basin, Nemaha Anticline and Sedgwick Basin. These features are all post-Mississippian in age. Furthermore, many small anticlines, domes, noses, synclines and depressions are superimposed on the Prairie Plains Monocline (Schulte, 1958, p. 42). In a structural geology sense, Winchell (1957a, p. 22) places Wilson County "on the Prairie Plains Monocline which dips at a low angle off the
flank of the Ozark Uplift;" he agrees that the dip (tilting) was effected in post-Permian time.

The strata in Wilson County strike approximately \( W 20^\circ E \) and dip westward at an average of about 5 m per km (25 ft/mi), but the prevailing attitude of the strata is modified locally by a flattening of the westward dip through horizontal to an eastward (reverse) dip. Many of the oil and gas fields of the county are located on structures formed by these local variations. The structures are commonly less than 8 km (5 mi) long and 4 km (2.5 mi) wide. The Fredonia Dome trends about \( N 55^\circ E \) and is the largest structural upwarp in Wilson County. It and the Longton Ridge, which projects approximately \( S 30^\circ W \) into Wilson County from Woodson County along the trend of the Silver City and Rose domes are the major folds in the area (see also Merriam, 1963, p. 146, 152, 204, 205).

**Surface Indications of Structure**

**Faults.** Six faults were observed in Wilson County; all are small and apparently of little importance. They were seen only in creeks or roadcuts (Figure 48), and because they could not be traced laterally, they are not shown on the geologic map. The greatest stratigraphic displacement on any of the faults is estimated to be about 8 m (25 ft). The faults displace the Tonganoxie Sandstone Member of the Stranger Formation in roadcut exposures
Figure 48. Normal faults in the Tonganoxie Sandstone Member of the Stranger Formation in Wilson County. (A) Roadcut exposure in the NE 1/4 Sec. 16, T 27 S, R 14 E. Strata at base of hanging wall correlate approximately with the uppermost strata in the footwall. (B) Detail of the hanging wall of the same exposure showing subsidiary normal faults. Heads of the two hammers (circled) are on the same stratigraphic plane.
in the SE 1/4 Sec. 9 and the NE1/4 Sec. 16, T 27 S, R 14 E; the Iola Limestone in a creek exposure in the NW1/4 Sec. 6, T 29 S, R 16 E; the Stanton Limestone in roadcut exposures in the SW1/4 Sec. 7 and NE 1/4 Sec. 18, T 29 S, R 16 E; and the Plattsburg Limestone in an exposure in a roadcut in the NE1/4 Sec. 18, T 29 S, R 16 E. Five of the faults trend nearly north-south; the other trends nearly east-west. Those that cut strata of the Tonganoxie and Plattsburg dip westward 45° and 12° respectively; the remainder are nearly vertical.

Folds. Exposed folds in Wilson County are of small magnitude and apparently have both structural and sedimentational origins. A series of parallel undulations in the Drum Limestone are exposed in the bed of Washington Branch about 5 km (3 mi) east of Neodesha near State Highway 37, and similar folds are exposed in the Dennis Limestone in the beds of tributaries of Dry Creek in the NE1/4 Sec. 19 and NE1/4 Sec. 30, T 30 S, R 17 E. The undulations in the Drum Limestone trend approximately N 45°E and those in the Dennis trend about N 25°E. The folds in the Drum have an amplitude of about 0.5 m (1.5 ft). The horizontal distance from crest to crest of the undulations in the Drum is about 9 m (30 ft) but ranges from more than 2 to 11 m (7-35 ft). The distance between crests of the folds in the Dennis ranges from 2 to 6 m (6-21 ft). The undulations may represent slight compressional folding between uplifts to the northwest and
southeast or could reflect slumping of underlying beds prior to lithification. Both limestones are very thin, and slight lateral flowage of the underlying and overlying shales prior to complete lithification and during downwarping could have allowed such undulations to form.

The arching of beds of the Iola Limestone just west of Barnhill Bridge in the NW 1/4 sec. 6, T 29 S, R 16 E (Fig. 35B) is interpreted as having resulted in part from compaction over a reef core, and in part from initial dip, but it may be the result of compressional folding. A thin limestone bed that overlies the arched bed has not been folded and makes the depositional origin more likely.

A few larger folds or areas of uplift were mapped in the county. The most readily recognized are the Silver City Dome and the Fredonia Dome (anticline). The Silver City Dome occurs at the north border of the county, but only the southern half of the structure is in the county. (Figure 49). It can be seen best from a vantage point half a mile north of the county line just east of the northeast corner SE 1/4 SW 1/4 Sec 36, T 26, R 13 E. The Fredonia Dome is a subsurface feature on whose western extension a gas storage reservoir was located in the 1950's a few miles east of Fredonia (Plates 5, 9). A structural cross section shows that the Mississippian thins over the Fredonia Dome (Plate 7). Several upwarps, apparent on the geologic map (Plate 1), are difficult to observe directly in the field. The nearly circular outcrop of Chanute Shale about 5 km
(3 mi) northeast of Altoona and the elongate exposure of the Chanute Shale 9 to 10 km (5.5-6 mi) east of Altoona are examples.

Joints. Vertical joint systems are conspicuous in many of the hard limestone and sandstone beds in the county. The major trends and attitudes of the joints were observed in the field (Figure 49), but most of the trends shown on the geologic map were taken directly from aerial photographs. The density of the joint pattern on the geologic map thus reflects both the conspicuousness of the joint system in the rocks and the size and clearness of the outcrops of jointed rock on the aerial photographs, of which two examples are shown at different scales (Figures 50, 51). On photographs, the joints are clearest in limestone units about 4.6 to 9 m (15 to 30 ft) thick; they are obscure but detectable in thick sandstone units.

The joints fall into two general groups that trend about N 55° E and N 35° W, but in some areas other trends are superimposed upon these, and in other areas local deviations occur (Plate 1). A similar set of joints was mapped and reported upon by Ward (1964, p. 92, 100). The major set he measured in Greenwood County and counties to the west trended from N 50° E to N 70° E (average N 60° E) with essentially a vertical dip. A subsidiary set of joints trended N 24° W to N 56° W, average N 35° W. He believed them to be of middle Permian age, probably...
Figure 49. Vertical joint system in the Stanton Limestone at the Wilson County State Lake quarry (SE 1/4 Sec. 17, T 27 S, R 16 E).
Figure 50. Joint system in the Stanton Limestone as shown on aerial photographs (Secs. 7 and 18, T 28 S, R 16 E). The main trend is N 55° E; the secondary trend is N 35° W.
Figure 51. Joint system in the Stanton Limestone as shown on aerial photographs (NW 1/4 Sec. 19, T 28 S, R 16 E). The main trend is about N 55° E; the secondary trend is N 35-45° W.
related to thrust or wrench faulting in the Ouachita Mountains.

**Subsurface Indications of Structure.**

Records of wells drilled for oil and gas in Wilson County furnish much subsurface information on the character and position of stratigraphic units. Subsurface geologic studies show that during Pennsylvanian time, the Midcontinent region was subjected to rapid and intense deformation, and that much of southeastern Kansas was a low-lying area in which Pennsylvanian and older Paleozoic rocks were at many times and in many places exposed to erosion. Major structural features that controlled sedimentation in southeastern Kansas during Pennsylvanian time were a southern extension of the Nemaha Uplift, and the Bourbon Arch (Fig. 47). These features restricted the Cherokee Basin, a shallow northward extension of the Arkoma Basin of Oklahoma, to the southeastern corner of Kansas (Merriam, 1963, p. 179-180). The Ozark Uplift formed the eastern boundary of the Cherokee Basin.

Eustatic fluctuations of sea-level as a result of Gondwanan glaciation have been suggested to account for the cyclic nature of Kansas Pennsylvanian sedimentation. During periods of transgression, the Cherokee sea advanced northward from Oklahoma, inundating the Cherokee Basin and Shelf and creating marine conditions. During periods of regression, deltaic sediments prograded across the Cherokee
Periods of deltaic progradation added second-order modifications to eustatic cyclothem development (Boardman and others, 1984).

In the present study, the Fort Scott ("Oswego") Limestone was the stratigraphic datum selected for detailed contouring (Figure 52; Plate 9) because it is the most readily recognized Pennsylvanian unit in the subsurface of the county, and its depth is generally carefully recorded by drillers or its position readily picked on electric and radioactivity logs. The structural contours on the top of the Fort Scott Limestone show that strata in Wilson County strike N20° to 30°E (average about N 25°E) and dip generally westnorthwest at approximately 5 m per km (25 ft/mi). The subsurface altitude of the top of the Fort Scott ranges from about 90 m (300 ft) above sea level near the northeastern corner of the county to about 60 m (200 ft) below sea level near the southwestern corner. The structural relief at this horizon is about 150 m (500 ft) across the county, but maximum local closure is only about 45 m (150 ft).

Superimposed upon the regional dip are many reversals and deviations in strike and dip that impart an amoeba-like pattern to the structural picture (Fig. 52; Plate 7). The structural pattern is based on information from the logs of about 15,000 wells. Because many of the well records have neither precise locations nor elevations, many wells had
Figure 52. Structure contour map on the top of the Fort Scott Limestone in Wilson County. Contour interval is about 15 m (50 ft).
to be located on the basis of surface geology or arbitrary placement near the centers of quarter sections, and elevations had to be taken from topographic maps. Most of the errors introduced by this procedure have probably been removed through generalization of an originally more detailed structural contour map. The well logs are seemingly fairly accurate because there is a close agreement in stratigraphy from well to well. The use of data from a large number of wells made possible the recognition and elimination of inaccurate or specious information.

Anomalies shown by the contours are the result of structural movement, differential compaction, and lateral variations in sedimentation. The complexity of the structural contours in the eastern part of the county is due in large part to local variations in sandstone and limestone thickness and in part to local structural movement. Some anomalies apparently indicate places where thick elongate sandstone bodies were only slightly reduced in thickness by compaction as compared to the reduction of the enclosing shale units. Other small irregularities seem to indicate places where dome-shaped growths of limestone were surrounded and enclosed by muds that compacted much more than the limestones. The structures that formed in either of these ways are of comparatively small magnitude and local extent and only slightly modify the regional
structural pattern. They are very important, however, because many are loci for accumulations of oil and gas.

W. L. Stryker (1925) utilized all available records of wells drilled in Wilson county before 1925 and prepared an excellent short report on the subsurface geology of the county. Included were a structural contour map of the upper surface of Mississippian rocks and two subsurface cross sections, one trending northeast and the other northwest. Lithologic variation in the strata were shown graphically in the cross sections. Information from many new wells was used in the preparation of the more detailed structural contour map of the upper surface of Mississippian rocks for the present report (Figure 53). This map verifies the general picture presented by Stryker (1925). Comparison of structural contours drawn on the top of the Fort Scott Limestone (Fig. 52 and Plate 7), and on the top of rocks of Mississippian age (Fig. 53) shows an increase in closure on several of the upwarps. The increase in closure seemingly indicates progressive uplift in those areas after Mississippian time. A decrease in complexity of the contour lines between Mississippian and Ordovician time may be due to more complete information for the younger strata but may indicate also the effects of local, short-lived, structural movement and differential compaction in post-Ordovician time. A structural map contoured on the top of rocks of Ordovician age (Figure 54) shows that the most prominent structures are along the
Figure 53. Structure contour map on the top of rocks of Mississippian age in Wilson County. Contour interval is about 15 m (50 ft).
Figure 54. Structure contour map on the top of rocks of Ordovician age in Wilson County. Contour interval is about 15 m (50 ft).
trend of the Fredonia Dome. This dome is also prominent on
the structural contour maps of Mississippian strata and the
Fort Scott Limestone. The isopachous map of Mississippian
strata (Fig. 41) shows a thinning of the strata of
Mississippian age over this structure, thus providing
further evidence of the long history of localized upward
movement.

Subsurface structure or lithologic changes are also
located by geophysical investigations. A ground
magnetometer survey made by Hambleton and Merriam in the
area of igneous intrusion in southern Woodson County and
northern Wilson County showed several areas of greater than
normal magnetic intensity (Hambleton and Merriam, 1955; p.
113-128; Merriam and Hambleton, 1959, p. 165-167). In the
Wilson County part of the survey most of the magnetic
anomalies trend generally north-south (Figure 55). The
domal area underlain by the igneous intrusions coincides
best with an area of negative anomaly (shaded area on Fig.
55), but the outcrop pattern and known subsurface positions
of the intrusives agree neither in shape nor position with
the geophysical data. Furthermore, the elongate
configuration of the magnetic anomaly is at right angles to
the structural shape of the Silver City dome as shown by
structure contours. A relation to this structure is
therefore doubtful. Inasmuch as the structure contour map
shows no fold in the vicinity of Roper of the magnitude
Figure 55. Vertical intensity magnetic map of part of northern part of the Wilson County (from Hambleton and Merriam, 1955)
indicated by the contours in that area, and since none of the trends of the magnetic anomalies in the mapped area agrees with geologic structures, the magnetic effects must be related to other geologic features. Application of the “steepest gradient” method of approximating the depth of a magnetic anomaly (Vacquier and others, 1951, p. 3-5, 20, 21, 29) suggests that the rock body responsible for this anomaly is 0.8 to 1.6 km (0.5-1.0 mi) deep. An aeromagnetic map of Kansas shows the total intensity configuration in gammas of the subsurface of Wilson County (Figure 56). The two geophysical maps are in remarkable agreement in the area of overlap, and it seems likely, therefore, that the anomalies shown probably reflect lithologic changes or structure in the Precambrian basement rock.

Major Structural Features

Fredonia Dome. The Fredonia Dome (Herriam, 1963, p. 184, 205) is the most prominent structural feature entirely within Wilson County. This structure, which was first described by Stryker (1925, p. 1208), has its apex about 6 km (4 mi) east of Fredonia with a closure on the top of the Fort Scott Limestone of more than 30 m (100 ft). It is a composite, somewhat elongate structure, has a length of roughly 8 km (5 mi) and a width of 3 km (2 mi) (Plate 7, Figs. 52, 53, 54). The Fredonia Dome apparently has undergone uplift throughout Mississippian and later
Figure 56. Aeromagnetic map of Wilson County. Flight altitude 762 m (2500 ft), scale = 1:250,000, relative total intensity contour interval 50 gammas (modified from Yarger and others, 1981)
geologic time as recorded by variations in the thickness of the sedimentary sequence on and adjacent to the dome. For example, in the No. 3 Smith well (sec. 10, T 29 S, R 15 E) on the axial part of the dome, six formations of Mississippian age are only 65 m (215 ft) thick; whereas in the No. 5 Watt well (sec. 34, T 28, S, R 17 E) about 19 km (12 mi) east of the dome, these formations are 91 m (300 ft) thick. Middle Pennsylvanian strata in these wells thicken from about 305 m (1000 ft) in the Smith well to about 370 m (1220 ft) in the Watt Well. The thinning of sediments over the dome seemingly resulted from upward movement of about 90 m (300 ft) during Pennsylvanian and Mississippian time. Depressed areas ("peripheral sags"), made apparent by changes in thickness of the Mississippian strata (Fig. 41), are roughly parallel to the domal axis but are interrupted by structural offshoots from the main domal upwarp (Fig. 53).

The Silver City Dome. The Silver City Dome is a prominent topographic and structural feature at the northern border of Wilson County. It is an eroded dome whose rim is held up by the Tonganoxie Sandstone Member of the Stranger Formation and whose floor is cut through the Weston Shale Member of the Stranger Formation to the Stanton Limestone (Plate 1). Structural closure on the dome is approximately 53 m (175 ft). The Silver City dome originated differently than the Fredonia anticline, being caused largely by igneous intrusion (Figs. 6, 7). Potassic
lamproite of Cretaceous age intruded the area and accounts for about 41 m (135 ft) of the uplift. The remaining 12 m (40 ft) of uplift may reflect igneous intrusion into the underlying Mississippian strata, but it seems more likely that it is due to continuous upward structural movement during Pennsylvanian time because the folding appears to be progressively less in younger strata. Removal of igneous material from the logs of the wells drilled on the Silver City Dome and use of the base of the Stanton Limestone as a datum resulted in good correlation of stratigraphic units below the Stanton and shows that the upward curvature on the correlated beds below the lowest recognized intrusive sill extends only to about the middle of the Kansas City Group (Fig. 7). At the time of deposition of the Hertha Limestone, upward structural movement had apparently ceased, the remaining domal movement above being due to sill-like intrusions that uplifted the younger strata during injection of the igneous rocks (Fig. 6).

The Silver City Dome lies at the junction of two anticlinal trends directed about N 60° E and N 55° W. The N 60° E trend is in line with another area of igneous intrusion about 8 km (5 mi) to the northeast, the Rose Dome in Woodson County, which suggests that the two domes are genetically related.
CHAPTER FIVE: GEOLOGIC HISTORY

Being an account in proper sequence (from older to younger) of the many tectonic and depositional events that are recorded in the igneous, metamorphic and sedimentary rocks in Wilson County during the Proterozoic, Paleozoic, Mesozoic, and Cenozoic Eras.
GEOLOGIC HISTORY

The geologic history that follows attempts briefly to put into proper sequence, from oldest to youngest, the many structural movements and depositional environments reflected in the igneous, metamorphic and sedimentary rocks that underlie Wilson County. Starting in Precambrian time, more than 500 million years ago (Elsom, 1992, p. 15), Wilson County was covered by the sea, and clayey and silty muds were deposited. These muds accumulated to a great thickness before granitic, syenitic, and other types of magma were brought into contact with and were injected into them. At the time of these intrusive episodes the muddy sediments were metamorphosed to slate and schist, the area was raised above sea level, mountains were formed, and extensive erosion began.

For possibly the next 50 million years, the Wilson County area alternately extended above or foundered below sea level. However, erosion was the dominant process during Early and Middle Cambrian time and many thousands of feet of the intruded and metamorphosed sedimentary rocks (schist and slate) were removed and in many places granite, syenite, and basic igneous rocks were exposed. The mountains were worn down until the hills were only about 30 m (100 ft) high, and the valleys were only 15 to 30 m (50 to 100 ft) deep.
In late Cambrian time the sea transgressed upon this eroded and folded land surface, and quartz and feldspar from the weathered granite, accumulated to form a blanket of sand about 5 to 38 m (17-125 ft) thick (Lamotte Sandstone). As the sea continued to transgress, the shore moved farther inland across Wilson County, less and less land-derived debris was carried to this submerged area, and sea water charged with calcium and magnesium combined these elements with carbon and oxygen to form a dolomite deposit 27 to 53 m (90-174 ft) thick (Bonneterre Dolomite). The Cambrian Period ended with a slight withdrawal of the sea.

In Early Ordovician time, coarse sand was carried into the shallow sea that again covered Wilson County; roughly 6 m (20 ft) of coarse-grained, dolomite-cemented sand was deposited (Gunter Sandstone). Transgression of the sea deepened the water over Wilson County, and for the next 25 to 50 million years, waters charged with magnesium seeped upward, mixed with calcium-carbonate-rich sea water, and deposits of dolomite 174 to 251 m (573-824 ft) thick accumulated on the sea floor (Gasconade, Roubidoux, Jefferson City and Cotter Formations of the Arbuckle Group). During periods of high-silica concentration, sinuous, gel-like, siliceous bodies formed and were enclosed in the dolomite. Periodic lowering of sea level allowed oolite to form and accumulate, and active currents many times transported quartz sand grains into Wilson
County. Inasmuch as no sedimentary rocks that were elsewhere deposited in Late Ordovician, Silurian or most of Devonian time are present in the subsurface strata of Wilson County, the sea is presumed to have withdrawn from the county and to have left it as a land area undergoing erosion for nearly 100 million years. However, we can presume also, that as erosion progressed, the land surface was depressed locally, and roughly 230 m (750 ft) of Lower Ordovician (Arbuckle) dolomite and related sedimentary rocks were preserved within the county borders.

Near the end of Devonian time, the near-level surface that had been planed by erosion, was again covered by a shallow encroaching sea. Streams from the adjacent land brought 1 to 2 m (3 to 6 ft) of sand into the area (Misener sand) and deposited it in local accumulations along the shoreline, while fine terrigenous muds, 4 to 6 m (12-20 ft) thick and containing very abundant organic humus and many spores (Chattanooga Shale) collected along the shoreline and in estuaries (Fig. 43: Plate 8). Wind, tidal, and current action was at a minimum and, although the land-derived materials were widely distributed, very little agitation of the seawater accompanied their accumulation. The deepest part of the sea probably lay to the north and east during Late Devonian and Early Mississippian time, and the black shale accumulated to a slightly greater thickness in that direction (Fig. 43).
The sea continued to transgress upon the land, and during much of the next 15 to 20 million years of Mississippian time roughly 75 m (250 ft) of limestone accumulated. At the beginning of Mississippian time, little magnesium was available in the sea water or conditions conducive to magnesium carbonate precipitation were not present, and a 4 m (14 ft) deposit of almost pure calcium carbonate formed (Compton Limestone). An influx of argillaceous material during a minor fluctuation in sea level, or a period of greater current action brought roughly 7 m (22 ft) of mud into Wilson County (Northview Shale), and later an increase in silica content of the water led to the formation of botryoidal, siliceous aggregates which became enclosed in 3 m (11 ft) of dolomitic limestone (Sedalia Dolomite). This environment extended westward almost to the middle of the county. At times, the agitated waters formed oolites in profusion, crinoids abounded, and their remains formed into 6 m (20 ft) of thin limestone beds (St. Joe Limestone Member of the Fern Glen Limestone). The magnesium and silica content of the water increased, and during much of the remainder of Early Mississippian time about 44 m (140 ft) of cherty dolomitic limestone (Fig.43; Plate 8) accumulated (Reeds Spring Limestone Member of the Fern Glen Limestone and the Burlington Limestone). Irregularly shaped masses of colloidal silica gel formed and assumed characteristic
features in each different environment. Some of the resulting chert contained terrigenous debris, some was pure and cryptocrystalline, some was granular. Toward the end of Early Mississippian (Keokuk Limestone) time small masses of porous silica formed concurrently with chert and dolomitic limestone to a thickness of 13 to 31 m (44-101 ft) both before and after a shallowing of the sea had resulted in the formation and concentration of abundant oolites into a 3 m (10 ft) bed ((Plate 8) (middle part of Keokuk). Near the middle of Early Mississippian time a short period of structural uplift on the Fredonia Dome led to a lesser thickness of dolomitic limestone in the area of uplift (Fig. 43, Edwards No. 1) but at the end of Early Mississippian time, general uplift to the south had resulted in erosion, and the upper surface of the limestone unit (Keokuk) was beveled to a relatively flat surface.

Late Mississippian time began with a slow transgression of the sea upon a deeply weathered land surface. Wave action was at a minimum, and in the presence of bacteria and organic acids the clay was largely transformed into glauconite (Fig. 43). Short periods of wave action removed the fine material between the glauconite grains and rounded and concentrated the grains into a bed (Cowley). Transgression of the sea continued, many sponges and other invertebrate animals abounded, and their remains are now enclosed in a cherty limestone.
(Warsaw) of which only 26 m (85 ft) remains in Wilson County. Uplift had apparently begun again along the axis of the Fredonia Dome, and erosion in very late Mississippian time removed any uppermost Mississippian (post-Warsaw) deposits. At the end of Mississippian time a sea covered the Anadarko Basin and Ouachita Trough in southern Oklahoma, but apparently did not reach as far north as Wilson County where erosion was leveling the land surface except for a few deep channels.

In very late Mississippian time erosion continued for about 20 million years until all of Early Pennsylvanian and part of Middle Pennsylvanian time had elapsed and a surface of low to moderate relief had resulted in the Wilson County area. On this surface were concentrated large quantities of chert fragments that had accumulated either from in situ deep weathering of Mississippian cherty limestone or as abraded chert in stream and beach gravels. At the start of Pennsylvanian time the sea had regressed to its lowest point, erosion had continued to cut deeply into uplifted remnants of Upper Mississippian limestone, and dolomite beds and a nearly level peneplain surface was being developed. Early Pennsylvanian time was ushered in by considerable tectonic activity probably as a result of the collision of Gondwanaland and Laurasia. Lower Paleozoic strata were uplifted to form the Appalachian Mountain chain on the east (Alleghenian Orogeny), and the lower Paleozoic
sedimentary sequence of the Ouachita Trough to the south was undergoing erosion throughout Early Pennsylvanian (Morrowan) and early Middle Pennsylvanian (Atokan) time. By late Middle Pennsylvanian (Desmoinesian) time a period of alternating nonmarine and generally shallow-water marine conditions had begun, coal beds were forming upon seat earths in back-bay swamps, nearshore bar-type sand bodies and channel-filling sands were driven by onshore winds over the swamps, and limestone beds were accumulating in a nearshore marine and lagoonal setting. The sand, silt and clay debris of the Desmoinesian came primarily from the Ancestral Rocky Mountains on the west and the newly formed Ouachita Mountains to the south, with but minor contributions from the Appalachians on the east and the Canadian Shield area to the north. As the sea transgressed to the north in Desmoinesian time, a broad carbonate shelf was established, and cyclic sedimentation on a broad scale began in the Central United States. The Nemaha Ridge and the Central Kansas Uplift remained positive areas during this time, but the major source of clastic material was the Ancestral Rocky Mountains area to the west. In the roughly five million years remaining in Middle Pennsylvanian (Desmoinesian) time, the sea moved across Wilson County and back 15 or more times. Vegetation grew on the exposed swampy mud flats and in lagoons after each regression, and the plant debris gathered along the shoreline. This

425
vegetation was drowned by back-bay brackish water to be covered soon by lagoonal muds; the land plant debris compacted, generated heat, and formed beds of coal. During further transgression the sand in shoreline bars was transported forward across the lagoon, and strong winds from the direction of the sea pushed the sand farther inland, and valleys were filled with sand. Continued transgression moved the shoreline farther northward, the water deepened, shoreline sands formed elongate bars (shoestring sands), the water deepened and the predominant material reaching Wilson County was clay and silt which covered the sands.

In late Desmoinesian time the Arbuckle Mountains were strongly uplifted and contributed siliciclastic sediments from the south. As the shoreline retreated back across the area in late Desmoinesian time, the waters in local back-bay lagoons supported a calcareous marine plant and lagoonal fauna, and thin limestone beds formed intermittently as silt and clay filled the lagoons. Animal life that had flourished was covered, disintegrated, and gave up its life parts to form kerogen. Vegetation then grew and accumulated until a reversal of water movement initiated the cycle again. The sea in the first 5 to 10 oscillations did not have an environment suitable to limestone deposition or water sufficiently deep to bring in a fusulind fauna, but in the last 5 to 10 oscillations, the
marine environment had many minor fluctuations which led to the accumulation of several fossiliferous limestones and interbedded very fissile, black organic shales. Abundant life forms generated gaseous and petroliferous materials that migrated into bar-sand lenses and valley-fill sand bodies, later to become filled with oil and gas deposits. During early Missourian time, the Nemaha Ridge and Central Kansas Uplift to the west and north of Wilson County were covered by a thin sedimentary sequence from a northerly source and could no longer furnish debris to southeastern Kansas or to Wilson County.

A long period of erosion separated Middle Pennsylvanian (Desmoinesian) time from Late Pennsylvanian (Missourian and Virgilian) time, and an unknown thickness of strata was removed and the material redistributed. Sand locally filled the small topographic depressions left at the end of that time, but in most of Wilson County, the materials furnished to the transgressing sea were of clay and silt size. During the 5 to 10 million years of Late Pennsylvanian time (Missourian and Virgilian Stages), the sea transgressed and regressed across Wilson County many times. Lengths of time encompassed by cycles varied, and during some transgressions, the sea was moderately deep, thermoclines developed and fissile black shales accumulated for relatively long periods. At other times the county lay in a near-shore or shoreline environment for long periods,
many large banks were capped by a flourishing phylloid algae biota accompanied by a shallow-water fauna, and thick deposits of limestone were formed. Intermittent regressions of the sea allowed coal and unfossiliferous shale beds to form. Upward movement on the Fredonia Dome and adjacent small structural features locally modified the general sequence of deposition throughout the middle and late parts of Pennsylvanian time and led to areas of thin to thick limestone and shale accumulation and adjacent areas of thick sandstone accumulation. Different water depths and distances from land brought about living conditions suitable for the abundant entry of many kinds of marine animal and plant assemblages into the area, and at times provided very shallow water environments suitable to the formation of mud cracks and oolites. The accumulation of thick deposits of oolites and other calcareous materials, such as calcareous algal fragments, broken fossil fragments, crystalline limestone, and vuggy limestone occurred. This calcareous debris was combined with the fauna and flora to form distinctively different limestone units. The last marine sedimentation recorded in Wilson County is the relatively clear, shallow-water, calcareous deposition represented by the Plattsmouth Limestone Member of the Oread Limestone.

Although no record of sedimentation is preserved in Wilson County for the more than 200 million years that
included Permian, Triassic, Jurassic, Cretaceous, and most of Tertiary time, cyclic sedimentation similar to that of Pennsylvanian time is presumed to have continued until the westward tilt of the sedimentary sequence took place in Cretaceous time. Strata younger than those of very Late Pennsylvanian age were either not deposited or were removed by erosion from the Wilson County area prior to late Tertiary time when ice-age chert gravels of late Pliocene and Pleistocene age were deposited directly on the eroded surface of Upper Pennsylvanian strata. In Cretaceous time, however, peridotite magma evolved into a potassic lamproite that intruded Pennsylvanian strata in sheetlike bodies at several levels along the northern border of Wilson County and to the northeast in Woodson County where many blocks of Precambrian granite, that were carried upward by the lamproite, were inserted into the Pennsylvanian strata.

In Late Tertiary time, a large stream or river that headed in the Flint Hills area to the northwest of Wilson County flowed eastward to the longitude of Wilson County and then turned southward and flowed across Wilson County along a strike valley that lay west of the escarpment formed by the Stanton Limestone. There, thick accumulations of chert gravel were left upon the upper surface of the Stanton escarpment. Almost concurrently, another stream that originated somewhat farther south flowed eastward and southward into the northwestern part of
Wilson County and left remnants of chert gravel high on the Oread escarpment.

Late in Pliocene and early in Pleistocene time, the easternmost of the two south-flowing streams was presumably diverted out of the Wilson County area possibly by headward erosion of a stream that lay to the east (the present Neosho River). Meanwhile, the other south-flowing stream was also diverted southeastward, and a third major stream entered the western part of Wilson County. At times of maximum flow in the Pleistocene Epoch, the two southeastward-flowing streams cut downward and left chert-gravel remnants on the bedrock of the older valley floors. Each succeeding chert gravel deposit formed at a relatively lower level farther north on the north flank and farther south on the south flank of the Fredonia Dome than did the preceding deposit. The remnants of these cherty deposits contain an increasing amount of locally derived material with decreasing antiquity, which suggests that local relief changed from a near level plain in Tertiary or early Pleistocene time to about 70 m (200 ft) of valley deepened topography in late Pleistocene time. During Recent [Holocene] time relatively steep-sided canyons continued to be cut in areas of outcrop of thick limestone and sandstone deposits. Where argillaceous strata of low resistance to erosion were crossed, wide valleys with the broad floodplains seen today were formed along the river courses.
CHAPTER SIX: ECONOMIC GEOLOGY

Being an assessment of the natural resources of Wilson County and their approximate value.
ECONOMIC GEOLOGY

Economic Overview

The mineral resources of Wilson County include oil and gas, coal, cement, brick and tile, crushed rock, agricultural lime, and sand and gravel. The total value of Wilson County's mineral resources production from 1890 to 1992 exceeded $46 million. Of this total, fuels and related resources accounted for more than $25 million; other mineral resources were valued at roughly $21 million as follows: cement production totaled more than $11 million; brick and tile were estimated at possibly $2 million; crushed stone and agricultural lime amounted to more than $1 million; sand and gravel was valued at about $7,000; and coal was not reported in sufficient detail to be meaningful. The brick and tile figure used herein was estimated from average daily production and sales prices for brick and tile plants active in Wilson County. Data for petroleum resources were taken from figures provided in reports of the State Geological Survey of Kansas in its Oil and Gas Development bulletin reports, and from the Oil and Gas Journal, World Oil, and other sources.

SECTION 6A: FUELS RESOURCES

The fuels resources of Wilson County are principally oil and gas which have been developed over more than 100 years of drilling for those commodities using mainly cable tool methods in the first 50 (to 70) years and rotary
drilling methods during the last 50 years (Figure 57). The value of the fuels produced to 1993 is estimated at more than $25 million. This figure may be below the actual value because early production figures for gas are practically nonexistent, and the projection of marketing data for both oil and gas is necessarily based upon tenuous evidence. However, the available market figures for oil and gas provide an excellent indication of the value of the petroleum industry in Wilson County. These figures compare favorably with those of other counties classed as East-Range Counties (roughly those counties east of Wichita). Woody (1983, p. 6) states that the “East Range of counties of Kansas have yielded about 30 percent of the estimated 4.5 billion barrels of crude oil produced in Kansas. The Cherokee Group sandstones are a major contributor”. The minimum estimated depth of burial in the Cherokee Basin is at least 1067 m (3,500 ft). Such a thickness would have resulted in a total depth of burial for Cherokee Group sediments of more than 1200 m (4000 ft). Temperatures of 60 to 70 degrees centigrade are sufficient to generate hydrocarbons (Gould, 1975). Hydrocarbons are found mainly in sandstones of the Cherokee Group in Kansas. The petroleum must have been locally generated from many of the abundant, organic-rich shales and claystones (Hulse, 1978). The ranges of crude oils in sandstone reservoirs of the Cherokee Group in southeastern Kansas include light oils (36 to 42° API gravity) produced from depths of 427 to
Figure 57. Cable-tool and rotary rigs in Wilson County. (A) Cable-tool rig drilling on the Holland lease in SW 1/4 Sec. 34, T 30 S, R 16 E. (B) Rotary rig drilling on the Martin lease in SW 1/4 Sec. 10, R 17 E.
792 m (1400-2600 ft); medium oils (25 to 35° API) produced from depths of 244 to 427 m (800-1400 ft); and heavy oil (less than 25° API) from depths less than 244 m (800 ft). On a depth of burial basis, Wilson County oils would be classed mainly as light to medium oil (Figure 58). Ebanks (1979, p. 29), in a study of the tar-sands of the Cherokee Group in southeastern Kansas, made an attempt to determine the areal extents and relationships of tar-sand occurrences to one another. A series of maps showing the extent and thickness of each of the productive sandstone bodies and their tar versus fluid oil content was found to be impossible to construct because of insufficient subsurface data and apparent conflict of information in areas of closely spaced wells where correlation from well to well should have been possible. Ebanks and James (1974), Ebanks and others (1977), Wells (1979), and Ebanks and Weber (1982) described sandstone distributions and evaluated the heavy-oil and tar-sand potential of the Cherokee Group in southeastern Kansas and southwestern Missouri. Hulse (1978), studied the diagenesis and petrophysical properties of several petroleum-bearing sandstones in southeastern Kansas and related them to petroleum production (Staton, 1987, p. 10).

More than 22,000 wells are estimated to have been drilled for oil and gas in Wilson County. Most wells drilled prior to 1945 were drilled with cable-tool rigs similar to that shown in Fig. 57A. Portable rotary rigs
Figure 58. Graph showing viscosity of "Bartlesville sand" crude oils from Wilson County in relation to other eastern Kansas oils (at 70°F and atmospheric pressure) (data from Everett and Weinaug, 1955, p. 204)
of about 15,000 wells were collected and used in the preparation of this dissertation. The locations and types of major production of most of these wells are shown on Plate 5. Of those shown, approximately one-fourth are oil wells, one-half are gas wells, and one-fourth are dry holes. Pipelines that carry crude oil, petroleum products, and gas across the county are shown also, as are gas storage reservoirs and areas of secondary recovery projects (Plate 5).

History of Petroleum Development in Wilson County

According to Newell and others (1987, p. 6) drilling for petroleum in Kansas reportedly commenced near Paola in Miami County in 1860, only one year after Colonel Drake's historic well first produced oil in 1859 near Titusville, Pennsylvania. Indications that petroleum products might be of considerable economic value in Wilson County were provided as early as 1874 in an account written by J. S. Gilmore. Since the article was short and of some historical value, it is reproduced here. Gilmore's account appeared in the Wilson County Citizen [newspaper] dated June 12, 1874 as follows: "On Wednesday, May 27, the usual quiet and repose of the village of Guilford was startled by

437
a report scarcely excelled by a heavy cannon, and followed by a violent shaking of the earth, extending beyond the limits of the valley. The minds of the rural population were filled with doubts as to the cause of this sudden alarm, but on visiting the mill pond of Akin and Bros., where a party of well diggers were drilling for water, the cause of the shock became evident, and no fears of a repetition of the recent manifestations in North Carolina were entertained. The gentlemen engaged in drilling a stock well on the premises of the above, having reached a depth of 120 feet, all at once noticed the drill descend about six inches, evidently meeting with no obstruction, and at once a deep rumbling sound, like heavy thunder, came forth from the well, and drove the person who was tending the drill (at a depth of 27 feet, being at the bottom of an excavated well) to the surface, anticipating that a vein of water had been struck, which would at once fill the well to overflowing. Having reached the top, the drill was immediately withdrawn, but no water becoming visible, the drill was again lowered, and a few strokes given, but the noise became so terrific that all operations were suspended. A slight odor was emitted from the well, and the conclusion that something inflammable was escaping, induced the gentlemen to test its burning qualities. A match was at once lighted at the edge of the well, and had hardly commenced to burn when the report and shock that has been described took place, and the adventurous well digger,
with whiskers, eyebrows and hair missing, lay at some distance from the well, evidently meditating upon the peculiarity of combustibles. A solid column of flame shot up from the well at least 40 feet and continued to burn, attended with that same rumbling sound that at first indicated the presence of something escaping from the well. It continued to burn brightly until extinguished by several buckets of water thrown in the well. On visiting the spot the next morning, the noise still continued, and another application of a match at a much greater distance from the well than at first, was attended with similar results. A column of flame would burst forth from the well from 30 to 40 feet in height and be followed by a shock that would be plainly felt at a distance of one hundred yards. An idea of the rapidity that the gas was generated may be obtained from the fact that every 15 minutes during the whole day, on lighting a paper and throwing it towards the surface of the well, a similar report and shock took place. At last it took fire at the mouth of the drill hole and burned brightly until extinguished by a heavy rain on Sunday night that followed. No water in any quantity has appeared. The noise has ceased, and the usual quiet again 'reigns around'.” However, this indication of the presence of gas in quantity was not capitalized upon at that time, and another 20 years elapsed before wells were drilled for gas in the Guilford area of Wilson County.
According to Ver Wiebe and others (1948, p. 218, 219), "The first discovery of oil in Wilson County dates from the early 1880's. A report (Peckham, 1895, p. 375), referring to early petroleum development in Kansas states 'The most extensive field, however, was developed in 1883 and 1884 in Wilson, Neosho, and Montgomery Counties, some 400,000 barrels having been produced in these counties within a radius of some 20 miles of Neodesha, in Wilson County, in 1884.' It seems most likely that either Ver Wiebe is misquoting Peckham or Peckham is incorrect as all other accounts indicate that the first well was drilled in 1893 (not 1883) and that 400,000 barrels of oil is a viable amount of oil to have been produced by 1894. According to Haworth (1908, p. 29), oil was discovered near Neodesha in 1890 by W. M. Mills of Osawatomie who began prospecting for oil in the vicinity of Neodesha. Mills met with some success which resulted in his going east to Pittsburg where he interested the firm of J. H. Guffey and J. H. Galey in the enterprise. They came to Neodesha and began development work in 1893 and soon had two oil wells and a good gas well. The gas was piped to the city of Neodesha and was lighted there on the evening of July 4, 1894 (Haworth, 1908, p. 29). By the close of the year more than 40 wells near the city were producing gas. Still another version of the beginnings of oil and gas development in Wilson County is provided by F. W. Blackmar (1912, p. 923), who credits George W. Chase with the suggestion in 1888.
that oil and gas were to be found there. Chase endeavored to interest the citizens of Neodesha in prospecting for petroleum, but no known action was taken by the local group. In the latter part of 1892, however, Mills secured a franchise from the Neodesha City Council to supply its people with natural gas (Morgan, 1902, p. 887), and he made several unsuccessful attempts to lease the land within the town limits of Neodesha. Finally, in mid-October of 1892, a lease was signed with T. J. Norman giving Mills the right to drill on the Norman property in the eastern part of Neodesha on the banks of the Verdigris River (Allen, 1959). With little delay, Mills, on October 28, spotted the location (Smiley, 1931a, p. 99), and drilling operations began November 6, 1892 near the southeast corner of sec. 20, T 30 S, R 16 E. On November 25 the drillers, C. L. Bloom and R. P. Bryson, drilled through a gas sand into an oil sand, and on November 28, at a point 6.7 m (22 ft) into the sand and at a depth of 255 m (835 ft) the hole began to fill with oil. The fact that oil had entered the hole was not publicized; the well was capped, and another attempt to find gas was made in the SE1/4 NE1/4 SW1/4 Sec. 19, T 30, R 16 E, on the J. K. DeMoss farm on the south bank of a bend of the Fall River about 1.6 km (1 mi) west of the No.1 Norman well. This well also began to fill with oil, and on January 12, 1893, it too was capped. The search for gas had now become a search for both oil and gas, and on June 12, 1893, a third well, which proved to be a good gas well,
was completed. This, the first commercial gas well in Wilson County, was drilled on the J. J. Haag farm in the NE 1/4 sec. 14, T 30 S, R 15 E, about 5 km (3 mi) west of Neodesha on the banks of the Fall River (Morgan, 1902, p. 887, 888). The well was completed to a total depth of 299 m (980 ft) on June 12, 1893, in four sandstone units that spanned the position of the "First Bartlesville sand" and "Second Bartlesville sand" between 257 m (843 ft) and 299 m (980 ft). All sandstone units contained gas, the third sandstone at 277 to 281 m (908-922 ft) showed a little oil.

During the summer of 1893, drilling proceeded slowly and resulted in 2 gas wells and 13 oil wells, all near Neodesha (Morgan, 1902, p. 888). By now a year had elapsed and neither of the wells drilled by Mills in November of 1892 and January of 1893 had been shot or production obtained. On August 5, 1893, the No. 1 DeMoss was shot with a strong charge of dynamite, and two months later (October 4, 1893), the discovery well, the No. 1 Norman, was shot. A charge of 30 quarts of nitroglycerin, the explosive usually employed in the eastern oil fields, was set off at depths of 245 and 249 m (805 and 817 ft) in the Norman well (Smiley, 1931b, p. 99) which started flowing at 371 barrels a day. Production soon dropped to 12 barrels a day (Smiley, 1931a, p. 15) and settled down to about 5 barrels. The amount gradually dwindled to about half a barrel a day, and this amount was still being produced 25 years later in 1917, when water broke through the casing
and the well had to be plugged and abandoned (Smiley, 1931b, p. 100). The No. 1 DeMoss was put on the pump February 28, 1894, thus becoming the first oil well pumped in the Midcontinent field (Smiley, 1931b, p. 99).

The years 1894 and 1895 saw the exit of Mr. Mills, the expansion of work by the Guffey and Galey interests, and the entrance of the Forest Oil Company interests into the picture. On February 3, 1894, Mills sold his interest to Guffey and Galey for $4,000 (Smiley, 1931b, p. 99). and returned to Osawatomie. In the meantime, Guffey and Galey had been actively leasing, and by the middle of 1894, they had acquired about 44,520 km² (700,000 acres) of leases in the vicinity of Neodesha, had completed 5 wells, 4 of which were shot lightly, and had fitted them for pumping. They pumped an average of 12 barrels a day each, the crude being stored in two large steel tanks with a total capacity of 70,000 barrels (Morgan, 1902, p. 887-890; Weeks, 1894, p. 511). By the end of 1894, 34 oil wells with an initial production of 10 to 35 barrels per day were in operation (Weeks, 1895, p. 375). In addition, 8 gas wells and 61 dry holes had been drilled, making the year's total 103 wells (Bright, 1956, p. 445). Additional storage tanks were added, and in 1895 Guffey and Galey found themselves with 150,000 barrels of oil in storage, an actual production of 800 barrels daily in the Neodesha field, and 21 wild-cat producers widely scattered elsewhere, good for perhaps 1,000 barrels more (Smiley, 1931b, p. 100). At about that
time the Forest Oil Company, a subsidiary of the Standard Oil Company (Weeks, 1896, p. 699; Haworth, 1908, p. 207), set up their Kansas Division on October 30, 1895, and bought out the interests of Guffey and Galey (Weeks, 1896, p. 699) for $225,000 cash. The deal included 65 oil wells, 12 gas wells, and about 13,500 km² (212,341 acres) of leases. Thirty-two more oil wells were completed in 1896 (Oliphant, 1897, p. 847), and by January 1, 1897, two more storage tanks had been erected at Neodesha and held about 250,000 or 300,000 barrels of crude oil (Morgan, 1902, p. 889). The need to furnish an outlet for this oil had become so acute by then that the Standard Oil Company decided to erect a refinery at Neodesha, the first refinery in the Midcontinent field. On February 15, 1897, construction began, and on May 11, 1897, the first batch of crude oil was charged to the stills which had a capacity of 500 barrels of crude per day (Smiley, 1931b, p. 100). The next several years proved this capacity to be inadequate to the supply, and in 1902, two more stills were added (Johnson, 1903, p. 334). The capacity was thus increased to 1,000 barrels which was soon exceeded by the supply, and in 1904, the capacity was increased to 5,000 barrels (Douglas, 1910, p. 138; Bright, 1956, p. 446). In 1900, both oil and gas were found near Fredonia, Benedict and Buffalo (Ver Wiebe and others, 1948, p. 219; also see Jewett, 1954, p. 351). Still another date is given by Owen (1975) who stated that although sporadic drilling found
minor amounts of oil and gas in eastern Kansas in the years that followed, the first significant commercial oil field in Kansas was developed in Wilson County near Neodesha in 1893 (Owen, 1975).

Meanwhile, excellent gas wells had been drilled and shot, and by 1898 good gas fields had been established near Neodesha and Benedict. The Prairie Oil and Gas Company had been organized and incorporated under the laws of Kansas for the express purpose of taking over the Forest Oil Company's western holdings; on January 1, 1901, the transaction was completed. More than 100 producing oil wells, a dozen gas wells, and the refinery with its pipelines and tanks thereby came under the ownership of the Prairie Oil and Gas Company. Subsequent efforts in Wilson County and nearby counties signaled the beginning of an era of continuous discovery that resulted in the development of the great Midcontinent oil and gas field.

Prices paid for crude oil, which averaged about 85 cents per barrel when Prairie took over, rose during the first few years to $1.38 per barrel in 1903. In the latter part of 1903, the Prairie Oil and Gas Company, for the purpose of grading oil, drew an arbitrary east-west line through the middle of Wilson and Neosho Counties and classed all oils north of the line as heavy oils and those south of the line as light oils. Light oils, of gravity 32° Baume or higher, brought several cents more per barrel than heavy oils, and producers in the northern part of the
county began to look elsewhere for production. Later, Prairie began buying strictly on a gravity basis and graded all oils of 31° Be and upward in one class but graded those below 32° Be in several classes on a sliding scale. In buying the heavier oil (less than 32° Be), they deducted a few cents per barrel for each half degree Be or fraction thereof. This grading action combined with a drop in price in 1904 resulted in the premature abandonment of many oil fields in the northern part of the county, a condition which continued until the time of World War I.

Gas, on the other hand, began a period of expansion in about 1904, partly due to increasing use in manufacturing and partly due to the entry into this field of an energetic and competitive company. According to Bright (1956, p. 444): "In 1904 real gas development of the southeastern Kansas field was organized by the Kansas Natural Gas Company, a concern initiated by T. N. Barnsdall of Pittsburgh, Pennsylvania, using $12,000,000 of eastern capital. By 1906, through consolidation of local holdings, excepting a few small companies, the Kansas Natural Gas Company controlled the output of the Kansas field, centering its supplies at Altoona, just north of Neodesha in Wilson County, and at Dearing, south of Independence in Montgomery County. Pipe lines were laid into the Joplin, Missouri mining district, and north to Topeka, Lawrence, Kansas City, Leavenworth and Atchison. By 1906 a
population of over 1,000,000 was being served by this company."

Haworth, in 1908 (p. 213) had written "The production of gas was greatly increased during 1905...The Kansas Natural Gas Company...now owns nearly all the good production of Montgomery and Wilson counties, the two richest gas fields in the Midcontinent area."

The search for gas between 1906 and 1913 resulted in the completion of 535 new producing gas wells, an average of about 67 each year (Moore and Haynes, 1917, p. 203). Gas in both the Vilas and Fredonia fields had been developed by 1907, and wells ranging from 56,000 to 840,000 m³ (2-30Mcf) of gas were being brought in near Vilas, and many ranging from 84,000 to 140,000 m³ (3-5Mcf of gas) were completed just east of Fredonia (Haworth, 1908, p. 225, 226). These wells were all "sand gas" wells drilled into the "Bartlesville sand" of the Cherokee Group. "Shale gas" did not become a prime target for drilling until about 1921, when new "sand gas" wells had become relatively rare and when a simple and cheap device for separating the gas and salt water became generally available. "Shale gas" wells, although of smaller production than "sand gas" wells, were slower to decline. The promise of long life, low cost of operation, small percentage of dry holes, and the fact that as much as 70 percent of the open flow could be taken without injury to the well, made "shale gas" wells...
a good economic investment at that time (Charles and Page, 1929, p. 367).

Interest in oil and gas decreased during the early part of the World War I period but picked up in 1917, oil again becoming the prime target of the drillers. Increased activity continued for several years, but during the period 1914-1917, large discoveries were made farther west in Kansas, and the large companies concentrated more and more of their efforts in the areas of Greenwood, Butler, Harvey and Sedgwick Counties. The days of the big companies in Wilson County passed, and the small operators, who had contributed continually from the beginning but had been in the background almost out of sight, came to the fore and have maintained the role of petroleum in the county’s economy to the present.

Oil Production

Oil has been produced continually in Wilson County since August 1893 and has amounted to more than 6 million barrels. As shown on Plate 7 (wells 15 and 29), oil production has come largely from sand bodies in the Cherokee Group. These lenticular sandstone units of the Cherokee occur at depths of about 215 to 335 m (700-1100 ft) and include the “First Bartlesville sand,” the “Second Bartlesville sand” and the “Burgess sand” (Plate 8, Table 2). Other oil production came from a locally developed sandstone bed in the Vilas Shale, from the “Weiser sand” of
the Bandera Shale, from the "Peru sand" of the Labette Shale, from the "Squirrel sand" of the Cabaniss Formation and from porous zones at the tops of rocks of Mississippian age and rocks of Ordovician age.

In some areas pools are controlled partly by their structural settings and partly by the simple to complex trends of the sandstone bodies. The depth of occurrence of sandstone bodies in the Cherokee Group is unpredictable, and serendipity plays as great a role as geologic knowledge when drilling in unexplored areas. Astute sedimentologic observation, however, led Haworth (1908) to recognize not only that anticlinal structures controlled the positions of oil traps, but also that many sandstone bodies are elongate in nature and that this shape controlled the dimensions of an oil pool. Later, H. Wood Bass of the U.S. Geological Survey made detailed maps of these elongate pools in the Cherokee Group and referred to them as "shoe string" sand bodies in Greenwood and Butler Counties (Bass, 1934; 1936; Bass and others, 1937). Thickness studies using many wells in Wilson County suggest that the sandstone bodies in this county may have originated as offshore bars as well as channel-filling sands. Many have biconvex forms which could in part be depositional or could in part be due to differential compaction.

Oil in Wilson County ranges in gravity from 39° A.P.I. in the "First Bartlesville sand" to 18° A.P.I. in the "Second Bartlesville sand". Strata of different ages

449
commonly contain oil of different gravity in the same area, and strata of the same age may contain oil of different gravity in different areas. A sufficient number of gravity determinations are available for the “First Bartlesville sand” and the “Second Bartlesville sand” to allow generalizations to be drawn concerning the variations in gravity of the contained oil. The “First Bartlesville sand” contains the highest gravity oil; as high as 39° A.P.I. The gravity ranges down to 27° A.P.I. nearly 5 km (3 mi) northeast of Altoona and similarly about 5 km (3 mi) northeast of Buffalo (Figure 59). A line limiting oil of gravity less than 30° A.P.I. trends irregularly north and east from near Altoona, as shown on Figure 59. Oil of gravity greater than 35° A.P.I. is concentrated in the general vicinity of Neodesha.

Oil from the “Second Bartlesville sand” is much lower in gravity, ranging from 18° to 34° A.P.I. The higher gravity is found in the vicinity of Neodesha. The lower gravity oil occurs in the structurally highest areas, and the higher gravity oil generally occurs in structurally low areas (Figure 60). Oil gravity readings from the other producing units are not sufficiently numerous to warrant generalization concerning their variations. A single determination for oil from the sandstone bed in the Vilas Shale indicates a gravity of 30° A.P.I. Oil from the “Weiser sand” is generally of low gravity ranging from 23° to 27° A.P.I. Oil from the “Squirrel sand” ranges from
Figure 59. Gravity of oil in the "First Bartlesville sand" in Wilson County.
Figure 60. Gravity of oil in the "Second Bartlesville sand" in Wilson County.
22° to 29° A.P.I. Oil from rocks of Mississippian age ranges in gravity from 19° to 31° A.P.I. The only record for "Arbuckle" oil showed a gravity of 22° Baumé.

Other physical properties of oil from Wilson County, for which data are available, include specific gravity, thermal value, fractionation products, and viscosity. Calculations for specific gravity of the oils from the "Bartlesville sand" range from 0.835 to 0.924. The oil with the highest specific gravity (0.924) came from the Benedict field and that with the highest Baumé gravity (37.1) came from the Neodesha field as reported by Haworth (1908, p. 314) and Moore and Haynes (1917, p. 174,). Oil from the Guilford pool had a heating value of 19,510 Btu per pound and 19.9 percent gasoline by volume at 200°C. A complete fractionation chart for this sample was reported on by Whitaker, Campbell, and Estes (1917, p. 181-187). Results for four samples from the Neodesha field in Wilson County were given by Haworth (1908, p. 208).

Everett and Weinaug (1955, p. 197-221) tested certain physical properties of more than 450 samples of eastern Kansas crude oils. The figures for gravity, viscosity, and interfacial tension of the 10 samples from Wilson County are shown in Table 2. The A.P.I. gravity has been used to correlate other physical properties (Figure 61), as well as to indicate origin and similarity of crude oils. The gravity of the oil can be used to obtain an approximate value of the viscosity (generally within 10 centipoises) by
Figure 61. Comparison of A.P.I. gravity and boiling point of crude oils from Wilson County with national averages after figure 20 in "Petroleum Refinery Engineering" by W. I. Nelson, New York, McGraw-Hill Book Company, 1941, by permission).
finding the point of intersection of the A.P.I. gravity and
the curve shown on Figure 58. However, plotting of gravity
against viscosity of samples from known formations did not
result in the successful differentiation of formations and
led Everett and Weinaug (1955, p. 207) to believe that
these characteristics are too similar in eastern Kansas
oils to allow correlation on that basis. An attempt to
correlate interfacial tension measurements with gravity of
the oil (Table 2) indicated that there is no apparent
correlation between these two physical properties either
(Everett and Weinaug, 1955, p. 209). The viscosity of oils
from the Altoona field is much higher than for other
samples (Table 5).

Data on distillation properties of crude oil from
Wilson County (Table 3) were furnished by W. G. Mayhood
(personal communication, May, 1959). Samples from the
“Weiser sand,” the “Squirrel sand,” the “First Bartlesville
sand,” and the “Second Bartlesville sand” were distilled,
and the A.P.I. gravity, viscosity, and distillation
temperatures and other physical properties were determined
(Table 3). These data made possible the comparison of
Wilson County crude oils with stocks from elsewhere in the
United States (Fig. 61). This was done on the basis of the
“Characterization Factor” of the oil, which is defined
(Nelson, 1941, p. 77) as the specific gravity of the oil
(at 60°F) divided into the cube root of the temperature
(degrees Fahrenheit absolute). Characterization factors
calculated for Wilson County crudes are: "Weiser sand" 11.6, "Squirrel sand" 11.2, "First Bartlesville sand" 11.6, and "Second Bartlesville sand" 11.4 (cf. Table 4).

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraffin hydrocarbons</td>
<td>12.7</td>
</tr>
<tr>
<td>Pennsylvania stocks</td>
<td>12.1-12.5</td>
</tr>
<tr>
<td>Midcontinent stocks</td>
<td>11.8-12.0</td>
</tr>
<tr>
<td>Gulf Coast stocks</td>
<td>11.0-11.5</td>
</tr>
<tr>
<td>Cracked gasolines</td>
<td>11.5-11.8</td>
</tr>
<tr>
<td>Cracking plant feeds (combined)</td>
<td>10.5-11.5</td>
</tr>
<tr>
<td>Recycle stocks</td>
<td>10.0-11.0</td>
</tr>
<tr>
<td>Cracked residums</td>
<td>9.7-11.0</td>
</tr>
<tr>
<td>Benzene</td>
<td>9.8</td>
</tr>
</tbody>
</table>

(From "Petroleum Refinery Engineering," written permission to reproduce obtained from McGraw-Hill Book Company, Inc., Copyright, 1941).

Table 4. Typical Characterization Factors for various oil stocks (Nelson, 1941, p. 77).

As thus designated, crude oil tested from the "Squirrel sand" and from the "Second Bartlesville sand" are nearer to Gulf Coast stocks than to Midcontinent stocks (Table 3, Table 4). This relationship suggests that much of the oil in the Pennsylvanian, Mississippian, and Ordovician strata in Wilson County migrated northward from southern Texas during the long period of geologic time available. Roughly 300 million years have passed since the last remaining strata of Pennsylvanian time oil generation and migration could have begun some 200 million years earlier in Early Ordovician time. The long migration route from south Texas...
to Kansas, a distance of about 1125 kilometers (700 miles),
could have been traversed easily by fluid movement of only
0.25 to 0.51 cm (0.1 to 0.2 in) per year, a not
unreasonable figure. Therefore, we may assume that the oil
that resembles the Gulf Coast stock had migrated during
Ordovician to Mississippian time from south Texas and had
become mixed with Kansas stock that had migrated laterally
and upward from similar and older strata in the subsurface
of southeastern Kansas and northeastern Oklahoma. The oil
could then have been flushed along fault systems and
channelways that had developed during any of the periods of
structural movement in Early Ordovician and later time when
uplift had occurred and truncation at unconformities had
developed fracture porosity and erosional channels along
which the fluids could have moved. The long periods of
unrest that resulted in unconformities at the tops of the
Osagian Stage, the Kinderhookian Stage, the Chattanooga
Shale, and the Cotter and Jefferson City Dolomites of the
Arbuckle Group all could have contributed to the
development of easy pathways for later migration of pre-
Mississippian and Mississippian oil. In Early Pennsylvanian
time also the Wilson County area would have been subjected
to a long period of erosion and/or nondeposition.
Sediments of the Morrowan and Atokan Stages, found
elsewhere in the Midcontinent region, are entirely missing
in the subsurface of Wilson County; strata of the Cherokee
group rest directly upon an erosion surface that is
underlain by a cherty residue of material (chat) weathered from the Warsaw and Keokuk limestones of Mississippian age.

Any oil generated locally from the Mississippian limestones and dolomites and the Chattanooga Shale could have migrated laterally and upward and have been trapped in the relatively porous "Bartlesville sand" bodies in the lower part of the Cherokee Group (Middle Pennsylvanian). The enclosing shales of the Krebs and Cabaniss Formations would have served as excellent seals to trap the oil in the sand bodies. The gravity and boiling point of crude oil samples (Table 3, Fig. 61) from Wilson County, when plotted and compared with graph data from Nelson (1941, figure 20) and as observed in Figure 61, indicate that most Wilson County crudes fall closest to the mixed-base No. 2 category. However, samples 6 and 8, from the "First Bartlesville sand," plot closest to line No. 3 and may have paraffin-base affinities (Fig. 61).

Production of oil is dependent to a large extent upon the permeability and porosity of the sandstone or other rocks in which the oil accumulated and from which it must be removed. Furthermore, in secondary recovery operations, it is important to know the expectable rate of movement of fluid through the rock and the number of barrels of oil recoverable per km² (acre). Porosity and permeability studies show that in Cherokee sandstone reservoirs, the fluid will move more rapidly in the lower part of the sequence; thus, the fluid may move even faster in the
fingers of the lower part which will then decrease the vertical-sweep efficiency of reservoirs undergoing enhanced recovery processes. Because the upper portions of the oil-sand reservoirs have lower porosities and permeabilities as well as smaller pore throats than sandstone reservoirs in the lower portions of the Cherokee Group, an uneven sweep could result. Injection of fluids may never come in contact with unrecovered oil in the upper part of a sandstone reservoir while the lower part of the reservoir is even more thoroughly swept (Craig, 1971). The permeability and porosity of the rocks are utilized in calculating these data and, because of the wide variation in permeability between the different strata, and even within any one stratum, tests must generally be run on samples taken in each well or area under consideration.

Of the sandstone units for which data are available (Table 5), the “Second Bartlesville sand” had the highest maximum permeability (334.0 md); the “First Bartlesville sand” had the lowest minimum permeability (0.012 md); and the “Third Bartlesville sand” had the greatest average permeability (116.8 md). However, the latter figure was based upon only two readings. The “First Bartlesville sand” had the highest maximum porosity (23.0 percent); the “First Bartlesville sand” and the “Second Bartlesville sand” each had the same lowest minimum porosity (12.2 percent); and the “Second Bartlesville sand” had the
greatest average porosity (17.8 percent). Tests on two samples of the "Mississippi lime" show it to have a much lower permeability and porosity than is recorded in the sandstones (Table 5).

**Relation of Oil Accumulation to Structure and Stratigraphy**

Oil accumulation is related both to structure and to stratigraphy. Many of the oil pools are located near the tops of structural highs, but most of the pools appear to be slightly off-structure, generally to the west or northwest (Plate 7). This relationship probably reflects tilting of previously formed structures into which oil had already migrated and been trapped. As a result of such tilting, the former crests of the structural highs migrated westward. In reservoirs with strong gas pressure, eastward readjustment to the new top of the high seemingly was almost complete; in others, the movement was negligible. Oil on the flanks of structures of very low relief, such as in the vicinity of Neodesha, apparently readjusted only slightly.

Oil in distinct linear trends, such as those in R 17 E, apparently occurs in shoestring-type sandstone bodies. This control is primarily stratigraphic, the oil being held in the body by the enclosing shale despite structural modifications; however, differential compaction below and above such bodies has generally produced a
slight structural high in the overlying rocks. A crescent-shaped trend of oil production in the northeastern part of the county may be related to a bar-type shoestring sandstone accumulation in “First Bartlesville” time but not at other times. Thus, of much economic importance in oil exploration in Wilson County is knowledge of both the time and the place during which a shoreline of the Pennsylvanian sea remained relatively stationary for a considerable period, because at such times thick sand bars would have been able to form in certain places. On the other hand, erosion would have been able to cut deep curving channels into the older strata, and sand could have accumulated there. In the outcropping and subsurface Pennsylvanian rocks of Wilson County, seven such periods of sand accumulation are represented and, although the effects are relatively local in this county, they may be of significance in oil accumulations downdip to the west.

The stratigraphic record shows that in early Lawrence time (Ireland Sandstone Member), and early and late Chanute time (Cottage Grove and Noxie Sandstone Members), part of the area of Wilson County was dry land and was being eroded. During these periods, channels were cut into the underlying, newly deposited strata; they were then filled with sand-sized debris which was covered by clay-size material. The thickest deposits of the Ireland Sandstone Member of the Lawrence Formation appear to trend generally north-south near the west edge of the county. The deposits
may, however, represent three separate valleys cut in east-west directions rather than a single north-south meandering channel. Several sheet-type sandstone bodies comprise the upper part of the Ireland but are thin and relatively unimportant for oil accumulation in Wilson County.

The Tonganoxie Sandstone Member of the Stranger Formation is a channel-filling sandstone that is fairly coarse-grained only in the west-central and possibly the northwestern parts of the county. Elsewhere the debris is poorly sorted and too fine grained to make an effective reservoir. Similar variations probably occur in the subsurface to the west. The lower part of the Cottage Grove Sandstone Member of the Chanute Shale probably filled a small structural basin that extended into Wilson county from the east. Data from drillers logs suggest that deep channels were filled by 15 to 30 m (50-100 ft) of sand of the Cottage Grove and Noxie members (locally called the “New Albany sand” and “Layton sand” by drillers) both southeast of Vilas and in an area from about 5 km (3 mi) east of Fredonia southward to the Wilson-Montgomery county line. A fairly persistent blanket-type accumulation of the “New Albany sand” seems to occur generally in the western part of the county north of New Albany, north and east of Fredonia, and east of Buxton and LaFontaine.

Preliminary study of other sands in the subsurface shows a sandstone trend in the Galesburg Shale from Buxton northeast to Altoona. In few local areas, sands in the
subsurface occur in both the upper and lower parts of the Bandera Shale. In the Bandera Shale, the "Weiser sand" is thick along an arcuate belt from about midway between Neodesha and Buxton northeast to Altoona, and then southeast and south to the corner of the county. In the Cherokee Group, the thickest trend of "Squirrel sand" goes from Benedict westward possibly 5 km (3 mi), and then northeast to the north of Buffalo and into Woodson County. It then swings southeast into the northeastern part of Wilson County and southwest past Vilas about 5 km (3 mi) before again swinging south toward the south line of the county. The "First Bartlesville sand" in the northeastern part of the county has a similar shape but is more nearly circular. This trend is about 1.6 km (1 mi) west of the "Squirrel sand" trend. Structural highs along the "First Bartlesville sand" trend have not been adequately tested. The "Second Bartlesville sand" and "Third Bartlesville sand" apparently accumulated more nearly as blanket-type deposits, but local elongate accumulations of the "Second Bartlesville sand" occur near the east line of the county.

Secondary Recovery

In general, a fluid will move more rapidly in the lower portion of a transgressive sandstone because of the larger size of the grains of quartz and other minerals. This results in a more thorough sweep of the oil from the
lower part and a relatively smaller sweep in the upper, more fine-grained part of the sandstone body. The second sweep may reach into the upper part of the sandstone or, more likely, merely sweep the lower part a second time. This problem may be compounded by the presence of several different fluids with differing viscosities, molecular sizes, shear strengths and other mechanical properties, because each fluid will behave differently in the rocks (Craig, 1971). Furthermore, the ubiquitous presence of iron in pyrite, siderite, ankerite and chlorite in the sandstones may result in potentially damaging chemical reactions in the reservoir, unless the reduced iron and carbonate minerals in the reservoir are chemically stabilized prior to and during injection of the acidic chemicals used in oil production. The iron oxide precipitates would block pore throats and halt or slow down fluid movement unless preventive action was taken. According to Almon and Davies (1979, p. 390) the problem can be avoided if an oxygen scavenger and an iron chelating agent were added to the acid, and care was taken to recover all the acid introduced into the well. Lenticular, shoestring-type sandstone deposits lend themselves best to secondary recovery operations, and in Wilson County such operations have been in progress for more than 50 years. Permits for 62 water-flood projects and one salt water disposal project have been issued (as of January 1989) by the State Corporation Commission, the first having been
issued in April 1938. The locations of many are shown on Plate 5. Forty-seven of the water-flood projects have been in sandstone units of the "Bartlesville" zone, ten have been in the "Squirrel sand," and five have been in the "Weiser sand" (Table 6).

A detailed report on the Gillilan and Carr project in secs. 9 and 16, T 29 S, R 17 E was included in a history of water flooding of oil sands in Kansas by Grandone (1944, p. 141-144; Tables 1-7) and is typical of most such operations in the county. Before application was made for water-flooding, the area under lease had been virtually depleted of oil that was recoverable by primary methods. The first increase in the rate of oil production as a result of water injection occurred seven months after the initiation of water-flooding. All wells were shot with nitroglycerin by using one quart per 0.3 m of sand in the input wells and total charges of 40 to 80 quarts in the sand section of producing wells. The sand averaged about 8 m (25 ft) in thickness. Water was injected at pressures of 32 to 39 kg per cm² (450-550 psi) measured at the well heads, and oil was produced by pumping (Grandone, 1944, p. 142, 143). The cumulative production at the end of three years of secondary recovery operations was 0.125 barrels per meter² (507 barrels per acre). An extension of this water-flood was put into operation in March 1954 by the Keas Drilling Co. as their Thayer project. In 1955, secondary recovery oil amounted to 48,659 barrels (Weinaug, 1956, Table 1).
In the first four years of operation, about 145,000 barrels of oil were produced.

In 1964 a rather comprehensive report on a water-flood project by the Schermerhorn Oil Corp. at the "Wiggins Pool" in secs. 8, 17, and 20, T 28 S, R 17 E in Wilson County was published (Johnston, 1964, p. 3-9). The project covered a productive area of 2.0 km$^2$ (495 acres) into which water injection was started in September, 1959. By March, 1964, 58 water-input wells and 105 additional wells had been drilled into a "shoestring sand" lens at an average depth of 233 m (765 ft). Analyses of more than 100 rotary cores indicated that the Bartlesville sand lens had the following average characteristics: Porosity, 18.7 percent; permeability, 58.8 md; oil saturation, 39.2 percent; and water saturation, 40.4 percent. The discovery well was drilled in 1936 by cable tools; it was completed that year with an initial daily production of 100 to 125 barrels of 28° API gravity oil. All wells were completed with 17 cm (6.5 in) casing set, and were shot with 100 quarts of nitroglycerin. The sand lens of the Wiggins Pool trends N-S, is about 3.2 km (2 mi) long, 0.8 km (0.5 mi) wide, and has a 5.2 m (17 ft) average thickness of sand. The 58 water-input wells were drilled by rotary methods and fractured hydraulically through perforations with 500 pounds of sand and 1,600 gallons of water. Seventy new producing wells were drilled, perforated, and fractured with 2,000 to 3,000 pounds of sand and 3,100 gallons of
oil. Brine for the flood was obtained from a supply well completed in dolomite of the Arbuckle at a depth of 2073 m (6800 ft). Primary oil recovery between 1936 and 1964 amounted to 443,459 barrels (9.8 bbl/m²; 900 bbl/acre); waterflood oil recovery between October 1960 and April 1964 was about 332,000 barrels (8.2 bbl/m²; 800 bbl/acre). Within three months after waterflooding started, oil production increased from 1000 barrels per month to 4000 barrels per month. Maximum total monthly production reached 14,000 barrels in April 1962, and leveled off to an average of about 11,000 barrels per month at the time of Johnston's report (1964). The cumulative oil from primary production in Wilson County by 1994 was about 8.7 million barrels; cumulative secondary recovery production from the Schermerhorn "Wiggins" Project, the Keas "Thayer" Project, and other secondary recovery projects by 1990 was estimated at 3 million barrels. This gives an estimated cumulative county total of roughly 12 million barrels of oil by 1994.

**Oil Refining**

Refining of oil in Wilson County began in 1897 when the storage of oil above ground and the lack of transportation facilities made necessary the installation of a refinery within reach of this growing producing area. Neodesha was then the hub of Midcontinent oil production and was a logical choice as the site of the first refinery.
in the Midcontinent region. Thus, on February 15, 1887, the Standard Oil Company of Kansas began construction of a 500-barrel per day refinery at Neodesha (P. E. Moon, written commun., May 8, 1959). The refinery consisted of two crude stills, one steam still, one agitator, a pump house and tanks. The first crude was charged to the stills in May 1897 and was distilled by the “Batch Process” into refined oils, naphtha, and fuel oils. During 1897 and 1898, a very close relationship was maintained between the refining company and the Forest Oil Company, the major producer, such that no more oil was produced than the refinery wished to handle (Haworth, 1899, p. 10). In 1898, 88,000 barrels of refined oil was marketed (Haworth, 1899, p. 10, 45). In 1899 the refinery reported a total consumption of 85,215 barrels (42 gallons each) of crude oil, from which the operators obtained 29,972 barrels (50 gallons each) of refined oil, and 5,990 barrels (50 gallons each) of naphtha and gasoline, with a residue of 33,000 barrels (42 gallons each) of fuel oil (Haworth, 1900, p. 38). By 1902 control of the production was impossible, pipelines were extended as far as Chanute and Humboldt, and the capacity of the refinery was doubled to 1,000 barrels per day (Haworth, 1903, p. 36; Oliphant, 1904, p. 557). In 1904 the capacity was increased to 2,500 barrels with 10 stills in operation (Williams, 1904). There were then about 150 tanks in the tank farm, each with a capacity of 33,000 to 60,000 barrels of crude. In 1914 two more
batteries of crude and coke stills were built (P. E. Moon, written commun., May 8, 1959). In 1916, 7,500 barrels of oil a day were refined (Moore and Haynes, 1917, p. 380). By 1919 the capacity had been increased to 12,000 barrels (Moore and Boughton, 1921, p. 32), and in the next two years, two batteries of atmospheric pressure stills, 20 more Burton shell stills, and 40 Burton tube stills were built, and two batteries of coke stills were converted to continuous operation. These expansions were necessitated by better transportation of crude oil to the refinery from areas to the west and south. The first Holmes-Manley unit was built in 1927, and in 1932 a second unit as well as other thermal cracking facilities and a modern gas recovery plant were constructed.

In 1932 the refinery was purchased by the Standard Oil Company of Indiana and began utilizing crude oil from outside Kansas. By 1937 the gathering system had been greatly enlarged, refrigerated storage had been added for the light gasolines, and the cracking unit had been rebuilt to a two-furnace unit with soaking drums. In 1949 a naphtha reformed unit was added making the operation a three-furnace cracking unit. Expansion to a crude running capacity of 19,700 barrels per day was begun in January 1951, and crude runs were increased to that amount in February 1952. Pipeline capacity was increased to 17,000 barrels per day of oil, and new equipment included a stacked reactor-type Foster-Wheeler catalytic cracking unit.
with its own vapor recovery and alkylation unit. The cracking unit was designed to charge 9,000 barrels per day of gas-oil and to operate at about 55 percent conversion. The alkylation unit had a capacity of approximately 1,100 barrels per day of aviation alkylate (P. E. Moon, written commun., May 8, 1959). In 1958 construction was completed on a 6,000 barrel Ultraformer and a 6,000 barrel Hydrofining unit (Schoewe, 1958, p. 211), and in 1959 the crude capacity of the Neodesha refinery was reported as 23,100 barrels per calendar day and 24,300 barrels per stream day (Oil and Gas Journal, 1959, p. 123).

Several smaller refineries operate in towns in adjacent counties, and because of the wide variation of the crude oils from Wilson County, much of its crude is handled by the smaller refineries. Refineries of the Chanute Refining Company and the Mid-America Refining Company, Inc., at Chanute in Neosho County take the bulk of the variable Wilson County crude, but some of this oil in the southern part of the county is taken to the Cooperative Refinery Assn. refinery at Coffeyville in Montgomery County. In 1958 the Mid-America Refining Company, Inc. added 15,000 barrels per day to the crude capacity and 400 barrels per day to the asphalt capacity at its Chanute refinery (Schoewe, 1959, p. 258).
Gas Production

Wilson County has been an active gas producing region since 1893, and in the 100 years that followed more than 4.2 billion cubic meters (150 billion ft$^3$) of gas are estimated to have been obtained from reservoirs at depths ranging from 61 to 457 m (200-1500 ft). Undoubtedly much gas was lost, and possibly only 2.8 billion m$^3$ (100 billion ft$^3$) have been marketed.

Analyses of four samples of “shale gas” from Wilson County are given in Table 7. Several samples of town supply and “sand gas” wells in Wilson County were also analyzed (Table 7). The average methane content of all samples analyzed was 91 percent; ethane averaged three percent. The total paraffins averaged 94 percent, and the heating value averaged 38 thousand kilojoules per thousand cubic meters (38kJ/mm$^3$) or 36 British thermal units per cubic meter (36 Btu/m$^2$) or 1020 Btu per thousand cubic feet (1020 Btu/mcf).

During the development of the gas-producing area of Wilson County, gas occurrence was recorded on the well log as the well was drilled. Upon completion of the well, production was commonly obtained from one or more horizons above the major producing zone as well as from that zone. In establishing the important gas-producing horizons in each area, the deepest producing zone was assumed to be the major producer; in many wells the nearest gas-bearing units up the hole contributed to the total gas flow. In
preparing gas production maps, the area in which the stratigraphic unit being mapped was possibly a contributor is included within the bounding lines (Plate 11). This is particularly true of the area of production from the Fort Scott Limestone ("Oswego lime"). On the basis of average sale prices for different periods of production, the gas is estimated to have had a market value of somewhat more than $2 million.

**Gas Storage**

Gas was first stored in natural reservoirs in Wilson County in May 1942 near Buffalo by the Union Gas System. In August 1949 Union began storage in a second natural reservoir near Fredonia. The Buffalo unit covered an area of about 2.3 million m² (560 acres) and in 1958 had an ultimate capacity of about 6.4 million m³ (225 million cubic ft, Mcf) of gas at 81 pounds gage pressure; at the Fredonia unit, the area was about 3.0 million m² (750 acres) with an ultimate capacity of about 10.8 million m³ (380 Mcf) of gas at 89 pounds pressure. Storage at Buffalo was in the Iola Limestone at 58 m (190 ft) depth; at Fredonia the "New Albany sand" was used at 73 to 82 m (240-270 ft) depth. The Iola Limestone was the more permeable formation. At Buffalo 30 wells were drilled and plugged before conversion to gas storage; at Fredonia only 23. There were 13 input wells and seven observation wells at the Buffalo unit; at Fredonia there were 11 input wells and

**Oil and Gas Fields**

Descriptions of the oil and gas fields include areas of oil production, areas of gas production, depths to producing horizons, history of drilling, initial production, and rock pressures at the time of initial production. Limits of the oil and gas fields, as "established" by the Kansas Nomenclature Committee (Figure 62), add to the record of the development of the Wilson County part of the Midcontinent field. In areas as large as the Fredonia or Neodesha fields, a producing zone, because of the regional westward dip of the strata, may be 61 m (200) greater in depth in the western part of the field than in the eastern part. Thus the vertical distance of the producing horizon above or below a stratigraphic datum such as the Fort Scott Limestone ("Oswego lime") is the important measurement in correlating producing zones.

**Altoona Oil and Gas Field**

Oil. Possibly the first oil well in Wilson County lies in the Altoona field. Edwards (1881, p. 41) records a "coal oil well" in the SE 1/4 NW 1/4 Sec. 27, T 29 S, R 16 E on the C. W. Prange farm near the south line of the field. No total depth or other data are available for this well, however, and the Norman well at Neodesha is the undisputed first commercial well in the county.
Figure 62. Limits of oil and gas fields in Wilson County as established by the Kansas Nomenclature Committee.
Oil was discovered near the Altoona field at about the turn of the century, and by 1907 four oil pools had been developed (Haworth, 1908, pl. XIX). The largest lay just southwest of town across the Verdigris River, another was just northwest of town, another at the northeast corner of town, and the fourth about 1.6 km (1 mi) northeast of town. Production was from the "First Bartlesville sand" between 244 and 259 m (800-850 ft) depth in 1.5 to 6.1 m (5-20 ft) of sand. Later discoveries in the northeastern part of the Altoona field extended significant production from the "First Bartlesville sand" to the "Second Bartlesville sand" also. Production from the "Squirrel sand" came from three pools northeast of Altoona. Production from the "Weiser sand" was obtained only from the extreme southwestern corner of the field (Plate 10A, C, D).

Production from the "Second Bartlesville sand" was mainly from the "Wiggins pool" in secs. 17 and 20, T 28 S, R 17 E, in sand from about 8 to 11 m (25-35 ft) thick at depths between 274 and 305 m (900-1000 ft). The pool was discovered in 1936, was developed rather slowly, and within 20 years had about 40 producing wells. Total production is estimated to have amounted to somewhat more than 300,000 barrels of 27° API gravity oil as estimated from Kansas Geological Survey figures (Jewett, 1949; Ver Wiebe and others, 1948, 1949, 1950, 1951, 1952, 1953, 1954, 1955; Goebel and others, 1956, 1957, 1958, 1959). Oil from the "First Bartlesville sand" in the Altoona field ranges from
28° to 33° API gravity; oil from the "Squirrel sand" ranges from 22° to 28° API gravity; and oil from the "Weiser sand" ranges from 24° to 26° API gravity. Initial production from wells in this field ranged from five to 50 barrels of oil per day.

Gas. Gas was discovered near Altoona in 1901, was piped to the town that year, and by 1902 a large area of gas production had been outlined north and east of town (Haworth, 1903, map facing page 38). Drilling in 1903-05 was mainly to the "Second Bartlesville sand" at about 275 m (900 ft), although gas was first encountered in the "Oswego limestone" at about 200 m (650 ft) depth. Initial production of some of the wells was 56,640 to 169,920 m³ (2-6 Mcf) per day. Many shallow "shale gas" wells were drilled to the black shale of the "Oswego limestone" in this area in 1916-17 and again in 1923-24. Initial production in "shale gas" wells was 14,160 m³ (500 Mcf) of gas per day, only about one-fourth the production of "sand gas" wells, but production in "shale gas" wells continued in most areas for a considerably longer period than in "sand gas" wells. Continued search for gas extended the area of production, and no clean-cut break exists between the Altoona, Altoona East, Vilas, or Humboldt-Chanute fields (Plate 11A).

Small shows of gas were recorded at about 91 m (300 ft) depth in the first black shale above the base of the Kansas City Group in a few wells, but the shallowest production of gas came from the "Weiser sand" at 137 to
152 m (450-500 ft) depth. Gas production, ranging from 566 to 14,160 m$^3$ (20 to 500 mcf) per day, was reported in several wells in small areas east and south of Altoona. The shallowest gas was in a sand body about 3 to 8 m (10-25 ft) thick in the lower part of the Bandera Shale. Some "shale gas" from the black shales in the "Oswego lime" was recorded in nearly all gas wells in the Altoona field. Gas from this horizon contributed 1415 to 7080 m$^3$ (50 to 250 mcf) per day to the flow being obtained from other zones. Gas production from the "Squirrel sand" in this field was almost entirely east and northeast of Altoona at depths of about 198 m (650 ft). Maximum initial production of wells in this sand was greater than 28,000 m$^3$ (1 Mcf) per day. Production from the "First Bartlesville sand" supplemented that of the "Second Bartlesville sand" except near the center of the northeastern part of the field, where it extended beyond the production from the "Second Bartlesville sand" (Plate 11H, I). Production from the "Second Bartlesville sand" occurred at about 275 m (900 ft) depth and was mainly in the northern part of the field and in the area around Altoona (Plate 11I). Deepest production of gas in the Altoona field has been from 1.5 to 3 m (5-10 ft) of "Third Bartlesville sand" at about 300 m (1000 ft) depth in Sec. 36, T. 28 S, R 16 E (Plate 11 J).
Altoona East Oil and Gas Field

Oil. The Altoona East oil and gas field lies near the center of the east boundary of Wilson County and extends about 5 km (3 mi) eastward into Neosho County. Discovery and production of oil in the Altoona East field came about 40 years after the field was established as a gas producer. In the early mid-thirties, oil in the "Second Bartlesville sand" became the prime target for drilling in this area, and as a result, the Three Mounds pool in Secs. 9 and 10, T 29 S, R 17 E was discovered in about 1935. Production was obtained from 3 to 17 m (10-55 ft) of "Second Bartlesville sand" at about 260 m (850 ft) depth. The pool had been fairly well outlined and developed by 1938 and then subjected to water-flooding for a short period of time. Flooding was begun again in 1942 and again in 1956 but on only a small scale. An estimated 300,000 barrels of 28° and 29° API gravity oil has been produced from the Altoona East Field based on figures from (Ver Wiebe and others, (1950-1955), and Goebel and others (1956-1959).

Gas. Drilling activity in the Altoona East field occurred in three general periods at about 10-year intervals. As early as 1894, the area was tested for gas, and by 1908 several small gas producers had been drilled (Haworth, 1908, pl. XIX). The first good production, however, and the development of the field as a gas producer, was not until 1917, when production from the
"First Bartlesville sand" at about 244 m (800 ft) depth and from the "Third Bartlesville sand" at about 305 m (1000 ft) depth, was obtained in Sec. 3, T 29 S, R 17 E. Wells came in at more than 28,300 m³ (1 Mcf) of gas per day and lasted three to seven years before depletion. By 1924 most of these wells had been abandoned, and the urgency for gas made smaller producers profitable. Between 1924 and 1928, therefore, many "shale gas" wells were drilled in this area. They obtained production of 1416 to 2832 m³ (50-100 mcf) of gas per day at about 180 to 200 m (600-650 ft) depth. Many of the wells were drilled completely through the "Oswego lime" and into the top of the Cherokee Group. These wells generally encountered the "Squirrel sand" directly under the "Oswego lime" and obtained an additional strong flow of gas from that zone. Since 1935, many small areas of gas accumulation were discovered in the Altoona East field and gas production from the Wilson County part of the "Altoona-Earlton pool" area of the Altoona East field totalled about 12 million m³ (425 Mcf) of gas within a 5 year period (Ver Wiebe and others, 1955). Production from 25 to 35 wells averages about 2.3 million m³ (80 Mcf) of gas per year.

**Benedict Oil and Gas Field**

Oil. Oil production from the Benedict field area was obtained at least as early as 1896. In that year several producing wells were drilled both north and south...
of Benedict. Production was from the "Second Bartlesville sand" at 300 to 335 m (1000-1100 ft) depth in 8 to 24 m (25-80 ft) of sand. Drilling and discovery of small production continued intermittently until 1919, when a period of increased activity was initiated and several new pools mainly west and south of Benedict were brought in. The wells produced either from the "First Bartlesville sand" at about 300 m (975 ft) depth or from the "Second Bartlesville sand" at a depth of about 320 (1050 ft). Each sand was 3 to 6 m (10-20 ft) thick. Activity declined in about 1923 but increased again in 1928 when the pool two miles south of Benedict was discovered. A new pool about 3 km (2 mi) southeast of Benedict was discovered in 1953. Production was from the "First Bartlesville sand" at about 290 m (950 ft) depth in 5 m (15 ft) of sand. The wells produced 25 to 30 barrels per day of 31° API gravity oil. One well flowed naturally for five weeks before being put on the pump. Oil from the "Second Bartlesville sand" in the Benedict field is 28° to 31° API gravity.

Gas. The Benedict oil and gas field is recorded as the site of the first discovery of gas in large quantity in the county according to a newspaper account (Wilson County Citizen, June 12, 1874; see p. 435 this report), but there is no record of any specific attempt to obtain production of gas or oil from this area prior to 1895. In that year Guffey and Galey brought in a strong gas well near Benedict. After a period of idleness, a pipeline was laid
to Chanute, and for more than two years this one well supplied the entire city of Chanute (Haworth, 1908, p. 186). Gas in quantity was found northeast of Benedict in 1898, and several wells averaging more than 28,000 m$^3$ (1 Mcf) of gas per day were completed at about 320 m (1050 ft) depth and furnished the gas supply for both Benedict and Chanute. The main production was from the “Second Bartlesville sand” which was about 8 m (25 ft) thick, but gas from the “Oswego lime” was obtained also. By 1902 the productive area extended 3 km (2 mi) north and west of town, 1.6 km (1 mi) east, and 6 km (4 mi) south (Haworth, 1903, map facing page 38). Production from the “Second Bartlesville sand” had been developed in a large gas field northwest of Benedict by 1908 (Haworth, 1908, pl. XIX).

Between 1913 and 1916, several good gas wells with initial productions of 28,000 m$^3$ (1 Mcf) per day or more were drilled 5 km (3 mi) southwest of Benedict in the “First Bartlesville sand” at 290 to 305 m (950-1000 ft) depth and in the “Second Bartlesville sand” at about 335 m (1100 ft) depth. Wells with a million or more cubic feet per day gas production from the “First Bartlesville sand” were also drilled 1.6 to 3 km (1-2 mi) east of Benedict during this period. Production from younger beds was of the “contributory” type only and from small areas (Plate 11B, D, E).
Buffalo Oil and Gas Field

Oil. The discovery of oil and gas in the Buffalo field preceded the turn of the century, as recorded in the May 12, 1899 issue of the Wilson County Citizen, which stated that "near Buffalo, one mile from town ...is a magnificent gas well .... There are also six flowing wells nearby." By December 1902, 25 oil wells, classed as small producers, had been completed in a sand at 305 to 317 m (1000-1040 ft) depth (Johnson, 1903, p. 335), and the area around Buffalo was considered to be one of the older fields of the district (Haworth, 1903, p. 35). The oil production was principally from wells to the west and southwest of the town. The wells west of town were on the pump from 1902 to about 1907; at least 20 wells in the field southwest of town were producing oil in 1908 (Haworth, 1908, pl. XIX). An oil pool 4 km (2.5 mi) northeast of Buffalo had also been found by 1908 and was being extended. Major periods of activity in the development of that pool occurred in 1911, 1948, and 1958. Production was from the "First Bartlesville sand" at depths of 293 to 300 m (960-985 ft). Two sands, the upper one 1.5 m (5 ft) thick, the lower one 3 m (10 ft) thick, and separated by about 6 m (20 ft) of shale, both contained oil. The lower sand was the one generally produced.

The "First Bartlesville sand" was the chief oil producer of this field (Plate 10 D). The "Second Bartlesville sand" produced mainly in the southern part of
the field (Plate 10 E), and a small amount of production from the "Mississippi lime" had been obtained 3 km (2 mi) and 10 km (6 mi) east of Buffalo (Plate 10 F). Production from rocks of Mississippian age was from a "sandy" zone about 3 m (10 ft) below the top at a depth of about 370 m (1200 ft). The only production from rocks of Ordovician age in the Buffalo field was obtained just southeast of the town at a depth of 457 m (1500 ft). The pool was discovered in November 1924, and the first well produced 75 barrels of oil of about 22° B⁰ gravity. The pool was very small, and its production was cut down rapidly by the encroachment of salt water (Folger and Hall, 1933, p. 23).

Gas. Gas was discovered in 1899 in the Buffalo field, and in 1902 there were 30 gas-producing wells (Johnson, 1903, p. 335), the most prolific gas area being to the north of Buffalo (Haworth, 1904, p. 33). Folger and Hall (1933) record the discovery in 1928 of a gas pool in the center of the southern panhandle of the field; production of gas was from about 460 m (1500 ft). Folger and Hall (1933, p. 24) stated that about 10 wells were drilled, the largest with an open flow of 42,000 m³ (1.5 Mcf); rock pressures were about 315 pounds. They placed the production as being from the "Salt sand," but study of drillers' logs in the area shows the horizon probably to be the top of the "Arbuckle."

The main gas production above the "Arbuckle" was obtained from the "Second Bartlesville sand" (Plate 11 I)
from depths of 320 to 340 m (1050-1120 ft). Initial production ranged from about 10,000 to 180,000 m³ (350-6,500 mcf) per day, highest initial flow being from wells about 5 km (3 mi) east of Buffalo. Rock pressures averaged about 370 pounds. Smaller amounts of gas production were obtained from the "First Bartlesville sand" east and west of Buffalo (Plate 11 H), from the "Squirrel sand" east and northwest of Buffalo and northeast of Roper (Plate 11 G), from the "Oswego lime" as supplementary flow throughout most of the area except for the central part of the field (Plate 11 F), from the "Weiser sand" northeast of Roper and west of Buffalo, from black shales in the lower part of the Kansas City Group northeast of Roper, and from the Iola Limestone just southeast of Buffalo. The Iola Limestone production was obtained in about 1916 from a porous zone in the upper part at a depth of about 60 m (200 ft). Gas flow ranged from about 2800 to 11,200 m³ (100-400 mcf) per day at 20 to 30 pounds rock pressure. In 1942 the pool was converted to a gas storage reservoir with an ultimate storage capacity of at least 7,000,000 m³ (250 Mcf) of gas. In April 1959 a well that had an initial production rated at more than 56,000 m³ (2 Mcf) of gas per day and a rock pressure of 22 kg/cm² (315 psi) was completed just northeast of Roper in the "First Bartlesville sand" at a depth of about 300 m (985 ft).
Buxton Oil and Gas Field

Oil. The Buxton oil and gas field is 3 to 6 km (2-4 mi) south of Buxton in southwestern Wilson County. Inasmuch as the field outlines were established prior to 1920 (Snider, 1920, map on p. 164) the field was probably discovered during the period of increased drilling activity immediately following World War I. Moore and Boughton (1921, map opposite p. 16) show both oil and gas production. Although no logs of the producing oil wells were obtained, dry holes in the area record oil shows in the "First Bartlesville sand" at about 380 m (1250 ft) and in the top of the "Arbuckle" at about 520 m (1700 ft). Presumably, production was small and was from the "Arbuckle," although both zones may have produced in separated areas.

Gas. Gas production was apparently from both the uppermost sandy part of the Stanton Limestone and from the Cottage Grove Sandstone Member of the Chanute Shale (Plate 11 B, C), from depths of 122 to 152 m (400-500 ft).

Coffeyville-Cherryvale Oil and Gas Field

Oil. The Coffeyville-Cherryvale field extends approximately 1.6 km (1 mi) into Wilson County in the extreme southeastern corner. According to Jewett (1954, p. 301, 302), the Cherryvale part of the field was developed in 1904, the chief oil-producing formation being the
"Bartlesville sand." No oil production is indicated in the Wilson County part of the field.

Gas. Logs of wells in Sec. 34, T 30 S, R 17 E, indicate gas production from the "Oswego lime" at depths of 168 to 178 m (550-650 ft).

**Coyville Oil and Gas Field**

Oil. Oil production from the Coyville field dates back at least to 1908, at which time oil was obtained from a well less than 1.6 km (1 mi) east of town (Haworth, 1908, pl. XIX). This oil was apparently from the top of the "Mississippi lime" at approximately 400 m (1300 ft) depth. Exploration in about 1922 extended the Mississippian production to the southeast and discovered "Arbuckle" production south of town at a depth of roughly 500 m (1650 ft). Relatively small production was obtained.

Gas. Gas was produced from the "Squirrel sand" east and northeast of Coyville at depths of 290 to 305 m (950-1000 ft). Wells came in as strong as 45,000 m³ (1.6 Mcf) per day at 26 kg/cm² (375 psi) rock pressure. The "Oswego lime" augmented the production from the "Squirrel sand" locally, as did the "Weiser sand." Gas from the "Weiser sand" was also produced 5 km (3 mi) north of Coyville, beyond the established limits of the field in conjunction with flow from the upper part of the Plattsburg Limestone, the black shales in the Kansas City Group, and the "Second Bartlesville sand" (Plate 11 D, E, I).
Coyville West Oil and Gas Field

Oil. Production, apparently from the "First Bartlesville sand," was obtained in the Coyville West oil and gas field in about 1920. Moore and Boughton (1921, pl. III facing p. 16) show two oil wells in the field in 1921. In 1952 the field was extended to include the "Squirrel sand" (Goebel and others, 1956, p. 139), and production was obtained from both the "Squirrel sand" at about 335 m (1100 ft) and the "First Bartlesville sand" at about 365 m (1200 ft) depth. The combined production amounted to about 1,000 barrels per year of 24° API gravity oil from the "Squirrel sand" and 30° to 32° API gravity oil from the "First Bartlesville sand" (Plate 10C, D; Table 5).

Gas. Gas has been produced from 3 m (10 ft) of "First Bartlesville sand" in a few wells in the field. The strongest recorded flow is 250 mcf at 366 m (1200 ft) depth with a rock pressure of 35 kg/cm² (500 psi).

Fall River Oil and Gas Field

Oil. The Fall River oil and gas field lies entirely in Wilson County. Its southwestern corner, however adjoins part of the New Albany oil field of Elk County. Little oil has been obtained from this field in Wilson County despite its proximity to the prolific New Albany field where the shallow "New Albany sand" has been a good producer since 1920. Oil shows are recorded in the southern pool at 152 m (500 ft) depth in the Cottage Grove Sandstone Member of the
Chanute Shale (the correlative of the “New Albany sand” in the New Albany field) and in the “Weiser sand” of the Bandera Shale. The northern pool produced from the “First Bartlesville sand” at 335 to 350 m (1100-1150 ft) in 1920 and again in 1954 in 9 m (30 ft) of sand. In 1954, 196 barrels of oil were reported from the field (Ver Wiebe and others, 1955, p. 190).

A small pool about 5 km (3 mi) north of the Fall River field, called the “Stryker pool”, produced about 1,700 barrels of oil from the “Bartlesville sand” at about 400 m (1300 ft) depth (Ver Wiebe and others, 1955; Goebel and others, 1956, 1957; W. L. Stryker, verbal commun. June 1954). Earlier production (1924 and 1925) was from a sandy zone at the top of the Plattsburg Limestone or from a sandstone at the base of the Vilas Shale. Production was 50 to 150 barrels per day from a hard sandstone at 140 m (460 ft) depth.

Gas. Gas production was first obtained in the Fall River field in 1904 from the “Second Bartlesville sand” at about 365 (1200 ft) depth, but later production has been mainly from the top of the “Mississippi lime” at 381 to 396 m (1250-1300 ft) depth. Initial production in some wells in 1925 was greater than 28,000 m$^3$ (1 Mcf) per day. Lesser production has been obtained from the Iola Limestone, “New Albany sand,” “Squirrel sand,” and “First Bartlesville sand.” Gas was obtained from the area of the “Stryker
pool" from the “First Bartlesville sand” at about 390 m (1275 ft) depth as early as 1898.

Farmdale Gas Field
Gas. Gas was produced from the Farmdale field between 1922 and 1928. In 1924 and 1925, production was from the “Squirrel sand” at a depth of 260 m (850 ft). The field was small and short-lived.

Fredonia Oil and Gas Field
Oil. The Fredonia oil and gas field covers an area of about 260 km² (100 mi²) and completely surrounds the town of Fredonia. Oil production has been obtained from five separate horizons ranging in depth from 91 to 366 m (300-1200 ft). Throughout most of its life, gas has been more important than oil in the Fredonia field, but in 1959 oil was the most important commodity. Oil was discovered in the Fredonia field in August 1893 on the Hopkins farm in Sec. 3, T 30 S, R 15 E in the “Second Bartlesville sand.” The well was shot with 30 quarts of nitroglycerin between the depths of 312 to 315 m (1023-1034 ft) but was apparently not put into production until 1917.

Shallowest production has come from a small pool located northwest of Fredonia (Plate 10 B). No production figures are available, but apparently the oil was obtained from the “New Albany sand” at depths of 55 to 61 m (180-200 ft). The next shallowest production was in the
northeastern part of the field in the "Weiser sand" (Plate 10 C). Drilling in this sandstone body was most active during the period 1917 to 1921, and production was at a depth of about 215 m (700 ft) in 3 m (10 ft) of sandstone near the top of the Bandera Shale. Twenty-five barrels of oil from the "Weiser sand" were produced from this pool per year (Ver Wiebe and others, 1954, p. 182; pl. 1).

Oil production from the "First Bartlesville sand" has been obtained in only two small areas in the Fredonia field (Plate 10 D). Oil of 36° API gravity oil was obtained from the eastern area of the Fredonia field at a depth of about 275 m (900 ft) in 6 m (20 ft) of "First Bartlesville sand." Production amounted to slightly more than 100 barrels per year. The eastern pool was discovered in 1904, and the first wells came in at three to 10 barrels per day. The western pool was discovered in about 1929 and produced oil from about 3 m (10 ft) of "First Bartlesville sand" at 323 to 326 m (1060-1070 ft) depth.

The first oil obtained from the "Second Bartlesville sand" was in 1907 in Sec. 12, T 29 S, R 15 E at about 335 m (1100 ft) depth. The sand was about 12 m (40 ft) thick and had gas in the upper 3 m (10 ft) and oil in the lower 9 m (30 ft).

The largest and most prolific oil pool in the "Second Bartlesville sand" in the Fredonia field is located about 8 km (5 mi) southeast of town. Oil was discovered at depths of 335 to 365 m (1100-1200 ft) in 1917, and the pool was
named the Volunteer Field. Gas was found in the upper 3 m (10 ft) of sand; oil was in the lower 9 m (30 ft). Development was fairly rapid, and by 1920 more than 30 wells were producing from about 9 m (30 ft) of sand at a depth of about 350 m (1150 ft). The wells were shot with 40 to 60 quarts of nitroglycerin and flowed 10 to 200 barrels initially. The March 8, 1918 issue of the Wilson County Citizen recorded that the Volunteer No. 6 Well came in at "200 barrels initial production but should settle down to 35-50 barrels soon." This pool has been a very steady producer throughout the years averaging about 5,000 barrels per year. A small water-flood operation was started in 1955.

The "Second Bartlesville sand" is also the main producer in the pools just north of Fredonia. The sand is about 6 m (20 ft) thick and at a depth of 320 to 329 m (1050-1080 ft). These pools were discovered about 1915 and were developed and produced until 1927, when most of the wells were plugged and abandoned. The area was reopened and produced about 60 barrels of 26° to 32° API gravity oil in 1953 (Ver Wiebe and others, 1954, p. 182). Production increased to about 300 barrels in 1954 (Ver Wiebe and others, 1955, p. 190) and in 1955 was about 2,000 barrels (Goebel and others, 1956, p. 219). In 1956 production declined to about 1,550 barrels (Goebel and others, 1957, p. 224), and in 1957 it was about 650 barrels (Goebel and
others, 1958, p. 237). Production stabilized at about 500 barrels for several years.

The "Second Bartlesville sand" contained oil in two other small pools about 5 km (3 mi) south of Fredonia. The sand is 0.6 to 3 m (2-10 ft) thick at a depth of about 310 m (1025 ft). First production was obtained in 1919, but the southernmost pool was reopened in about 1949, and approximately 700 barrels per year of 28° API gravity oil were produced in the 1950's. Most of the wells were plugged and abandoned in 1957.

Oil production in the southernmost part of the field came from both the "Second Bartlesville sand" and the top of the "Mississippi lime." Oil was first produced in 1918 and 1919 from the "Second Bartlesville sand" at a depth of 366 to 381 m (1200-1250 ft). Initial production of 40 to 50 barrels was common. The pool was apparently reopened in 1953, and about 15 wells were intermittently in production for several years. Production of a small amount of oil from the top of the "Mississippi lime" at about 400 m (1300 ft) is also indicated on well logs. Production records show that about 300 barrels of 27° API gravity oil were produced per year in the 1950's. A small pool 3 km (2 mi) to the northeast was also reopened and produced oil from the "Second Bartlesville sand" at about 297 m (975 ft) depth in 5 m (15 ft) of sand. Production amounted to 700 barrels per year of 33° API gravity oil. The pool was discovered and produced originally in 1920-21.
Gas. Gas has been found in abundance in the Fredonia oil and gas field, the area of occurrence being considerably greater than that of oil (Plate 9 A). The first gas pool in this field was located about 3 km (2 mi) south of Fredonia in the NW 1/4 Sec. 24, T 29 S, R 14 E and was developed by the Kansas Natural Gas Company. Production began in 1895, and in the late 1950's gas sufficient for local farm use was still flowing. By 1903 a number of fair gas wells had been obtained, some within about 1.6 km (1 mi) or less of the town. Concerning these wells, Haworth stated "one interesting feature is that Fredonia has some shallow gas, being obtained at a little over 90 m (300 ft) beneath the surface" (Haworth, 1904, p. 34). The shallow gas occurred in the Cottage Grove Sandstone Member of the Chanute Shale ("New Albany sand") in a small structure in Secs. 7 and 8, T 29 S, R 15 E on the flank of the Fredonia Dome. This initial period of drilling (1903-09) was followed by two other periods, 1913-15 and 1928-30, in both of which additional good wells were drilled in this and adjacent pools. Elsewhere in the Fredonia field, good flows of gas were obtained from the "New Albany sand."

Wells good for 56,000 m³ (2 Mcf) per day of gas were drilled in this horizon in 1909 in Sec. 25, T 29 S, R 14 E; in 1918-20, 4200 m³ (150 mcf) of gas per day or more was found in the "New Albany sand" at about 80 m (260 ft) depth in Sec. 30, T 29 S, R 15 E; and in 1924 and again in 1938,
8400 to 56,000 m$^3$ (300-2000 mcf) of gas were obtained at 91 to 107 m (300-350 ft) depth in the “New Albany sand” in Secs. 27 and 28, T 28 S, R 14 E.

The next important gas-producing horizon below the “New Albany sand” is the “Weiser sand” (Plate 11 E) although small contributing flows may have been obtained from black shales and sandy zones in the Kansas City Group in several small areas (Plate 11 D). The largest area of production from the “Weiser sand” was in the eastern part of T 29 S, R 15 E. A well drilled in Sec. 5, T 29 S, R 14 E, came in at 18,200 m$^3$ (650 mcf) at a depth of 213 m (700 ft) in 6 m (20 ft) of “Weiser sand”. The black shales in the “Oswego lime” contributed generally to flow from other horizons throughout the area, but “shale gas” was not a prime target in this area as it was in the Altoona and Vilas fields. Production from the “Squirrel sand” was of minor importance in this field occurring in small areas only (Plate 11 G).

As early as 1903, wells with 14,000 m$^3$ (500 mcf) of gas per day were drilled to the “First Bartlesville sand” at a depth of 267 m (875 ft) in a small area in Sec. 36, T 29 S, R 15 E. Later and more significant production in this horizon came from areas north and south of Fredonia. The gas from the “First Bartlesville sand” north of Fredonia generally supplemented that of the “Second Bartlesville sand.” South of Fredonia, however, the “First Bartlesville sand” was the principal producer. Flows of
14,000 to 19,600 m³ (500-700 mcf) of gas per day were obtained at about 323 to 326 m (1060-1070 ft) around 1910 and again in 1930.

Deepest production of gas in the Fredonia field was from the “Mississippi lime” in the western, eastern, and southern parts of the field (Plate 11 J). Gas production was obtained from 1907 to 1914 at the top of the Fredonia Dome in Sec. 10, T 29 S, R 15 E from chert at the top of the “Mississippi lime,” and from a sandstone lying directly upon beds of Mississippian age. The sandstone falls in the vertical interval of the “Second Bartlesville sand” and is so classed in this report, although it could also be classed as “Burgess sand.” Wells came in at 84,000 to 140,000 m³ (3-5 Mcf) per day at depths of 305 to 350 m (1000-1150 ft). Production was supplemented by flows from the “First Bartlesville sand.” Wells with initial capacities of 14,000 to 56,000 m³ (500-2000 mcf) of gas per day were in production about 1910 from the “Second Bartlesville sand” and the “Mississippi lime” in the area around Sec. 30, T 29 S, R 15 E, and as far south as Sec. 20, T 30 S, R 15 E. The area was drilled in 1909-12 and again in 1918-20, production coming from depths of 328 to 342 m (1076-1124 ft).

The effect of these discoveries on industrial development in this area is well stated by Haworth (1908, p. 226), who noted that in 1907 “Another commercially important field developed within the past year lies east of
Fredonia. The wells here are not very large, ranging from three to five Mcf, but the field is so situated that the flow is consumed by various nearby manufacturing industries."

**Humboldt-Chanute Oil and Gas Field**

**Oil.** Exploratory drilling was begun about 1897 in the part of the Humboldt-Chanute oil and gas field that lies in Wilson County, and oil was discovered there sometime prior to 1907. By 1908, separate pools had been developed in Secs. 15 and 27, T 27 S, R 17 E, and Sec. 15, T 28 S, R 17 E (Haworth, 1908, pl. XIX). Production ranged from five to 20 barrels per day from about 9 to 15 m (30-50 ft) of "Second Bartlesville sand" at depths of about 275 to 300 m (900-980 ft). These areas were redrilled in 1915-18 and again in 1949-51 with considerable success, the new hydraulic-fracturing techniques making possible initial productions of 10 or more barrels per day in the later period.

**Gas.** The first gas production from the part of the Humboldt-Chanute field that lies in Wilson County was in 1901, when a small gas well was discovered by the Forest Oil Company in Sec. 9, T 28 S, R 17 E. The well produced "shale gas" from the "Oswego lime" at a depth of about 215 m (700 ft). The Wilson County part of the field did not, however, become an important gas producer until 1924-27, when the area underwent intensive drilling for "shale
Most of the "Oswego lime" wells drilled in the field had initial productions of 2832 to 14,160 m³ (100-500 mcf) per day. Production was from depths of about 200 to 215 m (650-700 ft), and the wells averaged nearly 100,000 m³ (3.5 Mcf) per day. Several wells were drilled to depths of about 290 to 305 m (950-1000 ft) and encountered 28,320 to 56,640 m³ (1-2 Mcf) of gas in the "Second Bartlesville sand." Production was also obtained in a few wells from the "Weiser sand" at about 170 m (550 ft), from the "Squirrel sand" at about 230 m (750 ft), and from the "First Bartlesville sand" at about 245 m (800 ft).

**LeFontaine Oil and Gas Field**

**Oil.** Exploratory drilling in this field began soon after the discovery of oil at Neodesha, and in 1896 drilling crews were active in the vicinity of LaFontaine (Morgan, 1902, p. 888). Schrader and Haworth (1906, p. 23) recorded that drilling in 1904 near LaFontaine resulted in oil wells of small production. The oil apparently came from the "First Bartlesville sand" at about 350 m (1150 ft) depth.

**Gas.** The Wilson County Citizen (March 22, 1918) recorded several drilling companies at work near LaFontaine, the drilling resulting in a good shallow gas field (Plate 11 C) at about 91 m to 107 m (300-350 ft) depth in the "New Albany sand."
Neodesha Oil and Gas Field

Oil. The Neodesha oil and gas field covers about 192 km² (75 mi²) in southeastern Wilson County. It is the major oil and gas producing field in the county. The first commercial oil well, the first commercial gas well, and the oil wells with the greatest initial production were drilled in this field. Drilling of the first commercial oil well, the T. J. Norman No. 1, began on November 28, 1892 at the southeast corner of Neodesha, but it was not shot or produced until October 4, 1893. When shot it flowed more than 370 barrels per day (Smiley, 1931a, p. 15; 1931b, p. 99-100). Drilling was active the next two years, and by 1895, “Sixty-eight wells were drilled, all within a radius of five miles of Neodesha, three being strong gas wells, and the greater majority of the remainder producing oil in paying quantities” (Morgan, 1902, p. 888). Sixty-five of the oil wells were netting about 800 barrels daily (Smiley, 1931b, p. 100); many of them had “an initial production of right around 100 barrels per day” (Haworth, 1904, p. 33), and about 150,000 barrels of oil was stored in tanks at the end of 1895. There were 161 producing oil wells in the field on July 1, 1903 (Haworth, 1904, p. 27), and oil activity reached a peak early in 1904 when the price of crude oil hit a high of $1.38 per barrel. This quotation lasted only a few days before the price began to drop and eventually reached the low price of 50 cents a barrel early in 1905 (Haworth, 1908, p. 215). At the peak of the
period, development about Neodesha extended northwest, west, south, and southeast from that city (Haworth, 1904, 33). The number of producing wells in the field reached almost 300, resulting in the production of about 600,000 barrels of crude. Also, the year 1895 saw the drilling of the Neodesha deep well by the Forest Oil Company immediately after they purchased the Neodesha oil properties from Guffey and Galey. The well went to a depth of 735 m (2412 ft) and bottomed in Precambrian granite. Cuttings, which were taken throughout the drilling, are described in Haworth (1908, p. 62-64).

Oil production in the Neodesha field was predominantly from the “First Bartlesville sand”; areas of production from other horizons were relatively small and scattered except for the “Second Bartlesville” sand-trend pools in the northeastern and southeastern parts of the field (Plate 10 C, D, E). The shallowest production came from the “Weiser sand” in the northern, eastern, and southwestern parts of the field. The Neodesha-Thayer pipeline of 1902 provided a direct connection for this oil production to be sent to the Standard Oil Company’s Neodesha refinery; the first oil was transported about the middle of December in 1902 (Haworth, 1908, p. 34). The northernmost “Weiser” pool in the Neodesha field produced shallow oil starting in 1950 at depths of 129 to 131 m (425-430 ft). Withdrawal has amounted to an average of about 600 barrels per year of 24° to 26° API gravity oil. “Weiser sand” production was
also obtained about 3 km (2 mi) to the southwest (Plate 10 C) at a depth of about 137 m (450 ft). Production from this pool also included 36° API gravity oil from the “First Bartlesville sand” at a depth of about 260 m (850 ft). The deeper production was first obtained between 1916 and 1917 but soon decreased in quantity. Later production has averaged about 2,000 barrels per year.

The production from the “First Bartlesville sand” was from depths ranging from less than 245 m (800 ft) in the southern part of the field to more than 270 m (900 ft) in the northwestern part of the field. An essentially continuous oil pool, about 6 km (3.5 mi) in width and eight miles or more in length, encompassed the area under and surrounding the town of Neodesha (Plate 10 D). Oil from this pool ranged in gravity from 33° to 39° API, the highest gravity was in the south-central part of the pool. Producing sands in this pool were not all interconnected, both structural and stratigraphic irregularities tending to separate the areas of accumulation. In some places small irregular upwarps delimited the boundaries of production; in others, structure had no apparent effect, but sand thickness and permeability seemed to be the controlling characteristics.

The large pool at Neodesha was the discovery pool of the southeastern Kansas area. About 10 wells were drilled in Secs. 8, 17, 19 and 20, T 30 S, R 16 E between 1892 and 1894, and all were completed as producers with initial
productions averaging 10 to 20 barrels per day. Drilling for oil was almost continuous between 1894 and 1908, wells ranging from 10 to 30 barrels upon completion being common. Several outstanding wells, all producing from the "First Bartlesville sand" at depths ranging from 236 to 251 m (775-825 ft), came in at 75 to 125 barrels during this period. A few wells went to the "Second Bartlesville sand" but obtained only small production. It was not until the period of increased oil demand during World War I that the lower sand was thoroughly tested. Many of the wells producing from the "First Bartlesville sand" were deepened, and many new wells were drilled. In this area the "Second Bartlesville sand" had two separate horizons, one near the top at about 270 m (890 ft) depth, the other near the base at about 297 m (975 ft) depth. Oil from the upper "Second Bartlesville sand" was locally produced in conjunction with the "First Bartlesville sand" where both contained oil. Generally, however, the "Second Bartlesville sand" contained gas rather than oil. The wells drilled from 1916 to 1921 averaged 10 to 20 barrels initial production, 30- to 35-barrel wells being exceptionally good. Several good wells were brought in between 1933 and 1936, and again in the late 1940s and early 1950s, mostly by redrilling of old pools. Some of the wells drilled between 1950 and 1958 had excellent initial production following fracture-treatment. The third well in a small pool being redrilled in 1956 in Sec. 16, T 30 S, R 16 E, for example, had an initial
production of 74 barrels per day and flowed for eight months before being put on the pump. Most of the oil from this pool came from about 6 m (20 ft) of "First Bartlesville sand" at 235 to 244 m (770-800 ft) depth. Production in the 1930's in this pool came from the "Second Bartlesville sand" as well, at depths of 262 to 268 m (860-880 ft).

The large pool at Neodesha produced about 475,000 barrels of oil in a ten year period. This figure includes about 8,000 barrels produced from a small pool in the "Weiser sand" immediately to the southwest of Neodesha, and about 3,300 barrels from a small "Bartlesville sand" pool about 5 km (3 mi) northeast of Neodesha. The production from the "Weiser sand" came from about 3 m (10 ft) of sandstone at depths of 140 to 146 m (460-480 ft). Production 5 km (3 mi) northeast of Neodesha came from the "First Bartlesville sand" at depths of 250 to 256 m (820-840 ft).

The greatest production from the "Second Bartlesville sand" in the Neodesha field was obtained from a sand trend in the northeastern part of the field. This sand trend was prospected at its southwestern end in 1894 but apparently without success. By 1921 a productive well had been drilled at the northeastern end of the trend (Moore and Boughton, 1921, pl. III), but the first developmental drilling seems to have been in 1927 and 1928. In 1935 a secondary recovery operation began, and between 1935 and
1938 many of the old wells were deepened and shot, and water input wells were drilled. A third period of increased activity apparently occurred between 1940 and 1944 when the Gilliland Carr water-flood project was in operation (Grandone, 1944, p. 142-144). The oil was from about 9 m (30 ft) of “Second Bartlesville sand” at depths of about 250 to 265 m (825-875 ft) and averaged about 30° API gravity. Data on initial production of oil in wells drilled early in the history of this pool were not available, but six wells drilled between 1946 and 1949 recorded six to 25 barrels per day and averaged 11 barrels. The pool was under water flood from 1949 to 1958, and during that time nearly 200,000 barrels of 28° to 30° API gravity oil was produced. Just southwest of the pool, and probably on the same trend, is another area in which production is from the “Second Bartlesville sand” at depths of 262 to 274 m (860-900 ft). Oil was not discovered there until about 1920, although a 12-barrel well had been drilled in a very small pool about a mile to the west in the same zone in 1896 (Plate 10 E). Production soon lagged, and in 1927 many of the wells were abandoned and plugged. The pool was apparently reopened in 1949 with the production of 546 barrels of oil (Ver Wiebe and others, 1950, p. 166). About 1000 barrels of oil per year were produced from this pool during the 1950’s.

Gas. The first search for a gas supply for the town of Neodesha was in 1892 and resulted in the discovery of
oil. Gas was found in June 1893 at the J. J. Haag farm in Sec. 14, T 30 S, R 15 E on the banks of the Fall River (Morgan, 1902, p. 888), and although gas was the chief objective of exploration, 13 of the 15 wells drilled in 1893 found oil rather than gas. However, gas was found in sufficient quantity, was piped into the city, and on July 4, 1894, was lighted for the first time (Haworth, 1908, p. 29). Three strong gas wells were completed within 8 km (5 mi) of Neodesha late in 1895 (Morgan, 1902, p. 888), and three more excellent gas wells were completed about 6 km (4 mi) east of Neodesha in 1896. The wells had initial productions of 283,200 to 339,840 m$^3$ (10 to 12 Mcf) per day (Haworth, 1904, p. 34). The gas came from a sandstone body 15 to 24 m (50-80 ft) thick in the stratigraphic interval of the Cherokee Group normally occupied by the Ardmore Limestone. For this reason, the area where this zone was productive is shown on both the “First Bartlesville sand” and the “Squirrel sand” maps (Plate 11 G, H). The depth to the productive zone was 195 to 229 m (640-750 ft). The best producing wells were drilled between 1903 and 1908, and production ranged from about 140,000 to 400,000 m$^3$ (5-14 Mcf) of gas per day per well. The average production of the wells was about 226,000 m$^3$ (8 Mcf) of gas per day. Rock pressures averaged about 9 kg/cm$^2$ (130 psi).

Two other periods of drilling, 1935 to 1937 and 1943 to 1944, resulted in only moderate production from the “First Bartlesville sand” in this area. Shallower
production from the “New Albany sand,” from sandstone and black shale of the Kansas City Group, from the “Weiser sand,” the “Peru sand,” and the “Oswego lime” in small, scattered areas throughout the Neodesha field (Plate 11 C, D, E, F) added 4,248 to 14,160 m³ (150-500 mcf) per day to the open flow of the deeper producers. The “New Albany sand” and rocks of the Kansas City Group were reached between 61 and 146 m (200-480 ft) depth, and the “Oswego lime” between 190 and 198 m (625-650 ft). “Shale gas” from the “Oswego lime” was mostly contributory to other production and amounted to only 1416 to 5664 m³ (50-200 mcf) of gas per day. A few “shale gas” wells with capacities of 11,328 to 14,160 m³ (400-500 mcf) of gas per day were completed in the western part of the field. Shallow wells producing 3540 to 6372 m³ (125-225 mcf) of gas per day were completed in the southeasternmost part of the field in 1910 to 1914; many “shale gas” wells were drilled in the Neodesha field in 1928 and 1929.

Production from the “First Bartlesville sand” east of Neodesha but west of the belt in which production came from both the “Squirrel sand” and the “First Bartlesville sand” (Plate 11 G, H) was obtained mainly between 1903 and 1911. Many wells had initial productions between 56,640 and 113,280 m³ (2-4 Mcf) gas per day with rock pressures of 17 to 19 kg/cm² (230-275 psi), but most had initial productions of 8496 to 14,160 m³ (300-500 mcf) of gas per day. Locally, two sands 9 m (30 ft) apart comprised the
"First Bartlesville sand." Each sand was about 7 m (20 ft) thick and contained gas, but the lower of the two sands was the most productive, yielding as much as 19,824 m$^3$ (700 mcf) of gas per day.

Production of gas from the northeastern part of the field was obtained from both the "First Bartlesville sand" at depths of 213 to 237 m (700-780 ft) and the "Second Bartlesville sand" at depths of 259 to 277 m (850-910 ft), with contributory production from the "Squirrel sand" at about 213 m (700 ft) depth, from black shales of the "Oswego lime" at depths of 172 to 191 m (575-625 ft), and from the "Weiser sand" at depths of 137 m to 152 m (450-500 ft). Highest initial production from wells in the "First Bartlesville sand" in this area was 42,480 to 107,616 m$^3$ (1.5-3.8 Mcf) of gas per day. Maximum initial production from the "Second Bartlesville sand" was from 28,320 to 84,960 m$^3$ (1-3 Mcf) of gas per day with rock pressures of 11.8 to 23.6 kg/cm$^2$ (170-340 psi). Several good wells in the "Second Bartlesville sand" had initial flows between 7080 and 14,160 m$^3$ (250-500 mcf) of gas per day at rock pressures of 9.7 kg/cm$^2$ (140 psi). Gas production greater than 28,320 m$^3$ (1 Mcf) per day and with a rock pressure of 19.4 kg/cm$^2$ (280 psi) has been obtained from the "Squirrel sand" in the northeastern corner of the field. A few "shale gas" wells in that part of the field had initial productions greater than 28,320 m$^3$ (1 Mcf) of gas per day, but most of them produced only 5,664 to 11,328 m$^3$ (200-400 mcf) of gas per day.
mcf) per day. Gas from the "Weiser sand" was practically all contributory production but in places amounted to almost 17,000 m³ (600 mcf) at 11.8 kg/cm² (170 psi) rock pressure.

Other production from the "Second Bartlesville sand" was in the area immediately surrounding Neodesha (Plate 11 I). Accumulation was somewhat spotty and ranged in depth from 244 m (800 ft) in the small pools just east of town to as much as 305 m (1,000 ft) in the small pools west of town. Wells drilled between 1902 and 1905 averaged about 85,000 m³ (3 Mcf) of gas per day and commonly came in at 42,480 to 155,760 m³ (1.5-5.5 Mcf) per day. Rock pressures ranged from 13.1 to 21.8 kg/cm² (190-315 psi). Many of the wells lasted five to 10 years before abandonment. The history of the Sipple No. 1 well in Sec. 7, T 30 S, R 16 E, is more or less typical of these wells. The Sipple No. 1 was spudded March 28, 1902, and was completed April 12, 1902 for 141,600 m³ (5 Mcf) of gas per day in 6 m (19 ft) of "Second Bartlesville sand" between 305 and 311 m (1002-1021 ft) depth. On November 5, 1904, the well was cleaned out and drilled about 1.5 m (5 ft) deeper in the sand. Gas volume came back to 28,320 m³ (1 Mcf) of gas per day. On March 27, 1905, the well was cleaned out and drilled about 2.4 m (8 ft) deeper. Gas volume increased to about 48,000 m³ (1.7 Mcf) of gas per day. On September 1, 1905, the well was cleaned out and drilled deeper in sand. Gas volume increased again to about 48,000 m³ (1.7 Mcf) per
day. In June 1911, the equipment was pulled, and the well was plugged. Wells completed in the "Second Bartlesville sand" between 1912 and 1917 generally came in at approximately 14,000 m³ (500 mcf) per day.

The deepest gas production in the Neodesha field was obtained in 1886 and again in 1916 from the "Mississippi chat" in Secs. 28, 29, and 31, T 29 S, R 17 E. Production as great as 56,640 m³ (2 Mcf) of gas per day was recorded. About 28,300 m³ (1 Mcf) of gas came from the "chat" at 294 to 299 m (965-985 ft) and an additional 28,320 m³ (1 Mcf) from the "Third Bartlesville sand" at 267 to 274 m (875-900 ft). Several other good gas wells obtained production from the "Third Bartlesville sand" in this pool. The "Peru sand" in the Labette Shale, about 6 m (20 ft) thick, added contributory gas to the "Third Bartlesville," "First Bartlesville," and "Oswego lime" production in this area. This is the only gas from the "Peru sand" in the county.

**Neodesha East Oil and Gas Field**

Oil. The Neodesha East oil and gas field is near the southeastern corner of Wilson County. Prior to 1950 it was considered to be a gas field only, but in that year oil in sufficient quantity to be produced was found in the "Second Bartlesville sand" at 275 to 285 m (905-935 ft) depth. Several additional wells were drilled and the production was increased from 328 barrels to 835 barrels. About 500
to 5000 barrels per year of 28° API gravity oil were produced from 5 or so wells in this small field in the 1950's and 1960's.

**Gas.** Gas was found in the "Second Bartlesville sand" in 1912; the discovery well showed an open flow of 50,970 m³ (1.8 Mcf) of gas per day. In 1954, 29 wells in the field produced 2,343,064 m³ (82.7 Mcf) of gas (Ver Wiebe and others, 1955, p. 199).

**New Albany Townsite Oil and Gas Field**

**Oil.** Oil was apparently discovered at New Albany in about 1903 (Williams, 1904) and again in 1918 when shallow oil was found at a depth of about 140 m (450 ft) in the "New Albany sand." In 1920 encouraging shows of oil were recorded in the top of the "Mississippi lime" at 384 to 390 m (1260-1280 ft), but little if any oil was produced.

**Gas.** According to Haworth (1904, p. 34), shallow gas was found at New Albany in about 1903. Drillers logs indicate that the production came from the "New Albany sand" at 122 to 152 m (400-500 ft) depth. Williams (1904) stated that "oil and gas have lately been discovered at this place [New Albany] and the town uses natural gas for fuel and light."

**Vilas Oil and Gas Field**

**Oil.** Oil production from the Vilas Field has been entirely from the "Bartlesville" zones. Production from
the "First Bartlesville sand" was brought in as early as 1904 to the east and north of Vilas (Plate 10 D) at about 250 m (825 ft) depth. The gravity of the oil produced from this sand was 28° to 30° API. "Second Bartlesville" production (Plate 10 E) occurred generally at depths between 297 and 305 m (975-1,000 ft) and consisted of 23° to 28° API gravity oil. More than 57,000 barrels of oil were produced from this field in 10-year periods.

Gas. The earliest successful drilling for gas in the Vilas field area was in 1899 when wells were brought in about 1.6 km (1 mi) southwest of Vilas at a depth of 320 m (1,050 ft) in the "Second Bartlesville sand". In 1902 Col. F. E. Isett organized the Isett-Irwin Oil and Gas Company which took leases near Vilas. In 1902 and 1903, areas north, east, and south of town were actively developed, and one well with an initial flow of 566,400 m³ (20 Mcf) of gas was brought in. Other wells with initial flows of 311,520 m³ (11 Mcf) of gas per day were common when drilled to the "First Bartlesville sand" at about 250 m (825 ft) depth. (Haworth, 1908, p. 34). The wells produced gas for five to 20 years before being plugged and abandoned. Development was at its peak about 1907 for, according to Haworth (1908, p. 225-226), "The most remarkable individual field discovered is about six miles southwest of Chanute. Here, on the high land between Neosho and Verdigris Rivers, a field has been developed almost entirely within the past year; some wells of this district are so large as to
compare favorably with the best wells drilled in Montgomery County two years ago. Wells ranging from two to 30 Mcf of gas per day seem to be comparatively common."

By 1925 the larger producers were rarities, and drilling was mainly for "shale-gas" production from the "Oswego lime" (Landes, 1937, p. 99). In 1933 Folger (Folger and Hall, 1933, p. 23, 24) stated that "the best known gas field of the county [Wilson] is the old Vilas field located about two miles east of that town. This pool, extending north-south is five miles in length by three-quarters of a mile in width, and furnished wells of five to 40 Mcf open flow. The lenticular sand body, in the upper Bartlesville zone, ranges in thickness up to a maximum of 140 feet. Some lenses were redrilled a second time and a third time after the demand for oil increased with the dwindling of the eastern Kansas reserves. The original rock pressure of about 300 pounds is now only two pounds, and the volumes of the wells from the last redrilling only 50,000 to 100,000 cubic feet."

Shale-oil, Phosphate, and Fertilizer Resources

In a general geologic sense, many marine black shales may be classed as oil shales. Because of their large amounts of carbonaceous organic matter, fluid and gaseous hydrocarbons can be produced from these shales by destructive distillation (pyrolysis). These shales are thinly laminated and commonly contain more than one percent
organic carbon in conjunction with small quantities of genetically interrelated uranium and phosphate. A marine origin is inferred on the basis of the fossil content and the lithologic uniformity of the rock over tens or hundreds of thousands of square miles. However, most of these shales contain recoverable oil in such small quantities, less than 15 gallons of oil per ton, that it is doubtful that they will be considered as a source of oil for many decades (Swanson, 1960, p. 3).

In southeastern Kansas, Runnels and others (1952, p.163) determined that the black, platy, fissile shales yield oil from trace amounts to a maximum of 22.8 gallons of oil per ton of shale. Schlinsog (1982) also studied the black, fissile shales of southeastern Kansas in order to determine their oil producing capacity. His work showed the Heebner Shale Member of the Oread Limestone, the Eudora Shale Member of the Stanton Limestone and the Anna Shale Member of the Pawnee Limestone as having the highest oil contents; 10.5, 16.4 and 18.3 gallons of oil/ton respectively (Schlinsog, 1982, p. 33, 34). The Heebner had an average vitrinite reflectance of 0.37% (range 0.23-0.47); the Eudora had an average of 0.40% (range 0.32-0.46); the vitrinite reflectance of the Anna shale was not measured. Since the optical properties of the organic matter most closely resemble those of woody plants, the vitrinite was probably derived from the higher plants,
rather than from plant material of an algal origin (Schlinsog, 1982, p. 37, 56).

The fissile black shale beds such as the Heebner and the Eudora contain abundant nodules and bands of phosphorite. As pointed out earlier, in Pennsylvanian time Kansas lay astride or just north of the equator where marine waters were warm and the phosphate-rich bottom waters could reach the concentration for phosphate-ion saturation. At that concentration, phosphorite either precipitates directly or replaces existing carbonate material (Manheim and others, 1975; Heckel, 1977; Malinky, 1980). Under those conditions, the total phosphate, particularly in the nodules, could reach 27 to 34 percent which, in conjunction with (1) oil yields greater than 10 gallons of oil per ton, (2) small but consistent uranium content, and (3) a nearby market for rock wool, road metal, rip-rap and other associated products, could be an economically feasible undertaking (Schlinsog, 1982, p.65-69). Furthermore, the phosphate content of 27-34% in the black shales is sufficient to serve as a potential source of fertilizer alone (Rose and Hardy, 1967).

**Coal Resources**

Coal occurs in two formations at the surface in Wilson County, and in the subsurface it has been recorded in the formations of the Cherokee Group in the logs of several wells. The youngest coal bed is in the upper part of the
Lawrence Shale. It is tentatively correlated with coal that is mined about 80 km (50 mi) to the north near Williamsburg, Franklin County. The Upper Williamsburg coal bed is only 1.3 to 6.4 cm (0.5-2.5 in) thick and is not of minable thickness in Wilson County. However, this coal has a much lower sulfur content than other coals in Kansas, only one or two percent S (Brady and others, 1976, p. 26) and it is gathered locally for home use in wintertime. Other coal beds that occur at the outcrop in Wilson County include the Upper Sibley soal bed beneath the Westphalia Limestone Member of the Stranger Formation and the coal beds in the Chanute Shale.

Outcrops of coal in the Chanute shale in the southeastern part of Wilson County were known from the time of the earliest settlement, and many farmers mined coal on their own properties and let others dig a winter’s supply for a dollar or two. A few small mines were operated commercially during the winters, and the coal was hauled by wagon to Neodesha and adjoining towns (Haworth, 1898a, p. 133). As noted by Haworth (1898a, p. 50): “The coal is most abundant near the surface to the west and southwest of Thayer where it is mined by stripping and by tunneling, and it supplies a large local demand.” The locations of many of these mines were shown on the atlas maps of Wilson County prepared during the early days of settlement. Whitla (1940, p. 62) pointed out that most of the mines in Wilson County are drift mines, but that one strip mine, the
Dunbar, was operated during 1939 in Sec. 21, T 29 S, R 17 E, where the coal was 0.5 to 0.6 m (1.5-2 ft) thick. The overburden at that mine averaged 4 m (12 ft) in thickness and consisted mainly of siltstone and two thin limestone beds. Strip mining at this location continued at least until 1945 (Abernathy, 1946, p. 141). The mine was inactive in 1958, but was active again prior to 1976 as reported by Brady and others (1976, p. 24). In addition to strip mining, other coal was obtained by drift, slope, and shaft mining in the past (Schoewe, 1944, p. 99-103).

The most detailed report on the coal in Wilson County is by Schoewe, and much of the data on coal given below are from his report. Schoewe (1944, p. 91-93) recognized that coal occurs at different horizons in the Chanute Shale, and that, at least one group of coal beds is above the Thayer coal. He pointed out also that the coal is generally in two or three layers separated by clay partings, and that it is as high in quality as the average coal mined elsewhere in Kansas (Schoewe, 1944, p. 97-99). Proximate analyses of two coal samples from Wilson County are given in Table 8. The coals average 51.1 percent fixed carbon, furnish 15,269 Btu per pound on a moisture and ash free basis, and are of bituminous rank. The coal area of Wilson and Neosho Counties was listed as the Thayer district by Whitla (1940, p. 11, 61-62) and was further subdivided by Schoewe (1944, p. 110-114) into the Thayer-Coal Hollow mining district in Neosho County and the Chetopa and Dry Creek mining
districts in Wilson County (Plate 4). The coal in the
Chetopa and Dry Creek districts is in three groups of beds;
one group is at the base of a reddish-weathering sandstone,
the second at the base of a whitish, platy siltstone, and
the third at the base of a yellowish-gray, thin-bedded,
silty sandstone (Plate 4). According to Schoewe (1944,
Table 7), a total of 18,661 tons of coal was mined between
1933 and 1942 in Wilson County. Most of this coal was from
the Dunbar strip mine. Schoewe (1944, Table 8) estimated
the total production from the county as 271,875 tons.
Reported production since 1942 totaled 416,130 tons
(L. L. Brady, personal communication, 1990).

Proved reserves of coal in Wilson County, following
procedures established in 1947 by the State Geological
Survey (Abernathy and others, 1947, p. 13-14), amount to
approximately 13 million tons of coal 0.25 m (10 in) or
more in thickness. Based on Schoewe (1944, p. 103-106) and
recent coal production (Brady and others, 1976, p.
24), the total coal mined from the Thayer coal bed in
Wilson County is estimated at 800,000 tons. Included in
this estimate is an area of about 4 km² (1000 acres) in
size in the Chetopa coal mining district that is underlain
by coal 41 cm (16 in) in thickness and another area of
about 35 km² (8500 acres) in the Dry Creek and Chetopa
districts that is underlain by coal 25 to 40 cm (10-16 in)
in thickness. Abernathy and others (1947, p. 15, 18)
estimated that 12,700,000 tons of proved reserves and
231,000,000 tons of potential reserves of coal 25 cm (10 in) or more in thickness were present in the Chanute Shale in Wilson County in 1946. In their calculation of potential reserves, known thickness of coal at an outcrop, at a drill hole, or in a mine, was regarded as indicating the presence of coal of the same thickness under an area of about 1040 km² (400 mi²) in size. Based primarily on the estimate by Schoewe (1958, p. 386-388) of more than 18,500 million tons of total coal resources in Kansas, Averitt (1975, p. 14) estimated the total to be 22,668 million tons by adding 4,000 million tons of estimated hypothetical resources. Stripping coal reserves were evaluated by Stroup and Falvey (1969) as 215.2 million tons, with 830.9 million tons of reserves for both stripping and underground methods. In a report on strippable coal reserves and resources in Wilson County, Brady and others (1976, p. 14, 39) showed strippable coal resources of the Thayer coal bed of 5.73 million tons for a strippable ratio of 30 to 1 or less, and a coal resource total of 7.88 million tons under an overburden thickness of 30 m (100 ft) or less. Minimum thickness of coal for the resource calculation was considered to be 0.3 m (12 in) or more. Wood and others (1983) consider the established coal reserve base (measured and inferred coal resources in place) at 2.8 million tons of strippable coal. The deep coal resources beneath more than 30 m (100 ft) of overburden total nearly 945 million tons of coal in Wilson County. This resource figure
represents the total of eleven coal beds in the county. The coal bed with the largest reserves is the Bevier coal in the upper part of the Cabaniss Formation with a total resource of over 240 million tons. The coal with the highest potential for deep coal development is the Weir-Pittsburg coal bed near the base of the Cabaniss Formation (Cherokee Group, Desmoinesian Stage). Its inferred resources of nearly 60 million tons exist with a thickness that exceeds 1.1 m (3.5 ft) (Brady, 1990, personal communication).

In a recent report on Kansas coals, Brady (1990) gives revised resources figures for the good quality high volatile A, B, and C bituminous coals; they amount to approximately 54 billion short (US) tons (49 billion metric tons) in some 32 beds. Of the total tonnage, 1.3 billion tons is strippable coal in 17 beds, and 53 billion tons is deep coal in 32 beds; these beds include lignite. Coal beds having resource potential are almost entirely in strata of Pennsylvanian age, and account for 99.9 percent of the total recorded coal production in the state of Kansas; these beds account for nearly 300 million short tons (272 million mt) of coal over the past 140 years (Brady, 1990, p. 1). Most production has come from the high volatile bituminous coal in the southeastern Kansas area. Wilson County lies near the northwestern edge of the highest productive area; its estimated total resource potential is only 60 million short tons of a total of 2,000
million inferred short tons (Brady, 1990, p. 13). Of particular interest in 1990 were other coal products for future use. These products included methane gas, large amounts of which were being developed in coal districts in New Mexico, Colorado and Alabama. Medium volatile bituminous coal would be the ideal rank, if the methane were present in large quantities. The high volatile A bituminous coal of southeastern Kansas is slightly lower in rank, but it still would have good potential. Stoeckinger (1989a, 1989b) reported that the high volatile A and B coals of the Cherokee Group of southeastern Kansas have a gas content as high as 220 cubic feet per ton (1989b, p. 1). Five coal-bed methane wells were reported on by Stoeckinger (1989b, p. 10) in Neosho and Labette Counties adjacent to and near Wilson County. These wells were producing from the Weir and Riverton coals, both of which underlie Wilson County. One of the Weir coal-methane wells was completed in 1985, and in 1989 was still producing 6.2 million m³ (220 Mcf) per day from a coal bed thickness of 1.5 m (5 ft) at a depth of 284 m (932 ft). The coal’s gas content was 6.2 m³ (220 ft³) per ton. Published gas production figures for this well, as of 1/1/89, averaged roughly 5 million m³ (190 Mcf) per day for the last year reported, giving a total production of 1.94 billion m³ (69,236 Mcf) for the last 12 months (Stoeckinger, 1989b, p. 10). If these figures are reliable, gas from coal may become a major industry in Wilson County in the future.
Fuels Dependent Industries

Industries using raw materials from outside Wilson County were attracted to the county by cheap fuel in the form of an abundant and continuous supply of natural gas. These industries included lead and zinc smelting and bottle glass production. In 1899 the lure of cheap gas prompted the Cherokee-Lanyon Zinc Company to build a lead-zinc smelter at Neodesha under an agreement that the town would supply the company with a tract of land and drill a gas well for their use. The well came in flowing at the rate of 113,000 m³ (4 Mcf) daily (Clark, 1970, p. 37).

Smelters. The Lanyon Bros. Spelter Company completed their lead-zinc smelter in 1902 near the northwest corner of Neodesha, (Haworth, 1903, p. 30). A similar smelter was built about 0.8 km (0.5 mi) north of Altoona by the Cockerill Lead and Zinc Company in 1902 and 1903 (Williams, 1904); it operated at least until 1910 (Douglas, 1910, p. 173). The Lanyon Bros. smelter was bought in 1903 by the Granby Mining and Smelting Company and was enlarged and operated until 1917. When Granby purchased the smelter, the company also acquired gas leases on 0.08 km² (20 acres) of land within the city limits of Neodesha and by 1904 had obtained leases on over 5 km² (1200 acres) in Neodesha and Newark townships. The company committed itself to supply gas to the town of Neodesha as part of the agreement. Also in 1904, gas rights were acquired by the Federal Betterment Company and several
other enterprises on 28 different tracts in Wilson County (Clark, 1970, p. 37, 41). Smelters built and operated between 1900 and 1930 are shown at Altoona, Fredonia, and Neodesha by Clark (1970, Fig. 8, p. 48). No smelters are currently operating (1994) in Wilson County.

Glass. The first glass plant in Wilson County was built by the Neodesha Bottle and Glass Company near the northwestern corner of Neodesha in 1903 (Douglas, 1910, p. 207-208). Its first output was on October 19, 1904. The specialty of the plant was flint-glass bottles for the apothecary trade, and 30 tons of glass sand per day was used in the production of about three carloads of bottles per week. The cost of gas increased in 1910, and the plant ceased operations in 1911. Meanwhile, also in 1903, the Midland Glass Company of Independence was importing sand from quarries near Fredonia for use in its plant where fine glass was manufactured. That same year the Caney Chronicle reported that five glass plants in Montgomery County had been organized in order to develop glass-sand deposits and had agreed to invest $20,000 in machinery to crush the sandstone. The results from the crushing of local sandstone beds were unsatisfactory, however, and the sand had to be imported (Clark, 1970, p. 30-31).

The Fredonia Window Glass Factory was built in 1904. It was rated as a 36-blower plant and had an output of one carload (500 boxes) daily. The plant appears on maps dated as late as 1921 and was presumably operating at least until
The sand of the Tonganoxie Sandstone Member of the Stranger Formation was selected for use at the Fredonia plant (Schrader and Haworth, 1906, p. 47) and was used in a few batches run by the Midland Company at Independence (Douglas, 1910, p. 208). Only a small quantity of sand with a low enough iron content was available, however, and most of the sand used in the glass manufacture was brought from Illinois and Missouri (Douglas, 1910, p. 208; Clark, 1970, p. 31). A third glass plant in Wilson County, built by the Altoona Glass Company, is shown at the southeast corner of Altoona in the Atlas of Wilson County (Ogle, 1910). In all, seven glass plants were operated in Wilson County, five in Fredonia. Their years of incorporation, according to Clark (1970, p. 135), were 1903 (Fredonia Window Glass Factory), 1912 (Monarch Glass Machine Co.), 1919 (C. F. Lutes Glass Co.), 1925 (Lariaux Glass Co.), and 1929 (Fredonia Flat Glass Co.). Gas, as a fuel for the glass plants, became cost ineffective as the price increased, the supply from local gas fields dwindled, and the glass plants were forced to close down or convert to coal or oil. Through the efforts of C. F. Lutes of the Coffeyville Window Glass Company and a group of Fredonians, gas wells were leased, pipelines laid, and the fires kept burning. The Lutes plant in Fredonia continued to operate at least through 1929 (under four different managements) but not as a primary producer (Clark, 1970, p. 131). No glass plant is currently active (1994) in Wilson County.
OTHER MINERAL RESOURCES

The mineral resources of Wilson County, other than fuels and fuels-dependent industries, include limestone, shale, sandstone, and gravel. Of these, limestone and shale have the greatest economic value.

Limestone

Products derived from limestone are the most valuable economic materials obtained from the hard rock natural resources of Wilson County. Cement and crushed rock combined have been valued at more than $6 million. Agricultural lime also has formed a part of the product derived from limestone, and the manufacture of rock-wool may be important in the future.

Knowledge of the chemical composition and abundance of the limestone is important in determining the use and feasibility of any proposed limestone operation. Thickness and distribution of the limestone units are discussed elsewhere in this report; chemical data on limestones are shown in Tables 9 and 10. The purer limestones, which are 95 percent or more calcium carbonate, are commonly designated high-calcium limestones. In Wilson County only one limestone unit, the Stoner Limestone Member of the Stanton Limestone, contains in some areas more than 95 percent calcium carbonate (Table 9). In selected areas, therefore, limestone from the Stoner could be used in the metallurgical industry as flux for both iron and steel.
production, in the manufacture of glass and glass-fiber, as the raw material for quick and hydrated lime (used in paper and pulp manufacture), in the textile industry, in water softening, and for structural purposes (Runnels, 1951, p. 88-93). Several limestone units in the county, the Plattsmouth, Leavenworth and Toronto Limestone members of the Oread Limestone, the Haskell Limestone Member of the Lawrence Formation, the Stoner Limestone Member of the Stanton Limestone, and the Spring Hill Limestone Member of the Plattsburg Limestone contain approximately 90 percent calcium carbonate (Table 9), and are suitable for cement, crushed stone and agricultural lime.

Knowledge of the minor chemical constituents of the limestone is also necessary in some operations; for example, limestones low in aluminum, phosphorus, arsenic, antimony, and sulfur could be used in the manufacture of acetylene, and those low in iron, manganese and vanadium could be used in the production of whiting. Spectrochemical analyses showing the presence and abundance of these minor constituents are given in Table 10.

Cement. Cement is the most valuable product derived from limestone in Wilson County. It has been produced continuously since 1905 near Fredonia. Three other cement plants that were active in the county are now defunct. The production of cement is feasible only because of the ready availability of abundant natural gas.
Cement manufacture began in Wilson County at Neodesha, where the Indian Portland Cement Company began operations early in 1905 with a rated capacity of 1,800 barrels per day. In January 1908 the plant was purchased by the United Kansas Portland Cement Company; its capacity was enlarged to 8,300 barrels in 1909 (Douglas, 1910, p. 189-192). Operations ceased in 1912 (Clark, 1970, p. 87). A second plant at Neodesha, that of the American Portland Cement Company was also completed in 1905. That plant was closed in 1909.

The Fredonia Portland Cement Company plant was also constructed in 1905 and had an initial capacity of 500 barrels per day (Douglas, 1910, p. 192). Its capacity was increased in 1908 and again in 1931, six years after its purchase in 1925 by the Consolidated Cement Company of Chicago. In the 1931 modification, the plant was dismantled, its equipment was upgraded, and its capacity was increased. Improvements were made again in 1936, followed in 1955 by major changes that brought the rated capacity of the plant to 2,300,000 barrels per day (Schoewe, 1956, p. 295). No name change was involved when ownership went from one group to another over its 90 years of operation. The ingredients used in cement production at the Fredonia plant are comparable to those of other plants in the so-called "Gas Belt" of eastern Kansas. In general, about 270 kg (590 lbs) of dry solids are used in producing one barrel of cement. About 225 kg (490 lbs) is limestone,
about 41 kg (90 lbs) is clay, and 5 kg (11 lbs) is gypsum. Thus, approximately 1/2 million tons of limestone would be used during a year of peak capacity production, and almost $6 million worth of cement would be produced in that year. The material used at the Fredonia plant is mainly Stanton Limestone and contains 85.22 percent calcium carbonate, 4.48 percent magnesium carbonate, and a calculated equivalent calcium carbonate of 89.64 (Table 9, sample 10). The Fredonia plant is the only cement plant operating in 1994 in Wilson County.

The Altoona Portland Cement Company began operations in 1907 (Warne, 1955, p. 10; Clark, 1970, p. 70) at a site about 7 km (4.5 mi) north of Altoona high on the Stanton escarpment near the center of Sec. 30, T 28 S, R 16 E. (Ogle, 1910, p. 51). When construction was completed in 1907, the promoters of the cement plant arranged a merger with the Richardson Gas and Oil Company, which was committed to supply the town of Altoona with gas. The Altoona Portland Cement Company thus assumed the obligations of the gas company as well as its holdings consisting of a gas distribution plant, gas properties, gas leases, and the connecting pipelines. At the outset the company earned more from the sale of gas than in the manufacture of cement (Clark, 1970, p. 70). As a result, the cement plant was allowed to deteriorate, the production of cement became minimal, and gas was preferentially supplied to a local zinc smelter, a brickyard and a glass
plant at Altoona rather than to the town's citizens or to the cement plant. Sales of gas earned $84,000 in 1910 which went largely into dividends for the preferred capital stock of the corporation. The company was forced into bankruptcy in 1913, as were the Altoona [Cockerill] Zinc Smelting Company, the Altoona Vitrified Brick Company, and the Kerr Glass Company which, at that time, was leasing the glass plant from the defunct Altoona Cooperative Glass Company (Clark, 1970, p. 70). The Altoona Portland Cement Company was reorganized in 1916, but apparently operated rather unsuccessfully until it finally went out of business in about 1928.

**Crushed rock and agricultural lime.** Other commercial operations utilizing limestone in Wilson County include agricultural lime and crushed stone. The first commercial crushed rock and lime quarry was located about 3 km (2 mi) southeast of Guilford in the center of the north one-half, Sec. 30, T 28 S, R 16 E. The quarry started operation in 1904 and supplied rock for ballast on the Missouri Pacific Railroad (Williams, 1904). Many small quarries are shown on maps of Wilson County prepared by Edwards (1881), Schrader (1908) and Ogle (1910). Since 1940 crushed rock has been used abundantly as road rock and as aggregate for construction work; several sizeable quarries have been opened in the Stanton Limestone, in the Plattsburg Limestone, and in the Haskell Limestone Member of the Lawrence Formation. Many of the quarries were used
only intermittently, and in 1958 only two permanent-type installations were in operation. One, operated by the Benedict Rock and Lime Company, was started in 1944 in the Stanton Limestone about 1.6 km (1 mi) northeast of Benedict. The Stanton in that area is about 11 m (35 ft) thick. The rock was crushed into a product that is roughly three-fourths crushed rock and one-fourth agricultural lime. The other large operation was opened in 1945 by the Carr Rock Products Company and is located just northwest of Neodesha on Little Bear Mound. The Rock quarried consisted of both the Stanton and Plattsburg Limestones. The Carr Rock Products Company has utilized its portable crushing units in five other quarries in the county, all in the Stanton Limestone. The quarries were located in the SW 1/4 Sec. 36, T 27 S, R 16 E, in the SW 1/4 Sec. 19, T 28 S, R 14 E, in the NE 1/4 Sec. 18, T. 29 S, R 16 E, in the NE 1/4 Sec. 26, T 29 S, R 14 E, and near the center of the south line of Sec. 7, T 30 S, R 15 E (Plate 1). Approximately 300,000 tons of limestone were quarried each year in the county by these two companies, the State Highway Department, and small operators. Of the total only about 35,000 tons were used in making agricultural lime; the remainder was for crushed rock used in construction work and as road metal.
Shale

Brick and Tile. The Ceramic Division of the State Geological Survey has investigated the shale formations of Kansas in order to determine which shales are best suited to particular uses. Chemical analyses of shale samples from the Lawrence Formation at Buffalo, from the Weston Shale Member of the Stranger Formation at Fredonia, and from the Chanute Shale in the NE 1/4 Sec. 29, T 29 S, R 17 E are listed in Table 11. Results of kiln tests to determine optimum firing temperature for shale from the Buffalo and Fredonia plants are given in Tables 12 to 15. The optimum firing temperature for samples from Wilson County would be about 1182° C (2160° F).

Brick and tile are the chief products made from clay in Wilson County. Of the 60 plants in the 10-county region of southeastern Kansas between 1890 and 1930, eight were in Wilson County as follows: one each at Buffalo and Buffville, and two each at or near Neodesha, Altoona and Fredonia (Clark, 1970, p. 54). The Chesnut hand-molded brick plant at Fredonia was apparently the first commercial brick-making operation in the county. It was located in the northwest part of Fredonia and operated between 1884 and 1893 with a capacity of 4,000 to 6,000 hand-molded bricks per day. The bricks were fired with wood and were the construction materials used in many of the old buildings in Fredonia including the Fredonia Hotel and the
Opera House. With the discovery of gas in 1893, several other operations were started. The first was that of the Verdigris Valley Vitrified Brick and Tile Company at the north edge of Neodesha. The plant operated only twelve years, between 1890 and 1902, before being moved to a new site about 6 km (4 mi) south in Montgomery County. In 1902 the Fredonia Brick and Tile Company constructed a plant that operated until about 1940 at South Mound, Fredonia, with a capacity of 100,000 to 125,000 bricks per day. Between 1903 and 1928, the Kansas Buff Brick and Manufacturing Company operated a plant with a capacity of 40,000 to 50,000 bricks per day at Buff Mound south of Altoona. The company produced the only buff-colored bricks in the county but also fired white, yellow, mottled, and red building bricks. Between 1918 and 1920, the plants at Fredonia and Buff Mound produced bricks valued at about $900,000. The total value of brick production in the county during that three-year period was almost $2 million (Norman Plummer, written commun., July 1959). The Durham Brick Plant, owned by D. W. Durham of Fredonia, operated for a short time prior to 1904 with a daily capacity of 40,000 to 50,000 bricks (Williams, 1904). The last brick plant to go into operation in Wilson County, the Altoona Vitrified Brick Company, began operations in 1906. The plant was located about two miles north of Altoona in the SW 1/4 Sec. 32, T. 28 S, R 16 E; it apparently marketed bricks between 1906 and 1912 when, according to county
records, operations ceased. The United Brick and Tile Company, a holding company headquartered in Chicago, was merged with the Kansas holdings of United Clay Products Corporation at Coffeyville, Iola, and Weir City to which were added plants at Neodesha and Wichita. The Capital resources of United Clay surpassed $9 million in 1932 (Clark, 1970, p. 84).

Two plants, one west of Buffalo and the other west of Fredonia, were active in 1959 with a combined capacity of more than 200,000 bricks per day. The Buffalo Brick Company west of Buffalo, operated by the Acme Brick Company of Fort Worth, Texas, was constructed in 1903 with a capacity of 100,000 to 125,000 bricks per day. In their initial operations, vitrified paving bricks, red building bricks, and repressed building bricks comprised the major part of the output (Williams, 1904), but in about 1930, face-brick and tile facilities were added. Because much of the raw material had a high shrinkage factor, tile was a minor product of the plant. Between 45,000 and 60,000 face and common bricks were made per day. The Excelsior Brick Company plant was constructed in 1904 at the foot of West Mound, Fredonia, and went into production in 1905. The plant, as it appeared in 1936, is shown in Figure 63A. Nine round downdraft kilns and one 52-chamber Haigh continuous-chamber kiln were housed in the plant which had a capacity of 120,000 bricks per day in 1958. A large clay
Figure 63. Excelsior Brick Co. operation near Fredonia. (A) Aerial view of the plant taken in 1936 - courtesy Excelsior Brick Co. (B) Planer in operation in pit.
planer was utilized in the quarrying operation (Figure 63B). Face bricks, common bricks, building tile, and drain tile were the major products. Six textures were added to the extruded bricks, which were then selectively fired to 14 different shades. About 40 percent of the face bricks were flashed.

The Neodesha and Buff Mound plants used the Lane-Bonner Springs Shale in their operations; the Altoona plants used the Vilas Shale; and the Fredonia and Buffalo plants used the Weston Shale Member of the Stranger Formation. About 8 to 12 m (25-40 ft) of shale is exposed in the working face at the Fredonia and Buffalo plants. The upper 1.5 to 3 m (5-10 ft) is yellowish gray and is somewhat more friable than the lower, light bluish-gray portion. A mixture of the two colors produced the best results; the yellowish colored shale was generally kept at less than one-third of the total.

Production of brick and associated products by the Acme Brick Company at Buffalo and the Excelsior Brick Company at Fredonia amounted to more than 100,000 bricks per day in 1959, or roughly 30 million bricks per year. These included both common and face bricks in a ratio of two common to one face. The bricks were worth about three-quarters of a million dollars and used more than 57,000 m$^3$ (75,000 yds$^3$) of shale per year.

Riprap. An operation of considerable significance to the economy of Fredonia about the turn of the century
was the preparation of railroad riprap from shale. The clay of the Weston Shale Member was excavated from four trenches approximately 15 m (50 ft) wide and 457 m long (1500 ft) that were dug adjacent to the Atchison, Topeka and Santa Fe line just north of Fredonia in the NW 1/4 sec. 1, T 29 S, R 14 E. This clay furnished the raw material, which was then fired and the clinker distributed as base for the railroad. Clay from the Weston Shale Member, taken from trenches of similar size in the NW 1/4 sec. 11, T 29 S, R 14 E, furnished material used by the Consolidated Cement Corporation in the manufacture of cement.

Light-weight Concrete and Aggregate. Other uses for which shales from Wilson County have been tested include lightweight concrete and construction aggregate. Concerning these uses of shale, Plummer and Hladik stated (1951, p. 9): “The demand for lightweight aggregates in preference to heavier materials is based on the two important advantages of decreased total weight of the concrete structure and better insulation against both heat and sound transmission. The decreased weight means that less material is required for foundations and supporting structure.” They state further (1951, p. 10): “Although the use of these lightweight materials as a concrete aggregate is doubtless of major importance, their utility is by no means limited to this application. Bloated shale is also an ideal aggregate for bituminous matt road surfacing.”
Bloating is the important characteristic in the production of lightweight aggregate. Almost any clay or shale will bloat under some conditions, but many are not suitable for the production of lightweight aggregate. Bloating should occur at less than 1315°C (2400°F) or fuel costs generally will be excessive (Table 13). Furthermore, bloating should occur over a wide range in temperatures to allow the bloated product to form prior to the fluid glass stage. Otherwise, the glass formed will stick to the kiln lining and cause excessive erosion of the refractories (Plummer and Hladik, 1951, p. 22).

The suitability of the Lawrence Formation and the Weston Shale Member of the Stranger Formation for the manufacture of lightweight concrete and construction aggregate (Tables 14, 15) and for ceramic railroad ballast was determined by Plummer and Hladik (1951, p. 26-36). In order to test the bloating characteristics of these shales, two samples, one from the shale pit at Buffalo and one from the shale pit at Fredonia, were subjected to the rapid-firing test, and samples from each pit were given the batch-type rotary kiln test. The rapid-firing test (Table 13) showed that although the unbloated vitrified clays from Buffalo and Fredonia had an original density of about 2.2 g/cm³ (143 lb/ft³), the density of each sample decreased after bloating at a temperature of 1010°C (1850°F) with a slight reduction in volume. Considerable pore space is indicated by the 15.86 and 13.42 percent absorption for the
two samples after five hours immersion in boiling water (Table 13). The percentage loss on ignition gives an indication of the percentage loss of weight in changing from raw material to the finished product. Firing at 1177°C (2160°F) produced little change in density from the 2.2 g/cm³ (143 lb/ft³) original and resulted in a reduction in volume with very low absorption. The best results by the rapid-fire method were at 1238°C (2260°F) at which temperature the shale had a large decrease in density, an expanded size, and a high absorption percent. The shale from Buffalo had the lowest density and the greatest pore space (Table 13).

Chemical composition also affects the bloating properties. A clay having an alumina content in excess of about 25 percent is usually too refractory to bloat satisfactorily within a reasonable range in temperature. The alumina content of shale from the Fredonia plant is close to this maximum (Table 11). Shales or clays containing a relatively high proportion of calcium or magnesium compounds tend to form a fluid glass a few degrees above the initial softening point and standardized products are difficult to obtain because incipient fusion and complete fusion are not separated by a sufficient range in temperature (Plummer and Hladik, 1951, p. 22).

In the batch-type rotary kiln, the unit weight of crushed unsized aggregate made from the Weston Shale Member of the Stranger Formation from Wilson County at the optimum
bloating temperature of 1177° to 1188°C (2150-2170°F) is 720 kg/m³ (44.9 lbs/ft³) for the sample from the Buffalo area and is 450 kg/m³ (28.2 lbs/ft³) for the Fredonia area sample (Table 14). Kiln samples have lower densities than bricks formed during the rapid-firing procedures because, in the case of bricks, the density is that of a solid aggregate; whereas, in the rotary kiln procedures, the density is that of crushed material of irregular shape and includes a large percentage of voids between particles. The size distributions of pieces of the Weston Shale Member aggregate from the kiln experiments is given in Table 15. Inasmuch as tests have shown that a certain percentage of sizes will produce aggregates that combine to form concrete building blocks of greater strength, an optimum grading scale has been experimentally determined (Table 15). The Weston Shale Member aggregates did not form sizes of the correct proportions; they were resized by sending the coarser aggregate (resulting from one pass) through the rolls again, this time set 0.5 cm (3/16 in) apart. The additional pass increased the percentage of fines to approximately the optimum grading, and the resulting size mixtures had unit weights of 825 and 650 kg/m³ (51.6 and 40.5 lbs/ft³).

**Rock Wool.** A test was made in 1936 to determine the suitability of a mixture of the Weston Shale Member of the Stranger Formation and the Stanton Limestone from Wilson County for use in the production of rock wool. In the test
a sample of shale from the Excelsior Brick Company quarry was combined with limestone from the Consolidated Cement Company quarry and sandy clay from the top of West Mound at Fredonia (Plummer, 1937, p. 36-38). The mixture was blown at 1550°C (2822°F) with a steam blast of 4.2 kg/cm² (60 lbs/in²). The result was a slightly coarse, white rock wool whose fibers ranged from three to 50 microns in diameter and averaged 12 microns (Plummer, 1937, p. 38). The chemical composition of the calcined mixture from which the wool was blown was estimated as 45 percent silica, 13 percent alumina, 5.3 percent ferric oxide, 34 percent calcium oxide, and two percent magnesium oxide. The carbon dioxide content of the raw mix was 24 percent (Plummer, 1937, p. 36).

Sandstone

Sandstone was an important building material in the early days of settlement of Wilson County, and many small quarries were opened near the larger towns. Sandstone was quarried from the Ireland Sandstone Member of the Lawrence Formation and from the Tonganoxie Sandstone Member of the Stranger Formation in the western part of the county. Edwards (1881, p. 23) reported that a good building-stone and flagging-stone quarry in the southwestern part of Newark township furnished the rock used in paving the sidewalks in Neodesha. Haworth (1898b, p. 71) reported that the stone for buildings in Neodesha was obtained "from the
heavy sandstone immediately under the town, the quarries principally being along the bank of the creek just at the northeast border." Other quarries were opened near Altoona and Fredonia, and local sandstone can still be seen in the foundations and walks of many houses in these areas.

The Tonganoxie Sandstone Member of the Stranger Formation near Fredonia was considered suitable for use as glass sand, and Schrader and Haworth (1906, p. 54) reported: "Perhaps the best is in the southern part of Fall River Township, in the SE 1/4 Sec. 22, about four miles southwest of Fredonia. Here the rock is exposed over an area of 10 to 50 acres and appears to be about 12 feet in thickness." Concerning this same occurrence, Schrader (1908, p. 6) stated: "It is reported that the glass factory at Fredonia procures its sand from the sandstone of this region." However, the iron content of the sandstone proved too high for satisfactory glass sand.

Chert
Abundant chert gravel from deposits in many parts of Wilson County (Plate 1) furnished road metal for most of the section-line roads. The thicker deposits have been exhausted and crushed rock has largely replaced the chert gravel.
CHAPTER SEVEN: SUMMARY AND CONCLUSIONS

Being brief statements that summarize a few of the more interesting results of the geologic investigation of Wilson County, particularly the role that cyclicity played in the generation of the various stratigraphic units now represented within the county boundaries.
SUMMARY AND CONCLUSIONS

This detailed investigation of Wilson County has provided additional insight into, and has made possible the drawing of, relevant conclusions regarding many perplexing aspects of southeastern Kansas geology. Many of the topics investigated had hitherto merely been enumerated or alluded to in studies of the stratigraphic sequence and structural evolution of southeastern Kansas but had not been adequately treated. Among the more interesting of these geologic facets in Wilson County are those concerning: (A) The occurrence of basic igneous rocks of Cretaceous age and associated metamorphic effects; (B) the variety of rocks in the Precambrian basement; (C) the large number of unconformities recorded in lower Paleozoic strata; (D) the extreme number, surprising lateral extent, and changes in thickness and composition of Pennsylvanian strata; (E) the great variety and abundance of fossil remains in the strata of Pennsylvanian age; (F) the origin of chert gravels in Wilson County; (G) the paucity of geological structures and features in Wilson County; and (H) the variety of economic resources available for human use in Wilson County.

A) Following its discovery by a mining engineer in Colorado in 1877, a domal area underlain by soft, very micaceous yellow material at the northern edge of Wilson County has attracted the attention of miners and geologists
for more than 100 years. The near proximity of this uplifted area to the Tri-State Lead-Zinc District of Kansas, Missouri, and Oklahoma prompted many miners and local citizens to prospect for silver and lead at the uplift, and for nearly two years the domal area was a beehive of activity before it was realized that no valuable ore was likely to be extracted. The accumulation of about 100 tents and a few large wooden buildings that arose was called Silver City because silver ore was found in some of the prospect holes. Between 1879 and 1939 some 13 reports were written about the Silver City Dome mainly by professors at eastern Kansas colleges. These reports made it known in 1879 that the silver ore was from Colorado and had been "salted" into the prospect pits by the discoverer who had by then disappeared. Following my entry on the scene in 1950 and after publication of my report in 1954, some 16 additional reports have been published. At the time of my report the term, mica-peridotite, seemed best to fit the mineralogy of the igneous intrusive (biotite, olivine, hypersthene, augite, apatite, titanite, magnetite). Recognition that the amphibole (hypersthene) was actually a potassic richterite led to the reclassification of the intrusive as belonging to the lamproite clan.

Associated with the lamproite are strata of Pennsylvanian age that show the effects of moderate
metamorphism. Sandstone beds of the Ireland Member of the Lawrence Formation and of the Tonganoxie Member of the Stranger Formation have been modified locally to greenish-gray quartzite, the Haskell Limestone Member of the Lawrence Formation has become a hornfels, and limonite oolites of the South Bend Member of the Stanton Limestone have been changed to black magnetite. A few fragments of Precambrian granite were also found dispersed in the yellowish micaceous clay. The granite fragments had been rafted to their present stratigraphic position as inclusions in the lamproite magma as it made its way through the basement rocks at temperatures as high as 800° C and pressures which are presumed to have reached 200 to 300 bars.

Study of logs of wells drilled atop the Silver City Dome and in the immediately adjacent area indicate that the uplifted area is the result of sill-like intrusions of igneous material into country rock that underlies the dome. The time of intrusion has been determined to be Late Cretaceous (90 million years) in age. It is believed that the Silver City Dome occurs near the west end of a structural lineament that extends eastward from Missouri, through Illinois and Kentucky, to Virginia.

(B) Precambrian rocks occur in Wilson County only in the subsurface except for those rafted upwards at the Silver City Dome in Cretaceous time. Six wells bottomed in
Precambrian rocks, four in igneous rocks, (three granite, one syenite) and two in metamorphic rocks (one schist, one gneiss). The tops of these basement rocks range in depth below sea level from 355 to 460 m (1167-1500 ft). One well was drilled an unbelievable 301 m (986 ft) into granite before the responsible person called a halt. The deepest Precambrian well in Wilson County reached 1022 m (3352 ft) total depth.

(C) Subsurface studies also detail many interesting observations concerning the lower part of the Paleozoic sequence. Five erosional unconformities are recognized as occurring below the base of the Pennsylvanian strata. These gaps are found (1) between Upper Cambrian silty dolomite and Lower Ordovician sandy dolomite, (2) between Lower Ordovician oolitic dolomitic limestone and Devonian sandstone and black carbonaceous shale, (3) between a slightly cherty limestone unit and cherty dolomitic limestone of Mississippian age, (4) between the cherty dolomitic limestone and an overlying slightly cherty dolomitic limestone of Mississippian age, and (5) between slightly cherty dolomitic limestone and cherty non-dolomitic limestone of Mississippian age. A major unconformity separates the cherty Mississippian limestone from a sand, shale, and coal sequence of middle Pennsylvanian age. The strata of Cambrian, Ordovician, Devonian, and Mississippian age are separable from each
other mainly on the basis of their insoluble residues each of which has its characteristic type of chert or quartz sand or fossil content. These subsurface studies break this lower Paleozoic sequence into seven limestone, four dolomite, two shale, and one sandstone formation. Most of the limestones and dolomites are cherty; a few are locally oolitic. One shale is black and carbonaceous, the other is greenish gray. The only named sandstone formation rests directly on the Precambrian rocks.

(D) Strata of Pennsylvanian age that crop out at the surface in Wilson County appear at first glance to be a rather monotonous sequence of nearly flat-lying beds of limestone, sandstone, and shale. A closer look, however, reveals the presence of easily recognized features that occur in sets of strata which tend to set them apart as distinctive units. Bedding characteristics, whether planar or cross-beded, whether thick- or thin-beded, whether massive or fissile, tend to separate these units into segments or packets made up of strata of different origins and diverse geologic environments. The sequential arrangement appears to be cyclical in nature and the geologist soon realizes that he is indeed working with repetitious groups of stratigraphic units that reflect the presence of the same environment of deposition time after time after time, and that during the Pennsylvanian Period the area presently occupied by Wilson County was a small
part of a broad, slowly subsiding sedimentary platform. The platform served as a base across which a shallow-water epicontinental sea transgressed and regressed periodically, each time leaving behind an accumulation of detritus which later became a segment of the sedimentary sequence we now find. By definition each transgressive-regressive cycle began with (a) the deposition of sandy or clayey, carbon-rich (coaly) non-marine sediment which was followed sequentially upward by (b) shallow-water, generally clayey marine shale, (c) a thin relatively shallow-water bio-rich, calcareous marine shale deposit, (d) an anoxic, essentially stagnant-water deeper marine shale unit, (e) a moderately shallow-water marine claystone, (f) a calcium-rich abundantly biotic, moderately shallow-water, well-aerated marine deposit, and finally (g) a return to deposition of a continental, sandy to clayey non-marine sequence. Some major cycles have additional minor beds included within, or appended to, the basic cycle.

The outcropping Pennsylvanian strata of Wilson County contain a sequential arrangement of at least six major cyclic units to a total thickness of roughly 220 m (725 ft). Each major segment of the stratigraphic sequence is believed to be laterally persistent over several hundreds of square kilometers (miles), and most do not change in thickness by more than ten percent over the area of outcrop and generally maintain the same sedimentary and biologic
character over the same distance. Exaggerated thickness changes can be related to filling of erosional channels cut deeply into underlying sediments prior to consolidation, or to the upward and lateral growth of huge algal colonies.

(E) The great variety and abundance of fossil remains of marine plants and invertebrate animals has made Wilson County a paleontologist's paradise. Codiacean and phylloid algae are the most common plant remnants found, although leaves of land plants occur locally along bedding planes in a few non-marine shales. Leaflike algal remains occur mainly in mound complexes where good overall circulation and nutrient replenishment has resulted in a high-density collage of invertebrate fossils along the mound edges. The large and varied invertebrate fauna found in this photic-zone environment with good circulation can be contrasted with the much less robust fauna (orbiculoid brachiopods and various conodonts) that occurred in the relatively deep, stagnant water and anoxic bottom conditions of the black, fissile shale regime.

Abrupt thickening of limestone units and rapid lateral facies changes associated with algal-mound complexes characterize locations of major phylloid-algal growth in Wilson County. Each facies is represented by a distinctive lithology. For example, the mound lithofacies is dominantly a calcilutite; the channel lithofacies and the westward-dipping rim facies are dominantly calcarenites.
Each of these lithofacies has a closely associated abundant and diverse invertebrate biota. The mound lithofacies is dominated by phylloid algae, the channel lithofacies is dominated by echinoderm debris, and the rim facies is dominated by brachiopods. All are features of a shallow-water marine environment with strong sunlight penetration but relatively poor circulation and low nutrient replenishment. The channel facies occupies a long, linear, sand-filled, algal-poor elongate low area adjacent to and parallel to the rim lithofacies which is composed of a relatively wide, rimming drape of skeletal sands, small muddy banks, and local oolite shoals. Major invertebrate groups are extremely abundant and diverse, consisting especially of brachiopods, echinoderms, bryozoans, packets of pelecypods, and locally abundant foraminifers and fusulinids.

In this environmental setting, calcareous algae are assumed to have proliferated as turbidity decreased; mounds could have developed as the algal fronds trapped and bound carbonate mud that contained fragments of invertebrate faunas. A barrier-reef origin in which phylloid algae were the frame-building organisms is also possible. Periods of structural downwarp and/or compression of the underlying sedimentary sequence could also have filled an additional living space requirement necessary for the
upward growth of the algal flora. Erosion or wedging out of reef talus could have been contributing factors.

Thick limestone formations of Pennsylvanian age in Wilson County characteristically cover large areas and generally are of relatively constant thickness except where growths of phylloid algae are well established. Such algal growths may double or triple the calcareous sedimentary sequence within a kilometer (mile) or two laterally. Where thickest their added weight during growth may have created a lateral displacement of unconsolidated sediment in the underlying strata thus allowing the water depth of the algae to remain relatively constant during their time of growth and thereby satisfying their sunlight requirement.

Five genera are represented in the algal fauna. Four of these genera are green algae. Of these four, two are the Codiacean algae Anchicodium and Eugonophyllum, the third is the Dasycladacean alga Epimastopora, and the fourth is the Solenoporacean alga Parachaetetes. The fifth genus, Archaeolithophyllum, an encrusting coralline red alga, is represented by two species, A. missourienne and A. lamellosum. Algal stromatolites are also represented, some as simple encrustations, others as massive cauliflower-shaped heads. Others occur as saucer-like cups, and others as large complex toadstool shapes several feet in diameter.

(F) The chert gravel deposits in Wilson County are topographically positioned at four general levels in
relation to the present drainage system. These gravels reflect periods of ameliorated climate at the ends of the major Tertiary and Quaternary ice ages. The climatic changes resulted in deep weathering of chert-rich limestone strata that lay to the north and west of Wilson County and in making available great quantities of water to streams and rivers. These factors led to increased erosion and to the considerable rounding of chert pebbles now found in deposits associated with terrace-like features in Wilson County. Analysis of the flow patterns of the present drainage systems of Wilson County suggests that the former rivers flowed across the county in broader valleys than at present. Also suggested is the possibility that entrenchment over time allowed the Verdigris River to migrate generally northward, whereas the Fall River appears to have migrated generally southward and westward. Migrations appear to have begun as early as Nebraskan time and to have continued through Kansan and Illinoian time. Flood plains were as much as six miles wide in late Pliocene time; they are entrenched into about three miles width currently in their broadest parts and are less than one mile wide where they cross the thick limestones of the Stanton and Plattsburg Formations.

(G) Other than the extensive tracts containing prodigious growths of phylloid algae, only two structural features in Wilson County are worthy of summation, the
Fredonia Dome and the Silver City Dome. The Fredonia Dome is a short, complex anticlinal feature that lies about 6.5 km (4 mi) northeast of Fredonia and trends about N 20-30 W. It has a length of about 5 km (3 mi) and a width of about 3 km (2 mi). Oil production from the Fredonia Dome is mainly from 6 to 9 m (20-30 ft) of "Second Bartlesville sand" of the Krebs Formation at depths of 320 to 335 m (1050-1100 ft); the oil is 26-32° API gravity. Gas wells, good for 84,000 to 140,000 m³ (3-5 Mcf) per day, were drilled into the Mississippian "chat" atop the Fredonia Dome as early as 1907 at depths of about 300-350 m (1000-1100 ft) but most production has come from the "Weiser sand" of the Bandera Shale and the "Oswego lime" of the Fort Scott Limestone (Marmaton Group) and the "Second Bartlesville sand" of the Krebs Formation (Cherokee Group).

Only the southern one-half of the Silver City Dome lies in Wilson County. Drilling for oil and gas revealed that sill-like intrusions of lamproite were responsible for more than 65 m (210 ft) of uplift of the domal feature. Small quantities of oil and gas have been recovered from the area of the Silver City Dome in both Wilson and Woodson counties.

(H) The most important economic products of Wilson County, other than farming, are in the petroleum arena. Oil and gas have been produced in economic quantities since the early 1890's, particularly in the Neodesha area, but
not exclusively there, as the oil and gas fields near Fredonia, Altoona and Buffalo also have "Bartlesville sand" and "Burgess sand production." It is generally believed that much of the oil in the "Bartlesville sand" formed in situ or migrated updip from lower Cherokee beds. However, some of the oil has characterization factors near to those of Gulf Coast stocks, and the possibility that much oil has migrated along fracture zones from southern Texas to southeastern Kansas cannot be ruled out. Migration of oil was probably promoted by the persistent structural activity that took place in the southern Midcontinent region on a somewhat regular basis in Paleozoic and later time.

The presence of a very calcareous fauna and flora had a great influence on the accumulation of thick calcium carbonate deposits which provide material for the manufacture of cement in Wilson County. Also of economic value are the clay-rich sediments that allow for a successful brick and tile industry.

A summary account of the geology of Wilson County would be incomplete if mention were not made of the outstanding contribution of James Croll of Great Britain and Milutin Milankovitch of Serbia who, through use of their mathematical skills and scientific acumen, solved the knotty problem that concerns the sequential nature of the great ice-sheet accumulations of the Cenozoic Era. Their recognition that the periods of time involved in an
understanding of the intricate movements of the Earth and Sun relative to each other had to be measured in many tens of thousands of years in order to account for the magnitude of the glacial debris and for the cyclical nature noted in the glacial deposits of northern Europe. Having the solution to that Cenozoic riddle in hand, we are now able to apply the same treatment to the waxing and waning of the great continental ice sheets of Paleozoic time and thus to develop a clear understanding of the cyclic sedimentation concept inherent to the treatment of the Pennsylvanian strata of the Midcontinent Region of the U. S.

My exhaustive study of Wilson County in the 1950's provided a springboard or destination for a great number of geologic investigations in eastern Kansas and parts of the adjacent or nearby states. Geology professors at colleges in the states of Kansas, Missouri, Nebraska, Oklahoma, Iowa, Texas, Ohio, Illinois, Wisconsin, Pennsylvania, and Connecticut encouraged their graduate students to choose specific geologic problems that would carry them to Wilson County, Kansas, as a starting or ending point for studies dealing with (1) stratigraphy, sedimentology, and cyclic sedimentation, (2) mineralogy, diagenesis, and environment, (3) fossil content (fauna and flora), (4) structural and igneous geology, and (5) mineral resources. Their studies ran the gamut of tracing specific geologic formations and
groups of formations along their paths of outcrop or through the subsurface (51 students), mineralogic studies involving trace elements, clay minerals, insoluble residues, etc. (24), fossil content and distribution (18), faults, folds, and the Silver City Dome (6), and studies of oil, gas, and coal (9). The total of 108 students included 88 for the Masters degree and 20 for the Ph. D., making Wilson County probably the most geologically investigated county in Kansas. I am proud to have been an inspiration for so much high-class, low-priced geologic information at the college level.
CHAPTER NINE: REFERENCES

Being a complete listing of all materials referred to in
the text of this dissertation about Wilson County.
REFERENCES


____, 1946, Strip-mined areas in the southeastern Kansas coal fields: Kansas Geol. Survey Bull. 64, pt. 4, p. 125-144.


Adams, D. J., 1959, Relationships of physical characteristics of the Bluejacket sandstone (Middle Pennsylvanian) to petroleum production: M.S. thesis, University of Kansas, 79 p.


____, Girty, G. H.; and White, D., 1903, Stratigraphy and paleontology of the Upper Carboniferous rocks of the Kansas section: U. S. Geol. Surv., Bull. 211, 123 p.


Alexander, R. R., 1975, Phenotypic lability of the brachiopod Rafinesquina alternata (Ordovician) and its correlation with the sedimentologic regime: Jour. Paleo., v. 49, p. 607-619.


_____, 1982, Carbonate dissolution in nearshore terrigenous muds; the role of physical and biological reworking: Jour. Geol., v. 90, p. 79-95.


Anderson, R. Y., 1982, Orbital forcing of evaporite


_____, and others, 1981, Inventory and evaluation of potential oil shale development in Kansas: Dept. of Energy study, 42 p.


Ball, S. H., 1964, Stratigraphy of the Douglas Group (Pennsylvanian, Virgilian) in the northern Mid-continent


——, 1981, Type areas of the Seminole and Holdenville Formations: in Type Areas of the Seminole and Holdenville Formations, Western Arkoma Basin, Dott, R., ed., AAPG Midcontinent Regional Meeting, Field Trip No. 2, Guidebook, p. 1-10.


____, 1969, Chemical changes affecting dissolved calcium during the bacterial decomposition of fish and clams in sea water: Marine Geol., v. 7, p. 253-274.


____, and Heckel, P. H., 1989b, Reply to comment on glacial-eustatic sea-level curve, etc., Geology, v. 19, p. 91-94.


Bramlette, M. N., 1925, A subsurface correlation of the stratigraphic units from Russell County to Marion County, Kansas: Kansas Geol. Survey Bull. 10, pt. 2, p. 87-93.


Brondos, M. D., 1974, Diversity and paleoecology of some ostracodes from the Upper Pennsylvanian of Kansas (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 6, p. 97-98.


Burgess, W. J., 1976, Geologic evolution of the Mid-continent and Gulf Coast areas—A plate tectonics view: Gulf


Byers, C. W., 1974, Shale fissility; relation to bioturbation: Sedimentology, v. 21, p. 479-484.


Campbell, K. S. W., and McKellar, R. G., 1969, Eastern Australian Carboniferous invertebrates; sequence and affinities: in Campbell, K. S. W., ed., Stratigraphy and Paleontology, Australian National Univ. Press,
Canberra, p. 77-119.


Carothers, M. C., 1979, Depositional setting of the Cambridge Limestone (Conemaugh Group), and Upper Pennsylvanian (Missourian) marine transgression in the Appalachian Basin (abs.): 9th Internat. Cong. Carboniferous Stratigraphy and Geology, Abs. of Papers, p. 29.


Chamberlain, R. E., and Lemish, J., 1980, Basement control of structure within the Forest City Basin of Iowa [abs.]: Geol. Soc. Amer., Abs. w/Prog., v. 12, n. 7, p. 400-401.


of the Mid-continent area: Jour. of Geol., v. 40, p. 46-61.


1:500,000.


Coveney, R. M., Jr., 1979, Sphalerite concentrations in Mid-Continent Pennsylvanian black shales of Missouri and Kansas: Econ. Geol., v. 74, p. 131-140.


Cress, L. D., 1981, Climatic and structural controls of stacked algal lime and mound development in Oquirrh Group (Pennsylvanian and Permian), Deep Creek Mountains
southeastern Idaho (abs.): Amer. Assoc. Petrol. Geol., v. 65, p. 914.

Croll, James, 1864, Climate and time: Phil. Mag., v. 28, p. 121-137.


Davard, E., Strasser, A., and Jedoui, Y., 1990, Spiny ooids—Early subaerial deformation as opposed to late burial compaction: Geology, v. 18, p. 816-819.


Dimitracopoulos, K. J., 1979, The Bethany Falls Limestone; regressive limestone of the Swope cyclothem, southeast Kansas: unpub. report, 18 p.


Donahue, J., and Rollins, H. B., 1974a, Introduction: in


Donovan, R. N., 1978, Late Pennsylvanian and Permian cornstones (Caliche) in Oklahoma (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 10, n. 1, p. 4.


Duncan, R. A., and Richards, M. A., 1991, Hot spots, mantle plumes, flood basalts, and true polar wander:


______, 1981a, Diagenesis of Pennsylvanian fan-delta sandstones and interbedded shelf carbonates, Texas Panhandle (abs.): GSA Abs. w/Frogs., v. 13, n. 7, p. 443.


Ebanks, W. J., Jr., 1979, Correlation of Cherokee (Desmoinesian) sandstones of the Missouri-Kansas-

_, and James, G. W., 1974, Heavy crude oil-bearing sandstone of the Cherokee Group (Desmoinesian) in southeastern Kansas: in Hills, L. V., ed., Oil Sands, fuel of the future; Canadian Soc. of Petroleum Geol. Memoir 3, p. 19-34.


field conference, Four Corners Geol. Soc., p. 185-203.


Ellison, S. F., Jr., 1941, Revision of the Pennsylvanian conodonts: Jour. Paleo., v. 15, p. 107-143.


____, 1957, Glaciations and their causes; in Craig, H., ed., Proceedings of Conference on recent research in climatology, La Jolla, CA, p. 36-42.

____, 1969, Interglacial high sea levels and the control of Greenland ice by the precession of the equinoxes:  

582


____, de Boer, P. L., and Premoli Silva, I., 1990, Cycle stratigraphy: in Ginsburg, R. N., and Beadoin, B.,
eds., Cretaceous resources, events, and rhythms—Background and plans for research: NATO ASI theories, Dordrecht, Klewer, p. 139-172.


Fraser, G. S., 1970, Petrology of the Hall and Pontiac Limestone members (Upper Pennsylvanian) in Livingston


Gilmore, J. S., 1902, History of Wilson County, Kansas: in


____, and others, 1960, Oil and gas developments in Kansas during 1959: Kansas Geol. Survey Bull. 147, 254 p.


Gribbin, John, Ed., Climatic changes, Chap. 8: Cambridge Univ. Press, Cambridge, p. 139-149.


Gundrum, L. G., 1980, Demosponges as substrates; an example from the Pennsylvanian of North America; Lethaia, v. 12, p. 105-119.

Gunnell, F. H., 1933, Conodonts and fish remanis from the Cherokee, Kansas City, and Wabaunsee groups of Missouri and Kansas; Jour. Paleo., v. 7, p. 281-297.


Harris, J. W., 1985, Stratigraphy and depositional environments of the Krebs Formation (lower Cherokee Group, Middle Pennsylvanian) in southeastern Kansas: M.S. thesis, Univ. of Kansas, 120 p.


_____ and _____, 1982, Comparative organic geochemistry of shales and coals from Cherokee Group and lower part of Marmaton Group of Middle Pennsylvanian age, Oklahoma,


——, 1895a, The stratigraphy of the Kansas coal measures: Kansas Univ. Quart., v. 3, p. 271-290.


594


, and Bennett, John, 1908, General stratigraphy: Kansas Geol. Survey, v. 9, p. 57-121.

, and Kirk, M. Z., 1894, A geologic section along the Neosho River from the Mississippian formation of the Indian Territory to White City, Kansas, and along the Cottonwood River from Wyckoff to Peabody: Kansas Univ. Quart., v. 2, p. 104-115.

, and Piatt, W. H. H., 1894, A geologic cross section along the Verdigris River from the State line to Madison: Kansas Univ. Quart., v. 2, p. 115-118.


, 1887, A geological section in Wilson County, Kansas: Kansas Acad. Sci., v. 10, p. 6-8.


1985, Recent advances in interpretation of late Paleozoic cyclothems—Guidebook for Midcontinent: in Watney, W. L., Keesler, R. L., and Newell, K. D., Convenors, Recent interpretations of late Paleozoic cyclothems: SEPM-
Proceedings of the 3rd Ann. Mtg. and field Conf.,
Mid-Continent Sec.-Kansas Geol. Survey Spec. Publ.,
p. 23-70.

, and Hatch, J. R., 1992, Comment and reply on
Contrasting depositional models for Pennsylvanian black
shale discerned from molybdenum abundances": Geology,
p. 88, 89.

, and Meacham, J. F., 1981, New data on Missourian
(Upper Pennsylvanian) stratigraphy of the Forest City
Basin, southwestern Iowa and adjacent Nebraska (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 13, p. 280.

, and Pabian, R. K., 1981, Compatibility of crinoid
faunas with eustatic model for deposition of
Midcontinent Pennsylvanian cyclothems (abs): Geol. Soc. Amer., Abs. w/Prog., v. 13, p. 281.

, and others, 1978, Field guide to Upper Pennsylvanian
cyclothemic limestone facies in eastern Kansas: Kansas Geol. Survey Guidebook Series 2, 75 p.

, and others, 1991, Biostratigraphic correlation of
sustatic cycloths (Basic Pennsylvanian Sequence Units)

Hedberg, H. D., 1936, Gravitational compaction of clays and

Heling, D., 1978, Diagenesis of illite in argillaceous
sediments of the Rhinegraben: Clays & Clay Min., v. 13,
p. 211-220.

Henbest, L. G., 1958, Ecology and life association of fossil
algae and foraminifers in a Pennsylvanian limestone,
McAlester, Oklahoma: Cushman Found. Foram. Res.,
Contrib., v. 9, p. 104-111.

, 1958a, Geologic and ecologic significance of the


Hitchon, B., 1981, Genetic links between shales, formation fluids, and ore deposits; example for zinc from Alberta, Canada (abs.); Geol. Soc. Amer., Abs. w/ Prog., v. 13, No. 7, p. 473.

Hite, R. J., 1974, The role of the evaporite basin in the


Houseknecht, D. W., and Kacena, J. A., 1983, Tectonic and


Hull, Edward, 1868, On the physical geology of Tennessee and adjoining districts...[with notes and comments by A. P. Foiratsu in Amer. Geologist reproduction]; Geol. Soc. London, Quart. Jour., v. 47, p. 69-77; Amer. Geol. v. 7, p. 345-351; Geol.Mag., v. 8, p. 45-46.

Hurst, A., and Irwin, H., 1982, Geological modelling of clay
diagenesis in sandstones: Clay Minerals, v. 17,
p. 5-22.

Hutter, T. J., 1976, The biostratigraphy and taxonomy of
chitinozoans of the Leavenworth Limestone,
Pennsylvania (Virgillian) of eastern Kansas: M.S.

Hyne, N. J., ed., 1984, Limestones of the Midcontinent:

Imbrie, J., 1955, Quantitative lithofacies and biofacies
study of Florena shale (Permian) of Kansas: Amer.

____, 1985, A theoretical framework for the Pleistocene ice
ages: Journal of the Geological Society, v. 142,
p. 417-432.

____, and Imbrie, K. P., 1979, Ice ages--solving the
mystery: Enslow, Short Hill, N. J.

____, and Imbrie, J. Z., 1980, Modeling the climatic
response to orbital variations: Science, v. 207,
p. 943-953.

____, Laporta, L. F., and Merriam D. F., 1964, Beattie
Limestone facies (Lower Permian) of the northern

____, and Purdy, E. G., 1962, Classification of
modern Bahamian carbonate sediments; in Ham, W. E.,
ed., Classification of carbonate rocks: Memoir 1, Amer.

____, and others, 1984, The orbital theory of Pleistocene
climate--Support from a revised chronology of the marine
δ¹⁸ record; in Berger, A. O., and others, eds.,
Milankovitch and Climate, part 1: Reidel Publ. Co.,
p. 269-305.

Amer., Bull., v. 64, p. 869-878.

Ireland, H. A., 1955, Pre-Cambrian surface in northeastern
Oklahoma and parts of adjacent states: Amer. Assoc.

____, 1956, Upper Pennsylvanian arenaceous Foraminifera


, 1949, Oil and gas in eastern Kansas: Kansas Geol. Survey Bull. 77, 308 p.


, 1959, Graphic column and classification of rocks in Kansas: Kansas Geol. Survey, chart.


, and Muilenberg, G., eds., 1957, Kansas Geological


Jordan, L., 1957, Subsurface stratigraphic names of Oklahoma:


Kaesler, R. L., Peterson, R. M., and Brondos, M. D., 1979, Environmental control of patterns of hierarchical diversity among Late Paleozoic Ostracoda (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 9, p. 1042.


Kidder, D. L., 1962, Distribution and origin of Mid-continent


___, 1991, Replies to comments on "Pennsylvania time
scales and cycle periods:” Geology, v. 19, p. 405-410.


____, 1981b, Reply to comments on plate tectonics of the ancestral Rocky Mountains: Geology, v. 9, p. 388-389.


Knight, C. L., 1957, Ore genesis; the source bed concept: Econ. Geol., v. 52, p. 808-817.


Lane, H. R., 1967, Uppermost Mississippian and Lower Pennsylvanian conodonts from the type Morrowan region, Arkansas: Jour. Paleont., v. 41, p. 920-942.


Leach, D. L., 1979, Temperature and salinity of the fluids responsible for minor occurrences of sphalerite in the Ozark region of Missouri: Econ. Geol., v. 74, no. 1, p. 21.


, 1951, Pre-Pennsylvanian rocks: in Moore, R. C., Frye, J. C., Jewett, J. H., Lee, Wallace, and O'Connor,


____, and Herriam, D. F., 1954, Cross sections in eastern Kansas: Kansas Geol. Survey Oil and Gas Inv. Rept No. 12, 8 p.


Lindsay, C. G., 1981, Heavy mineral analysis of various Pennsylvanian sandstones in Webster County, Iowa (abs.): Geol. Soc. Amer., Abs w/Proc., v. 13, p. 286.


MacLeod, N., 1981, Four Upper Pennsylvanian benthic marine communities from the Wolf Mountain Shale (Canyon Group) north-central Texas (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 13, p. 287.


_____ , 1985, Application of the concept of megacyclothem to the Shawnee Group (Virgilian) in Kansas: in Watney, W. L., and others; Midcontinent Section Field
Conference, Society Econ. Paleontologists and Mineralogists, p. 73-74.


____, 1990, Lithology as a key to depositional environments in Midcontinent Virgilian rocks (abs.): Geol. Soc. Amer. Abs. with Programs, south-central section, p. 28.


____, 1981, So-called limestone "concretions" in Pennsylvanian black "shales", carbonate bases in Carboniferous carbonaceous environments (abs.): Geol.
Soc. Amer., Abs. w/Prog., v. 13, p. 309.


Long, D. T., and Powell, R. J., 1980, Paleobiology of juvenile (nepionic?) conodonts from the Drum Limestone (Pennsylvanian, Missourian-Kansas City area) and its bearing on apparatus ontogeny: Jour. Paleo., v. 54, p. 1058-1074.

and von Bitter, P. H., 1974, Revision of conodont biofacies nomenclature and interpretations of environmental controls in Pennsylvanian rocks of eastern and central North America (Abs.): Geol. Soc. America Abs. w/Prog., v. 6, p. 530.


by the Israel program for scientific translations, Jerusalem, 1969, 484 p.)


Moore, G. E., 1979, Pennsylvanian paleogeography of the
southern Mid-continent: in Hyne, N. J., ed.,
Pennsylvanian sandstones of the Mid-continent, Tulsa

Moore, R. C., 1929, Environment of Pennsylvanian life in
North America: Amer. Assoc. Petro. Geol., Bull., v. 13,
p. 459-487.

_____ , 1930, Sedimentation cycles in the Pennsylvanian of the
northern Midcontinent region (abs), Geol. Soc. Amer.
Bull. v. 41, p. 51-52.

_____ , 1932, A reclassification of the Pennsylvanian
System in the Northern Midcontinent Region: Kans. Geol.

_____ , 1936a, Stratigraphic classification of the
22, 256 p.

1936b, Stratigraphic evidence bearing on problems of
continental tectonics: Geol. Soc. America Bull., v. 47,
no. 11, p. 1785-1808.

_____ , 1937a, Upper Carboniferous rocks of southeastern
Kansas and northeastern Oklahoma: Kansas Geol. Soc.,

_____ , 1937b, Guide to field study of Pennsylvanian rocks in
southeastern Kansas and northeastern Oklahoma; Part 2,
between Independence, Kansas, and Coffeyville, Kansas:
p. 44-55.

_____ , 1940, Carboniferous-Permian boundary: Am. Assoc.

_____ , 1948, Classification of Pennsylvanian rocks in Iowa,
Kansas, Missouri, Nebraska, and northern Oklahoma:

_____ , 1949, Divisions of the Pennsylvanian System in

_____ , 1950, Late Paleozoic cyclic sedimentation in central
United States: Internal. Geol. Cong., 18th Proc.,
Pt. 4, p. 5-16.

_____ , 1958, Introduction to Historical Geology: McGraw-Hill
Book Co., 656 p.

_____ , 1959, Geological understanding of cyclic sedimentation
represented by Pennsylvanian and Permian rocks of the
northern Midcontinent region: Twenty-third Field


, and Boughton, C. W., 1921, Oil and gas resources of Kansas, Wilson and Montgomery Counties: Kansas Geol. Survey Bull. 6, pt. 6, 32 p.


——, 1990, Stratigraphy, petrology and depositional environments of sandstones in the Rock Lake Shale Member of the Stanton Limestone (Missourian Stage, Upper Pennsylvanian) in southeastern Kansas: Kansas Geol. Survey Geol. Ser. 5, 44 p.


Mukhopadhyay, B., and Brookins, D. G., 1976, Rb-Sr whole-rock


Neumann, A. C., and Land, L. S., 1975, Lime mud deposition and calcareous algal in the Bight of Abaco,


____, 1934, Some mid-Pennsylvanian invertebrates from Kansas and Oklahoma—I. Fusulinidae, Brachiopoda: Jour. Paleol., v. 8, p. 422-432.


____, 1937a, Late Paleozoic pelecypods; Pectinacea-Text: Kansas Geol. Surv., v. 10, pt. 1, 123 p.

____, 1937b, Late Paleozoic pelecypods; Pectinacea—Plates: Kansas Geol. Surv., v. 10, pt. 1, 37 p. (unnumbered).

____, 1942, Late Paleozoic pelecypods; Mytilacea: Kansas Geol. Surv., v. 10, pt. 2, 115 p.


Norton, C. W., 1976, Foraminiferal distribution and paleogeography of the Brush Creek marine event


———, 1914, Geology of the Nowata and Vinita quadrangles, Oklahoma: Unpubl. manuscript, Oklahoma Geol. Survey.


____, 1979, Paleoecology, provincialism and substitution among Late Pennsylvanian crinoids of the Midcontinent United States: in Pennsylvania Cyclic Platform Deposits of Kansas and Nebraska, 9th Int. Cong. of Carboniferous Stratig. & Geol., Field Trip no. 10, p. 75-79.

____, 1981, Late Paleozoic fish and shark remains from southeastern Nebraska (abs.): Neb. Acad. Sci., Trans., v. 9, p. 33.


____, and Strimple, H. L., 1979, Notes on biometrics, paleoecology, and biostratigraphy of Cibolocrinus

630


Parks, J. M., 1976, Summary of evidence for ecologic reef origin of Dry Canyon Late Pennsylvanian bioherms, Sacramento Mountains, south-central New Mexico (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 8, no. 7, p. 1042.


Peckham, S. F., 1895, What is bitumen?: Franklin Institute Jour., v. 150, p. 370-383.


Phleger, F. B., 1960, Ecology and distribution of Recent...
Foraminifera: Johns Hopkins Press, Baltimore, 297 p.


____, 1981, Stratigraphy, petrography, and depositional environments of the Pawnee Limestone, Middle Pennsylvanian (Desmoinesian), Midcontinent North America: Ph. D. dissertation, Univ. Iowa, 279 p.


Rao, C. P., 1981, Geochemical differences between tropical (Ordovician) and subpolar (Permian) carbonates, Tasmania, Australia: Geology, v. 9, p. 205-209.


636


Reid, R. P., and Browne, K. M., 1991, Intertidal stromatolites in a fringing Holocene reef complex,


Roedder, E., 1967, Environment of deposition in stratiform (Mississippi Valley-type) ore deposits, from studies of fluid inclusions; in Genesis of stratiform lead-zinc-barite-fluorite deposits (Mississippi Valley type deposits); a symposium, New York, 1966; Econ. Geol. Mon. 3, p. 349-361.


Rollins, H. B., Carothers, M., and Donahue, J., 1979, Transgression, regression, and fossil community succession; Lethaia, v. 12, p. 89-104.

_____ , and Donahue, J., 1974, Comments on the depositional environments of the Brush Creek marine event (Conemaugh Group, Pennsylvanian) in southern Ohio: in Donahue, J., and Rollins, H. B., eds., Conemaugh (Glenshaw) Marine


Russell, J. L., 1974, Comparison of two Late Paleozoic red shales of the Midcontinent region (abs.): Dissert. Abs., v. 35, p. 2265B.

Russell, J. L., 1977, High intertidal mudflat origin for Late Pennsylvanian and Permian red shales in the Midcontinent (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 9, no. 1, p. 71.


Sarg, J. F., 1979, Sedimentology of the Ames Limestone (Conemaugh Group) in the Pittsburgh (Pennsylvania)


Schoewe, D. C., 1944, Coal resources of the Kansas City Group, Thayer bed, in eastern Kansas: Kansas Geol. Survey Bull. 52, pt. 3, p. 81-136.


Segerstrale, S. G., 1957, Baltic Sea: in Treatise on Marine


Siebels, C. J., 1979, Petrographic analysis of the Stoner Limestone Member, Stanton Formation (Upper Pennsylvanian), Midcontinent: unpub. rept., 17 p.


—, 1931b, Site of the Mid-Continent’s discovery well, now a barnyard to be preserved: Oil and Gas Jour., v. 30, no. 29, p. 98-100, Dec. 3, 1931.


Southard, J. B., 1975, Bed configurations: in Depositional environments as interpreted from primary sedimentary
structures and stratification sequences, Soc. Econ.

Spackman, W., Riegel, W. L., and Dolsen, C. P., 1969,
Geological and biological interactions in the swamp-
marsh complex of southern Florida: in Dapples, E. C.,
and Hopkins, H. E., eds., Environments of coal

Spears, D. A., 1976, The fissility of some Carboniferous

Spencer, R. S., 1967, Pennsylvanian Spiriferacea and
Spiriferinacea of Kansas: Univ. Kansas Paleo. Contrib.,
Paper, 14, 35 p.

Srodon, J., 1979, Correlation between coal and clay
diagenesis in the Carboniferous of the Upper Silesian
coal basin: in 1978, Mortland, M. M., and Farmer, V. C.,
eds., Internat. Clay Conf., Elsevier, New York,
p. 251-260.

Stach, E., 1975a, The lithotypes of humic and sapropelic
coals: in Coal Petrology, Gebruder Borntraeger, Berlin,
p. 132-139.

______, 1975b, Seam identification: in Stach's Textbook of
Coal Petrology, Gebruder Borntraeger, Berlin,
p. 310-316.

Stanley, D. J., and Maldonado, A., 1979, Levantine Sea—Nile
Cone lithostratigraphic evolution: quantitative analysis
and correlation with paleoclimatic and eustatic
oscillations in the Late Quaternary: Sedimentary Geol.,

Stanley, S. M., 1970, Relation of shell form to life habits
of the Bivalvia (Mollusca): Geol. Soc. Amer., Mem. 125,
296 p.

Stanton, R. J., Jr., 1976, Relationship of fossil communities
to original communities of living organisms: in
Scott, R. W., and West, R. R., eds., Structure and
Classification of Paleocommunities, Dowden, Hutchinson,
and Ross, Stroudsburg, Pa., p. 107-142.

Staton, M. D., 1987, Stratigraphy and depositional
environments of the Cherokee Group (Middle
Pennsylvanian), central Cherokee Basin, southeastern

beneath coals: a modern analog, Snuggedy Swamp, South


Stein, C. H., 1971, Distribution and diversity of Pennsylvanian marine faunas relative to water depth and distance from shore: Lethaia, v. 4, p. 403-412.


Stout, T. M., 1981, The comparative method in stratigraphy; stage redefinition of the Late Carboniferous and "Early Permian" of the northern Midcontinent (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 13, p. 318.


Sweet, W. C., 1977, Hindeodus: in Ziegler, W., ed., Catalogue of Conodons, E. Schweizerbartsche Verlagsbuchhandlung,
Stuttgart, p. 203-224.


Tilton, Jo Lo, and Bain, H. F., 1897, Geology of Madison County: Iowa Geol. Surv., ann. rpt., v. 7, p. 489-539.


____, 1969a, The biota of the Pennsylvanian (Virgilian) Leavenworth Limestone, Mid-Continent region, Part I; Stratigraphy, paleogeography, and sediment facies relationships: Jour. Paleo., v. 43, p. 1001-1018.

____, 1969b, The biota of the Pennsylvanian (Virgilian) Leavenworth Limestone, Mid-Continent region, Part 2; Distribution of algae: Jour. Paleo., v. 43, p. 1313-1330.


----, 1981, Geologic applications of Upper Pennsylvanian ichthyoliths from the Midcontinent region (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 13, no. 7, p. 570.


Udden, J. A., 1903, Foraminiferal ooze in the coal measures of Iowa: Jour. Geol., v. 11, p. 283-284.


University of Florida Agricultural Experiment Station, 1948, Soils, geology and water control in the Everglades region: Bull. 442, 168 p.


Upshaw, C. F., and Hedlund, R. W., 1967, Microspores from the upper part of the Coffeyville Formation (Pennsylvanian, Missourian), Tulsa County, Oklahoma: Pollen and Spores, v. 9, p. 143-170.


van Eysinga, F.W.B. (compiler), 1978, Geologic Time Table, 3rd edition, Elsevier, Amsterdam


Ver Wiebe, W. A., and Vickery, W. R., 1932, Index to the
stratigraphy of eastern Kansas and adjoining areas:
p. 105-119.

, and others, 1948, Oil and gas developments in Kansas

, 1949, Oil and gas developments in Kansas during 1948:
Kansas Geol. Survey Bull. 78, 186 p.

, 1950, Oil and gas developments in Kansas during 1949:
Kansas Geol. Survey Bull. 87, 176 p.

, 1951, Oil and gas developments in Kansas during 1950:

, 1952, Oil and gas developments in Kansas during 1951:
Kansas Geol. Survey Bull. 97, 188 p.

, 1953, Oil and gas developments in Kansas during 1952:
Kansas Geol. Survey Bull. 103, 201 p.

, 1954, Oil and gas developments in Kansas during 1954:
Kansas Geol. Survey Bull. 107, 204 p.

, 1955, Oil and gas developments in Kansas during 1955:

Visher, G. S., Ekebafe, S. B., and Rennison, J., 1975, The
Coffeyville format (Pennsylvanian) of northern Oklahoma;
a model for an epeiric sea delta: in Broussard, M. L.,
ed., Deltas, Models for Exploration, Houston Geol. Soc.,
p. 381-397.

_____, and Rennison, J., 1978, The Coffeyville format
(Pennsylvanian) of northern Oklahoma; a model for an
epeiric sea delta: Geol. Soc. Amer., South-central Sect.,
Pre-meeting Field Trip, Guidebook, 26 p.

Vogt, P. R., 1986, Magnetic anomalies and crustal
magnetization: in Vogt, P. R., and Tucholke, B. E.,

Von Bitter, P. H., 1972, Environmental control of conodont
distribution in the Shawnee Group (Upper Pennsylvanian)
Art. 59, 105 p.

_____, and Heckel, P. H., 1978, Differentiation of black
"core" shales in Missourian and Virgilian cyclothems
(Pennsylvanian) in Iowa and Kansas, using conodonts
(abs.): Geol. Soc. Amer. Abs. w/Prog., v. 10, p. 510.

659
and Merrill, G. K., 1978, "Naked" species of Gondolella (Conodontophorida); their distribution, taxonomy, and evolutionary significance (abs.): Geol. Soc. Amer., Abs. w/Prog., v. 10, p. 240.


_, 1970b, Isostatic response to loading of the crust in Canada: Canadian Jour. of Earth Sci., v. 7, p. 716-733.


_____, 1985c, Evaluation of the significance of tectonic sedimentary control versus eustatic control of upper Pennsylvanian cyclothems in the western Mid-continent; in Watney, W. L., and others; Mid-continent Section Field Conference, Soc. Econ. Paleontologists and Mineralogists, p. 105-140.


Weller, J. H., 1930, Cyclical sedimentation of the Pennsylvanian Period and its significance: Jour. Geol.,
V. 68, p. 97-135.


___, 1958, Cyclothsms and larger sedimentary cycles of the Pennsylvanian: Jour. Geol., v. 66, p. 195-207.


Whitehouse, U. G., and McCarter, R. S., 1958, Diagenetic

Whitla, R. E., 1940, Coal resources of Kansas--post-Cherokee deposits: Kansas Geol. Survey Bull. 32, 64 p.


Williams, F. O., 1904, In the heart of the oil fields, Wilson County, 1904: Printed by the Neodesha Register, Neodesha, Kansas, 136 p. (unnumbered).


Williams, N., 1978, Studies of the base metal sulfide deposits at McArthur River, Northern Territory, Australia; II. The sulfide-S and organic-C relationships of the concordant deposits and their significance: Econ. Geol., v. 73, p. 1036-1056.


Wilson, F. W., 1957a, Barrier reefs of the Stanton Formation (Missourian) in southeast Kansas: Kansas Acad. Sci. Trans., v. 60, no. 4, p. 429-435. (Also M.S. thesis, Kansas State Univ., 50 p.)


Wilson, M. E., 1988, Petrology and petroleum geology of the


Woody, M. D., 1983, Sedimentology, diagenesis, and


Zhang, Chengliang, 1982, Preliminary observations on vestiges of glaciation at the base of Middle Carboniferous rocks in the southern part of Jilin Province, China: in Hambrey, M. J., and Harland, W. B., eds., Earth's pre-Pleistocene glacial record: Cambridge Univ. Press, 274 p.

Ziegler, A. M., Scotese, C. R., and Barrett, S. F., 1982,


CHAPTER EIGHT: APPENDICES

Consisting of sets of basic data for which material was too numerous to include in the text: for example (1) basic chemical data for the limestone members of the Oread, Lawrence, Stranger, Stanton, Plattsburg, Iola, and Drum formations, (2) chemical and petrographic materials (3) drawings of selected constituents of the fauna and flora of Wilson County. (4) copies of measured sections of outcropping rocks in Wilson County. (See also under folded materials in large envelopes the listings of tops and bottoms of major stratigraphic units encountered in drilling for oil and gas in Wilson County, and under published material are four selected reports on the geology of Wilson County by me.)
APPENDIX A
CHEMICAL ANALYSES OF LIMESTONE UNITS THAT CROP OUT
IN WILSON COUNTY

Chemical analyses of limestone samples from Wilson County have been reported on by Runnels and Schleicher (1956, p. 83-103) and Galle (1967, p. 97-109). These analyses include data on several members of the Oread Limestone, on the Haskell Limestone Member of the Lawrence Formation, on the Westphalia Limestone Member of the Stranger Formation, on the Stanton Limestone, on the Plattsburg Limestone, on the Iola Limestone and on the Drum Limestone. Runnels and Schleicher reported the results of a study of the compositions of 325 samples of the above listed limestones from the eastern one-third of Kansas. The data are directed to their use in an industrial sense as well as to their use in agricultural science. A high calcium limestone is required in industry, particularly in the production of quick and hydrated lime, whiting, and white cement; the presence of iron, manganese, or vanadium is undesirable. In ordinary cement moderate amounts of phosphorus, magnesium, and titanium are of considerable concern. In the manufacture of acetylene, a high calcium limestone that is low in aluminum, phosphorus, arsenic, antimony, and sulfur is demanded. For use in agriculture the presence of small
carbonate, may be beneficial to soils and plants. In the upper 6 to 8 inches of soil, small amounts of boron, zinc, copper, manganese, and molybdenum are beneficial. Boron is needed in amounts of 1 to 2 pounds of available boron per acre, zinc in a concentration of 2.5 pounds per acre. Copper is beneficial when present in soils in the amount of 2 pounds per acre, but addition of as little as 2 ounces per acre will greatly benefit depleted soils. The proper amount of manganese is believed to be 25 to 50 pounds per acre. The presence of approximately one ounce of molybdenum per acre has been found to greatly stimulate the process of nitrogen fixation. Elements known to be detrimental to soils and plants include silver, selenium, tellurium, thallium, arsenic, antimony, chromium, and lead. These elements can also be harmful to animal consumers of plants when present in excessive amounts (Runnels and Schleicher, 1956, p. 83-84). Galle (1967, p. 97) thought that a geochemical study might show a cyclic trend in the chemical constituents within a single formation and, for that purpose, he chose the several limestone members of the Oread Limestone throughout Eastern Kansas. He collected samples at regular intervals along the entire outcrop length of the Oread Limestone. Illitic clay, a siliceous, potassium, magnesium, aluminum and iron-rich hydrated oxide was found to be a common constituent of the Oread in conjunction with pyrite and chert. The chemical analyses of the Oread Limestone show
that the lateral variation of purity of the limestone is
great and unpredictable and that parallelisms in the
chemical constituents of superimposed limestones deposited
at different times seem to occur.

The locations of samples taken by Runnels and
Schleicher (1956, p. 86) are shown on Figure 64; locations
of those obtained by Galle (1967, p. 98) are on Figure 65.
Also shown on Figure 65 is a measured section of the Oread
Limestone by Galle (1967, p. 98). Chemical analyses of
the Kereford, Plattsmouth, Leavenworth, and Toronto
Limestone Members of the Oread Limestone, provided by
Galle (1967, p. 101, 102, 104, 107) are given in Table 16.
Chemical analyses from Runnels and Schleicher (1956) for
samples from the Plattsmouth, Leavenworth, and Toronto
Limestone Members of the Oread Limestone, for the Haskell
Limestone Member of the Lawrence Formation, for the
Westphalia Limestone Member of the Stranger Formation, for
the Stoner Limestone Member of the Stanton Limestone, for
the Spring Hill and Merriam Limestone Members of the
Plattsburg Limestone, for the Raytown and Paola Limestone
Members of the Iola Limestone, and for the Dewey Limestone
Member of the Drum Limestone are given in Table 17 as
extracted from Runnels and Schleicher (1967, Plates 2 and
3).
Figure 64. Map showing locations of limestone samples from eastern Kansas (From Runnells and Schleicher, 1956, p. 86)
Map of sample locations  
Measured section of Oread Limestone  
(From Galle, 1967, p. 98).

Figure 65. Map showing the locations of samples and a measured section showing the relative positions of limestone members of the Oread Limestone (from Galle, 1967, p. 98).
C) O N

%
g

rHC
CM
CO
OO
T}’
4Lf)C
CD
5O
OO
>d
C
C)
ïo
CO
O

s OO ooo
dd ddd

m

O

CO

M CO

TO

o o

a

rH O

0
88 i
g3 8 0 0
^0 d d
d

■a I

'a : | : S 3
'a 1 S's!?

H to S

s 0 0 0,0
d d o 'd

00 1

o 333,8
d d d 'd
05 8 c5o o 3
d d oid d

5
d d ' 11 1
TO8 8 80 8
d
05 05

N

d d ^d
^

8

”

,

TO

•
>
i
't
lO
030
M5
'l> 0 TOTO 53 3
I
T
5
03
d d d d d d d rJ
tH

r-4 lO

8 83
TO

SSS g
M W C4M •

83398
9! 8 5 8 8 8

8 8 8 33 s
TOd d 88 8

If) CO O
<
?>oitr-0>

8 888S8
dd d dd

885

53 8
0 03 d

8 g Kto C S
8 d ddd
" 88833
m 88388

888
888
835
888

38
85 S
RS 5
38 3

s 80885
W 03CMd d

588
"3S

38 3

S 3^828
8 8 3 TOTO0
53 33 3
I àiààii
” 05TOm OTd
&oË
t
to&
M t
to
o

335
333
21
5^8
522

83 S
TOTO s
55
Ô
5
toto

f-î

8

Î

t-

M

W

CO CO

tH

0> l> O O)
CO T)' to to

O) CO

to

f-

rH

O)M (OO
C*3 tH rj‘ to
0> O CD 0>
CO cq N

88

CO

ÏÏ

YTTV
RSS8

111

^O OW

fill
UiV)ViVi

I#

:î3 & w

S

TO

TO

O

H

05 3

s 8 8 388
05 d 05'd d d

to CO Tp to
CO CO N

w

?V
COc>

%E

&g&

toto
fU (U o dJ
W W WWW
K W toS Œ

S pii

II

O
O) to
CO »H OJ CO

678


### Kereford Limestone Member

<table>
<thead>
<tr>
<th>Loc. Lab. No.</th>
<th>County</th>
<th>Locality</th>
<th>Sec. T.S.</th>
<th>R.B.</th>
<th>Thickness</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>58307</td>
<td>Greenwood</td>
<td>SW</td>
<td>8-26-13</td>
<td>7.0</td>
<td>10.11</td>
<td>2.45</td>
<td>2.55</td>
<td>0.08</td>
<td>45.92</td>
<td>0.65</td>
<td>0.23</td>
<td>0.02</td>
</tr>
<tr>
<td>25</td>
<td>59261</td>
<td>Greenwood</td>
<td>C</td>
<td>6-27-13</td>
<td>2.0</td>
<td>51.32</td>
<td>3.49</td>
<td>2.42</td>
<td>0.45</td>
<td>21.74</td>
<td>0.45</td>
<td>0.38</td>
<td>0.52</td>
</tr>
</tbody>
</table>

### Plattsmouth Limestone Member

<table>
<thead>
<tr>
<th>Loc. Lab. No.</th>
<th>County</th>
<th>Locality</th>
<th>Sec. T.S.</th>
<th>R.B.</th>
<th>Thickness</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>59262</td>
<td>Greenwood</td>
<td>NW</td>
<td>1-26-12</td>
<td>2.0</td>
<td>9.05</td>
<td>3.59</td>
<td>3.20</td>
<td>0.25</td>
<td>42.13</td>
<td>2.89</td>
<td>0.42</td>
<td>0.12</td>
</tr>
<tr>
<td>25</td>
<td>52205</td>
<td>Wilson</td>
<td>SW</td>
<td>23-27-13</td>
<td>3.0</td>
<td>3.64</td>
<td>1.23</td>
<td>1.35</td>
<td>0.07</td>
<td>51.30</td>
<td>0.72</td>
<td>0.13</td>
<td>0.01</td>
</tr>
<tr>
<td>26</td>
<td>55174</td>
<td>Greenwood</td>
<td>NE</td>
<td>3-28-12</td>
<td>7.1</td>
<td>3.36</td>
<td>0.97</td>
<td>1.30</td>
<td>0.07</td>
<td>51.46</td>
<td>1.20</td>
<td>0.09</td>
<td>0.03</td>
</tr>
<tr>
<td>27</td>
<td>52361</td>
<td>Elk</td>
<td>SE</td>
<td>21-29-12</td>
<td>9.0</td>
<td>1.61</td>
<td>0.41</td>
<td>0.64</td>
<td>0.01</td>
<td>53.96</td>
<td>0.43</td>
<td>0.07</td>
<td>0.03</td>
</tr>
<tr>
<td>28</td>
<td>58293</td>
<td>Elk</td>
<td>SW</td>
<td>22-30-12</td>
<td>17.5</td>
<td>2.45</td>
<td>0.61</td>
<td>0.92</td>
<td>0.01</td>
<td>53.04</td>
<td>0.34</td>
<td>0.05</td>
<td>0.03</td>
</tr>
</tbody>
</table>

### Leavenworth Limestone Member

<table>
<thead>
<tr>
<th>Loc. Lab. No.</th>
<th>County</th>
<th>Locality</th>
<th>Sec. T.S.</th>
<th>R.B.</th>
<th>Thickness</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>FeS₂</th>
<th>TiO₂</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>59266</td>
<td>Greenwood</td>
<td>SW</td>
<td>8-26-13</td>
<td>1.2</td>
<td>3.88</td>
<td>0.90</td>
<td>2.20</td>
<td>0.11</td>
<td>50.06</td>
<td>1.06</td>
<td>0.06</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>58313</td>
<td>Greenwood</td>
<td>NW</td>
<td>15-27-13</td>
<td>1.4</td>
<td>3.00</td>
<td>0.79</td>
<td>1.84</td>
<td>0.22</td>
<td>50.37</td>
<td>1.62</td>
<td>0.08</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>58314</td>
<td>Elk</td>
<td>SW</td>
<td>25-28-12</td>
<td>1.8</td>
<td>3.41</td>
<td>0.64</td>
<td>2.44</td>
<td>0.15</td>
<td>50.00</td>
<td>1.15</td>
<td>0.06</td>
<td>trace</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>58295</td>
<td>Elk</td>
<td>C</td>
<td>25-29-12</td>
<td>1.7</td>
<td>2.89</td>
<td>0.68</td>
<td>1.64</td>
<td>0.07</td>
<td>n11</td>
<td>51.66</td>
<td>1.09</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>28</td>
<td>58296</td>
<td>Elk</td>
<td>SW</td>
<td>22-30-12</td>
<td>1.9</td>
<td>2.31</td>
<td>0.53</td>
<td>1.18</td>
<td>0.21</td>
<td>52.49</td>
<td>0.23</td>
<td>0.05</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

### Toronto Limestone Member

<table>
<thead>
<tr>
<th>Loc. Lab. No.</th>
<th>County</th>
<th>Locality</th>
<th>Sec. T.S.</th>
<th>R.B.</th>
<th>Thickness</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>52294</td>
<td>Greenwood</td>
<td>NW</td>
<td>10-26-11</td>
<td>9.0</td>
<td>4.56</td>
<td>0.92</td>
<td>3.04</td>
<td>0.02</td>
<td>50.10</td>
<td>0.61</td>
<td>0.08</td>
<td>0.03</td>
</tr>
<tr>
<td>25</td>
<td>52204</td>
<td>Wilson</td>
<td>W</td>
<td>23-27-13</td>
<td>4.0</td>
<td>5.85</td>
<td>1.60</td>
<td>1.34</td>
<td>0.07</td>
<td>49.92</td>
<td>0.80</td>
<td>0.18</td>
<td>0.03</td>
</tr>
<tr>
<td>26</td>
<td>58310</td>
<td>Elk</td>
<td>SE</td>
<td>1-29-12</td>
<td>6.5</td>
<td>8.55</td>
<td>2.02</td>
<td>2.50</td>
<td>0.08</td>
<td>47.35</td>
<td>0.76</td>
<td>0.17</td>
<td>0.04</td>
</tr>
<tr>
<td>27</td>
<td>58299</td>
<td>Elk</td>
<td>S</td>
<td>25-29-12</td>
<td>0.3</td>
<td>6.32</td>
<td>1.76</td>
<td>1.92</td>
<td>0.11</td>
<td>47.59</td>
<td>1.72</td>
<td>0.24</td>
<td>0.06</td>
</tr>
<tr>
<td>28</td>
<td>58300</td>
<td>Elk</td>
<td>SW</td>
<td>27-30-12</td>
<td>1.2</td>
<td>7.43</td>
<td>2.02</td>
<td>2.72</td>
<td>0.13</td>
<td>46.64</td>
<td>0.99</td>
<td>0.31</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 17. Chemical analyses of the limestone members of the Oread Limestone from Wilson County and areas immediately adjacent to Wilson County (from Galle, 1967, p. 101, 102, 104, 107).
APPENDIX D

SILVER CITY DOME--A CRETAEOUS IGNEOUS INTRUSION
IN WILSON AND WOODSON COUNTIES--ITS DISCOVERY

GEOLOGY, PETROGRAPHY AND CHEMISTRY

Being an addition to text pages 59 to 72.
Appendix B begins with an account of the discovery of the intrusive rocks along the Wilson-Woodson County line. The account was told to me in 1951 by W. L. Stryker of Fredonia, Kansas, after an exhaustive search had been made for an original researched account written by his daughter, Polly, as a composition for her English class at the University of Kansas in 1935. Unfortunately, the search was fruitless, and, therefore, I can record here only the story approximately as told to me by Mr. Stryker.

Silver City—its discovery, history, and demise.

"On a hot summer day in 1877, a middle aged man in well-worn, patched dungarees and leading a heavily laden mule came over the brow of a low hill in southeastern Kansas some 15 miles north of Fredonia, the county seat of Wilson County. He threw himself down in the shade of a black-jack oak and took a long swill of water from the bottle he had filled a few hours earlier from a tributary to the Verdigris River. His mule stood patiently nearby cropping at the short prairie grass. As he gazed around him, he realized that before him lay a nearly circular depression about two miles across and three miles long. After a few minutes of lazy gazing, his eyes came to rest near where he was sitting, and he noted a
grayish-green rock lying nearby. With his boot he scooped the rock to a point within reach of his hand and picked it up. He looked at it at first with normal curiosity and then with considerable interest. Not only the greenish color caught his attention, but attached to the rock in places was a coating of golden colored flaky material. As a disillusioned prospector who had spent some years in the gold fields of California and had just left the gold-silver camp at Cripple Creek, Colorado, his mind reflected back to the rocks he had worked in at those places. He also realized that he had seen no rocks like these as he had traveled through the uninteresting limestone, shale and sandstone of the prairie country of eastern Colorado and western Kansas. He recognized immediately that he held in his hand a rock of considerable interest. Was it a single specimen or were there more like it in the vicinity? He quickly got to his feet and nearby found many, many more rocks of greenish color with the golden material adhering to their surfaces. He found that the golden material could be readily brushed from the rock's surface and was very light and flaky. He took his equipment from the mule and soon made the standard prospector tests for gold on the flaky material. Every test proved negative. He then turned his attention to the gray-green rock. When struck with his hammer, it emitted a distinct ring; when scratched with his knife, the knife blade was dulled; when broken, it sparkled in the sunlight like quartz. His mining experience in California and Colorado had
introduced him to the qualities of such rocks, and he had learned that gold and silver were associated with them in many places, but only here had he found the quartzite embedded in or covered by this glistening golden-colored mica. He decided to prospect the area more thoroughly, and as he unpacked the mule, he took off two cloth sacks containing samples of silver ore he had brought with him from Colorado. He opened the bags and compared the Colorado samples with those he had picked up off the ground. Some of the Colorado rocks were very similar to those that surrounded him. He returned them to their bags, took his pick and shovel and began digging a pit. Where digging in the mica rock, progress was rapid; but in the quartzite, a bar and pick were needed. He had dug a pit almost three feet deep when darkness set in. After a short night's sleep, he was up and digging again. By noon the pit was six feet deep and chips and slabs of the greenish quartzite and a grayish black rock were heaped into a pile. A few cubes of pyrite and dark-gray galena were noted in some of the quartzite and black blocks, but he found no silver minerals like those in his specimens from Colorado.

After several days of digging prospect holes throughout the area of greenish quartzite, black rock, and golden mica rock he felt he was on a wild-goose chase. While sitting in the shade of one of his prospect pits, he recalled an unhappy experience he had had in the gold fields of California. After several months there, and with little success, he made
the acquaintance of a presumably successful miner who, as it turned out, was a scoundrel. After a few weeks, the presumably successful miner offered to sell him a mine that he claimed was on an excellent vein. Upon inspection, the gold could be seen in the quartz specimens they dug from the underground face of the mine. He paid the miner his asking price for the claim; but after a few hours of heavy labor, he realized that he had been cheated. The only quartz with gold was in the pieces he had brought out initially. The prospect had been 'salted' and the miner had disappeared. Having learned his lesson, and being none too honest himself, the thought occurred to our prospector in the shade that day that such an arrangement might profit him also. He therefore used most of the samples containing native silver, barite and pearceite from Colorado as material with which to salt the deeper prospect holes he had dug.

The next day he went to the nearby town of Yates Center where he filed a series of claims on all the property containing the quartzite, showed the claim agent some of the material from Colorado, but supposedly from the quartzite area, and the rumor soon started of a silver strike about 15 miles north of the town of Fredonia in Wilson County. Within a few days, many of the nearby farmers had visited the site, had seen the samples with silver showing and soon many claims had been bought. Samples from the prospect holes were immediately sent away for assaying locally and in the East and some were found to contain silver in quantity. A tent
city of 100 or more tents sprang up, a few more-substantial wooden buildings were added, a mayor was elected, the name Silver City was chosen for the townsite, and a community of 500 or more inhabitants occupied the area. All of his claims by now having been sold, our middle-aged prospector disappeared over the horizon one night.

Prospecting, however, continued for more than a year, pyrite and galena were occasionally found in the quartzite and black rock, but eventually the prospectors became discouraged, the farmers went back to their farms, and the miners hunted for new and hopefully more productive territory. Within eighteen months of its beginning, the boom was over and nothing remained of Silver City except a few dilapidated sheds and the name, which was applied to the domal uplift by geologists who were drawn to the area by the reports of the discovery of silver in such an unlikely place as Woodson County, Kansas.

Early Geologic Reports — the Silver City Dome

The first geologic report on the area was a note by Prof. B. F. Mudge in the Transactions of the Kansas Academy of Science of 1879 who stated that "Much excitement has existed for a year past in Woodson County, Kansas [a mile north of the Wilson County line] in relation to the alleged mines of gold and silver at Belmont [Township]. These reports induced me, in June, 1879, to visit the spot, in company with Prof. Hay...Some twenty shafts have been opened in the vain attempt to find valuable ores. These [shafts] enabled us to obtain a
most accurate knowledge of the metamorphic action... The moderate metamorphism was, in my estimation, clearly caused by the action of warm mineral siliceous waters, and probably under pressure. The change was most marked on the porous sandstones, and less so on the limestones and clay shales... The clay shales had assumed a more granular appearance, interspersed with small flakes of mica. We saw over thirty feet of this stratum in several places. But the most marked metamorphic action was seen in the common sandstone. Its porous character allowed the hot steam and vapor to penetrate freely into all portions of the stratum... This is seen in blocks of quartzite...[which] lie on the surface...[where also] were masses of quartz containing clear, glassy crystals, and...a number of specimens of beautiful amethyst... At the deepest shaft, Mr. Van Meter's, the bluish-green chert, or quartzite, is traversed by veins of white quartz, which was said to contain gold; but a portion which I took out did not yield a trace of that metal... I was told... that assays of rocks from these shafts had been made by chemists in Massachusetts and Colorado, and silver had been obtained, varying in amount from $5 to $6.25 per ton. This... is fully equal to the silver mines at Leadville [Colorado]... Though several thousand dollars have been spent, not a single ounce has been sold as a product of all the mines... Whether the ore was 'salted' before it started for Massachusetts, or whether the whole story was a fabrication, I do not know.” (Mudge, 1879, p. 13).
Robert Hay of Junction City, Kansas, who accompanied Professor Hudge on the excursion quoted above, also wrote a report which he titled "The Igneous Rocks of Kansas". It was prepared for presentation at a meeting of the Kansas Academy of Science in 1880 but was not read until their meeting of 1881 and was not published until their Transactions in 1883. Much of this paper deals with igneous and metamorphic rocks found in the Quaternary glacial erratics of Kansas and of the rocks of the Tri-State lead-zinc district which extends into southeasternmost Kansas. In his report Professor Hay had this to say about the Silver City area. "About three years ago, the papers of the State were agitated by reports of a silver region in Woodson County. It was said that assays made in the East and in Colorado of ores sent from this region, showed a yield of a considerable amount of silver to the ton; but samples sent to Prof. Patrick, at Lawrence and to Prof. Kedzie, at Manhattan gave no such assays, and the excitement began to die out, though one or two local enthusiasts are still toiling on... I was to visit the region and report on its geology...and had the privilege of going in company with Prof. Hudge. We spent the greater part of two days examining a district not exceeding three hundred acres in area... Twelve months after my first visit, I went over the ground again, accompanied by Prof. Middaugh, of Humboldt... On the surface were some quartz fragments as if they had been seams in clay. A shaft showed a limestone about two feet thick, underlaid for many feet deep with slaty shale
containing some mica. The limestone had fossils. Going east the limestone changed to a dark massive-looking rock, not unlike some igneous rocks, but the traces of fossils were still plain. Instead of shale, there was a loose earth under, with more mica; the rocks still horizontal. Farther east...the surface rocks are quartzose; green mostly, and dipping at a considerable angle. The loose earth is now yellower, and farther east nearly black, and is rich in mica. We called it micaceous dirt...North and east...the surface rocks...are all altered into quartzite, green and some dark, blackish, olive, but many retaining their horizontal position...Others are considerably tilted up, showing violent force in a very narrow area. About the middle of the south edge of the area, and again at the eastern end, there are masses of brecciated rock, the uniting material being quartz. Here then we have, without doubt, metamorphic rock in situ—quartzite and breccia. About the middle of the north edge of the area is a shaft twelve feet deep, six or eight feet long, and five feet wide. It shows the metamorphosis beautifully. A mass of white quartzite, solid (but also in part greenish, with many pores and holes filled with crystals)...This shaft yields...beautiful amethysts, and some that may possibly be beryl. The deepest shaft is that of Mr. Van Meter...It is 70 feet deep. It has 35 feet of water in it. We descended to the surface of the water. The rocks near the surface are the altered sandstones and limestones; below is the micaceous dirt (dark colored). This is crossed in all directions by
seams of dark-blue (or purplish) stone of great hardness, from one to twelve inches thick, and below the dirt is now solid and has thin quartzose bands in it... This blue rock and these quartz bands...are what the miners expect will yield silver or gold. We don't. In the Puckett shaft, farther east, the shale...reappears with laminae of green carbonate of copper... We regard the dark-blue rock as...true igneous rock. We think long before other rocks were removed from the surface, this was pushed up from below into cracks and fissures, probably finding here there was no outlet... The thin veins of quartz and the crystals are probably due to infiltration in the cracks that were made as the mass cooled, while the micaceous dirt is perhaps altered shale... Prof. Patrick, who has also visited Silver City in Woodson County, pronounces that half-mile of land the most remarkable mineral district he has ever visited; and I, thinking the same, do not wonder that some uneducated men, seeing silicifications very like what we see in Colorado, should have become infatuated with the idea of finding the precious metals. They see resemblances—a lack of geological knowledge hinders them detecting differences" (Hay, 1883, p. 17, 18).

The next mention of igneous or metamorphic rocks near or in Wilson County is in a report by W. H. Twenhofel some 34 years later, published in the American Journal of Science, volume 43. Twenhofel noted (1917a, p. 363) that while examining territory in Wilson and Woodson Counties in the interest of the Fredonia Gas Company, he found granite
boulders apparently in Pennsylvanian strata. He stated (p. 368) that "these are all the places where granite boulders were observed. The surrounding country for from ten to fifty miles in every direction was quite thoroughly examined and at no place was a single granite boulder found". The area of boulders is in Woodson County at the Rose Domes, 4 to 6 miles east-northeast of the Silver City Dome. The boulders are of Precambrian granite enclosed in micaceous rock which Twenhofel described as being merely a normal micaceous shale. Of pertinence to the Wilson County occurrence of quartzite and micaceous rock, however, is the statement that two quartzite boulders at the Rose Dome closely resemble the quartzites which crop out near the village of Middletown, five or six miles to the southwest. This location would place them practically at the Silver City Dome.

In the American Journal of Science, volume 44, for 1917, Sidney Powers, having just read Twenhofel's paper in volume 43 of the same journal, wrote as follows: "Twenhofel presents strong arguments to show that these boulders were deposited contemporaneously with...shales and sandstones of Pennsylvanian age. He also believes that the boulders reached the positions where now found through the agency of ice, because 'the sediments with which they appear to be associated were deposited in quiet waters--waters absolutely unable to transport boulders of the size of those which are now present'" (1917, p. 146). Powers admitted that Twenhofel had said that he recognized the possibility that the boulders
could have come from a Precambrian knob that extended above the land surface in Pennsylvanian time in the same region, but he [Twenhofel] rejected this theory because he believed that somewhere nearby, such an outcrop should exist, and there was none. Powers then pointed out that "if granite is encountered in wells in Kansas at a depth of only 550 feet, it is quite probable that at places granite occurs still nearer the surface, and it might have been undergoing erosion somewhere in the vicinity of Woodson County during deposition of the Le Roy [Weston] shales" (Powers, 1917, p. 147).

In that same year, Twenhofel (1917b) published an extensive report in the Bulletin of the Geological Society of America for which he used the title "The Silver City Quartzites: A Kansas Metamorphic Area" (1917b, p. 419). Twenhofel again stated that the work was done in the interest of the Fredonia Gas Company and implied that since the quartzites were found at the eastern end of a long east-west ridge that formed the northeastern flank of a small anticline, there may be oil possibilities related to this structure. In a general statement about the geologic setting, he placed the youngest rocks in the Lawrence Shale which he described as consisting of red, yellow, gray, blue, and black shales and sandstones of ferruginous colors. He wrote that "generally there are many bands of shale and sand which contain mica (apparently muscovite) in great abundance" (Twenhofel, 1917b, p. 421). He wrote that next below was a thin, "compact, very dark blue, semicrystalline limestone of
fine texture and brittle fracture [that is] characterized by a highly developed vertical jointing..." (p. 421). Another group of shales were believed to separate the thin limestone from the Stanton Limestone, the lowest rocks exposed in the vicinity. Concerning the Silver City anticline, he stated that it had the form of an elliptical dome and stated further that the northeastern margin of the dome "is considerably irregular and it is clear that in the development of the anticline, considerable crushing and fracturing occurred there. There is no evidence of faulting...The Lawrence shales and sandstones...consist throughout the [metamorphic] area...of very hard, compact quartzites, which locally contain small cavities lined with crystals of quartz and, more rarely, of pyrite. There is no trace of the red colors which are characteristic of the rocks of this division in surrounding areas, but instead there are shining gray and greenish shades. In the sunlight the quartzite sparkles brilliantly, and it was probably this characteristic which led to its being mistaken for silver ore. Examination of the rock in thin-sections proves it to be composed of grains of pure quartz sand cemented with quartz with a variable proportion of chlorite in those portions which are of greenish shades" (p. 424). Concerning the prospecting, Twenhofel went on to say that the "shafts are now largely filled, but much of the debris which was thrown from them remains scattered over the ridge, and this debris contains no igneous rocks" (p. 424). He also stated: "Near the top of
the south side of the ridge are several very excellent cold-
water springs. Since they occur on that side of the ridge
from which the strata are inclined, it is rather difficult to
explain their presence except on the assumption that the
water rises along fractures" (p. 424).

Farther in the report, Twenhofel continued: "The notes
which follow were kindly prepared for the writer by Prof. A.
N. Winchell...'In thin section the dark green color of the
fragments is found to be due to abundant well-crystallized
lamellae and needles of dark green chlorite...There is also
some rare hornblende and rather common grains of
epidote...The epidote is not only pleochroic, but also varies
in color in different crystals from golden yellow to brown
and brownish gray...The broken zone furnished...channels
[that] served as paths...for hot solutions coming from
greater depths...[and] caused the growth of chlorite,
epidote and hornblende. Such solutions were probably wholly
or partly of igneous origin’” (p. 426). Of another sample,
Prof. Winchell was quoted as writing “In thin section...the
groundmass [is] plentifully sprinkled with rounded grains of
feldspar. The chief constituents are orthoclase and finely
divided argillaceous material, including chlorite, sericite,
and kaolin. There are rare crystals and fragments of zircon,
apatite, and magnetite. Recrystallization has developed a
mineral of hazy grayish brown to brownish green color having
high relief and strong birefringence; it is biaxial and
negative with a large optic angle and a granular habit; it is almost certainly epidote" (Twenhofel, 1917b, p. 426).

Twenhofel continued: "Two wells have been drilled on the Silver City anticline... In the well of Location 2, the drillers constantly complained that they were not finding rocks with which they were familiar and which they had found in the wells of the vicinity...[In the other well] the rocks did not materially differ from those of well number 1, except that the abnormal rocks were met at a slightly greater depth...In each well rocks were encountered which the drillers identified as mica... large quantities of hydrated mica. Black limestones were indicated in the logs. These were found to contain no calcium carbonate, but to be hardened chloritized material containing hydrated mica" (Twenhofel, 1917b, p. 427).

The abundant mica and black rock were noted by me in 1950 when I first began mapping in the area of the Silver City Dome. Fortunately, I recognized the golden micaceous earth as the intrusive mass that was responsible for the metamorphism of the sandstone to greenish-gray quartzite. I realized also that the apatite had been introduced into the joints in the thin dark-gray limestone, presumably during the intrusive activity.

In 1919 Twenhofel wrote a short note titled "Additional facts relating to the granite boulders of southeastern Kansas." In this report (1919, p. 133-134), he provided the description of a well drilled at Rose Dome a quarter of a
mile due south of the largest accumulation of boulders. The boulders may correlate with weathered and fresh granite rocks noted in the well. However, no mention of very micaceous shale was made in the well log.

In 1921, Twenhofel and E. C. Edwards authored a report on the metamorphic rocks “at a place known as Silver City in Woodson County” (1921, p. 63). The report contained an excellent, for its day, map depicting the structure of both the Silver City and Rose anticlines (1921, p. 65). They stated that the metamorphic rocks at the Silver City Dome crop out along the south slope and over the top of the ridge which margins the basin on the north. They stated also that (p. 66) “within the metamorphic area...the sandstones are hard, compact, greenish colored quartzites which locally contain cavities lined with quartz and pyrite...Thin sections show that the rock is composed of quartz with a small percentage of chlorite.” Concerning the limestone they reported that (p. 67) “the cracks in the limestone are filled with hard black chert” or “brecciated and replaced by greenish black chert...A thin section of the rock filling the cracks in the limestone shows that it is really pure chert, but where the chert has completely replaced the limestone considerable chlorite is present.” Where “it is throughly brecciated, the fragments are completely replaced by greenish chert and are held together by a cement composed of hornblende and chlorite...Thin sections show that...the green parts contain chert together with needles and laminae of
chlorite, golden-yellow to brownish and brownish-gray epidote and rare hornblende" (p. 67). Twenhofel and Edwards stated later that two wells were drilled on the anticline. They wrote (p. 68) that "no igneous rocks were encountered in either well, but in each well, rocks were penetrated which the drillers identified as mica. This proved to be fine-grained sandstone containing a great deal of partially detrital mica. 'Black limestones' were also encountered. These were found to contain no lime, but appeared to be black shales containing considerable chlorite. Both the micaceous rocks and the chloritic black shales had a soapy feel. It is obvious that the metamorphism extends to great depths and with depth for greater distances from the Silver City ridge..." (p. 68). "It is quite probable that an intrusive igneous rock may lie beneath the Silver City ridge" (p. 69). Associated with the granite at Rose Dome "were seen a few [boulders] composed of chert and greenish quartzite" and "on the road near the school house in the southwestern corner of section 18, there are small quartz veins in the rocks" (p. 69). "During the past year, a letter was received from Dr. Sidney Powers which stated that one of his assistants had found metamorphic rocks beneath the boulders which "show precisely the same metamorphism as does the Silver City area" (p. 70). Also, "a letter from Mr. V. H. Hughes gave the information that the 'shale with which the boulders are more or less closely associated is distinctly metamorphosed. In the test well drilled, some of the material penetrated
between the depths of 1,190 feet and 1,250 feet also shows evidence of metamorphism” (p. 70). A copy of a letter from Sidney Powers to Mr. E. DeGolyer was sent to Professor Twenhofel by Dr. Powers in which a “dacite dike” was said to have been penetrated in a well drilled to a depth of 1250 feet near the center of section 24 at Rose Dome. Mr. Hughes stated that “the last thirty feet of rock penetrated drilled extremely hard. The driller was able to average less than six inches of hole per hour, and the drill had to be sharpened for at least every two feet of hole made” (Twenhofel and Edwards, 1921, p. 71). Examination of thirteen samples from that interval showed calcite, chert, quartz, pyrite, and optically inactive material. One of the envelopes containing a sample gave the information that during washing, mica floated away.

In a letter to C. N. Gould dated November 1, 1922, Professor Twenhofel says that “possible occurrences of igneous rocks in Kansas... are at Silver City and near Rose, both in Woodson County. Each occurrence is associated with... a dome or anticline...The anamorphosed sediments at Silver City are best explained by the occurrence of an igneous intrusion at no great distance beneath the surface” (Gould, 1923, p. 548, 549).

In 1926 Professor Twenhofel published a fourth report titled “The intrusive granite of the Rose Dome, Woodson County, Kansas”. Data in this report have some bearing on the igneous rocks at the Silver City Dome, the southern one-
half of which is in Wilson County. Twenhofel (p. 404) stated that "during 1923 a well was drilled on the Rose Dome not over 300 yards northwest of the western edge of the largest pile of granite blocks....This well was drilled to a depth of 1,685 feet and samples were collected from the lowest 400 feet. These have been carefully studied, and the study has shown that contact metamorphic minerals are present in abundance...The driller states that the drill cuttings contained much mica, and that some of the particles were a quarter of an inch in diameter. It is probable that the samples which were collected show less of this mineral than actually is present in the rocks" (p. 404). Twenhofel concluded that the rocks at Rose Dome are intrusive based on "the presence of contact metamorphic minerals in the rocks penetrated by the well near the northwest margin, and the occurrence of pronounced hydrothermal metamorphism in the Silver City area some four to five miles to the southwest" (p.406, 407). "The well of which samples from the lower 400 feet were studied is known as the Parsons or Lieurance well. Most of the samples contain contact metamorphic minerals as diopside, pyroxene, and dark brown mica" (p. 407, 408). The log of the well is given on pages 408 and 409 of Twenhofel's report. He stated that the log from the depth of 1287 feet to the bottom was prepared from study of the samples. The log shows that nearly every sample from 1340 to 1582 feet contained brown mica and pyroxene, or serpentine, or needle-like crystals of green diopside and cubes of pyrite. From
1618 feet depth to the total depth of the well at 1685 feet are similarly described rocks. There would appear to be two similar intrusive bodies, the uppermost being 242 feet thick and the lower at least 67 feet thick. They are separated by about 30 feet of white to gray cherty limestone. "In the Silver City area... the sandstones... and limestones have been silicified, brecciated, and recemented by a matrix containing epidote and hornblende. The metamorphism is readily accounted for by the assumption of an intrusive body of igneous rock beneath the surface" (Twenhofel, 1926, p. 410). He apparently still had not recognized the mica peridotite as the intrusive body at both domes.

In his final paper on the Woodson County intrusive, Prof. Twenhofel, with Bernard Bremer, wrote about "An Extension of the Rose Dome Intrusives, Kansas." Twenhofel recapitulated his knowledge of the Silver City and Rose Dome area and then described cuttings from the Eagle No. 1 well drilled by the Southwestern Gas Company in the southwest corner of Sec. 31, T.26 S, R 16 E (correct location is C NE1/4 SW1/4 Sec. 19, T 26 S, R 16 E; see Knight and Landes, 1932, p. 6,7). The well is south and east of the occurrence of the Rose granites and about 5 miles east of the Silver City Dome. The samples do not give the complete log, nothing being listed above 1151 feet. Twenhofel stated that "the samples studied indicate that a basic igneous rock was penetrated in the well through a thickness of 102 feet, or from the depth of 1,151 feet to 1,253 feet" (p. 758). He
then provided a log of the well from 1154 to the total depth of 1640 feet. Between 1154 and 1220 feet the rocks are described as fine-grained light brownish material containing quartz, brown mica, kaolin, and serpentine. He then stated that "the well probably entered the 'Mississippi lime' horizon at about the depth of 1,266 feet and may have entered older rock at about 1,500 feet. The part of the well below 1,253 feet shows normal sedimentary materials of which most are limestone and chert" (p. 759). On page 760 he stated that "from 1,151 to 1,253 feet the well penetrated a black rock composed of olivine, brown mica, and a fine-grained brown aggregate which does not extinguish between crossed nicols. Olivine is very plentiful...Along contacts it is more or less altered to serpentine and perhaps chlorite...The junior writer identified a white mineral resembling tremolite and a few grains of pyroxene and hornblende, and he thought some inclusions in the brown mica might be magnetite...The rock seems to contain no feldspar whatsoever and evidently is a fine-grained peridotite...The fact that a normal unaltered pre-Pennsylvanian sequence lies below the igneous rock shows that the latter is a dike, sheet, or flow...It is suggested that the contact metamorphic minerals and black rocks of the Lieurance well, and the metamorphic rocks of Silver City are all manifestations of the intrusion of a large igneous body into the Pennsylvanian and older sediments at some date later than the deposition of the Pennsylvanian strata...and that the Rose Dome granite porphyries represent the parent body
and the black rocks minor intrusives therefrom" (Twenhofel and Bremer, 1928, p. 761).

In 1932 a detailed report on the Silver City and Rose Domes (and a dome farther north near Neosho Falls) in Woodson County was published by G. L. Knight and K. K. Landes. They noted that the domes are circular or elliptical in plan view. "Although small in area, covering from four to six square miles only, they had closures as large as 140 feet" (p. 1). "This article stresses the apparently causal relationship between the anticlines and igneous intrusions and suggests that these structures could properly be termed laccoliths" (p. 2). They add little to the written record at the Silver City Dome, but at the Rose Dome, they mention "a westward-striking granite porphyry dike that crops out along the north flank of the dome. This dike has metamorphosed the sediments for a short distance from the contact" (p. 6). Additional data on minerals from wells at the Rose Dome are furnished by Knight and Landes (1932, p. 7). "Cuttings from the Tad Parsons well from a depth of 1,410-1,474 feet, furnished by W. L. Stryker, consist almost entirely of pyrite, quartz, and galena. The percentages of quartz and galena present are considerably less than that of the pyrite. Small crystals of sphalerite were observed in cuttings of the Rose well from a depth between 1,334 and 1,344 feet. The occurrence of hydrothermal galena and sphalerite about 70 miles distant from the northwest edge of the Tri-State zinc and lead mining district is of considerable interest" (p. 7). "An incomplete
set of cuttings was examined from the Diver No. 1 well described as being in Sec. 18, T 26 S, R 16 E, which is on the east flank of the Rose Dome. What is apparently an altered dike rock was encountered between 1,525 and 1,590 feet. This corresponds to the middle of the three 'black rock' zones in the Lieurance well described by Twenhofel (1917, p. 409), as occurring between 1,508 and 1,572 feet. The thickness of the zone is almost identical in the two wells. The fact that this altered igneous rock was encountered at practically the same level in the two wells suggests very strongly that the rock body is a sill instead of a dike. The most abundant constituent of the 'black rock' is a very dense and dark-colored serpentine. Scattered through the serpentine are books of brittle mica, very fine grains of magnetite and nearly colorless crystals of olivine. The olivine, as judged by its optical properties, is much closer to the forsterite than the fayalite end of the series. The igneous rock was evidently originally of basic or ultra-basic composition and was subjected to extensive hydrothermal metamorphism which caused the alteration of the pyroxene minerals to serpentine with the separation of magnetite and the alteration of biotite to brittle mica" (p. 8). They continued: "The presence of hydrothermal minerals was noted at a number of horizons in the Diver well. Cuttings from between depths of 1,000 and 1,030 feet contained a large amount of brown mica, quartz, pyrite, and actinolite. Cuttings from the 10 feet immediately overlying the
serpentine consist of altered limestone with abundant brown mica. Cuttings from a depth between 1,600 and 1,602 feet, a short distance below the serpentine, consist of dolomitic marble, which contains abundant wollastonite and calcite and subordinate amounts of serpentine and brittle mica” (p. 8). Knight and Landes stated further that “W. L. Stryker, petroleum geologist of Fredonia, Kansas, has observed some other phenomena suggestive of igneous activity. The cuttings from a well drilled in the NE cor. of Sec. 34, T 26 S, R 15 E, contained some very large mica plates. Wells drilled on a fairly sharp anticline in the southwest part of Section 10 and in the northwest part of Sec. 15, T 27 S, R 15 E, northern Wilson County (about 4 miles southeast of the Silver City Dome) encountered not only large plates of mica but also asphalt in a deeply buried sandstone. The large mica flakes may have been deposited by hydrothermal solutions emanating from an igneous mass. The asphalt is perhaps a residual product of petroleum which at one time filled the interstices in the sandstone, but later suffered a natural distillation caused by magmatic heat” (Knight and Landes, 1932, p. 12).

Samuel Weidman, in order to set the record straight, wrote (1933, p. 1,268) that in 1929 he “observed fine dark blue and also coarse gray quartz rocks occurring as scattered fragments in the soil near one of the old mining shafts; microscopic examination indicated their igneous origin. These loose fragments of igneous rocks appear to be distributed in a narrow belt several feet wide, extending
east-west, essentially parallel with a zone of fractured and sharply tilted beds... Two kinds of igneous rock are represented in the loose fragments in the soil. One is a dark-colored dense aphanite...the weathered surface showing a distinct globular or spheroidal texture characteristic of volcanic rock. The spheroids surrounded by rims range from 1 to 10 millimeters in diameter (p. 1268). "Microscopically it is porphyritic, both phenocrysts and the spheroids being enclosed in a fine-grained chloritic groundmass. The phenocrysts, probably originally feldspar, are much changed to green chlorite, epidote, and several colorless minerals probably including some fibrous quartz and zeolites. The dark aphanitic rock appears to be completely altered, but its macroscopic appearance as well as the crystal form of phenocrysts in groundmass indicate its igneous origin. The light-colored rock is coarse-grained, with coarse quartz in blebs and stringers ranging from 1 millimeter to 2 centimeters in thickness...Under the microscope, it is seen to contain much orthoclase, both the quartz and orthoclase containing much fibrous actinolite? and some epidote and apatite. Much of the actinolite? and epidote occurs in radiating aggregates. The needles of actinolite (inclined extinction and positive elongation) extend from the borders out into the quartz, and form veinlets in the quartz" (p. 1269). "The coarse quartz-orthoclase rock is apparently not a normal igneous rock but a pegmatitic phase. The black dense porphyritic aphanite is probably a normal igneous
intrusive. Both phases were chloritized and epidotized during the later stage of hydrothermal action accompanying the magmatic intrusion. The silicification of the surrounding Pennsylvanian sandstone in the Silver City area to quartzite is interpreted as accompanying effects of the hydrothermal action. The writer has observed veinlets of actinolite? in quartz in brecciated phases of the pegmatitic dike of the nearby Rose Dome area indicating...a close association in the intrusive phenomena of the two localities” (Weidman, 1933, p. 1270).

In 1938 D. C. Shaffner of the College of Emporia, Emporia, Kansas made a geologic excursion to the Rose and Silver City Domes. At the Rose Dome he noted several areas of slight metamorphism; whereas, at the Silver City Dome he detected several areas of extreme metamorphism. He noted pink, gray, green and black quartzites along a ridge and "on the south slope of the ridge, a short distance from the prospect holes which are quarried in the quartzite, a considerable exposure of yellow clay and mica flakes marks some prospecting activities” (p. 223). On the ridge to the north, Shaffner collected some specimens of "a fine pure white vein of quartz [which] has embedded in it a few angular fragments of green quartzite” (Shaffner, 1938, p. 224). He believed that the "mother liquor" or "magmatic solutions" varied progressively from that which formed the micaceous rock and silicified the sandstone to quartzite to one charged
with SiO₂ which engulfed the broken quartzite into the pure white quartz vein material at a slightly later time.

An exhaustive report was written by Tolman and Landes titled "Igneous Rocks of the Mississippi Valley Lead-Zinc Districts" in 1939. On pages 97 to 99, they discuss briefly the Rose and Silver City Domes, among others in Woodson County. They mentioned again, as in the Knight and Landes (1932) report, that at the Rose Dome is "a westward-striking granite porphyry dike [that] crops out along the north flank of the dome. This dike has metamorphosed the sediment for a short distance from the contact" (p. 98). The presence of the granite porphyry was again well documented and was presumed to be dike-like in form. Other data of interest in this report are the several evidences of the presence of galena, sphalerite and pyrite in well cuttings of at least two and possibly more wells in the Rose Dome and nearby areas (Tolman and Landes, 1939, p. 98).

Later Geologic Reports -- The Silver City Dome

The next report, chronologically, is by the author (Wagner, 1954). Prior to extracting data from that report, it seems to be appropriate to outline the circumstances under which I became involved. The northern two-thirds of Wilson County in southeastern Kansas was the only area in eastern Kansas covered by adequate new topographic maps in 1950, and Wilson County was selected as a cooperative geologic mapping project to be funded jointly by the U.S. Geological Survey
and the Kansas Geological Survey. Immediately upon my arrival at Fredonia, the county seat of Wilson County in early June 1950, geologic mapping was begun along the boundary with Elk County to the west so that I could take advantage of the experience and knowledge of George Verville who was at that time mapping easternmost Elk County. Together we mapped the two mile strip of geology along the common boundary between Elk and Wilson counties, and when that was finished, I had a fairly good grasp of the nature of the rocks in that area. Since the strike of the strata trended slightly east of north, I struck eastward along the north line of Wilson County, where it abutted with Woodson County. As with Elk County, I overlapped about one mile into Woodson County as I mapped the geology eastward. I had mapped about eight miles along the northern boundary when I came across some rocks that were not familiar to me. I had had no chance to do the normal literature search before arriving in Fredonia and had no idea that an anomalous area such as that on which I stood was a part of Kansas geology. I saw gray-green quartzite where I expected yellowish-brown sandstone. I saw very micaceous soft clay where I expected medium-gray or yellowish-gray bedded siltstone and claystone. A thin dark-gray limestone appeared in its proper place and thickness, but all else had changed. Blackjack oak and sumac grew luxuriously along part of the hill, and a small stream flowed into a pond that had apparently been excavated for use by cattle. I sat down and studied my topographic map and the
lay of the land around me. I walked out the limits of golden mica-covered ground and marked the locations on the map. I scrambled over the greenish quartzite blocks and soon realized that there was a pattern to their locations. They appeared to occur in lines roughly parallel to the contours of the hill. I mapped the extent of the larger pieces and then traced the locations of the smaller fragments. I found a few pieces of black rock that were not calcareous but appeared to be finely crystalline. Mica flakes adhered to them and to the fragments of greenish quartzite. Having done this much, I followed some road tracks up the hill and found a farmhouse. It belonged to George Hill, a man in his early 50s. I showed him my map and told him my problem. He smiled. It turned out that late in the Great Depression during the 1930's the Works Progress Administration (WPA) was looking for projects of public value with which to provide work for the large numbers of unemployed men so as to keep them in funds and food. One of the representatives on the board in Fredonia envisioned a public park and recreation area on George Hill's land, because this particular area had free-flowing clean water from a natural spring. It was useless for farming because of the hard rocky ground, and George Hill's father was willing to allow access to the land as long as people used it properly. He would, however, retain title. The project was approved, and the WPA workers moved the largest green quartzite blocks into windrows aligned along the hillslope. An area was soon cleared,
picnic tables constructed and placed, the spring water was diverted into a pond that was stocked with fish, and the place was called Hills Pond. People came from miles around when the recreation area was opened, and they returned from time to time. But the grass turned brown, sumac and blackberry vines grew rapidly, the fish were fished out or had died, and within a few years, the area was no longer an attraction. It reverted back to a natural hill, cattle found the pond and lived happily in the vicinity. Some thirty years later, I stumbled upon the area, reconstructed the geologic features as best I could onto my map, and as the first cold blasts of winter were now felt in the air, I moved with my family to Lawrence, the site of the headquarters of the Geological Survey of Kansas and the location of the University of Kansas. Thin sections were made of the brownish-black specimens I had collected at and near the Hills Pond and the minerals were identified. Included were phlogopite mica, serpentine, nontronite, illite, tremolite-actinolite, magnetite, and titanite along with small relics of the minerals that originally composed the rock, namely biotite mica, olivine, apatite, hypersthene, and augite, titanite, and magnetite. The rock was medium-grained, and I decided that the term mica-peridotite best fitted the mineralogy. A library study of the literature and perusal of records on file at the Geological Survey and at the University of Kansas revealed that the presence of these rocks had been known for some 70 years. The reports described ahead of this
section relating my arrival on the scene had already appeared in the literature but I was not aware of them. I also discovered that K. K. Landes had sent a specimen of the black rock from the Silver City Dome to E. W. Heinrich who had in February 1948 sent a letter to Landes stating that the rock was a fine- to medium-grained peridotite. Another opinion was obtained by W. W. Hambleton who gave a sample to P. C. Franks for study. The response from Franks in June 1953 affirmed that the rock was a fine- to medium-grained peridotite. Meantime, I had sent a sample to Charles Milton of the U.S. Geological Survey in Washington, D.C. Milton also classed the rock as a peridotite that "was composed originally of olivine, biotite, diopsidic-augite and relatively abundant sphene; but most of the olivine has been altered to serpentine and phlogopite, the biotite to phlogopite and vermiculite, and the diopsidic-augite to green chlorite. Weathering resulted in the formation of mixed-layer clay minerals, limonite, and magnesite(?)" (Charles Milton, written communication, July, 1956).

When writing my report (Wagner, 1954), I thought I would name the peridotite after the Silver City Dome but found that name had been preempted for use as the Silver City Granite (Keroher and others, 1966, p. 3603). I therefore decided on the name "Hills Pond Peridotite" because of the good exposures in the bank of the recreation area pond.

The type locality of the Hills Pond Peridotite was designated as 500 feet east and 100 feet south of the center
of the north line of Sec. 32, T 26 S, R 15 E. The extent of the main outcrop of the deeply weathered igneous body is shown in figure 1 of my report (Wagner, 1954) which indicates that the peridotite is bounded on the north by a fault, has several sill-like bodies that extend southward as determined by their being intersected in several wells. Hambleton's interest in the Silver City Dome continued and during the winter of 1953-1954, he and D.F. Merriam performed a magnetometer survey of the Rose Dome-Silver City Dome area. Their vertical intensity magnetic map shows strong negative anomalies over both the Rose Dome and Silver City Dome areas (Hambleton and Merriam, 1954, p. 127-128). Twenty-two diamond drill holes were put down by the Geological Survey of Kansas in 1955 in order to establish the dimensions of the intrusive body and to provide fresh samples of both the igneous body and the metamorphic rocks. Two additional areas of outcrop of the peridotite were mapped, as well as eight areas of metamorphosed sediments, one of which is in roadcuts along the north line of the NE1/4 of Sec. 6, T 27 S, R 15 E in Wilson County. The metamorphic effects at this location are an increase of porosity and slight silicification in the South Bend Limestone Member of the Stanton Limestone. The porosity increase is apparently the result of alteration of limonitic oolites to a more soluble form of iron and subsequent removal of the oolites and enlargement of the cavities thus formed. Chemical analyses performed at the Geological Survey of Kansas show a 13 percent increase in
silica and magnesia and a compensating loss in calcium and water in the metamorphosed strata.

Other metamorphic effects were noted in the halo that surrounds small areas of golden mica rock in the NE 1/4 NW1/4 Sec. 32 and center of the N1/2 N1/2, Sec. 32, T 26 S, R 15 E and in road cuts along the common north-south line between sections 31 and 32, T 26 S, R 15 E (Wagner 1954). Metamorphic effects in the South Bend Limestone Member of the Stanton Limestone consist locally of the complete disintegration of the oolitic limestone facies into a white calcareous clay containing small (1 mm) black spheres that are attracted to a magnet. Other effects are silicification and the addition of greenish crystals of epidote and tremolite-actinolite. In places, the thin dark-gray Haskell Limestone Member of the Lawrence Formation has been invaded along the joint system by dark-colored hydroxyapatite and jasperoid. Locally, the entire 14 inches of the Haskell has been replaced by the apatite and jasperoid. The Vinland Shale Member of the Stranger Formation is similarly phosphatized locally; generally, however, the clay portions of the shale are unaltered even in areas where the more silty portions have been completely silicified and chloritized as have the coarser grained rocks, such as the Ireland Sandstone Member of the Lawrence Formation and the Tonganoxie Sandstone Member of the Stranger Formation along the margins of the main intrusive (Wagner, 1954, Fig. 1). Acid hydrothermal solutions or vapors charged with silica, magnesia, alumina,
and locally phosphate apparently accompanied intrusion, filled the voids of the sandstones and siltstones with silica, and combined with indigenous iron and carbonate of the affected strata to form chlorite, sericite, epidote, and other metamorphic minerals. The presence of quartz veinlets cutting the intrusive body indicates that some action of silica-rich solutions occurred after crystallization of the peridotite.

The lateral extent of the peridotite intrusives to the south into the subsurface of Wilson County can be approximated by use of descriptions written by the oil men who drilled the wells in the general area. An experienced driller familiar with the section of rocks being drilled could tell the type of material (limestone, sandstone or shale) in which he was drilling by the action of the cable which he gripped loosely with his hand and by the cuttings that circulated out of the well head. Unusual materials were recognized and recorded in the drillers logs of several wells in northern Wilson County. The logs of the Hase, Bentley and Young wells recorded hard black rock and/or mica rock at several depths (Figure 53). These I interpreted as sills of mica-peridotite intruded into the sedimentary sequence (Fig. 53). The Puckett and Honor Lodge wells, located about a mile south of the Silver City Dome, have no such rocks and show the normal stratigraphic section of the area. The log of the No. 1 Hase Well (NW cor. Sec. 6, T 27 S, R 15 E) recorded black rock and black mica rock between 915 and 1105 feet.
depth; the log of the No. 1 Bentley well (SE cor. NW1/4 NW1/4 Sec. 6, T 27 S, R 15 E) recorded mica rock from 910 to 1060 feet and from 1142 to 1155 feet; the log of the No. 1 Young well (SE cor. NE1/4 NE1/4 Sec. 5, T 27 S, R 15 E) showed mica rock from 300 to 350 feet, 620 to 650 feet, 805 to 820 feet, and 1040 to 1055 feet. The log of the No. 1 Young well also recorded granite(?) from 350 to 375 feet and black rock from 820 to 830 feet. It seemed very likely that these anomalous rocks represented altered and unaltered igneous rock similar to the grayish-yellow very micaceous clay that crops out less than one mile to the north or similar to the dark blackish-green micaceous rock cut in core-drill holes at shallow depth where the Geological Survey of Kansas drilled directly down into the intrusive. By removing these unusual rocks from the logs of the wells shown in Figure 53, the uparched beds became a nearly normal sequence (Figure 54).

Following the publication of my report in 1954 (GQ49) and my transfer to Washington, D. C., in 1955, other geologists became increasingly interested in the Silver City Dome and some 16 reports have since been published. A report that described the Tonganoxie Sandstone Member of the Stranger Formation (Winchell, 1959a, p. 24 and plate 3) mentioned and figured the Silver City Dome with a closure of 50 feet. Pearn (1959) performed thermoluminescence studies on six samples of the metamorphosed Haskell Limestone Member of the Lawrence Formation from the Silver City Dome. The age calculated was only 60 million years. This must be
considered a minimum age since the alpha counts were somewhat questionable (Pearn, 1959, p. 52).

Franks (1959), described in detail the results of thin-section studies of samples of the peridotite taken from diamond-drill cores. These studies showed that in most places, the rock was a serpentinized mica peridotite that contained about 25 percent phlogopite and less than 10 percent each of olivine, diopsidic augite, and a light-reddish-brown pleochroic amphibole as phenocrysts and as broken remnants of crystals in the serpentine groundmass. Minor constituents included apatite, magnetite, and perovskite. Locally in the subsurface, the rock had a groundmass that was composed almost completely of fine-grained phlogopite and broken phenocrysts of the major constituents given above. At the surface, the serpentine groundmass had weathered in large part to nontronite(?), and the phlogopite had weathered to a mixed-layer vermiculite mineral (Franks, 1959, p. 1083). He used a combination of optical and X-ray diffraction techniques to determine the presence of pectolite in the groundmass of core samples from a 30-foot-thick peridotite intrusive whose top was at a depth of 765 feet in a well in Sec. 32, T 26 S, R 15 E. Franks indicated that the pectolite occurred as a major component (possibly 20% of the rock) in the upper 10 feet of the sill where it intruded Pennsylvanian shale, and stated that “Directly below the pectolitic rock, the sill holds
phenocrysts of amphibole, augite, and olivine in a groundmass composed mainly of very fine grained phlogopite...The groundmass also includes 1 or 2 percent perovskite as anhedral patches or blebs as large as 0.1 mm in diameter. The perovskite grains are surrounded by subcircular patches of a brown, radially fibrous carbonate (dolomite?) as much as 0.3 mm in diameter that is clouded by leucoxene. The patches of dolomite(?) approximate 8 percent of the rock, and seemingly have replaced other components of the groundmass. Trace amounts of magnetite as anhedral grains, measuring less than 0.03 mm in diameter, are scattered through parts of the groundmass and as inclusions in the phlogopite books” (p.1089). Some of the books measured as much as 2 mm in length in the main body of the sill where they constituted as much as 40 percent of the rock. Nontronite(?) made up about 3 percent of the rock and occurred as green patches measuring as much as 2 mm in length. Mellilite (near gehlenite) was also present in the groundmass as patches of squarish uniaxial negative grains. Pectolite approximated 25 percent of the rock and was the major component of the groundmass (Franks, 1959, p. 1084).

D. F. Merriam, in his excellent book “The Geologic History of Kansas” again brought up the question concerning the relationship of the granite boulders to the adjacent rocks at the Rose Dome. He briefly recapitulated current knowledge (1963) and was able to add the following: “Recently, however, the granite was dated 1220 million years
by the Rb/Sr method by the U.S. Geological Survey for the Air Force Office of Scientific Research...as part of the Advanced Research Agency Project VELA UNIFORM (E. G. Lidiak, written communication, August 21, 1963). Thus, the age of the granite seemingly is Precambrian, and [the] relation of the granite to the Rose Dome is again open to speculation. The most satisfactory explanation based on present evidence is that the granite is blocks of Precambrian basement that were incorporated as xenoliths in an intrusive peridotite plug, and that the boulders on the present surface are residuals weathered out of the igneous rock" (Merriam, 1963, p. 154, footnote).

An interesting but altogether factually misleading report that includes the Silver City and Rose Domes was written by H. E. Wheeler in 1965. Wheeler believed he had evidence for a "St. Francois thrust" (p. 1652) that displaced rocks a distance no less than 330 miles (Wheeler, 1965; p. 1652). He carried his hypothetical evidence of near-horizontal transport of Precambrian rocks, by various and devious maneuverings, all the way from the St. Francois Mountains of southeastern Missouri eastward to a point 45 miles into Illinois and westward across Missouri into northeastern and southeastern Kansas and into Oklahoma, a distance no less than 300 miles. I wish to take him to task only for his description of the Silver City Dome because there, although he referred to my geologic quadrangle map of the Fredonia quadrangle (Wagner, 1954), he completely ignored
the evidence presented in that report that the mica
peridotite was an intrusive body, but he also ignored similar
evidence by Knight and Landes (1932), Weidman (1933),
Schaffner (1938), and Franks (1959). Rather, he went back to
an 1883 report by Hay and noted that Hay appeared to have
come somewhat closer to the truth when he stated: "We judge,
then, that the metamorphic agency (heat) has been applied
here from above and under great pressure" (Wheeler, 1965, p.
1656).

Other geologists also found H. E. Wheeler's article
provocative and regrettable and wrote discussion articles
refuting his claims in the Bulletin of the American
Association of Petroleum Geologists of 1966 (vol. 49, no. 10,
p. 1647-1665). These men included R. R. Wheeler of Commerce,
Texas; P. C. Franks of Lawrence, Kansas; W. R. Huelberger of
Austin, Texas; W. C. Hayes of Rolla, Missouri; P. E.
Gerdemann of Bonne Terre, Missouri; and J. D. Moody of New
York, N. Y. Franks discussed the Silver City and Rose domes,
among the other Kansas structures that H. E. Wheeler moved
into position as klippen by his St. Francois thrust (Wheeler,
1038-1039) pointed out that Wheeler "seems to conclude that
the ultramafic rock, which is intrusive into Silver City
dome, and the associated contact-metamorphic rocks not only
are allochthonous, but also are in their present geologic and
topographic position as a result of large-scale thrusting...
By study of surface exposures, records, and cores from 22
diamond-drill holes ... and of samples and records of nearby oil and gas tests, Wagner (1954) found that sills of mica peridotite finger from a dike-like feeder southward into Pennsylvanian limestone and shale. Moreover, Wagner indicated sills of peridotite that are as much as 1,000 feet or more below the land surface on Silver City dome. Subsequent logging by Franks of seven additional rotary and core holes drilled by private interests testing the ultramafic rock of phlogopite and vermiculite does little to modify Wagner’s cross section. Contact metamorphic effects at Silver City Dome are extensive and varied. Contact-metamorphic rocks form an aureole as wide as 1,000 feet around the surface exposures of the main mass of mica peridotite...Wheeler (p. 1656) attempts to portray the alkaline ultramafic rock and contact metamorphosed country rock as being something other than an ‘altogether cryptic feature on the prairie’ and to attribute their occurrence to large-scale thrusting’ (Franks, 1966, p. 1039).

In a footnote in H. E. Wheeler’s fanciful article dealing with his hypothetical, all-encompassing St. Francois thrust, he referred to a report on “Explosive igneous activity along an Illinois-Missouri-Kansas axis” that was authored by F. G. Snyder and P. E. Gerdemann (1965, p. 465-493). Wheeler blatantly wrote: “Among the eight areas cited in ‘evidence’ of such an ‘igneous axis’ are the Weaubleau area, Decaturville dome, and Rose dome, each of which is discussed herein. None of these shows evidence of igneous
activity" (Wheeler, 1965, p. 1658). Wheeler was wrong, of course, about there being no evidence of igneous activity at Rose Dome. I cannot imagine his writing such a statement, given the literature he, himself cited. However, I have no comment on the Weaubleau or Decaturville structures that Wheeler mentioned in his footnote as I have not investigated them.

In the part of their report that concerned the Rose and Silver City Domes, Snyder and Gerdemann (1965) interpreted the associated granite, basic rock, and metamorphism as being the result of a post-Pennsylvanian intrusive. They pointed out that "the presence of a granite intrusive at Rose Dome appeared anomalous when all other igneous bodies were of deep-seated alkaline type. This anomalous situation may be clarified by results of recent work of the Crustal Studies Laboratory, Balcones Research Center, University of Texas, as reported by Rodger E. Denison (written communication). A Rb/Sr measurement on Rose Dome granite gives an age of 1220 ± 90 million years. The Rose Dome granite, according to this determination, is Precambrian in age ... The granite could be a Precambrian erosional remnant, but this seems unlikely in view of the thick sedimentary section in the area and the great distance to Precambrian a short distance from Rose Dome. It seems more plausible that the granite is in the form of blocks or large fragments carried upward from the basement. This could have been accomplished during
emplacement of the basic rocks” (Snyder and Gerdemann, 1965, p. 487).

In the meantime Franks (1965, p. 65, 66) published an abstract of a talk he gave at the Geological Society of America meeting in Miami Beach. In his abstract he wrote “Additional conclusive evidence of the intrusive nature of the 'granite' has been found: a boulder of the 'granite' not only shows flow structure, but also has inclusions of metamorphosed shale [hornfels]...The hornfels on the 'granite' boulder most likely is metamorphosed Weston Shale. Proximity to alkaline mica peridotite exposed at Silver City Dome, about 5 miles southwest, and the presence of mica peridotite in the subsurface of Rose Dome may mean that the peridotite and 'granite' are genetically related. Then, emplacement of the 'granite' was not only post early Virgilian, but probably as young as Cretaceous or even early Tertiary” (Franks, 1965, p. 66).

As was pointed out by Snyder and Gerdemann (1965, p. 489), if the Paleocene K/Ar age determination on mica from a basic rock at the Silver City Dome was correct (Paul Franks, written communication), it indicated that the Kansas intrusive was considerably younger than those to the east and that magmatic activity along the structural axis spanned a period from Late Cambrian to early Tertiary time. The age determination on both the granite and the peridotite should be confirmed (Snyder and Gerdemann, 1965, p. 490).
Reliable age determinations on the mica-peridotite were finally forthcoming in 1967 in a report by R. E. Zartman, M. R. Brock, A. V. Heyl, and H. H. Thomas. Franks and I had provided fresh rock samples to them from the Silver City and Rose Domes and were furnished with the following results:

Mica-peridotite sample 556 from an outcrop in the bank of Hills Pond, NW1/4 NE1/4 sec. 32, T 26 S, R 15 E, Silver City Dome, gave a potassium-argon age of 91±5 m.y. Mica-peridotite sample 557 from a drill core in hole 21, depth 31.0 feet, located just west of Hills Pond, NE1/4 NW1/4 sec. 32, T 26 S, R 15 E, Silver City Dome, gave a potassium-argon age of 90±5 m.y. Mica-peridotite sample 703 from drill core in drill hole 3, depth 54.6 feet, located 1866 feet north, 1240 feet west of the SE corner Sec. 13, T 26 S, R 15 E, Rose Dome, gave potassium-argon age of 88±4 m.y. All these ages were in good agreement and give a Late Cretaceous age, averaging approximately 90 million years (Zartman and others, 1967, p. 852, 856, 858). Concerning regional implications, they had this to say: "The peridotites in Rose Dome and Silver City Dome...in southeastern Kansas give K-Ar ages that are Late Cretaceous...[the] intrusions are at the western end of a structural lineament described by Snyder and Gerdemann (1965) and Heyl and others (1965) ... This line of faults and structures extends eastward across Missouri just south of the 38th parallel of latitude" (p. 865). "The line of faults that follows the 38th parallel extends eastward from Illinois across the entire length of Kentucky... [into] eastern West
Virginia, and in the Shenandoah Valley of western Virginia near Staunton ... [following] the less well-defined eastern extension of the structural lineament along the 38th parallel" (Zartman and others, 1967, p. 866, 867).

The next reference to the Wilson and Woodson County intrusive rocks was by Hayes (1967) who believed that dickite crystals that he collected while participating in a Geological Society of America field trip in 1945 to study algal limestones in the Lansing Group of southeast Kansas were of hydrothermal origin. Hayes wrote that the dickite occurred as snow-white powder in small pockets in limestones east and south of Fredonia, that the dickite-filled pores ranged in size from a fraction of a millimeter to a centimeter across, and that the dickite appeared as discrete, exceptionally well crystallized, pseudo-hexagonal plates whose infrared and DTA patterns conform to previously published data for dickite (Hayes, 1967, p. 893, 894). He believed that the relationship of dickite to igneous intrusions suggested a hydrothermal origin for the dickite and could, therefore have reflected cooling of magmatic water below the temperature of dickite formation away from the proposed igneous source; the highly porous limestones of the Lansing Group could have conducted significant volumes of water rapidly for miles and have provided the widespread distribution of the dickite (Hayes, 1967, p. 895).

In two reports published in 1971, Bickford, Franks, Mose, Wagner and Wetherill provided evidence, both from
rubidium-strontium isotopic measurements and from petrologic and mineralogic studies, that specific metamorphic and intrusive effects that occurred at the Rose and Silver City Domes are too similar to be coincidental, and therefore the two domes are related in time and in occurrence. Although the studies were made mainly on rocks from the Rose Dome, the results were clearly also applicable to the rocks at the Silver City Dome. As noted by Bickford and others (1971, p. 2864) “Most of the samples, in hand specimen, resemble typical medium- to coarse-grained plutonic rocks consisting of quartz, microcline, plagioclase, and much altered biotite. However, all of the 35 samples studied in thin section are brecciated to some degree and display a curious matrix between grains. This matrix is a fibrous to microgranular mass of quartz and feldspar that shows a variety of volcanic textures and structures” (Bickford and others, 1971, p. 2864). Samples similar to these were described from the Silver City Dome by Winchell (in Twenhofel 1917b, p. 426) in which the groundmass was said to be plentifully sprinkled with rounded grains of feldspar. Knight and Landes reiterated almost the same description (1932, p. 5), and Tolman and Landes in 1939 recorded that two types of igneous rocks were found at the Silver City Dome—a black, dense porphyritic aphanite, which was thought to be the normal igneous intrusive, and a pegmatitic quartz-orthoclase rock (p. 99). They credited this discovery to Samuel Weidman (1933, p. 1270). Also, during my investigations in 1950-
1952, I found two pieces of granite-like material in the float at the prospect-pit area at the Silver City Dome with similar groundmass material. It seemed likely, therefore, that sources of igneous activity at the Rose and Silver City domes were more closely related than had been previously believed, but that the Rose Dome received a greater quantity of Precambrian granite as xenoliths.

The isotopic studies of Bickford and others (1971) resulted in determining that the granitic rocks at the Rose Dome included three types: (1) coarse-grained, apparently plutonic material, (2) recrystallized granitic breccia, and (3) granitic breccia showing pronounced alignment of quartz and feldspar grains that was suggestive of flow. Eight whole rock analyses performed on type (1) "granite" yielded an isochron indicating an age of 1190 ± 100 m.y. Although the eight samples of granite types (2) and (3) do not plot on the whole rock isochron, each of the samples yielded a calculated Rb/Sr age which was Precambrian, and if the obviously brecciated samples had been eliminated from consideration, all but one of the remaining sample analyses would have plotted on the isochron indicating an age of 1190 m.y. with an initial Sr$^{87}$/Sr$^{86}$ ratio of 0.706. Considering the complex geochemical history of these rocks, it was difficult to determine the error in this age, but it was certainly not greater than ± 100 m.y. Thus, it seemed to be clear that the samples were of Precambrian age, and that their age was probably between 1100 and 1300 m.y. Studies of
mineral separations from three whole rock samples of k-
feldspar and plagioclase yielded an 1176 ± 50 m.y. isochron
with an initial Sr\(^{87}\text{Sr}^{86}\) ratio of 0.707. Although the
granitic rocks at the Rose Dome were associated in the
subsurface with an 88 m.y. old mica peridotite, their Rb-Sr
isotopic age of 1200 m.y. was consistent with the age of
Precambrian basement rocks in this area (Bickford and others,

Franks, Bickford and Wagner (1971) were responsible for
writing part 2 of these studies. Part 2 was concerned with
petrologic and mineralogic studies which suggested that the
intrusion temperatures of the alkaline ultramafic magma were
probably greater than 800° C if fluid pressures were in the
range from 200 to 300 bars. These temperatures led to
metamorphism of the granitic inclusions at the Rose Dome and
to the formation of high sanidine and high albite from
original microcline and albite. The high temperatures of the
peridotite magma also led to partial melting of the granitic
rocks. A quartzofeldspathic matrix showing volcanic textures
tended to bind mineral and rock fragments together to produce
the varied range of textures and structures of the granitic
xenoliths (Franks and others, 1971, p. 2869). The same
temperatures and textural effects would probably apply in the
Silver City Dome area also. A chemical analysis of
noncalcareous mica-rich peridotite from the Silver City Dome
(drill hole 2H, 59.3 ft. depth) is listed in Table 18,
column 4). In their report Franks and others (1971,
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>73.08</td>
<td>74.09</td>
<td>35.91</td>
<td>45.76</td>
<td>52.19</td>
<td>66.72</td>
</tr>
<tr>
<td>Al₂O₃ (including MnO, if present)</td>
<td>12.78</td>
<td>10.83</td>
<td>5.24</td>
<td>6.31</td>
<td>21.51</td>
<td>16.19</td>
</tr>
<tr>
<td>Total iron oxide (as Fe₂O₃)</td>
<td>1.97</td>
<td>2.25</td>
<td>9.42</td>
<td>8.32</td>
<td>8.37</td>
<td>6.20</td>
</tr>
<tr>
<td>FeO</td>
<td>0.42</td>
<td>0.93</td>
<td>20.29</td>
<td>22.31</td>
<td>1.99</td>
<td>1.18</td>
</tr>
<tr>
<td>CaO</td>
<td>0.75</td>
<td>0.90</td>
<td>8.19</td>
<td>1.56</td>
<td>0.93</td>
<td>0.30</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.97</td>
<td>0.74</td>
<td>0.08</td>
<td>1.52</td>
<td>0.31</td>
<td>0.85</td>
</tr>
<tr>
<td>K₂O</td>
<td>7.64</td>
<td>7.58</td>
<td>5.72</td>
<td>6.30</td>
<td>9.01</td>
<td>2.46</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.48</td>
<td>0.93</td>
<td>2.45</td>
<td>2.45</td>
<td>1.21</td>
<td>0.97</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.11</td>
<td>0.39</td>
<td>0.62</td>
<td>0.28</td>
<td>0.18</td>
<td>0.06</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.05</td>
<td>0.03</td>
<td>0.27</td>
<td>Trace</td>
<td>0.07</td>
<td>0.01</td>
</tr>
<tr>
<td>Sulfide Sulfur</td>
<td>0.01</td>
<td>0.01</td>
<td>0.15</td>
<td>0.04</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Loss on ignition (1000°C)</td>
<td>0.92</td>
<td>0.96</td>
<td>11.57</td>
<td>4.38</td>
<td>3.89</td>
<td>5.16</td>
</tr>
<tr>
<td>TOTALS</td>
<td>100.18</td>
<td>99.64</td>
<td>99.91</td>
<td>99.23</td>
<td>99.70</td>
<td>100.13</td>
</tr>
</tbody>
</table>

Analyst, George Shimer, State Geological Survey of Kansas
1. Coarse-grained "granite," surface boulder, Rose Dome
2. Fine-grained "granite" showing flow structure, surface boulder, Rose Dome
3. Calcereous mica-rich peridotite containing limestone xenoliths, drill hole 3, 53.0 ft. Rose Dome
4. Noncalcereous mica-rich peridotite, drill hole 2M, 59.3 ft., Silver City Dome
6. Unmetamorphosed Weston Shale Member of the Stranger Formation, center N line, sec. 13, T 26 S, R 15 E, Rose Dome.

Table 18. Representative chemical analyses of selected samples of igneous, metamorphic, and sedimentary rocks from the Silver City and Rose Domes. (From Franks, Bickford, and Wagner, 1971, p. 2874)
p. 2872-2877) provided excellent descriptions of textures, structures, and mineralogic properties, based largely on thin-section examination. X-ray powder diffraction studies and other petrographic and geochemical techniques were also applied. One point Franks and others (1971, p. 2879) made was that the peridotite at both the Rose and Silver City Domes was highly alkaline (Table 21, columns 3 and 4). Chemical analysis showed between 5 and 7 percent K₂O in these rocks. For comparison, Tables 19 and 20 from Cullers and others (1985, pp. 1386, 1387) and from Berendsen (1990, p. 21) provide data on the major and trace element contents of samples from the Silver City and Rose Domes.

Franks and others (1971, p. 2880) wrote that both the textural and structural evidence from the Rose and Silver City Domes suggested that the mica peridotite was intruded gently as a mobile fluid in which phenocrysts of early-formed olivine, phlogopite, pyroxene, and amphibole were suspended. There was no strong evidence to indicate that explosive gas-phase transport and emplacement of the alkaline peridotite and its xenoliths took place.

Metamorphic effects at the Silver City and Rose Domes are somewhat similar, but quartzite was the most obvious effect at the Silver City Dome, and hornfels was most noticeable at the Rose Dome. "A combination of several features indicates that the igneous rocks of the Rose Dome [and the Silver City Dome] were emplaced under conditions of high temperature and low pressure" (p. 2882). "If low fluid
Table 19. Major and trace element contents of the Hills Pond Lamproite at the Silver City Dome (Extracted from Cullers and others, 1985, Tables 2 and 3, p. 1386 and 1387). (2A) Major element content (Extracted from Cullers, and others, 1985, Table 2, p. 1386) (2B) Trace element content (Extracted from Cullers and others, 1985, Table 3, p. 1387) (2C) Additional trace element content (Extracted from Cullers and others, 1985, Table 3, p. 1387)

### 19 A. Major Element Content

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃¹</th>
<th>MgO</th>
<th>CaO</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>TiO₂</th>
<th>MnO</th>
<th>LOI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>42.7</td>
<td>4.0</td>
<td>7.68</td>
<td>22.5</td>
<td>3.03</td>
<td>6.33</td>
<td>0.34</td>
<td>1.9</td>
<td>0.09</td>
<td>10.9</td>
<td>99.5</td>
</tr>
<tr>
<td>37</td>
<td>41.6</td>
<td>4.4</td>
<td>7.83</td>
<td>22.5</td>
<td>3.70</td>
<td>6.17</td>
<td>0.31</td>
<td>2.2</td>
<td>0.09</td>
<td>10.2</td>
<td>99.0</td>
</tr>
<tr>
<td>50</td>
<td>42.7</td>
<td>3.9</td>
<td>7.99</td>
<td>20.8</td>
<td>3.90</td>
<td>6.79</td>
<td>0.42</td>
<td>2.53</td>
<td>0.09</td>
<td>10.3</td>
<td>99.4</td>
</tr>
<tr>
<td>57</td>
<td>45.8</td>
<td>4.3</td>
<td>8.20</td>
<td>18.5</td>
<td>2.70</td>
<td>8.40</td>
<td>0.58</td>
<td>2.80</td>
<td>0.10</td>
<td>8.0</td>
<td>99.4</td>
</tr>
<tr>
<td>64</td>
<td>49.8</td>
<td>4.5</td>
<td>7.00</td>
<td>16.7</td>
<td>1.55</td>
<td>9.46</td>
<td>0.99</td>
<td>2.95</td>
<td>0.09</td>
<td>7.4</td>
<td>100.4</td>
</tr>
<tr>
<td>Average</td>
<td>44.5</td>
<td>4.2</td>
<td>7.74</td>
<td>20.2</td>
<td>2.98</td>
<td>7.43</td>
<td>0.53</td>
<td>2.48</td>
<td>0.09</td>
<td>9.4</td>
<td>99.6</td>
</tr>
<tr>
<td>Surface</td>
<td>41.6</td>
<td>4.0</td>
<td>7.3</td>
<td>24.7</td>
<td>3.0</td>
<td>6.0</td>
<td>0.38</td>
<td>2.0</td>
<td>0.10</td>
<td>10.9</td>
<td>100.0</td>
</tr>
</tbody>
</table>

1 = Total Fe as Fe₂O₃; 2 = LOI loss on ignition; Surface = weathered surface sample, not included in average.

### 19 B. Trace Element Content (ppm)

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>La</th>
<th>Ce</th>
<th>Sm</th>
<th>Eu</th>
<th>Yb</th>
<th>Lu</th>
<th>Rb</th>
<th>Th</th>
<th>Hf</th>
<th>Ta</th>
<th>Sc</th>
<th>Cs</th>
<th>Th</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>139</td>
<td>260</td>
<td>11.3</td>
<td>2.65</td>
<td>0.73</td>
<td>0.15</td>
<td>227</td>
<td>11.5</td>
<td>12.9</td>
<td>3.6</td>
<td>11.0</td>
<td>&lt;0.5</td>
<td>--</td>
</tr>
<tr>
<td>37</td>
<td>142</td>
<td>262</td>
<td>11.5</td>
<td>2.67</td>
<td>0.70</td>
<td>0.15</td>
<td>204</td>
<td>11.7</td>
<td>13.6</td>
<td>3.7</td>
<td>11.5</td>
<td>&lt;0.3</td>
<td>--</td>
</tr>
<tr>
<td>50</td>
<td>157</td>
<td>290</td>
<td>12.8</td>
<td>3.08</td>
<td>0.73</td>
<td>0.16</td>
<td>193</td>
<td>13.0</td>
<td>16.1</td>
<td>4.4</td>
<td>12.5</td>
<td>&lt;0.3</td>
<td>--</td>
</tr>
<tr>
<td>57</td>
<td>195</td>
<td>354</td>
<td>16.7</td>
<td>3.40</td>
<td>0.78</td>
<td>0.18</td>
<td>217</td>
<td>16.4</td>
<td>19.9</td>
<td>5.8</td>
<td>14.6</td>
<td>&lt;0.3</td>
<td>0.64</td>
</tr>
<tr>
<td>64</td>
<td>199</td>
<td>396</td>
<td>18.5</td>
<td>3.44</td>
<td>0.80</td>
<td>0.14</td>
<td>156</td>
<td>15.6</td>
<td>17.3</td>
<td>4.8</td>
<td>13.0</td>
<td>&lt;0.4</td>
<td>--</td>
</tr>
<tr>
<td>Average</td>
<td>166</td>
<td>312</td>
<td>14.2</td>
<td>3.05</td>
<td>0.75</td>
<td>0.16</td>
<td>199</td>
<td>13.6</td>
<td>16.0</td>
<td>4.5</td>
<td>12.5</td>
<td>&lt;0.4</td>
<td>0.64</td>
</tr>
<tr>
<td>Surface</td>
<td>156</td>
<td>273</td>
<td>12.0</td>
<td>2.6</td>
<td>0.80</td>
<td>0.13</td>
<td>215</td>
<td>12.7</td>
<td>13.6</td>
<td>4.1</td>
<td>10.9</td>
<td>0.59</td>
<td>0.85</td>
</tr>
</tbody>
</table>

### 19 C. Additional Trace Element Content (ppm)

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Ba</th>
<th>Co</th>
<th>Cr</th>
<th>[REE]¹</th>
<th>La/Lu²</th>
<th>Eu/Sm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>4,450</td>
<td>68.9</td>
<td>2,600</td>
<td>528</td>
<td>95</td>
<td>0.23</td>
</tr>
<tr>
<td>37</td>
<td>5,200</td>
<td>64.3</td>
<td>1,540</td>
<td>539</td>
<td>97</td>
<td>0.23</td>
</tr>
<tr>
<td>50</td>
<td>6,440</td>
<td>62.7</td>
<td>1,440</td>
<td>599</td>
<td>98</td>
<td>0.24</td>
</tr>
<tr>
<td>57</td>
<td>8,200</td>
<td>60.3</td>
<td>1,190</td>
<td>731</td>
<td>106</td>
<td>0.20</td>
</tr>
<tr>
<td>64</td>
<td>10,030</td>
<td>50.2</td>
<td>1,040</td>
<td>805</td>
<td>142</td>
<td>0.19</td>
</tr>
<tr>
<td>Average</td>
<td>6,840</td>
<td>61.3</td>
<td>1,562</td>
<td>640</td>
<td>108</td>
<td>0.22</td>
</tr>
<tr>
<td>Surface</td>
<td>5,250</td>
<td>65.2</td>
<td>1,700</td>
<td>567</td>
<td>134</td>
<td>0.22</td>
</tr>
</tbody>
</table>

1. [REE = total REE content in ppm, including interpolated values from chondrite-normalized plots for the REE not analyzed.
2. These are the La/Lu ratios from chondrite-normalized (c.n.) plots
3. These are Eu/Sm ratios in ppm.
<table>
<thead>
<tr>
<th>Element</th>
<th>Range of least altered Silver City lamproites</th>
<th>Range of least altered Rose Dome lamproites</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>41.6 - 49.8</td>
<td>26.5 - 31.4</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.00 - 2.95</td>
<td>2.7 - 2.8</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>3.9 - 4.5</td>
<td>4.6 - 4.8</td>
</tr>
<tr>
<td>Total Fe-Fe₂O₃</td>
<td>7.00 - 8.20</td>
<td>8.7 - 11.8</td>
</tr>
<tr>
<td>MnO</td>
<td>0.09 - 0.10</td>
<td>0.16 - 0.17</td>
</tr>
<tr>
<td>MgO</td>
<td>16.7 - 22.5</td>
<td>16.1 - 16.8</td>
</tr>
<tr>
<td>CaO</td>
<td>1.55 - 3.30</td>
<td>13.0 - 14.4</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.31 - 0.99</td>
<td>0.05 - 0.10</td>
</tr>
<tr>
<td>K₂O</td>
<td>6.17 - 8.46</td>
<td>6.7 - 7.5</td>
</tr>
<tr>
<td>K₂O + Na₂O/Al₂O₃</td>
<td>1.6 - 2.6</td>
<td>1.6 - 1.7</td>
</tr>
<tr>
<td>K₂O/Na₂O</td>
<td>9.6 - 19.9</td>
<td>67 - 150</td>
</tr>
<tr>
<td>FeO/FeO₂+MgO</td>
<td>0.24 - 0.29</td>
<td>0.33 - 0.39</td>
</tr>
<tr>
<td>La</td>
<td>199 - 199</td>
<td>265 - 330</td>
</tr>
<tr>
<td>Lu</td>
<td>0.14 - 0.18</td>
<td>0.13 - 0.43</td>
</tr>
<tr>
<td>Hf</td>
<td>156 - 227</td>
<td>165 - 198</td>
</tr>
<tr>
<td>Ba</td>
<td>4450 - 10,000</td>
<td>887 - 1250</td>
</tr>
<tr>
<td>Th</td>
<td>11.5 - 16.4</td>
<td>32.1 - 47.6</td>
</tr>
<tr>
<td>Hf</td>
<td>12.9 - 19.9</td>
<td>19.9 - 20.0</td>
</tr>
<tr>
<td>Ta</td>
<td>3.6 - 5.8</td>
<td>9.0 - 9.6</td>
</tr>
<tr>
<td>Co</td>
<td>50.2 - 68.9</td>
<td>54.8 - 56.5</td>
</tr>
<tr>
<td>Sc</td>
<td>11.0 - 14.6</td>
<td>18.1 - 19.7</td>
</tr>
<tr>
<td>Cr</td>
<td>1040 - 2600</td>
<td>1150 - 1700</td>
</tr>
<tr>
<td>Cs</td>
<td>&lt;0.4</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Table 20. Major and trace element contents of lamproites from the Silver City and Rose Domes (from Berendsen, 1990, p. 21)
pressures in the range from 200 to 300 bars are reasonable, magmatic temperatures and temperatures of metamorphism may have been in the range from 700° to 840°C during intrusion of the mica peridotite (Franks and others, 1971, p. 2883).

Franks and others concluded (p. 2885) that "the boulders of granite rock on Rose Dome ... are fragments of Precambrian basement that were rafted to the present stratigraphic position during Late Cretaceous time as inclusions in an alkaline mica-peridotite magma. The less dense granitic basement materials seem to have been concentrated in the upper parts of the phlogopite-bearing peridotite intrusive which was emplaced ... about 90 m.y. ago. The temperatures of the peridotite magma were unusually high during emplacement, probably somewhat greater than 800°C" (p. 2885). "Load and fluid pressures during intrusion and metamorphism are thought to have been in the range of 200 to 300 bars." (Franks, and others, 1971, p. 2886).

Merrill, Bickford, and Irving in an extended abstract (1977, p. 130?) for the first time recognized and reported upon the presence of potassic richterite in the Hills Pond Peridotite. "The richterite occurs in fan-shaped bladed aggregates and less commonly as bladed crystals about 0.5 mm long. It is colorless in plane light and faintly pleochroic in shades of pale pink. Optically, richterite is negative with 2V of about 60°, and typically is zoned showing undulose extinction with angles increasing from edges of grains inward". Almost instantaneously the literature seemed to be
teeming with richterite-bearing basic to ultra basic igneous rocks that had formerly been referred to as potassic lamprophyres, mantle peridotites, phlogopite-bearing lherzolites, mica-rich minettes, potassium-rich alkaline rocks, mica-peridotites, olivine kimberlites, ultrapotassic peralkaline minettes, katungites, richterite-bearing kimberlites, and ultrapotassic basalts. All were falling into a lamproite terminology such as ultrapotassic lamproitic rocks, olivine lamproites, olivine-diopside lamproites, mica-rich lamproites, etc. The name peridotite which had been a catch-all term for “plutonic rocks composed chiefly of olivine with or without other mafic minerals such as pyroxenes, amphiboles, or micas, and containing little or no feldspar,” was replaced by the term lamproite—“a group name for dark-colored hypabyssal or extrusive rocks rich in potassium or magnesium” (definitions from Bates and Jackson, 1980, Glossary of Geology, 2nd edition, p. 348, 466).

A new definition of lamproite was written (Jaques and others, 1984, p. 230) as follows: “A potash and magnesia-rich lamprophyric rock of volcanic or hypabyssal origin belonging to the ultrapotassic rock series. Minerals commonly present as major primary constituents include one or more of the following: Olivine, clinopyroxene (typically diopside), phlogopite (typically titaniferous), leucite, amphibole (typically potassic richterite), orthopyroxene, sanidine, and glass.” Atkinson, Hughes and Smith (1984, p. 224) pointed out that “olivine lamproites are peridotites,
often micaceous, containing two generations of olivine, xenoliths of mantle peridotite, and xenocrysts of magnesiochromite, pyrope, and chrome diopside." In a comprehensive report titled "A Review of the Mineralogy of Lamproites", R. H. Mitchell (1985, p. 413) stated that "other primary minerals may include priderite, perovskite, apatite, wadeite, spinel, and nepheline." Xenoliths and xenocrysts (including olivine, pyroxene, garnet and spinel) of upper mantle origin may be present, and diamond may be present as a rare accessory. Lamproite may be of either basic or ultrabasic composition, and is characterized by high \( \text{K}_2\text{O}/\text{Na}_2\text{O} \) ratios and high abundances of Rb, Sr, Ba, Zr, Nb, Pb, Th, U and light-rare-earth-elements (LREE). Mitchell also included data on the Hills Pond occurrence and referred to the reports by Franks and others (1971) and Merrill and others (1977) but not to Berendsen and others (1985) or to Cullers and others (1985); therefore, I assume that Mitchell's report preceded the other two. He defined lamproites and a lamproite clan (Mitchell, 1985, p. 413), but his definition was so nearly identical to that of Jaques and others (1984, p. 230) that it will not be reproduced here. Mitchell documented the mineralogy, petrography, and element compositions of micas (Table 21), of titanian richterites (Table 22) and of spinels (Table 23) of the Hills Pond intrusive along with those of several other lamproite occurrences. He classed the Hills Pond intrusive as a richterite-diopside-madupitic lamproite in which the
Table 21. Representative compositions of mica from the Hills Pond Lamproite at the Silver City Dome (From Mitchell, 1985, p. 422)
Table 22. Representative compositions of titanium potassic richterites from the Hills Pond Lamproite and those from other areas (From Mitchell, 1985, p. 430)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>52.90</td>
<td>54.03</td>
<td>52.55</td>
<td>52.57</td>
<td>51.58</td>
<td>52.45</td>
</tr>
<tr>
<td>TiO₂</td>
<td>5.27</td>
<td>5.03</td>
<td>5.03</td>
<td>7.35</td>
<td>4.32</td>
<td>5.73</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.20</td>
<td>0.45</td>
<td>0.62</td>
<td>0.37</td>
<td>0.76</td>
<td>0.67</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>0.00</td>
<td>0.05</td>
<td>0.05</td>
<td>0.03</td>
<td>0.07</td>
<td>0.00</td>
</tr>
<tr>
<td>FeO*</td>
<td>3.49</td>
<td>4.94</td>
<td>2.19</td>
<td>3.66</td>
<td>3.62</td>
<td>7.54</td>
</tr>
<tr>
<td>MnO</td>
<td>0.12</td>
<td>0.13</td>
<td>0.02</td>
<td>0.09</td>
<td>0.14</td>
<td>0.13</td>
</tr>
<tr>
<td>MgO</td>
<td>19.87</td>
<td>18.67</td>
<td>20.23</td>
<td>17.79</td>
<td>20.86</td>
<td>16.75</td>
</tr>
<tr>
<td>CaO</td>
<td>6.45</td>
<td>6.67</td>
<td>5.88</td>
<td>6.25</td>
<td>4.79</td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.52</td>
<td>4.91</td>
<td>4.56</td>
<td>4.79</td>
<td>3.90</td>
<td>5.61</td>
</tr>
<tr>
<td>K₂O</td>
<td>5.28</td>
<td>4.28</td>
<td>4.59</td>
<td>4.64</td>
<td>4.77</td>
<td>3.36</td>
</tr>
<tr>
<td>BaO</td>
<td>0.00</td>
<td>0.14</td>
<td>0.08</td>
<td>0.12</td>
<td>0.63</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>97.23</td>
<td>97.30</td>
<td>96.51</td>
<td>97.26</td>
<td>96.90</td>
<td>97.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural formula based upon 23 oxygens</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>7.573</td>
<td>7.711</td>
<td>7.539</td>
<td>7.538</td>
<td>7.456</td>
<td>7.584</td>
</tr>
<tr>
<td>Al</td>
<td>0.034</td>
<td>0.075</td>
<td>0.101</td>
<td>0.059</td>
<td>0.127</td>
<td>0.114</td>
</tr>
<tr>
<td>Ti</td>
<td>0.567</td>
<td>0.536</td>
<td>0.539</td>
<td>0.719</td>
<td>0.467</td>
<td>0.623</td>
</tr>
<tr>
<td>Cr</td>
<td>0.000</td>
<td>0.004</td>
<td>0.000</td>
<td>0.000</td>
<td>0.034</td>
<td>0.000</td>
</tr>
<tr>
<td>Fe</td>
<td>0.418</td>
<td>0.586</td>
<td>0.261</td>
<td>0.437</td>
<td>0.437</td>
<td>0.912</td>
</tr>
<tr>
<td>Mn</td>
<td>0.015</td>
<td>0.012</td>
<td>0.000</td>
<td>0.008</td>
<td>0.015</td>
<td>0.016</td>
</tr>
<tr>
<td>Mg</td>
<td>4.243</td>
<td>3.971</td>
<td>4.323</td>
<td>3.798</td>
<td>4.493</td>
<td>3.613</td>
</tr>
<tr>
<td>Ca</td>
<td>0.991</td>
<td>0.712</td>
<td>1.027</td>
<td>0.900</td>
<td>0.966</td>
<td>0.743</td>
</tr>
<tr>
<td>Na</td>
<td>0.987</td>
<td>1.357</td>
<td>1.267</td>
<td>1.329</td>
<td>1.089</td>
<td>1.575</td>
</tr>
<tr>
<td>K</td>
<td>0.965</td>
<td>0.775</td>
<td>0.821</td>
<td>0.845</td>
<td>0.878</td>
<td>0.620</td>
</tr>
<tr>
<td>Ba</td>
<td>0.000</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.005</td>
<td>0.000</td>
</tr>
<tr>
<td>CAT</td>
<td>15.784</td>
<td>15.743</td>
<td>15.883</td>
<td>15.703</td>
<td>15.967</td>
<td>15.800</td>
</tr>
</tbody>
</table>

"Total Fe calculated as Fe₂O₃; CAT = cation sum.
1. Hills Pond; 2. Smoky Hills; 3-4. Leucite Hills; 5. Prairie Creek; 6. south-east Spain"
Table 23. Representative compositions of spinels from the Hills Pond Lamproite and those from other areas (Mitchell, 1985, p. 430)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiO₂</td>
<td>2.45</td>
<td>9.95</td>
<td>11.88</td>
<td>13.03</td>
<td>7.74</td>
<td>6.83</td>
<td>10.41</td>
<td>12.09</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>2.86</td>
<td>0.13</td>
<td>0.10</td>
<td>0.10</td>
<td>0.35</td>
<td>0.13</td>
<td>0.00</td>
<td>0.13</td>
</tr>
<tr>
<td>Cr₂O₃</td>
<td>57.96</td>
<td>22.75</td>
<td>19.41</td>
<td>13.04</td>
<td>0.05</td>
<td>0.08</td>
<td>0.07</td>
<td>0.71</td>
</tr>
<tr>
<td>FeO*</td>
<td>25.27</td>
<td>60.10</td>
<td>59.37</td>
<td>65.38</td>
<td>83.31</td>
<td>84.24</td>
<td>78.18</td>
<td>75.52</td>
</tr>
<tr>
<td>MnO</td>
<td>1.19</td>
<td>1.27</td>
<td>1.21</td>
<td>1.23</td>
<td>0.84</td>
<td>0.78</td>
<td>2.02</td>
<td>2.13</td>
</tr>
<tr>
<td>MgO</td>
<td>8.80</td>
<td>4.40</td>
<td>4.79</td>
<td>4.71</td>
<td>1.71</td>
<td>1.50</td>
<td>4.05</td>
<td>4.33</td>
</tr>
<tr>
<td></td>
<td>98.57</td>
<td>98.60</td>
<td>96.76</td>
<td>97.49</td>
<td>94.00</td>
<td>93.57</td>
<td>94.73</td>
<td>94.91</td>
</tr>
<tr>
<td>Recalculated analyses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>6.18</td>
<td>30.00</td>
<td>28.54</td>
<td>33.60</td>
<td>54.10</td>
<td>55.79</td>
<td>50.89</td>
<td>46.84</td>
</tr>
<tr>
<td>FeO</td>
<td>19.71</td>
<td>33.11</td>
<td>33.69</td>
<td>35.15</td>
<td>34.63</td>
<td>34.04</td>
<td>32.39</td>
<td>33.37</td>
</tr>
<tr>
<td></td>
<td>99.15</td>
<td>101.60</td>
<td>99.62</td>
<td>100.86</td>
<td>99.42</td>
<td>99.83</td>
<td>99.69</td>
<td>99.60</td>
</tr>
<tr>
<td>Mol % end member spinels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgAl₂O₄</td>
<td>5.5</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.5</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Mg₂TiO₄</td>
<td>9.0</td>
<td>13.1</td>
<td>14.3</td>
<td>13.4</td>
<td>4.4</td>
<td>4.7</td>
<td>11.2</td>
<td>11.8</td>
</tr>
<tr>
<td>Mn₂TiO₄</td>
<td>--</td>
<td>2.1</td>
<td>2.1</td>
<td>1.4</td>
<td>1.4</td>
<td>1.3</td>
<td>3.2</td>
<td>3.3</td>
</tr>
<tr>
<td>Fe₂TiO₄</td>
<td>--</td>
<td>14.9</td>
<td>19.7</td>
<td>22.4</td>
<td>16.3</td>
<td>14.2</td>
<td>14.7</td>
<td>18.6</td>
</tr>
<tr>
<td>MnCr₂O₄</td>
<td>3.3</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>MgCr₂O₄</td>
<td>25.1</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FeCr₂O₄</td>
<td>45.9</td>
<td>24.2</td>
<td>20.6</td>
<td>15.3</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Fe₂O₄</td>
<td>11.3</td>
<td>45.5</td>
<td>43.3</td>
<td>48.8</td>
<td>77.3</td>
<td>80.1</td>
<td>70.9</td>
<td>65.4</td>
</tr>
</tbody>
</table>

*Total Fe calculated as FeO. All data from Mitchell's work.
micas are strongly zoned red-brown in a pleochroic poikilitic groundmass. An extreme alumina depletion at the crystal margins was accompanied by moderate iron enrichment at essentially constant titanium content (Mitchell, 1985, p. 418). The titaniferous magnesian nature of the micas from the Hills Pond Lamproite (Table 21) implied crystallization from a TiO$_2$-rich H$_2$O-bearing ultrabasic magma (Figure 66).

Also, tetraferrirphlogopite micas (Table 21) were clearly low-pressure phases (Mitchell, 1985, p. 421). In most cases the amphibole would have been classed as a titanian potasssian richterite that would be easily recognized by its unusual lemon-yellow to reddish-pink pleochroism. The common habit of the richterite showed as plates in a late-stage poikilitic groundmass which included earlier phase minerals such as mica-pyroxene and leucite. Commonly the richterite plates contained large numbers of tubular to vermiform fluid inclusions. The composition of the titanian potassic richterite from Hills Pond, given in Table 22, probably formed at a temperature below 1000° over a wide range of pressure and oxygen fugacity (p. 423). In these lamproites, the olivine-rich part occurred either as euhedral crystals or as anhedral bodies. In a potassic magma at depth, late olivine would have cooled with the resorption of early olivine and the formation of phlogopite mica. Olivines in lamproite would all have been forsteritic and poor in MnO and FeO (p. 426). When present, sanidine...
Figure 66. Compositional data on phlogopite micas from the Hills Pond Lamproite compared with those of other areas. (A) Al₂O₃ v/s FeO content from Kansas and Arkansas compared with West Kimberley phlogopite compositional trends; (B) Al₂O₃ v/s TiO₂ content for phlogopites from Kansas, the Ivory Coast, and Greenland; (C) Al₂O₃ v/s TiO₂ content of phlogopites from Kansas, the Ivory Coast, Greenland, and Arkansas compared with those from the Leucite Hills and southeast Spain (from Mitchell, 1985, p. 417, 418, 419).
was the only feldspar found in the lamproites; it generally occurred in a late stage groundmass phase. Its wide variety of morphologies ranges from quench stellate rosettes, to plumose fans of laths and prisms, or as euhedral blocky microphenocrysts, or as anhedral poikilitic plates. The habit was related to the degree of cooling or quenching of the parent magma (p. 428). Spinels were common only in olivine-rich or madupitic lamproites. Mitchell made it possible to compare the composition of the Hills Pond spinel with that of other localities (Table 23). The Hills Pond spinel fell in Group 2 of the four broad compositional groups of spinels defined by Mitchell (1985, p. 430):

Group 1 - Ti-poor (<1% TiO₂), aluminous (<10% Al₂O₃) magnesiochromites
Group 2 - Titanian (1-5% TiO₂), aluminous (1-10% Al₂O₃) magnesiochromites
Group 3 - Alumina-poor (<1% Al₂O₃) titanian (<5% TiO₂) magnesian (<5% MgO) chromites
Group 4 - Magnesian (<5% MgO) titaniferous magnetites.

The Hills Pond lamproite contained only Group 2 spinels. Mitchell also made it possible (Figure 67) to compare and to determine the relationships between spinel groups of different lamproites with those of kimberlites (Mitchell, 1985, p. 431). These data showed that whereas the overall evolutionary trends may be similar, the Hills Pond lamproite spinels were not enriched in titanium or total iron as compared to kimberlite spinels from Pilot Butte, Prairie
Figure 67. Compositional variations of spinels from lamproites compared with those of spinels from kimberlites (from Mitchell, 1985, p. 431).
Creek, or Jumilla. Overlap of the trends occurred only close to the base of the spinel prism, Groups 1 and 2 spinels (Mitchell, 1985, p. 431). Madupitic lamproites, such as those at Hills Pond were characterized by the presence of groundmass poikilitic phlogopite mica. Mitchell summarized that some minerals in lamproites, especially phlogopite, amphibole, and spinel exhibited sufficient compositional variation that they could be used to assess the relative degree of evolution of lamproitic rocks. Madupites probably did not crystallize from primitive unevolved magmas (Mitchell, 1985, p. 435).

In 1985 Berendsen and others pointed out that the lamproites in Wilson and Woodson counties were alkalic and ultra-potassic, and probably formed by a small percent melting of phlogopite-garnet peridotite where the $H_2O/CO_2$ ratio in the source would have been high. Preliminary studies indicated that deep-seated faults may have played important roles in the localization of the lamproites (Berendsen and others, 1985, p. 151).

That same year (1985), a report authored by Cullers, Ramakrishnan, Berendsen and Griffin appeared in which the lamproite bodies, as well as the metamorphosed and unmetamorphosed country rocks were analyzed in order to put limits on how the lamproite may have formed and evolved. The primary goal was to determine the nature of a source material that, when melted, would have produced such ultrapotassic rocks. A secondary goal was to see if crystal-melt
segregations or volatile transport into the country rock may have caused chemical variations within the intrusive rock. The strontium isotopic content of the lamproites was determined in order to place limits on the isotopic content of the sources (p. 1384, 1385). Unfortunately, Cullers and others (1985) carelessly call the intrusive body the “Silver City lamproite.” When writing my early report (Wagner, 1954), I automatically checked the availability of the name Silver City for rock nomenclature use and found that the name, Silver City, had been pre-empted for use as the Silver City Granite in Idaho, and, therefore, I could not use it. I used the name Hills Pond Peridotite for the igneous rock at the Silver City Dome, Kansas, because the mineralogy of a lamproite was at that time loosely defined and mica peridotite seemed to fit the mineral composition best. This problem has now been clarified and the intrusive rock at the Silver City Dome is properly called a lamproite. However, the distinguishing name “Hills Pond” should still be used for the intrusive in order to follow the recognized methods of nomenclature. The Cullers and others report (1985) should have used the accepted terminology as was done by Mitchell (1985) throughout his report—the existence of which Cullers and others must have been aware as they referred to Mitchell’s report in their references. Sadly, Cullers and others used the term “Silver City lamproite” throughout their report and provided clues only intermittently to the proper terminology. For example, on the first page, they said that
"The lamproites were intruded near or at the surface ... to form gentle dome-like areas called the Silver City (Hills Pond) and Rose domes" followed by...“Silver City lamproite was intruded...” (p. 1383). Their caption for Figure 2 (p. 1384) "Geologic map and sample locations of the Silver City (Hills Pond) lamproite (after Wagner, 1954)" is also incorrect. Not only is the caption incorrect, but they changed the map and its explanation so considerably that they should have noted after the title "(modified after Wagner, 1954)". Similarly, on page 1386, in Table 2, they used the heading Silver City Dome area (or Hills Pond). The two items are not synonymous; one is the name of an area, the other is the name of a rock unit. In addition, on the first page of the report (p. 1383), they stated that the lamproite produced hornfels, quartzite, and "marble" [their quotation marks] in the country rocks, and followed this statement directly by the reference (Wagner, 1954). My report does not use the term marble. Three lines later, they again referred to marble followed directly by the reference (Wagner, 1954). In referring to the works of Franks and others, they were also in error. Cullers and others (p. 1384) wrote that "The lamproite magma was estimated to have been intruded at a temperature in excess of 800°C and at a low pressure (225-300 bars)." They credited Franks and others (1971) with that statement, whereas Franks and others (1971, p. 2884) actually wrote "temperatures in the mica peridotite magma may have exceeded 800°C, if fluid pressures were in the range from 200
to 300 bars." Such careless referencing made the validity of the data in their entire report suspect, which is very unfortunate because there are many new and important data sets given by Cullers and others (1985). Among these data are diagrams and analyses of rocks encountered in four core holes drilled by the Geological Survey of Kansas. It would have been helpful to the reader if the totals for the major elements analyzed in the Hills Pond lamproite in core hole HP-21 at the Silver City Dome (Table 19A) had been averaged in their Table 2 (Cullers and others, 1985, p. 1386). However, they were not averaged; the figures shown in Table 19A of the present report (page 609) were averaged by me. The major elements of a weathered surface sample, marked "Surface" from the Silver City Dome, are shown in Table 19A, but are not included in the average.

The trace element and ancillary element content of the lamproite have also been analyzed at 5 depths in the core-hole HP-21 samples and for the surface sample (weathered) at the Silver City Dome. The core hole results are given in Tables 19B and 19C (extracted from Cullers and others, 1985, Table 2, p. 1386 and Table 3, p. 1387). Data for the surface (weathered) sample are included in the average shown on page 609, this report. Rubidium and strontium contents and ancillary data for the Hills Pond lamproite at 57 ft. depth at the Silver City Dome are shown in Table 24. The major elements and strontium were analyzed by atomic absorption; other trace elements were
Table 24. Rb and Sr contents and the Sr isotope results from the Hills Pond Lamproite at the Silver City Dome (From Cullers and others, 1985, Table 6, p. 1389)

<table>
<thead>
<tr>
<th>Depth (ft.)</th>
<th>Olivine</th>
<th>Phlogopite</th>
<th>K-richerite</th>
<th>Diopside</th>
<th>Spinel</th>
<th>Perovskite</th>
<th>Groundmass</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>34.0</td>
<td>13.6</td>
<td>1.9</td>
<td>4.4</td>
<td>4.0</td>
<td>--</td>
<td>42.1</td>
</tr>
<tr>
<td>37</td>
<td>26.5</td>
<td>17.4</td>
<td>3.4</td>
<td>2.0</td>
<td>2.2</td>
<td>--</td>
<td>48.5</td>
</tr>
<tr>
<td>52</td>
<td>16.9</td>
<td>19.7</td>
<td>3.0</td>
<td>2.4</td>
<td>2.6</td>
<td>--</td>
<td>55.4</td>
</tr>
<tr>
<td>57</td>
<td>19.4</td>
<td>20.8</td>
<td>6.8</td>
<td>2.3</td>
<td>3.1</td>
<td>0.5</td>
<td>47.1</td>
</tr>
<tr>
<td>64</td>
<td>9.3</td>
<td>20.3</td>
<td>2.3</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>68.1</td>
</tr>
<tr>
<td>Average</td>
<td>21.2</td>
<td>18.4</td>
<td>3.5</td>
<td>2.8</td>
<td>3.0</td>
<td>0.5</td>
<td>52.3</td>
</tr>
<tr>
<td>Surface</td>
<td>25.6</td>
<td>21.0</td>
<td>--</td>
<td>2.2</td>
<td>0.8</td>
<td>0.2</td>
<td>45.2</td>
</tr>
<tr>
<td>weathered</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 25b-8. Modal analyses (500 points) of the Hills Pond Lamproite, Drill Hole H. P.-21, at the Silver City Dome (From Cullers and others, 1985, Table 6, p. 1389)
analyzed by instrumental neutron activation methods (Cullers and others, 1985, p. 1385-1388). Modal analyses of the Hills Pond lamproite minerals at the Silver City Dome are summarized in Table 25. Notably absent from this lamproite are garnet, ilmenite, and mantle xenoliths.

Cullers and others (1985, p. 1386-1388) indicated that the major phenocrystic minerals in the Hills Pond lamproite were euhedral to subhedral phlogopite, diopside, and potassic richterite. Anhedral serpentine pseudomorphs after olivine and chrome spinel occurred in a predominantly serpentine groundmass. Perovskite, apatite and magnetite were accessory minerals. Groundmass minerals constituted 42 to 68 percent of the lamproite (Table 25). The anhedral serpentine pseudomorphs after olivine were completely altered to antigorite or lizardite and were cut in places by veinlets of chrysotile. The phlogopite occurred as prismatic, strongly zoned, slightly pleochroic, reddish-brown crystals partly altered to serpentine; apatite generally occurred as inclusions in the phlogopite. The diopsidic clinopyroxene occurred as colorless, subhedral, partially serpentinized grains; potassic richterite was not found in the weathered surface sample but was noted in core samples as a colorless to faintly pink, pleochroic mineral. It appeared as bladed, or fan-shaped crystals that were partially serpentinized locally. The spinels, which are titanium-rich, aluminous, magnesiocromites, occurred as scattered, square- to irregular-shaped crystals throughout the groundmass. They
were slightly anisotropic and generally dark reddish-brown; some crystals showed small areas having a faint greenish tint. Perovskite was found only in the surface sample of the lamproite and in the core sample at 57 feet. It occurred as anhedral to irregularly shaped crystals that were brown and nearly opaque. Magnetite formed small euhedral crystals scattered throughout the groundmass and also in areas of phlogopite and olivine alteration. The lamproite was weathered at the surface to mostly clay minerals (illite, montmorillonite, and mixed-layer montmorillonite) and phlogopite (Cullers and others, 1985, p. 1386, 1388).

A vertical variation in the abundance of major and some trace elements in the deep lamproite core at the Silver City Dome was noted by Cullers and others (1985, p. 1391). The Si, K, Na, REE, Ba, Th, and Hf abundances tended to increase with depth whereas Mg, Ca, Co, and Cr decreased with depth. These trends could be explained by changes in phenocryst/groundmass ratios or by volatile transport into the surrounding country rock. They also noted (p. 1397, 1398) that other vertical chemical variations could have occurred within the sills, and discussed the effects that could be due to combinations of crystal fractionation, multiple injection, flow differentiation, and metasomatism. In a discussion of melting models at mantle depths, Cullers and others stated (1985, p. 1395) that the lamproite at the Silver City Dome could have formed by melting of a metasomatized, phlogopite-rich peridotite. In a talk given
that same year by Berendsen (authored by Berendsen, Cullers, Mansker, and Cole) at the Geological Society of America's South-Central Section meeting, the belief that the Silver City lamproite formed from "a small percent melting of phlogopite-garnet peridotite" was reiterated (Berendsen and others, 1985, p. 151). Partial melting was also invoked for granite xenoliths in mica peridotite at Rose Dome in a 1986 report published in the American Mineralogist by Smith and Franks (1986, p. 60). They believed that "the melt formed by the addition of heat and water to granite xenoliths from a Late Cretaceous mica-peridotite host."

The year 1985 also saw the introduction of seismic reflection studies at the Silver City and Rose Domes. These studies were first reported on by Wojcik and Knapp in an abstract titled "Seismic reflection study of a lamproite intrusion, Silver City Dome, Woodson County." A north-south directed seismic-reflection profile was interpreted to indicate that the lamproite was intruded near the center of the dome (Wojcik and Knapp, 1986, p. 793). However, they also stated that the maximum closure was in the northern half of the dome and that relatively small closure occurred in the southern half of the dome. Wojcik (1986, p. 9) indicated that the study "supported a sill injection model of the dome origin."

Bergman (1987) provided a wealth of information on lamproites under the title "Lamproites and other potassium-rich igneous rocks: a review of their occurrence, mineralogy
and geochemistry." In his summary he stated (p. 103) "Lamproites are characterized by the general presence of phlogopite, diopside, leucite and K-richterite, occasional glass, olivine, sanidine, priderite, perovskite, wadeite, apatite and chrome spinel, and very rare ilmenite... Lamproite magmas are produced by the partial melting of old refractory mantle peridotite ... that was enriched in K-bearing and other incompatible-element-enriched phases, such as phlogopite and apatite, most probably as a result of some metasomatic event which occurred prior to melting. In contrast with alkali basalt and kimberlite melts, which are apparently produced from the partial melting of a CO$_2$-enriched mantle peridotite, ... water is the key volatile species involved with lamproite petrogenesis." The intrusive rock at the Silver City Dome is among those Bergman described and, fortunately, he used the proper place designation "Hills Pond" and credited P. Berendsen in a personal communication, dated 1984, with correctly noting that the mica peridotite at that locality was actually a madupitic lamproite (Bergman, 1987, p. 114). Thus, it appears that Berendsen was the first to determine, probably in 1984, that the intrusive rock at the Silver City Dome was a lamproite. Bergman's very detailed description of variations in lamproites makes it difficult to pigeonhole the Hills Pond lamproite into the clan because of the loose chemical constancy and the numerous rock names applied to rock types within these relatively indistinct rock groups. Bergman's definition of lamproite
In his discussion of the Hills Pond lamproite, Bergman stated (p. 114) that the Hills Pond lamproite area "is one of the rare occurrences in which lamproite forms well-developed sills and the only known occurrence of olivine-lamproite in well-developed sills." He showed the Hills Pond location in relation to other lamproites and associated rocks (p. 117), gave its average major element composition in relation to other ultrapotassic-potassic rock suites (p. 118), reproduced a generalized map and section (after Wagner, 1954) on page 121, provided a summary of the trace element geochemistry of the Hills Pond intrusive in relation to others (p. 145), illustrated the compositional space occupied by the Hills Pond lamproite on Mg number/SiO$_2$ mole % and TiO$_2$ mole % diagrams (p. 151), and listed the average CIPW normative composition of the Hills Pond lamproite in relation to comparable rocks (p. 152). In his discussion of lamproite mineral chemistry, Bergman noted (p. 156) that the diopside in the Hills Pond lamproite contained the highest TiO$_2$ weight percent (0.4-3.5), and that it (along with one other sample) had the lowest Cr$_2$O$_3$ (0.0-1.5 wt %). He noted that the K-Ti-niphonite is a common alkali amphibole observed as late-stage groundmass grains in most lamproite suites, including Hills Pond (p. 156). In comparing phlogopite compositions from lamproites with those from other rock types, Bergman (p. 162) diagrammed the Al$_2$O$_3$ (wt %) against the Mg number and showed that the Hills Pond lamproite fell near the center of
the entire range of lamproites. He noted (p. 164) that Barton and Hamilton (1979) had determined experimentally that the natural madupitic lamproites probably represented partial melts of phlogopite-pyroxenite or phlogopite-olivine-pyroxenite assemblages. In conclusion, Bergman (1987, p. 170) stated that lamproites were "a coherent but variable and exotic petrographic and chemical group of K-rich igneous rocks." They "often intrude crust that overlies fossil Benioff zones. Lamproites are partial melts of a metasomatized (i.e., phlogopite-, apatite-bearing) but depleted (in Na, Al, Ca) source-mantle peridotite ... A three-stage model (depletion-enrichment-melting), at least, is required to explain the evolution of the source regions of lamproite magmas. Lamproites differentiate by processes including crystal-fractionation, fractional resorption and volatile-phase transfer, among others" (Bergman, 1987, p. 170).

Berendsen and Blair (1988, p. 5) reported that "small granite xenoliths, up to a few centimeters in diameter, were also found by Berendson in a core of lamproite taken in 1984 from a depth of 920 feet at the northwestern end of the Silver City Dome." Berendsen and Knapp (1988, p. 1) stated in the preface to their field trip guidebook for the Cretaceous lamproites of the Silver City and Rose Domes that U.S.G.S. map Q49 was the first of "a number of excellent papers...dealing with the petrological, petrographical, geochemical, geochronological and geophysical aspects of the
occurrence.” Later in that guidebook Blair and Berendsen (1988, p. 11) stated that it was “difficult, if not impossible, to determine the overall structure of the Rose and Silver City Domes directly from outcrop data. Small mounds of granite boulders comprise the only outcrops at Rose Dome. Although the outcrops at Silver City are laterally extensive, only recently has an active mining program exposed the lamproite body for direct study” (Blair and Berendsen, 1988, p. 11). They point out also that several wells drilled for oil and gas have encountered lamproite sills at the Silver City Dome. The Ecco Ranch well, which produces oil from the “Bartlesville” sand at 1176 feet depth encountered at least 6 lamproite sills from 374 to 755 feet depth. The sills range from 10 to 30 feet in thickness (Blair and Berendsen, 1988, p. 12). Markezich (1988, p. 15) pointed out that studies using seismic reflection data at the Silver City Dome were begun in 1985 by Wojcik who used miniSOSIE as the source. In her study, Markezich (1988, p. 18, 23) used dynamite as a source in order to obtain higher energy and higher frequency than were possible with miniSOSIE. Processing of data included deconvolution, velocity analysis, automatic statics, frequency filtering, residual statics, stacking, complex trace analysis, migration, refraction statics, and slant stack. She concluded that the intrusions occurred as sills within a zone near the center of the north half of the Dome, that the sills are probably 6 to 11 meters thick, and that the strongest seismic reflections resulted
from acoustic impedance contrasts across contacts between metamorphosed strata and the lamproite (Markezich, 1988, p. 27, 38). Markezich, Knapp, and Wojcik (1988, p. 21-23) reviewed earlier geophysical efforts at the Silver City Dome. The latest data seemed to indicate that injection of the intrusive may have been near the center of the dome and that withdrawal during a late intrusive phase resulted in the partial collapse and distortion of the domal area and the formation of graben-like features along the margins of the structure. Sills were recognized only in the northern part of the dome. They apparently believed that a deep-seated magma body formed a feeder through which lamproite penetrated and shattered the rock. The zone that they believed contained the lamproite sills "is heavily fractured and is bounded on the north by a fracture zone" (Markezich, Knapp, and Wojcik, 1988, p. 26). Knapp, Markezich, and Wojcik (1988, p. 104) indicated that they believed the domal effect at the Silver City Dome resulted from intrusion of Upper Cretaceous lamproite as an infestation of sills near the center of the dome. Cooling and contraction of the intrusive lamproite caused a collapse that led to the formation of a double domal structure, the more pronounced dome being in the northern part. Knapp and Atkins-Heljeson (1988, p. 16-18) provided an interpretation of extensive gravity and aeromagnetic data in the Woodson and Wilson Counties area in order to determine the relations of the Silver City and Rose Domes to one another and to the regional structure. Their
gravity map showed that the two domes occur at the northwest edge of a ring feature whose center lay some 20 miles to the east-southeast of the dome. Their aeromagnetic map revealed a similar but more subdued ring feature with two indistinct domal structures along the northwest boundary.

Wojcik and Knapp (1990, p. 251) state that the structure at the Silver City Dome "developed in at least two phases. First, a gentle dome and marginal ring grabens formed as a result of deep magmatic activity. Later, a smaller and steeper dome and a centrally located downwarp were superimposed upon the gentle dome as a result of sill injection into the Pennsylvanian sequence and collapse of the rock column above the magma source." Their model, however, did not "preclude the possibility that a lamproite diatreme could have developed subsequently. Volatiles in lamproite magmas are H2O rich, and so these magmas boil at relatively shallow depths...The Hills Pond lamproite may represent a preboiling part of a lamproite body" (Wojcik and Knapp, 1990, p. 254).

Stephens and Knapp (1990, p. 2) reported that the source of the sills is "a seismically chaotic zone at a depth of approximately 750 meters...The zone is considered to consist of shattered country rock mixed with the igneous intrusive... Overlying this source is a region of discontinuous, high-amplitude, low-frequency events interpreted to be a sequence of sills interlayered with contact-metamorphosed sedimentary rocks. A large fracture
bounds the intruded region on the north and appears to connect to the principal magma body at depth and could have served as a conduit for the magma" (p. 2). "The fractures present in the zone containing sills are probably the result of sill penetration as well as the result of collapse after cooling" (Stephens and Knapp, 1990, p. 16).

Berendsen (1988) discussed the geologic setting, structure, petrography and mineralogy, elemental and trace element compositions, and industrial uses of the potassic lamproite at the Silver City Dome (p. 17-23). He agreed (p. 21) with Cullers and others (1985) "that the lamproite could have been derived by partial melting (about 2%) of a phlogopite garnet Iherzolite under high H2O/CO2 ratios in which the Iherzolite was enriched before melting in the incompatible elements by metasomatism." As noted by Berendsen, the Hills Pond Lamproite has been a source of interest for several economic ventures between the 1940's and 1988 (Berendsen, 1990, p. 21, 22). In 1942 the lamproite was considered to be a possible source for vermiculite, bauxite, chromite, and road ballast. In 1961 a mining operation was begun with the intent to produce insulating material. This operation lasted only about 5 years. Between 1966 and 1982 the lamproite was mined and marketed intermittently as a "complete" fertilizer. The last operation, which began in 1982, removed essentially all the yellowish gray weathered lamproite and was regarded as an open-pit mining endeavor. The maximum depth of mining was as much as 55 feet in deeply
weathered material in the center of the pit but shallowed rapidly in all directions. As stated by Berendsen (1990, p. 22) "the north wall of the pit is quite steep and coincides closely with the fault mapped by Wagner (1954). Access to the pit is gained from the east along a gentle incline." The operation was carried out by "Micro-lite, Incorporated" who marketed most of their product as an ingredient in cattle feed; about 28,000 tons of weathered lamproite was mined in 1988 (Berendsen, 1990, p. 22). The plant was still in operation when I (Wagner) visited it in 1991, but the amount of weathered material remaining was very small and the plant is probably closed now (1995).
APPENDIX C

SELECTED FAUNA AND FLORA OF PENNSYLVANIAN STRATA

Being a collection of drawings

of Wilson County fossils
Care was taken to compile data from all available sources concerning the faunal and floral constituents of each stratigraphic unit in Wilson County. This was done in order (1) to assess the growth in diversity of genera and species in time, (2) to determine the source and direction of migration of genera in time, and (3) to note which formations had shallow-water faunas or floras, platform-type faunas, deep-water thermocline-restricted faunas, or faunas with geosynclinal aspects.

Brachiopod and pelecypod faunas could be useful in determining environmental conditions in which restricted circulation in shallow bays or deep water was indicated; calcareous sponges could be used to define shallow seas and warm or cold water (Moore, 1952, p. 79); ostracodes might be of use in separating marine and fresh water environs; bryozoans, which are mainly shallow water indicators, can also live at considerable depths; and algae require shallow water and sunlight for their photosynthesis process. Planktonic foraminifers and other floaters, such as some cephalopods, are more difficult to use because their mobility makes them subject to the vagaries of storm conditions. One can come to pertinent conclusions from the faunal and floral contents of different units. For example, thin-shelled pelecypods
(Mytilus, etc.) indicated a preference for relatively shallow quiet marine to estuarine waters (Moore, 1952, p. 429, 430), as is shown by those at the base of the Haskell Limestone Member of the Lawrence Formation. Heavy-shelled articulated brachiopods, like Dictyoclostus, seem to have preferred the shallow sea bottoms on which they commonly lived in fixed position. Sponges, such as those of the Plattsburg Limestone, probably lived in shallow, relatively clear water in close proximity to the codiacean and dasycladacean algae of the large banks that proliferated in the Pennsylvanian seas of Wilson County. Other algae that coated sand grains or shell fragments (Osagia and Ottonosia) also formed in shallow, relatively well agitated sea water along with large laminated oncolite-forming algal balls and discs. Ostracodes are somewhat less useful than the other listed forms because they can tolerate a wider set of environmental conditions including greater depth range and more variable salinity requirements. Bryozoans also have considerable tolerance for depth and salinity but, being mainly sessile forms, they have attachment requirements and when found in soft sand or mud terranes they have probably been carried there by storm conditions. Some foraminifers are benthonic, but the vast majority are planktonic floaters, and their tests can be found in almost any environment. Their size allows them to be readily transported by current and wave action into catchment basins near the shoreline (Moore, 1952,
p. 50) or into deep water where they may form a thanatacoenosis (death assemblage). Conodont faunas are found mainly in thin organic-rich shaly layers but can also be abundant in shaly limestones or thin shale beds in sandstones; these conodonts may be the remains of pelagic organisms.

Study of the faunal listings indicate that groupings of individuals of very diverse zoological taxonomy occur together in tightly knit communal assemblages. Such assemblages may occur as a result of environmental choice of the individuals, whether it be a need for sunlight, a specific salinity, a temperature requirement, a solid bottom requirement for attachment, a loose bottom for burrowing, a specific depth of water, or a nearness to a food supply. Such communities are of interest when reconstructing the environment but do little or nothing toward providing an estimate of evolutionary change at the generic or species levels. Evolutionary changes of this type occur in the time frame of many millions of years; the sedimentary (paleontologic) record available in the outcropping rocks of Wilson County covers only a short period of geologic time, barely 3.3 million years. Therefore, very few changes at the species level could be expected and even fewer at the generic level. The disappearance of the brachiopod genus Mesolobus and of the foraminiferal genus Fusulina at the end of the Middle Pennsylvanian (Desmoinesian Stage) was followed by the
appearance of Triticites which then became the dominant fusulinid of Wilson County. Several different brachiopod genera also became important, Dictyoclostus, Neospirifer, Composita, and Meekella to name a few. Also important in the Upper Pennsylvanian strata are the pelecypods Myalina, Orthomyalina, and Aviculopecten, the gastropods Meekospira, Glabrocingulum, and Euconospira, the corals Caninia, Lophophyllidium, and Dibunophyllum, the crinoids Erisocrinus, Cibolocrinus and Stellarocrinus, the sponges Girtyocoelia and Heliospongia, the bryozoans Rhombopora and Archimedes, the ostracodes Bairdia and Hollinella, the cephalopods Domatoceras and Schistoceras, the alga Archaeolithophyllum, the holothurian Ancistrum, and the trilobite Ditomopyge. For convenience, drawings of many of these and other Pennsylvanian fossils of Wilson County are shown in Figures 68-75. Some of the drawings were made by me during course work at the University of Kansas; most others are from Newell (1937, 1942), Moore and Laudon (1943), Shimer and Shrock (1944), Moore (1949), Moore, Lalicker, and Fischer (1952), and Wermund (1975).

Finally, I should close this segment of the dissertation by stating that an expert could probably determine small changes in the shell configuration and ornamentation of a few genera and species in the geologic time frame of the fossil assemblages of Pennsylvania age in Wilson County, but such determinations are beyond the present abilities of the writer. I have observed,
however, that the faunal elements decrease in quantity as older strata are investigated. This most likely is a function of fewer and smaller exposures of these older strata within the county limits and does not necessarily reflect a smaller fauna or flora. Fewer fossils were recorded in the older strata for the same reason, a much smaller outcrop area to investigate. Another factor is, of course, the great quantity of data made available by study of the algal mound areas by more than 100 graduate students of Midcontinent colleges and universities over the last forty or so years.
Figure 68. Selected Pennsylvanian Brachiopods of Wilson County

763
Figure 69. Selected Pennsylvanian pelecypods of Wilson County
Figure 70. Selected Pennsylvanian gastropods of Wilson County
Figure 71. Selected Pennsylvanian ostracodes of Wilson County
Figure 72. Selected Pennsylvanian sponges and bryozoans of Wilson County
FORAMINIFERS

Ammobaculites  Ammodiscus  Climacammina  Cornuspira

Globivalvulina  Glyphostomella  Nodosaria  Orthovertella

Hyperammina

Rhabdammina

FUSULINID

Spiroplectammina  Tetrataxis

Triticeites

Figure 73. Selected Pennsylvanian foraminifers and a fusulinid of Wilson County
Figure 74. Selected Pennsylvanian crinoids and an echinoid of Wilson County
Figure 75. Selected Pennsylvanian Conodonts and corals, a holothurian, a trilobite and a cephalopod of Wilson County.
APPENDIX D

SELECTED MEASURED OUTCROP SECTIONS OF WILSON COUNTY

Having been measured in the field using plane table and alidade or steel tape, Jacob's staff, and pacing. Locations of measured sections are shown on Plate 12 (in pocket).

Stratigraphic sections. Measured by
Holly C. Wagner, 1950-1955

F = Fredonia quadrangle area
A = Altoona quadrangle area
N = Neodesha area

Vertical Scale - 1 inch = 10 feet

(Mapping began in the Fredonia (F) Quadrangle area. Sections measured outside Wilson County in adjacent parts of Elk, Greenwood, and Woodson Counties are not shown on the location map and are not included in these data.)
State Geological Survey of Kansas

T. 29 S., R. 13 E., County Wilson

Sec. 11-12

Locality description: Road cut in north-south road on line between Sections 11 and 12. Section is from top of hill to south post of gate in fence (which is .75 Measured by Holly C. Wagner Date 8/8/50 (Cont'd)

Remarks: Measured with hand level, and 6' steel tape.

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ss., fn., gr., tan to buff with limonite spots, massive, top not present</td>
<td>2'6&quot;</td>
</tr>
<tr>
<td>2</td>
<td>Ss., shaly, or Sh, sandy, reddish at base becoming tan or gray upwards, poorly exposed. Grades downward into</td>
<td>40'</td>
</tr>
<tr>
<td>3</td>
<td>Sh., light gray, slightly silty, minutely broken, several well-defined ironstone concretionary beds in the central ten feet. Thin concretionary beds at base also.</td>
<td>46'</td>
</tr>
<tr>
<td>4</td>
<td>Ls., grayish to tan, many sinuous-shaped bodies, uneven bedded, blotched appearance pronounced.</td>
<td>2'8&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Cls., slightly shaly, gray, very slightly silty, upper 6&quot; is made up almost entirely of shell fragments including myalinus, crinoid stems, bryozoans, etc.</td>
<td>2'9&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Ss., fn. gr., gray, streaked with brown</td>
<td>1'10&quot;</td>
</tr>
<tr>
<td>7</td>
<td>Cls. silty brown</td>
<td>0'6&quot;</td>
</tr>
<tr>
<td>8</td>
<td>Cls. carbonaceous, black</td>
<td>0'1/2&quot;</td>
</tr>
<tr>
<td>9</td>
<td>Cls. gray silty</td>
<td>0'2&quot;</td>
</tr>
<tr>
<td>10</td>
<td>Ls., chocolate brown, highly jointed, brown weathering made up almost entirely of small (1/8&quot;&quot;) oval to round bodies with dark centers (Osage algae), many shell fragments</td>
<td>1'3&quot;</td>
</tr>
<tr>
<td>11</td>
<td>Cls., slightly sandy, conglomeratic or fragmental consisting almost entirely of fragments of reworked limestone in a clayey matrix. Fragments from 1/16&quot; to 1&quot; in size.</td>
<td>1'8&quot;</td>
</tr>
<tr>
<td>12</td>
<td>Ls., sandy, impure, contains sandstone concretionary masses, also many fossils (fanestellate bryozoa, algal masses, brachiopods?), color grayish tan to chocolate brown.</td>
<td>1'10&quot;</td>
</tr>
<tr>
<td>13</td>
<td>Ss., limy, brown to gray, fn. gr., massive</td>
<td>0'1/2&quot;</td>
</tr>
<tr>
<td>14</td>
<td>Ss., fn. gr., very thin bdd, gray, micaceous, some concretionary zones in upper half. Ripple marked.</td>
<td>7'0&quot;</td>
</tr>
<tr>
<td>15</td>
<td>Ss., massive, jumbled bedding, lenticular, micaceous, light gray, brown weathering. 0&quot; to</td>
<td>7'0&quot;</td>
</tr>
<tr>
<td>16</td>
<td>Ss, finely banded, thin to medium bdd, micaceous, fn. gr. gray to light brown, many ironstone concretions in upper 12 inches.</td>
<td>3'0&quot;</td>
</tr>
</tbody>
</table>

(Cont'd)

772
State Geological Survey of Kansas

T. 29 S., R. 13 E., County Wilson

Sec. 11-12

Locality description: miles south of center of bridge

Measured by: Holly C. Wagner

Date: August 8, 1950

Remarks

Bed No. | Description                                                                 | Thickness |
--------|------------------------------------------------------------------------------|-----------|
17      | Sa. massive, ripple-marked, tan, fn. gr., dense, micaceous                  | 1' 0"     |
18      | Sa. gray, massive, fn. gr., lenticular (lensing north) contains pebbles of thin-bedded sandstone (many with contorted bedding suggesting unconsolidated condition at time of incorporation in the sandstone.) | 0" to 2' 6" |
19      | S1a. slightly sandy, very thin-bdd, gray, iron stained, micaceous, with 1" ironstone beds in lower foot and upper 2 ft. | 9' 6"     |
20      | Sa. ripple-marked, fn. gr., medium bedded, highly contorted, probably due to submarine slumping prior to consolidation. | 2' 0"     |
21      | Sa. fn. gr., thin bdd, gray, micaceous, ripple-marked. Brown-weathering, plant fragments. Base not exposed. | 12' 8"    |

(END OF SECTION)
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ls, dense, hard, dark gray, very fossiliferous to blotchy gray and orange color in many places. Two very pronounced joint systems nearly at right angles (N30E and N35W) and vertical. Top not distinctly exposed.</td>
<td>1'3&quot;</td>
</tr>
<tr>
<td>2</td>
<td>Shale, gray to tan, limy</td>
<td>0'2&quot;</td>
</tr>
<tr>
<td>3</td>
<td>Ls, dense, hard, dark gray, very fossiliferous. contains many &quot;Ottontosia&quot;.</td>
<td>0'5&quot;</td>
</tr>
<tr>
<td>4</td>
<td>Shale, dark gray, clayey, breaks into fine fragments. Upper 8&quot; are highly fossiliferous.</td>
<td>4'9&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Ls, chocolate brown, massive, made up largely of Osagia algae.</td>
<td>2'8&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Ss, fn. gr., gray, weathers tan to orange in color. Base not exposed</td>
<td>4'4&quot;</td>
</tr>
</tbody>
</table>
### Bed No. Description

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ls, dense, brownish gray on fresh surface, mottled gray and orange on weathered surface. Highly fossiliferous, mostly brachiopods and crinoid stems. Top not present.</td>
<td>2&quot;</td>
</tr>
<tr>
<td>2</td>
<td>Ls, poorly cemented, made up almost entirely of fusulinids. Probably both overlain and underlain by about 1 inch of clay shale</td>
<td>0'2&quot;</td>
</tr>
<tr>
<td>3</td>
<td>Ls, hard, wavy bedded, weathers to a smooth (relatively) surface, light gray, slightly mottled with orange, highly fossiliferous, brachiopods and crinoid stems predominate in upper part. Fusulinids mainly in lower part.</td>
<td>0'9&quot;</td>
</tr>
<tr>
<td>4</td>
<td>Ls, and shale, alternating in about 1&quot; beds, wavy bedded, full of fusulinids which weather out prominently, also some crinoid stems and brachiopods.</td>
<td>0'8&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Ls, massive, light gray, weathers yellowish, full of fusulinids, fairly well bedded.</td>
<td>0'5&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Sh, limy, full of fusulinids and cemented blebs of fusulinids, yellowish gray.</td>
<td>0'4&quot;</td>
</tr>
<tr>
<td>7</td>
<td>Ls, clayey, yellowish, full of fusulinids.</td>
<td>0'4&quot;</td>
</tr>
<tr>
<td>8</td>
<td>Sh, friable, many fossils, mostly fusulinids, light gray with much iron staining.</td>
<td>2'2&quot;</td>
</tr>
<tr>
<td>9</td>
<td>Coal, black, varies laterally (in 15 feet) from 3 inches thick to a series of lenses that pinch in between and are only about ½ inch thick.</td>
<td>0'3&quot;</td>
</tr>
<tr>
<td>10</td>
<td>Shale or limestone, purplish-blue color, unfossiliferous?</td>
<td>0'8&quot;</td>
</tr>
<tr>
<td>11</td>
<td>Sh, slightly sandy, gray to tan, base not exposed.</td>
<td>6'4&quot;</td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>Limestone. Top not exposed, light tannish gray color, gray</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>dense, many fusulinids, very bedded in beds about 1 inch thick.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>thickened by 1&quot; clay intervals filled with fusulinids.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Clay, gray to buff, highly fossiliferous.</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>Coal</td>
<td>0.1</td>
</tr>
<tr>
<td>4</td>
<td>Clay/Coal. Blue, gray.</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td>Covered interval but float suggests that it is dominantly clay shale, tan</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>colored at top but coming red at base.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Sandstone. Fine grain. Pea green. Calcarious.</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>Shale. Maroon and gray in color. Blotted.</td>
<td>4.0</td>
</tr>
<tr>
<td>8</td>
<td>Sandstone. Fine grained. Yellow green, thin bedded, calc.</td>
<td>0.7</td>
</tr>
<tr>
<td>9</td>
<td>Shale. Maroon and gray colored, blotted.</td>
<td>6.6</td>
</tr>
<tr>
<td>10</td>
<td>Limestone. Light gray to mottled tan color. Highly fossiliferous.</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Many of these. Many brachiopods.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>In general it appears to be thin bedded, but poorly bedded.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The beds are 1/2 to 1&quot; thick and break down into plates which strew the ground.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poorly exposed. The thickness given is approximate.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Covered interval but apparently is shale, gray</td>
<td>3.0</td>
</tr>
<tr>
<td>12</td>
<td>Sandstone. Massive, tan with orange dots.</td>
<td>0.3</td>
</tr>
<tr>
<td>13</td>
<td>Sandstone. Thin bedded, breaks into 1/2 to 1&quot; fragments</td>
<td>3.0</td>
</tr>
<tr>
<td>15</td>
<td>Sandstone. Thin bedded. Breaks down into small fragments.</td>
<td>1.5</td>
</tr>
<tr>
<td>16</td>
<td>Shale. Gray, clay.</td>
<td>3.5</td>
</tr>
<tr>
<td>17</td>
<td>Sandstone, massive, hard, base not exposed lt, tan color.</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Fine grained.</td>
<td></td>
</tr>
</tbody>
</table>
**Locality description**: In stream bed. Very good exposure of Haskell and Vinland.

**Remarks**: Ls., dark gray, dense, moderately fossiliferous, containing mainly crinoid stems and a few brachiopods and Ottonosia. Weathers dark gray with brownish cast. Distinct vertical jointing. 1.0"

**Measured by**: Holly C. Wagner

**Date**: Oct. 6, 1950

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ls., dark gray, dense, moderately fossiliferous, containing mainly crinoid stems and a few brachiopods and Ottonosia. Weathers dark gray with brownish cast. Distinct vertical jointing. 1.0&quot;</td>
</tr>
<tr>
<td>2</td>
<td>Ls., dark gray, thinly laminated, highly fossiliferous, rather granular, poorly bedded. 0.2&quot;</td>
</tr>
<tr>
<td>3</td>
<td>Claystone, very slightly silty, apparently unfossiliferous, dark gray, weathers light gray, poorly bedded 5:11&quot;</td>
</tr>
<tr>
<td>4</td>
<td>Ls., dense, flaggy, brown to gray, poorly bedded. Osaga algae present but not abundant, base not exposed. 2&quot;</td>
</tr>
</tbody>
</table>

**Thickness**

- 1.0"
- 0.2"
- 5:11"
- 2"
Bed No. | Description |
--- | --- |
| | Ireland SS channels down into Hopkins shale cutting out all but 3 and 1/2 feet of it. It comes down to within 2 and 1/2 feet of the Haskell Is., which is 2 and 1/2 feet thick at this point and only 2 feet thick 1000 feet SE. The Ireland is very strong and massive at this point and is a single bed 104 feet thick (maybe) Half of the SS slump block. |
State Geological Survey of Kansas

T. 27 S., R. 13 E. County Wilson

Sec. 2
Locality description: Section starts at the top of a gully just south of a tree (at head of gully) at or very near the top of the Toronto Ls., and proceeds downhill.

Measured by Holly C. Wagner
Date Oct. 17, 1950

Remarks: through the Lawrence shale. Hand leveled in flat stream bed - Probably inaccurate ± 1 foot.

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>La., light gray with tan to orange streaks, hard, dense but with some coarsely crystalline areas, highly fossiliferous made up mostly of crinoid stems and fragments with a few, very few, brach. remains.</td>
<td>0'10&quot;</td>
</tr>
<tr>
<td>2</td>
<td>La., light gray with tan to orange streaks, hard, dense, but with some coarsely crystalline areas, highly fossiliferous made of brachiopod (or mollusc?) remains with crinoid stems subordinate. Some &quot;swirly&quot; masses like ottonosis.</td>
<td>0'7&quot;</td>
</tr>
<tr>
<td>3</td>
<td>La., light gray, hard, dense, highly fossiliferous, with well preserved brachiopods and fusulinids abundant. Also, some molluscs(?) and crinoid stems. Weathers light gray with a very rough, hollowed and pitted surface.</td>
<td>0'8&quot;</td>
</tr>
<tr>
<td>4</td>
<td>La. dark dirty gray, dense, highly fossiliferous with well preserved brachiopods and fusulinids and crinoid stems and gastropods. Weathers tan to orange with a very rough, hollowed and pitted surface. Has several thin, interbedded clayey layers from which fossils weather out completely.</td>
<td>0'10&quot;</td>
</tr>
<tr>
<td>5</td>
<td>Sh. light gray to tan, clayey, filled with fossils mainly brachiopods and fusulinids which weather out beautifully. Some ½&quot; limestone beds included.</td>
<td>1'4&quot;</td>
</tr>
<tr>
<td>6</td>
<td>Sh. dark tan, highly fossiliferous in upper 3&quot;, unfossiliferous in lower part</td>
<td>1'0&quot;</td>
</tr>
<tr>
<td>7</td>
<td>Coal, black</td>
<td>0'4&quot;</td>
</tr>
<tr>
<td>8</td>
<td>Clst, bluish gray, sticky, unfossiliferous</td>
<td>1'0&quot;</td>
</tr>
<tr>
<td>9</td>
<td>Sh. tan with large reddish areas in it, unfossiliferous with variable zones of white and red limy concretions ranging in size from 1/8&quot; to 6&quot;, also 2' zone of small, well-formed crystals of calcite or gypsum occurs from 4 to 6' below top.</td>
<td>8'0&quot;</td>
</tr>
<tr>
<td>10</td>
<td>Sh. maroon with many 6&quot; limy concretions at top</td>
<td>5'2&quot;</td>
</tr>
<tr>
<td>11</td>
<td>Sh. light tan, sandy, somewhat limy with 2&quot; sandstone lenses near top</td>
<td>2'7&quot;</td>
</tr>
<tr>
<td>12</td>
<td>Ss. limy almost a limestone, micaceous or sericitic, many worm tracks, ripple-marked, greenish gray color on fresh surface (Cont'd.)</td>
<td>2'4&quot;</td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>1</td>
<td>Gray, light gray with greenish cast, friable, with several 1-2&quot; slightly limy sandstone beds in upper part.</td>
<td>6'0&quot;</td>
</tr>
<tr>
<td>14</td>
<td>Limestone concretionary zone, brownish red color</td>
<td>0'4&quot;</td>
</tr>
<tr>
<td>15</td>
<td>Sh, sandy, interbedded tan and gray layers 1/4&quot; thick</td>
<td>3'2&quot;</td>
</tr>
<tr>
<td>16</td>
<td>Ss, limy at very top, very fine-grained, composed entirely of fairlly well-rounded quartz grains, gray, well-sorted, speckled with limonite blebs, calcareous cement in upper 6&quot; only. Slightly disconformable on underlying shale. Weathers dark tan, many worm casts, ripple marked</td>
<td>3'5&quot;</td>
</tr>
<tr>
<td>17</td>
<td>Sh, sandy, gray to orange due to iron staining</td>
<td>9'0&quot;</td>
</tr>
<tr>
<td>18</td>
<td>Ss, dark orange color due to much iron oxide in blebs</td>
<td>0'8&quot;</td>
</tr>
<tr>
<td>19</td>
<td>Sh, gray to tan, very sandy</td>
<td>6'0&quot;</td>
</tr>
<tr>
<td>20</td>
<td>Ss, gray, some ironstaining but not in blebs, more like streaks, very fine-grained, well sorted quartz, weathers light-brownish-gray</td>
<td>6'0&quot;</td>
</tr>
<tr>
<td>21</td>
<td>Sh, light gray to dark tan, sandy</td>
<td>4'2&quot;</td>
</tr>
<tr>
<td>22</td>
<td>Ss, grayish tan, micaceous, slightly cross-bedded, very, very fine grained, quartz grains, well-rounded, no limonite streaks or blebs</td>
<td>8'7&quot;</td>
</tr>
<tr>
<td>23</td>
<td>Sh, sandy, light gray to tan, many brown to reddish ironstone concretions.</td>
<td>3'8&quot;</td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>Sandstone, very fine grained, between 10R6/6 and 10YR6/6 almost entirely quartz grains, spotted with dark brown blebs, probably iron oxide.</td>
<td>10.0</td>
</tr>
<tr>
<td>2</td>
<td>Covered interval-undoubtedly underlain by Robbins shale and Robbins shale only; concentration of SS float 75' above base 120.0 suggests sandstone bed near this point. SS is between 10R6/6 and 10YR6/6 in color, very fine grained, almost entirely fairly well rounded quartz grains.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Limestone, dark gray N3, dense, hard with many &quot;Oottonisia&quot; and shell fragments, also crinoid stems; this may or may not be in place. On weathered surface it is colored 10TR5/4 often weathers as one solid 1'1 slab.</td>
<td>1.3</td>
</tr>
<tr>
<td>4</td>
<td>Covered interval, what appears to be good exposure of shale, yellowish gray (5Y6/2 to 5Y6/4) in the central 3', Unfossiliferous where exposed; float suggests that there is a SS bed in the upper 5' of the covered interval.</td>
<td>12.3</td>
</tr>
<tr>
<td>5</td>
<td>Limestone, dark gray, N5 with a slight reddish cast, streaked 1.3 with chocolate brown, thin bedded, composed largely of fragments of brownish tan to reddish brown shale fragments (calcareous). Someosagia algal in the matrix. Thin layers composed almost entirely of brachiopod shells are found throughout. Also some ironstone concretionary bodies. Top not exposed.</td>
<td>1.3</td>
</tr>
<tr>
<td>6</td>
<td>Limestone, SYR4/1 (brownish gray to SR5/2 (grayish red)) consists almost entirely of shell fragments of brachiopods with some crinoid stems, fusulinids, rhomboporate bryozoans and shale fragments.</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>Limestone, Chocolate brown. (SYR4/4) dense, crystalline, consisting of fragments of tan shale, coal, and brachiopods shells in a crystalline dense matrix containing a few osagia algal and fusulinids which are abundant in the middle 1&quot;, crinoid stems and rhomboporate bryozoans are present.</td>
<td>2.0</td>
</tr>
<tr>
<td>8</td>
<td>Sandstone, very fine grained, clayey at top, almost white with sorted quartz grains, limonite streaked.</td>
<td>2.4</td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>Sandstone, massive, fine grained, almost entirely angular to sub-rounded</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Sub-angular quartz grains, limonite blebs throughout, cross bedded</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ripples marked, weathers with cupped appearance in many places. Massive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forms cliff 8' high above hill. Top of hill has 10YR 4/4 in upper half,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower half iron stained</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shale, silt, interbedded 5Y 4/2 and 10YR 6/4, the 10YR 6/4</td>
<td>17.3</td>
</tr>
<tr>
<td></td>
<td>Being most common</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Sandstone, very fine grained, very slightly silt size,</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>10YR 6/4, micaceous</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Shale, 5Y 4/2, very slightly silty, fissile</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>Sandstone, 10YR 6/4, thin bedded, very fine grained, massive</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Carbonaceous layers interlaminated</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Shale, 5Y 5/2, and 10YR 6/4 mottled, very slightly silty,</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Fissile</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Covered interval, almost certainly same shale as below and above it</td>
<td>5.1</td>
</tr>
<tr>
<td>8</td>
<td>Shale, tannish 10YR 5/4, clay, slightly silty with much gray</td>
<td>17.2</td>
</tr>
<tr>
<td></td>
<td>5Y 5/4 shale interbedded</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Shale, gray 5Y 5/4, clay, very, very slightly silty, Fissile</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>Breaks down into very thin plates which break into about 1/4' rhombs.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Has two massive beds that weather out as ledges, one at the top and the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>other 11 and 1/2 feet below the top</td>
<td></td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

T. 29 S., R. 14 E. County Wilson, Frandia, Kansas

Locality description: Captain creek- north 1/2 Sec. 24

Measured by: H. C. Wagner  Date 11/5/30

Remarks

Bed No. Description Thickness

1. Limestone, sandy (chemical analysis showed 37% silica) 9.0
   very fossiliferous, cross bedded in part, generally
   relatively thin bedded, color on fresh surface is between
   10YR8/3 and 10YR7/4. Weathers to a pitted irregular surface
   colored between 10YR4/2 and 10YR5/4. Fossils weather out in
   relief and consist of crinoid stems, gastropods, echinoderms
   brachiopods. The sand grains are almost pure white quartz,
   fine grained, sub-angular, with a few black chert pebbles and
   grains. A one inch thick bed occurs about 3.5' from the top.
   At about 1.5' above base is a zone or bed containing many
   ironstone fillings of small dolomite cavities and concretionary
   masses. In places, the bed is no more than a sandstone. Does not react to HCL. In lower part color is
   10YR6/2.

2. Limestone, massive, dense, hard, highly fossiliferous, often 2.5
   breaks to sheer face and fossils show as lines on face.
   Color N-7

3. Shale, highly fossiliferous, grades laterally into immature 0.2
   limestone. 10YR6/4, clay, no silt.

4. Limestone, massive, dense, hard, highly fossiliferous N-7 4.2
   Shale, N6, clayey, no silt, highly fossiliferous, crinoid
   stems, brachiopods, echinoderms, etc.

5. Limestone, massive, could be considered as a single massive bed, 17.0
   highly fossiliferous throughout. Fossils can be seen best on
   weathered surface. They are difficult to see in fresh surface.
   Color varies from 10YR6/2 at top to 7/7 in middle and bottom.
   Upper orange cast is due to iron staining. Tape unexposed.
   Drill operator says that they went down 100' deeper and were still
   in lime all the way.
Limestone, N8, very light gray, very fossiliferous including
- crinoidal stems, brachiopods,
- calcite (2), becomes quite clayey upwards and has a few thin
- clay lenses in the central 2'. Upper 5-7' (varies along
- the exposure) are relatively massive but wavy bedded, the beds
- (0.5-1.0' thick) are separated by thin 0.1' beds of
- fossiliferous shale. The upper part has many crinoid heads well
- exposed by weathering. The upper 5-7' are more ferruginous
- and weathers brownish. It is overlain by a few inches of
- chert gravel.

At the east end of the quarry another 1.5' of Is
- overlies this limestone. It is wavy bedded also and is
- overlain by about 2.5' of red sandy clay which has chert
- pebbles in the top.
Locality description:
Along road on line between section 11 and 14.

Measured by: H. C. Magner, Date: 11/9/50

Remarks:
Starting at top of hill and working down. Jacob Staff

Bed No. | Description | Thickness
--- | --- | ---
1 | Sandstone, 10YR5/4, very fine-grained, quartz grains, well sorted, subangular | 6.5
2 | Shale, 5Y6/1, light olive gray, clay, very slightly silt, moderately silt, very sandy in upper foot, many ironstone concretions | 39.0
3 | Sandstone, presence based on float, 10YR5/4, with limonite blebs, well sorted quartz grains, subangular, very fine grained | 1.0
4 | Shale 5Y6/1, clayey, many small ironstone concretions | 44.0
5 | Limestone, medium light gray #6, weathers to a darker gray, mottled with orange. Contains many brachiopods and Atonosia fossils, poorly exposed | 3.0
6 | Covered interval. Undoubtedly shale | 4.0
7 | Limestone, 10YR6/4, unfossiliferous and sandy at the base, becoming fossiliferous upwards, mostly Osagia algal, has a pebble-like zone in the middle | 5.4
8 | Siltstone, 5G6/1, ripple marked, shaly at the top, more massive below. Concretionary zone occurs about 7.5' below the top. Iron stained in layers, otherwise nearly white. Highly micaceous | 8.0
State Geological Survey of Kansas

Locality description: Section from watermost SS road north inaviors

Albany, north and east through the Toncanoxie SS to the
Haskell La.

Measured by: H. C. Wagner

Date: 11/10/50

Remarks

Bed No. Description Thickness

1. 2 S, hard, dense, many brachiopods(?), fossils and ottoniosia. Fresh surface 5YR5/6.

2. Covered interval. Float suggests a light greenish-gray clayey, somewhat silty.


4. Siltstone, thin bedded, same as one at base of L3, but thin 34.2 bedded and shaly. Micaceous, Ls interbedded with silty claysilts. Common. In places is very well bedded, thin bedded, almost like varved clays. Has a few ironstone concretionary beds about 20' below the top. A 3' good clay bed comes in about 4' below the ironstone concretions.

5. SS, hard, well sorted, subangular quartz grains, limonite stained, well bedded, 10YR6/6 blebs, very fine grained.

6. Siltstone, medium bedded, micaceous, poorly exposed 16.0

7. SS, prominent ripple marks, 10YR6/6, very round, some 3.4 limonite blebs, well sorted subangular quartz grains.

8. Siltstone, clayey, 10YR6/2 (yellowish brown) thin bedded, ripple marked.

9. Shale, blue, clayey (owner's data) about well. 81.0

Bed No.

3

4

5

6

7

8

9

Section starts on line with front doors of northermost two houses and goes northward. The owner of the east house reports that he had a well drilled just in back of his house 36' deep which was in blue shale after the first few feet. No water. He later dug a cistern over the well. He went through 2' of soil and then 3' of sandstone and 15' of blue shale. The cistern is 16' deep. Just south of the house another well went through about 4' of soil and 15' of SS and gravel before hitting the blue shale.

Hand leveled to top of hill and measured section and described going down —top of hill—top of Ls not here.

1. Ls, hard, dense, many brachiopods(?), fossils and ottoniosia. Fresh surface 5YR5/6.

2. Covered interval. Float suggests a light greenish-gray clayey, somewhat silty.


4. Siltstone, thin bedded, same as one at base of L3, but thin 34.2 bedded and shaly. Micaceous, Ls interbedded with silty claysilts. Common. In places is very well bedded, thin bedded, almost like varved clays. Has a few ironstone concretionary beds about 20' below the top. A 3' good clay bed comes in about 4' below the ironstone concretions.

5. SS, hard, well sorted, subangular quartz grains, limonite stained, well bedded, 10YR6/6 blebs, very fine grained.

6. Siltstone, medium bedded, micaceous, poorly exposed 16.0

7. SS, prominent ripple marks, 10YR6/6, very round, some 3.4 limonite blebs, well sorted subangular quartz grains.

8. Siltstone, clayey, 10YR6/2 (yellowish brown) thin bedded, ripple marked.

9. Shale, blue, clayey (owner's data) about well. 81.0

786
### Bed No. | Description | Thickness
--- | --- | ---
1 | Ls. N4, medium dark gray, poorly exposed except as float but 1.8 has limonite stained layer at top (about 1\(^\text{"}\) thick) and below that is uniformly N4 with many small fossil remains in a dense fine crystalline matrix. Some oval shaped ottenesia bodies. Breaks into rectangular blocks due to a vertical joint system and homogeneous nature. May be underlain by an oolitic layer that is highly fossiliferous and full of brachiopods. | 6.0
2 | Covered interval, probably maroon shales such as those next described. | 6.0
3 | Claystone, slightly silty, dark reddish brown, 10R3/4 with 20.0 mottled areas of light bluish gray claystone (not in beds) Upper part is filled with irregularly shaped limestone concretions which may be brown, red green, or white (or any combination of those colors) when broken open. | 20.0
4 | Siltstone. 5GY8/1, light greenish gray, micaceous, not calcareous, thin bedded and shaly except for a 0.6\(^\text{"}\) hard massive bed near the center. | 5.0
5 | Claystone, pure, dark reddish brown 10R3/4 somewhat mottled at the top. Has limy concretionary zone at base and grades into underlying claystone. | 8.0
6 | Claystone, slightly silty, very variable color ranging from dark reddish brown to light yellowish gray, with combinations of both together and large areas of mottled appearance. In general the color is greenish gray in the upper 2\(^\text{"}\) and reddish brown in the lower part. Has many limy nodules in the upper 2\(^\text{"}\). The lower 6\(^\text{"}\) is poorly exposed but looks like clayshale all the way. | 12.0
7 | Limestone, very highly fossiliferous mostly crinoid stems with a few brachiopods and corals. Weathers to a mottled appearance with 10YR8/2 predominant, the smaller areas being 10YR6/2 (dark yellowish?). Fresh surfaces is medium light gray, N6. Brachiopods becomes more prominent in lower parts. | 1.7
8 | Shale with a few limy beds included, very high fossiliferous with many brachiopods and fusulinids, some bryo.oa, pelecypods, and crinoid stems. Medium light gray color, N6. | 3.0
9 | Coal beds-black coal, weathered | 0.2
10 | Claystone, medium light gray N5 with slight bluish cast and light brown mottlings | 0.2
### State Geological Survey of Kansas

#### Locality description

<table>
<thead>
<tr>
<th>Sec.</th>
<th>County</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measured by</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Bed No. | Description | Thickness |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Claystone, very slightly silty, micaceous, pale olive</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>10Y6/2 grading downward into---</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Claystone, very slightly silty, moderate reddish orange</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>10R6/6 has many teardrop shaped calcareous concretions, septaria like in part, in the upper few feet.</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Siltstone, relatively massive at top becoming more and more shaly downward until the lower 3' becomes a silty claystone and shale. Dusky yellow 5Y6/4 color</td>
<td>9.0</td>
</tr>
<tr>
<td>14</td>
<td>Covered interval.</td>
<td>3.0</td>
</tr>
<tr>
<td>15</td>
<td>Sandstone, yellowish gray 5Y7/2 very fine grained, ripple marked, well sorted subangular quartz grains. Has well developed joint system, vertical, strikes N40E.</td>
<td>3.4</td>
</tr>
<tr>
<td>16</td>
<td>Covered interval</td>
<td>3.0</td>
</tr>
<tr>
<td>17</td>
<td>Sandstone, color 10YR7/2, very pale yellowish brown, dotted with orange and brownish blebs of limonite, very fine grained, well sorted subangular quartz grains. Some black grains also</td>
<td>3.4</td>
</tr>
</tbody>
</table>

---

788
**State Geological Survey of Kansas**

**T. 29 S., R. 14 E., County Wilson**

<table>
<thead>
<tr>
<th>Sec. 11</th>
<th>Locality description</th>
<th>Measured by</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>West Hound at Fredonia N side Weston shale</td>
<td>H. C. Wagner</td>
<td></td>
</tr>
</tbody>
</table>

### Bed Description

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sandstone, massive, cross bedded in part, well bedded in part, grayish orange 10YR7/2, medium grained, well sorted, subangular sand grains. Spotted with dark limonite blebs.</td>
<td>27.0</td>
</tr>
<tr>
<td>2</td>
<td>Sandstone, hard, massive, but is full of small fragments of ironstones, most of which are 1/8-1/4&quot; in diameter. Those in the soft matrix below are up to 3&quot; in diameter.</td>
<td>2.3</td>
</tr>
<tr>
<td>3</td>
<td>Breccia, poorly cemented, composed of tan shale and reddish ironstone concretions, with a light greenish powder on the surface of the matrix. This zone is 2-5&quot; thick.</td>
<td>0.2</td>
</tr>
<tr>
<td>4</td>
<td>Sandstone, poorly cemented, very fine grained, cross bedded, thin bedded, micaceous, colored from light yellowish brown 10YR6/4 to light grayish orange 10YR8/4, grains are fairly well sorted subangular and mostly quartz, if not all quartz, a few limonite blebs.</td>
<td>2.7</td>
</tr>
<tr>
<td>5</td>
<td>Siltstone, carbonaceous, with two well defined but wavey streaks of coaly matter 1/8-1/4&quot; thick at the center, silt is micaceous and sandy, thin bedded.</td>
<td>0.3</td>
</tr>
<tr>
<td>6</td>
<td>Sandstone, hard, very pale orange 10YR8/2, many limonite blebs, very micaceous, very fine grained, well sorted quartz grains, angular to subangular.</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>Siltstone, thin bedded, sandy, micaceous, with a few thin ss beds in it</td>
<td>1.0</td>
</tr>
<tr>
<td>8</td>
<td>Covered interval, probably silty shale</td>
<td>27.5</td>
</tr>
<tr>
<td>9</td>
<td>Shale, buff colored, slightly, silty with a few thin ss beds; sandstone beds are about 1/8&quot; thick and between 10YR8/2 and 10YR7/4 in color, pale orange shale, shales fresh is 5YR5/2, light olive-gray.</td>
<td>12.0</td>
</tr>
<tr>
<td>10</td>
<td>Shale, gray at base but becoming more buff colored upwards. Measured alone slope of cliff with 100' tape. Measured 75', angle 50 degrees.</td>
<td>63.0</td>
</tr>
<tr>
<td>11</td>
<td>Shale, same, Jacob staffed to base of cliff of old quarry.</td>
<td>11.7</td>
</tr>
<tr>
<td>12</td>
<td>Shale, blue gray, measured vertically where they are actually 30.0 cutting for brick plant.</td>
<td>30.0</td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>Limestone, Sandy, tuffaceous with many fusulinids, sandy, sandstone</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>with some fusulinids present; some have a sl. fossiliferous</td>
<td></td>
</tr>
<tr>
<td></td>
<td>part of bed is brown. Color very light brown.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shale, medium olive gray 5Y5/1, alluvial, with several 5Y3/1</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>thin clay and concretionary beds, has two thicker clay</td>
<td></td>
</tr>
<tr>
<td></td>
<td>concretionary beds 5' and 8' below the top of the hill</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(the Central Creek rises at the hill) Concretionary beds weathered to brown.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A 0.4' dark layer that is full of fusulinids and brachiopods and crinoid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>stems occurs 8' below the top of the hill.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Covered interval.</td>
<td>25.0</td>
</tr>
<tr>
<td>4</td>
<td>Limestone, Wavy banded, quite clayey at base and</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>fossiliferous. Fresh surface is between very light brownish</td>
<td></td>
</tr>
<tr>
<td></td>
<td>gray 5Y3/1 and light gray 7/7. Fossils are mainly brachiopods</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle and upper parts poorly exposed.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Shale, largely covered, but grayish black 2. Very pure clay</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>Fissile at base and light olive gray 5Y5/2 at the top.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper 0.5' is highly fossiliferous and calcareous.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Limestone, Hard, dense, vertical jointing, mod. dark gray 7/4</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>With a 0.5' fossiliferous zone at base which is fragmentary</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shells of brachiopods mainly and oolitic. Very good fossil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>collecting, shaly in upper part.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Shale, Greenish gray.</td>
<td>5.0</td>
</tr>
<tr>
<td>8</td>
<td>Shale, maroon.</td>
<td>6.0</td>
</tr>
<tr>
<td>9</td>
<td>Siltstone, micaceous, slightly calcareous, light greenish</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Gray 5Y3/1, hard.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Shale, Silty, Greenish gray and maroon, maroon predominates</td>
<td>2.2</td>
</tr>
<tr>
<td>11</td>
<td>Siltstone, Massive at base, shaly in most of it. Greenish, 6/8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gray.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Shale, Olive gray, very slightly silty.</td>
<td>0.5</td>
</tr>
<tr>
<td>13</td>
<td>Shale, maroon.</td>
<td>7.1</td>
</tr>
<tr>
<td>14</td>
<td>Shale, Greenish gray and maroon, Blotted.</td>
<td>2.0</td>
</tr>
<tr>
<td>15</td>
<td>Shale, Greenish gray.</td>
<td>2.0</td>
</tr>
<tr>
<td>16</td>
<td>Siltstone, Pink marlred, thin but massive, micaceous, welloid gray 2/2.</td>
<td>0.4</td>
</tr>
<tr>
<td>17</td>
<td>Shale, Greenish gray with 1/2-1&quot; concretion up to 3' from base.</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Silty.</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Siltstone, Yellow gray, 2/2, micaceous.</td>
<td>0.2</td>
</tr>
<tr>
<td>19</td>
<td>Shale, Gray, with ironstone (calcicoreous) concretion zone</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>At top, concretions up to 3' in dia.</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Shale, maroon.</td>
<td>1.5</td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>Siltstone, slightly calcareous, yellowish gray 5Y7/2, has 1.5\textsuperscript{1} shaly zone with limy ironstone concretions at the base, and very poorly banded.</td>
<td>1.5\textsuperscript{1}</td>
</tr>
<tr>
<td>2</td>
<td>Shale, ray and carbon, blottish, slightly silty.</td>
<td>2.4</td>
</tr>
<tr>
<td>3</td>
<td>Covered interval.</td>
<td>6.7</td>
</tr>
</tbody>
</table>
### Sec. 22 Locality Description

Along new 1-8 road about 1/3 mile east of Greenwood–Wilson county line.

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Covered to top of hill.</td>
<td>2.0</td>
</tr>
<tr>
<td>2</td>
<td>Limestone, light gray, very thin, dark bedded, white fossiliferous, weathers to a blotted orange and creamy tan color. Fossils are largely brachiopods and crinoids, present, also.</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>Shale, dark gray to hard, fissile at base, light olive gray and very fossiliferous in the upper part. Middle poorly exposed.</td>
<td>6.0</td>
</tr>
<tr>
<td>4</td>
<td>Limestone, hard, dense, dark gray, with a 0.3' oolitic or algal fossiliferous bed at the base. Vertical jointing.</td>
<td>1.7</td>
</tr>
<tr>
<td>5</td>
<td>Covered interval. The material on the hill slope has floated and slumped so badly that no bedrock is exposed. This covered interval appears to be mostly gray and maroon siltstone and shale with three (?) harder beds. The thickest bed is about 40' above the top of the Toronto and is about 8&quot; thick.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Limestone, hard, flinty, medium bedded, light gray N7, dense fossiliferous, with many wavy darker zones more or less parallel with the bedding. Becomes thinner bedded and darker colored at the top.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Limestone, very fossiliferous, clay, with three prominent fossiliferous claystone beds (1/2-1&quot;) interbedded. Fossils mainly fusulinids and brachiopods light gray N7 on fresh surface, yellowish gray and blotty on weathered surface.</td>
<td>0.9</td>
</tr>
<tr>
<td>8</td>
<td>Shale, very fossiliferous, full of fusulinids, brachiopods, and rhombohedral brachiopods; has a few limy zones in it. Color light olive gray 5G2/1.</td>
<td>1.6</td>
</tr>
<tr>
<td>9</td>
<td>Coal, black to dark brownish gray.</td>
<td>0.3</td>
</tr>
<tr>
<td>10</td>
<td>Shale, pure clay, light gray 5Y5/1 to dusky blue 5PB2/2 in color. Unfossiliferous.</td>
<td>0.4</td>
</tr>
<tr>
<td>11</td>
<td>Shale, clay, slightly silty, olive gray 5Y4/2, many 1/4&quot; limestone concretions in the lower part intermixed with a few pelletal ironstone concretions which are larger 1/2-1&quot;. Lowermost part is a zone of mottled color of dark reddish brown and olive gray.</td>
<td>3.8</td>
</tr>
<tr>
<td>12</td>
<td>Shale, clay, slightly silty, dark reddish brown, 10YR/4. A few pelletal ironstone concretions, oddly shaped, in the upper part.</td>
<td>6.0</td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

Locality description: Section measured upstream from junction of two branches of stream to S-1 road to Schuppman farm house.

Measured by H. C. Jasper

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sandstone, soft and shaly apparently, poorly exposed cut</td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>forms low gradient slope to top of hill.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Sandstone, cross bedded, medium grained, well sorted sub-rounded quartz grains, size of grains quite constant throughout. Has 6&quot; zone of ironstone concretions (may be fossiliferous) about 10'? above the base. Color is quite variable, but in general becomes slightly darker upwards although at bottom and for the first two feet it is most nearly moderate brown 5YR4/4. The following 15' is 10YR7/4 with a few orange to brown limonite blebs. The remainder is moderate yellowish brown 10YR5/4.</td>
<td>46.0</td>
</tr>
<tr>
<td>3</td>
<td>Shale, clay, very slightly silty, color varies from pale grayish blue 5pb6/2 to medium gray 5Y, where stained with limonite tan to buff. Many thin beds and zones of concretions of ironstone. Fissile, breaks into small fragments.</td>
<td>12.0</td>
</tr>
</tbody>
</table>
## Locality description

Measured by H. C. Wagner  
Date 4/3/51

**Remarks**

Covered interval.

### Bed No. Description Thickness

1. Sandstone, base not exposed, tan and buff 10X3/2-6/6 very fine grained, well sorted subangular grains, speckled with blems of limonite. Cross bedded, high angle cross bedding, ripple marked locally, hard, massive, forms a cliff 12' high, has a fairly continuous 16" zone about 11' from the top which is cavernous. Cross bedding most persistent near the base.  
24.0

2. Covered interval.  
43.0

3. Zone of concentration of sandstone blocks about 1-1.5' thick.  
2.0

58.0

5. Limestone, pale to dark yellowish orange 10YR6/6 to 10YR6/6, mottled appearance smooth to weathered surface, fossiliferous with crinoid stems, brachs, fusulinis ottonosia ?  
1.0

---

**Diagram**

- Bed No. 1: Sandstone, described as fine grained, well sorted subangular grains, speckled with blems of limonite. Cross bedded, high angle cross bedding, ripple marked locally, hard, massive, forms a cliff 12' high, with a cavernous zone 11' from the top. Cross bedding most persistent near the base.
- Bed No. 2: Covered interval.
- Bed No. 3: Zone of concentration of sandstone blocks about 1-1.5' thick.
- Bed No. 4: Covered interval.
- Bed No. 5: Limestone, described as pale to dark yellowish orange with a mottled appearance, smooth to weathered surface, fossiliferous with crinoid stems, brachs, fusulinis ottonosia.
<table>
<thead>
<tr>
<th>Sec. 11</th>
<th>Locality description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Section runs from top of hill W7 to bottom of hill in alluvium. There has been later slumping in the Robins shale with development of landslide topography locally and minor...</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Measured by H. C. Wagner</td>
<td>Date 4/4/51</td>
</tr>
<tr>
<td></td>
<td>Remarks</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B.1 No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Limestone, hard, very fossiliferous, full of osangia algae, soft brachs, and fusulinids. Lod rate 5YR4/4 to light brown 5YR6/4 on fresh surface. Weathers to very pale brown 5YR6/2. Has weathered zone about 1' thick in center portion which appears to be fragment calcareous material in a limonitic sandy, limy matrix. Base not exposed.</td>
<td>6.0</td>
</tr>
<tr>
<td>8</td>
<td>Covered interval, apparently medium dark gray clay shale N4/4.</td>
<td>11.0</td>
</tr>
<tr>
<td>7</td>
<td>Limestone, hard, Flinty, breaks to an uneven surface; two prominent joint systems, vertical, going N48W and N41R, very fossiliferous, many crinoid stems, brachs and molluscs, rhomboporate bryozoans. Weathers to very pale orange 10YR6/2 mottled with large areas of pale yellowish orange 10YR6/6 fresh surface medium dark gray N4/4, otoniosa not prominent, base unexposed.</td>
<td>3.0</td>
</tr>
<tr>
<td>6</td>
<td>Shale, light olive gray, easily broken, many small ironstone concretions in lenticular zones, poorly exposed.</td>
<td>13.0</td>
</tr>
<tr>
<td>5</td>
<td>Covered interval</td>
<td>27.0</td>
</tr>
<tr>
<td>4</td>
<td>Concentration of sandstone float and ironstone concretions locally, forms general terrace and break in slope.</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>Covered interval. Uppermost part is light olive gray clay shale 5Y5/2, completely covered with soil and ss float from there down.</td>
<td>50.0</td>
</tr>
<tr>
<td>2</td>
<td>Sandstone, very fine grained, well sorted quartz grains. subangular, iron stained along bedding planes and blebs, cross-bed strongly ripple marked locally. Forms massive blocks and cliff color grayish orange 10YR4/4. Base not exposed.</td>
<td>4.0</td>
</tr>
<tr>
<td>1</td>
<td>Covered to top of hill. Apparently is light olive gray clay shale 5Y5/2.</td>
<td></td>
</tr>
</tbody>
</table>
# State Geological Survey of Kansas

T. 28 S.R. 15E  County Elk and Wilson

<table>
<thead>
<tr>
<th>Sec. 32, 33</th>
<th>Locality description</th>
<th>Section measured downhill toward east from top of hill about 1000 ft west of se corner road.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured by H. C. Wagner</td>
<td>Date 4/15/51</td>
</tr>
<tr>
<td></td>
<td>Remarks</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Top of hill has root zone float of Plattsmouth limestone.</td>
<td>6.0</td>
</tr>
<tr>
<td>2</td>
<td>Limestone, blocky, very fine grained, highly fossiliferous,</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>but fossils mostly small fragment of brachiopod shells and crinoid stems. Some larger algal concentric growths.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uppermost inch is ironstained. Generally light olive gray 5Y7/1 on weathered surface and medium dark gray 10YR 4/1 on fresh surface. Highly jointed and breaks into angular blocks, poorly exposed.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Covered interval.</td>
<td>11.0</td>
</tr>
<tr>
<td>4</td>
<td>Siltstone, not calcareous, yellowish gray 5Y7/2, float forms</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>it can break in slope.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Covered interval.</td>
<td>21.0</td>
</tr>
<tr>
<td>6</td>
<td>Siltstone, noncalcareous, yellowish gray 5Y7/2, float forms</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>it can break in slope.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Covered interval.</td>
<td>18.0</td>
</tr>
<tr>
<td>8</td>
<td>Limestone, very fossiliferous, mostly crinoid stems, but</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>also many fragments of brachiopods, and mollusc, some corals. Rather wavy-beded, light gray N7 on fresh surface, weathered surface generally light gray N7 mottled with large areas of limonite staining, dark yellowish orange 10YR6/6. Top and bottom poorly unexposed.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Covered interval.</td>
<td>12.0</td>
</tr>
<tr>
<td>10</td>
<td>Siltstone, limy (may be silty limestone, but looks more like siltstone) Grayish orange on weathered surface 10YR7/4, pale yellowish brown 10YR6/2 on fresh surface. Weathered surface mottled. Fresh surface appears as crossbedded, unfossiliferous. Lenticular, Limy portion is in center. Grades laterally into very fine grained sandstone.</td>
<td>3.0</td>
</tr>
<tr>
<td>11</td>
<td>Covered interval.</td>
<td>15.0</td>
</tr>
<tr>
<td>12</td>
<td>Siltstone, light dusty yellow 5Y7/4, one bed 9&quot; thick.</td>
<td>0.8</td>
</tr>
<tr>
<td>13</td>
<td>Covered interval.</td>
<td>2.0</td>
</tr>
<tr>
<td>14</td>
<td>Siltstone, light dusty yellow 5Y7/4, thin bedded and ss, thin bed with shaly beds.</td>
<td>8.0</td>
</tr>
<tr>
<td>15</td>
<td>Covered interval.</td>
<td>5.0</td>
</tr>
<tr>
<td>16</td>
<td>SS, very fine grained, yellowish gray 5Y8/1 on weathered surface and fresh surface.</td>
<td>2.0</td>
</tr>
<tr>
<td>17</td>
<td>Shale, clayey, light olive-gray 5Y5/2, fissile some small ironstone concretions.</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Section measured from top of hill to road bend where Gastrophora has been cut into by road ditch.

Measured by: H. C. Wagner
Date: 4/4/51

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Covered from top of hill to top of SS</td>
<td>5.0</td>
</tr>
<tr>
<td>2</td>
<td>Sandstone, very fine grained, massive, hard cross bedded in part, slightly micaceous, pale reddish orange 10R8/6 to grayish orange 10YR7/4 with many limonite blebs throughout forms cliff. Bog not clearly exposed.</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td>Covered interval</td>
<td>19.0</td>
</tr>
<tr>
<td>4</td>
<td>Shale, clay, very slightly silty, friable, small ironstone concretions. Grayish orange 10YR7/4</td>
<td>4.0</td>
</tr>
<tr>
<td>5</td>
<td>Zone of concentration of SS blocks and break in slope.</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>Covered interval</td>
<td>18.0</td>
</tr>
<tr>
<td>7</td>
<td>Break in slope and lower limit of sandstone float.</td>
<td>2.0</td>
</tr>
<tr>
<td>8</td>
<td>Covered interval</td>
<td>3.0</td>
</tr>
<tr>
<td>9</td>
<td>Limestone float, Haskell Ls, goes laterally into l that is in place or nearly so. Seamed with thin veinlets of coarse calcite which form the end views of brachiopod or mollusk shells. Consists generally of light gray N7 limestone fragments in a 10YR7/6 yellowish orange matrix. Fragmental appearance is a dominant feature.</td>
<td>4.5</td>
</tr>
<tr>
<td>10</td>
<td>Shale, medium light gray, N6, friable, many small white nodular masses in the upper part. Poorly exposed.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Limestone, Fossiliferous, almost entirely made up of osagia algal, a few crinoid stems and fusulinids are also present. Hard, weathers into odd, rounded shapes. Osagia algal are oblate bodies, light gray, with dark brown centers usually. This limestone here is yellowish orange 10YR7/6 on both fresh and weathered surfaces. Poorly exposed</td>
<td>2.5</td>
</tr>
<tr>
<td>12</td>
<td>Siltstone, sandy, micaceous, very thin bedded, breaks into thin laminae like a shale, yellowish gray 5Y8/1. Has zones of ironstone and sandstone concretions.</td>
<td>18.0</td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

Locality description: Section taken from top of hill going east to creek.

Measured by H. C. Jasper  Date 4/4/51

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sandstone, very fine grained, slightly micaceous, hard. Massive, consists almost entirely of semi-rounded quartz grains, well sorted. Dark yellowish orange 10YR6/6 with dark limonite blebs scattered throughout. Base not exposed.</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>Covered interval.</td>
<td>22.0</td>
</tr>
<tr>
<td>3</td>
<td>Top of break in slope, many sandstone blocks concentrated.</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>Covered interval.</td>
<td>20.0</td>
</tr>
<tr>
<td>5</td>
<td>Concentration of sandstone blocks.</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>Covered interval.</td>
<td>16.0</td>
</tr>
<tr>
<td>7</td>
<td>Limestone, very fine grained, weathers to a hackly surface and very pale orange color 10YR6/2. Fresh surface medium dark gray N4. Very fossiliferous, crinoid stems most prominent, also a few corals, rhopoporane bryozoans and brach and mollusks. Three joint systems trending N46W, N40E and N5W. All vertically joints, base not exposed.</td>
<td>1.0</td>
</tr>
<tr>
<td>8</td>
<td>Covered interval.</td>
<td>5.5</td>
</tr>
<tr>
<td>9</td>
<td>Limestone, very fossiliferous, composed almost completely of osagia algae with a zone at the top with many ostracods. A few fusulinids and crinoids. Weathered surface pale grayish red 10R5/2. To very pale orange 10YR8/2. Weathers into thin plates and rounded masses.</td>
<td>4.5</td>
</tr>
<tr>
<td>10</td>
<td>Siltstone, yellowish gray 10Y/2. Micaceous. Very thin bed breaks into thin plates, shaly. Slightly sandy.</td>
<td>19.0</td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

T. 28 S. R. 14 E. County Wilson

<table>
<thead>
<tr>
<th>Sec. 19</th>
<th>Locality description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Section measured from top of outlier of thick Ireland Shale, south west to junction of road that runs west to small farm where Haskell outcrops.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Measured by H. C. Warner</td>
<td>Date 4/13/51</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sandstone, fine to medium grained, fairly well rounded, almost entirely quartz grains, well sorted, fine sand interbedded with medium sand, cross bedded, low angle cross bedding, some cretations in bedding, probably syngenetic. Weathered into cliff with several zones of cuspate or wavy surfaces. Massive-no interbedded silt or shale. Color varies from almost white to orange.</td>
<td>35.0</td>
</tr>
<tr>
<td>2</td>
<td>Covered interval, some sandy shale showing through</td>
<td>25.0</td>
</tr>
<tr>
<td>3</td>
<td>Break in slope</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>Covered interval.</td>
<td>16.0</td>
</tr>
<tr>
<td>5</td>
<td>Concentration of ss blocks.</td>
<td>.5</td>
</tr>
<tr>
<td>6</td>
<td>Covered interval.</td>
<td>39.0</td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

Locality description: Section from top of hill going south along road.

Measured by: H. C. Jagger
Date: 4/16/51
Remarks: Exposures fair

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sandstone, fine to mod. gr., sorting fair, mostly subangular.</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>Quartz grains, ironstained, massive to medium bedded, cross bedded.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shale, light gray, N7, ironstained, silty, scattered ironstone concretions, well exposed at contact with ss, poorly exposed below, some ss concretions also.</td>
<td>14.5</td>
</tr>
<tr>
<td>3</td>
<td>SS, fine grained, thin bedded, tan to orange, iron stained.</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Irregular markings like worm tracks on some bedding planes.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Shale, silty, light gray to tan, scattered ironstone concretions.</td>
<td>10.4</td>
</tr>
<tr>
<td>5</td>
<td>Tone of concentrated large ironstone and sandstone concretions.</td>
<td>3.3</td>
</tr>
<tr>
<td>6</td>
<td>Covered interval, gray silt, shale and sandy siltsone are exposed at intervals. Some ironstone concretions.</td>
<td>30.0</td>
</tr>
<tr>
<td>7</td>
<td>Limestone, Haskell.</td>
<td></td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

T. 22 S., R. 15 E., Wilson County, Kansas

Locality description: Section measured up in section from creek bed culvert southward to secondary road.

Measured by K. G. Wagner
Date 4/17/51

Remarks:

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limestone, very light gray, with many pelecypod remains many as good shells. Also filled with crinoid stems.</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>Main characteristics seem to be the coarse grained appearance due to the fossils, light color and the lugs.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Covered interval with gray shale in upper foot.</td>
<td>18.0</td>
</tr>
<tr>
<td>3</td>
<td>Limestone, medium bedded, wavy bedded, yellowish orange, poorly exposed.</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>Covered interval.</td>
<td>6.0</td>
</tr>
<tr>
<td>5</td>
<td>Limestone, medium to thin bedded, wavy beds with thin shale; beds interlaminated. Shale beds are light gray with many crinoid stems and a few brachiopods and fenestrate bryozoans. The limestone is very fossiliferous, made up in places almost entirely of crinoid stems of all sizes and a few (very few) brachiopod or pelecypod fragments. The [Acada alga (?) was noted. Limestone becomes less fossiliferous at top color is yellowish orange (10YR7/6) on weathered surface and is grayish red (10R4/2) to medium gray (N5) on fresh surface. A bed in the center has fragments of dark gray shale incorporated in it.</td>
<td>12.0</td>
</tr>
<tr>
<td>6</td>
<td>Shale, medium light gray (N6) as above noted, becomes very fossiliferous in upper portion with limy concretions in the upper part. Fossils are mainly crinoid stems with a few brachiopod (?) fragments.</td>
<td>4.5</td>
</tr>
<tr>
<td>7</td>
<td>Covered interval (probably same shale)</td>
<td>12.0</td>
</tr>
<tr>
<td>8</td>
<td>Shale, very slightly silt, color fresh medium light gray (N6) with a bluish cast. Weathers to yellowish red (10R1/4).</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Covered interval (probably same shale)
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Locality Description</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limestone, light colored, hard, compact, fossiliferous, 50.0% in wavy or irregular bedding.</td>
<td>It is dark yellowish brown (10YR 6/2) at the top and becomes progressively lighter (in general) downward for about 5' where it is very pale orange (10YR 6/2) somewhat mottled. There are thin 1&quot; beds of very fine grained, compact olive gray (5Y 6/2) limestone in this upper part. In the middle 30' the limestone is irregularly bedded but weathers into rounded flattish bodies a few with pitted or cavernous appearance, in general it is light yellowish gray (5Y 6/2) to light gray (10Y). The lower 15' is largely a very light gray, almost white, leaves in the upper part and thin zones of lime ironstone concretions throughout.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shale, slightly silty, light olive gray (5Y 6/2) with plant leaves in the upper part and thin zones of lime ironstone concretions throughout.</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Limestone, very fossiliferous, medium dark gray (8.5.4), uppermost part 1.0% is irregularly oolitic, the oolitic areas being separated by very fine grained fossiliferous limestone. The oolitic may be algal but look more like oolites to me. The central part is practically all fossils with brachiopod-collus fragements in a matrix of large Osaka alae. The lower part is oolitic and fossiliferous</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Shale, pure clay, no silt, light olive gray (5Y 6/2)</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Covered interval. 15' at top 3' looks solid but may be a slump block as it looks like white is previously described 10.0</td>
<td>rest of the medium is covered.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Shale, light olive gray (5Y 6/2) with some tan colored beds, 32.0% interbedded. Very slightly silty.</td>
<td>32.0</td>
<td></td>
</tr>
</tbody>
</table>

- **Locality Description**: Section starts atop of hill on S-W part of road and extends down the road along the N-S portion to farmhouse. Chert gravels are prominent at the top of the hill and have been quarried just south of road and on road top east of road. The limestone has been quarried just east of road. Exposures are fairly good. There are intervals of about a foot from time to time that are covered.
- **Remarks**: Bed No. 1: Limestone, light colored, hard, compact, fossiliferous, 50.0% in wavy or irregular bedding. It is dark yellowish brown (10YR 6/2) at the top and becomes progressively lighter (in general) downward for about 5' where it is very pale orange (10YR 6/2) somewhat mottled. There are thin 1" beds of very fine grained, compact olive gray (5Y 6/2) limestone in this upper part. In the middle 30' the limestone is irregularly bedded but weathers into rounded flattish bodies a few with pitted or cavernous appearance, in general it is light yellowish gray (5Y 6/2) to light gray (10Y). The lower 15' is largely a very light gray, almost white, leaves in the upper part and thin zones of lime ironstone concretions throughout. Bed No. 2: Shale, slightly silty, light olive gray (5Y 6/2) with plant leaves in the upper part and thin zones of lime ironstone concretions throughout.
- **Thickness**: The thicknesses of the beds are given in feet, with some intervals being covered.

---

**State Geological Survey of Kansas**

T. 115 S. R. 15 E. County Wilson

<table>
<thead>
<tr>
<th>Sec. 31</th>
<th>Locality description</th>
<th>Measured by H. G. Hensler Date 6/1/53</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Sec. 31**

- **Locality Description**: Section starts atop of hill on S-W part of road and extends down the road along the N-S portion to farmhouse. Chert gravels are prominent at the top of the hill and have been quarried just south of road and on road top east of road. The limestone has been quarried just east of road. Exposures are fairly good. There are intervals of about a foot from time to time that are covered.

---

**Remarks**: Bed No. 1: Limestone, light colored, hard, compact, fossiliferous, 50.0% in wavy or irregular bedding. It is dark yellowish brown (10YR 6/2) at the top and becomes progressively lighter (in general) downward for about 5' where it is very pale orange (10YR 6/2) somewhat mottled. There are thin 1" beds of very fine grained, compact olive gray (5Y 6/2) limestone in this upper part. In the middle 30' the limestone is irregularly bedded but weathers into rounded flattish bodies a few with pitted or cavernous appearance, in general it is light yellowish gray (5Y 6/2) to light gray (10Y). The lower 15' is largely a very light gray, almost white, leaves in the upper part and thin zones of lime ironstone concretions throughout. Bed No. 2: Shale, slightly silty, light olive gray (5Y 6/2) with plant leaves in the upper part and thin zones of lime ironstone concretions throughout.
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Covered interval with much limestone float as large blocks</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>Lay have come down from above.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Shale, light olive gray 5Y5/2 with black fissile shale</td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td>in the lower part.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Shale, light olive gray 5Y5/2, slightly silty with a zone</td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td>of ironstone concretions in the center of this exposure.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Covered to intersection of roads and alluvium below.</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Sec. Locality description Sections 8.9.16 lines. Section measured from top of hill along N-S road between sec 8,9 and down to stream along E-W road between sec 9,16.
Measured by H. G. Wagner Date 5/2/51
Remarks

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S, medium grained, well sorted quartz grains, subangular, ironstained.</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>Covered interval. Somewhere in this covered interval is the contact between the ss and ls. The ss apparently has a conglomerate bed at the base which is filled with shell fragments, crinoid stems, rounded ironstone pebbles(?) in a medium grained quartz sand matrix.</td>
<td>6.5</td>
</tr>
<tr>
<td>3</td>
<td>Ls, fine grained, fossiliferous, medium bedded, wavy bedded. With some interlaminated sh and ss beds at the top. Weathers into a cupped or scalloped surface. ss beds are almost brick red. Shales are light olive gray, both somewhat fossiliferous.</td>
<td>6.0</td>
</tr>
<tr>
<td>4</td>
<td>Ls, medium gray/N2, fine grained, very fossiliferous, almost 0.5 entirely crinoid stems, massive, weathers out as a single, distinct bed. Strongly jointed vertically; trends generally N40E and N60W.</td>
<td>15.0</td>
</tr>
<tr>
<td>5</td>
<td>Ls, thin bedded, composed of fragments of ls in a limey matrix, weathers out in a mottled appearance.</td>
<td>0.5</td>
</tr>
<tr>
<td>6</td>
<td>Ls, thin bedded to medium bedded, fossiliferous, brecciated. Weathers into relatively smooth surfaces generally, light medium gray N6 often mottled darker due to sinuous areas of &quot;Ottosasia&quot;?</td>
<td>15.0</td>
</tr>
<tr>
<td>7</td>
<td>Limestone, medium bedded, light gray/N7, almost white. Weathers into pock-marked appearance, wavy. Wavy bedded. Large fossils make it appear coarse grained.</td>
<td>7.0</td>
</tr>
<tr>
<td>8</td>
<td>Covered interval.</td>
<td>3.0</td>
</tr>
<tr>
<td>9</td>
<td>Limestone, fine to medium bedded, mottled tan and light gray. Weathers into weathered surface, very white on fresh surface, hard, wavy bedded, weathers to a pitted surface.</td>
<td>4.0</td>
</tr>
<tr>
<td>10</td>
<td>Ls, hard, medium gray N5, full of small osaia alcal or oolitic at the top, larger in middle. May be separated from overlying limestone by about a foot of shale.</td>
<td>0.8</td>
</tr>
<tr>
<td>11</td>
<td>Shale, light olive gray/N67/7/base not exposed.</td>
<td>4.0</td>
</tr>
</tbody>
</table>
**Locality description**
Along E-W road between sec. 4 and 9 from top of hill to intersection of roads at W end of sec. Cherty gravels

**Measured by** H. C. Wagner
**Date** 5/2/51

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Covered interval. Has ss float at top of hill. ss is like that of F-41 interval occurs at base of break in slope and soil cracks suggest that it is shaly in the upper 4-5 feet.</td>
<td>7.0</td>
</tr>
<tr>
<td>2</td>
<td>Limestone, fine grained, medium gray to light gray with blotchy areas of iron stained ls in the upper and lower parts. The central part is medium bedded fossiliferous with wavy dark gray areas (Feronia) many fenestrate bryozoans and crinoid stems-also brachiopods. Broken, ironstained ls occurs at the base.</td>
<td>9.0</td>
</tr>
<tr>
<td>3</td>
<td>Shale, pale olive 10Y6/2, very slightly silty</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>Covered interval—probably the shale.</td>
<td>9.0</td>
</tr>
<tr>
<td>5</td>
<td>Ls, fine to med grained, (coarseness due to fossils), light gray to almost white, vuggy to pitted weathered surface. Base not exposed.</td>
<td>7.0</td>
</tr>
</tbody>
</table>
## Locality Description
Section taken along N-S road between secs. 3 and north downhill.

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Red soil—probably derived from weathering of limestone.</td>
<td>5.0</td>
</tr>
<tr>
<td>2</td>
<td>Black to olive gray soil—looks like shale in spots.</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td>Red soil with many chert gravels and large limestone blocks.</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>Limestone, in place, thin bedded, fairly evenly bedded, breaks into plates about 1&quot; thick, very fossiliferous. Almost entirely made up of crinoid stems in some places and brachiocods or mollusks in others. Femestellate bryozoa.</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>Shale, greenish gray (5Y6/1) to light greenish gray (5Y8/1). Very slightly silty, limy in the uppermost part at the base.</td>
<td>5.0</td>
</tr>
<tr>
<td>6</td>
<td>Limestone, very hard and massive, medium gray (6/8), full of crinoid remains, brachiopods and some Osagia alga.</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>Limestone, poorly bedded, breaks into small irregular fragments. Very fossiliferous brachiopods, mollusks and Osagia alga. Weathers tan, is mottled tan and gray on fresh surfaces.</td>
<td>1.5</td>
</tr>
<tr>
<td>8</td>
<td>Limestone, very hard and massive, medium gray (6/8), full of crinoid remains, brachiopods and some Osagia alga.</td>
<td>0.5</td>
</tr>
<tr>
<td>9</td>
<td>Shale, olive gray (5Y6/1).</td>
<td>6.0</td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

Locality description

Section starts at stream bottom about 1000' south of dam and pond and goes up hill to west of Capt. Creel, La., then north along strike to pond and west up hill to pumping shack.

Measured by H. C. Wagner  Date 5/3/51

Remarks that hill to pumping shack.

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limestone, oolitic, weathers pale yellowish brown (10YR6/2) poorly exposed; apparently has a pale yellowish brown sandstone associated with it (10YR6/2) Sandstone is up to 1' thick and is composed of well sorted, fairly well rounded, fine size quartz grains, very fossiliferous originally, the fossils now merely holes. The oolitic limestone also is quite fossiliferous.</td>
<td>7.5</td>
</tr>
<tr>
<td>2</td>
<td>Limestone, medium gray (5G) full of odd shaped darker areas with coarser grain (Ottonosia?), fairly well bedded although wavy. Very fossiliferous in the center, almost white and not so fossiliferous at the top.</td>
<td>18.0</td>
</tr>
<tr>
<td>3</td>
<td>Covered interval—undoubtedly shale.</td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>Limestone, very hard and brown at basal 6&quot; with many osagia algae. Above this it becomes very pitted (1/2&quot; pits) and fragmented appearance and very pale orange (10YR8/2) in color for about 10', then becomes almost white and very vuggy, brecciated appearing; holes up to 2&quot; toward top. Wavy bedded.</td>
<td>25.0</td>
</tr>
<tr>
<td>5</td>
<td>Shale, light olive gray (5Y6/1) very slightly silty</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>Limestone, clayey, almost entirely fossils, mostly large Osagia algae, some brachipods, rhomboropore brachiopods. Irregular lower contact. Upper 1 and 1/2&quot; are oolitic in appearance, mass of small osagia algae.</td>
<td>0.8</td>
</tr>
<tr>
<td>7</td>
<td>Shale, (covered interval at south but exposed south of dam) light olive gray (5Y6/1) very slightly silty.</td>
<td>15.0</td>
</tr>
<tr>
<td>8</td>
<td>Limestone, medium dark gray (5A) to brownish gray (5YR4/1) with many irregularly shaped (angular) areas of calcareous clay that is grayish orange 10YR7/4. Fine grained, somewhat fossiliferous with areas of secondary calcite throughout.</td>
<td>39.0</td>
</tr>
</tbody>
</table>
### Bed No. Description

1. **Limestone**, top not exposed, irregularly thick to thin bedded 4.0 light gray N7 very fine grained, with many angular areas of very light gray R8 is... Gives it a somewhat brecciated appearance. Has many interlaminated shaly beds in the basal 1.5' from which crinoid stems weather in profusion. In general this is quite fossiliferous and contains beds of crinoid stems while others are largely "ottonosia" or mollusk fossils. At the top, although not definitely as plane, was a large block of sandstone; very pale orange 10YR8/2, with many limonite blebs. Cross bedded.

2. **Shale**, light olive gray 5Y6/1, very fossiliferous at top 2.5 largely crinoid stems.

3. Covered interval—Dip may throw the above below the SS. 9.0

4. **SS**, fine grained, limonitic, orange to orange brown color 2.5 many holes where fossils have weathered out. At the base is a sandstone breccia the fragments being largely clayey limestone similar to that which is found below it. Very fossiliferous limestone and sandstone was full of shells too. Dark orange brown. Apparently is disconformable on the limestone.

5. **Limestone**, light-gray N7, very fossiliferous, wavy bedded, 4.0 irregular bedded, weathers brownish, many large mollusks and small brachiopods, also crinoid stems. Base not exposed.
State Geological Survey of Kansas

T. 29 S., R. 15 E., County Wilson

Locality description: East canyon on Joe Studebaker Farm. Section starts at top of hill and goes east to down to canyon bottom and then north along bottom to main creek.

Measured by H. C. Wagner Date 5/4/51

Remarks: Poor exposures, based largely upon large boulders that may have slumped some.

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ls, oolitic, white, with oolites composed of limonite giving rock a brownish appearance. Sandy, becomes brownish and more sandy at base. Weathers into rounded masses.</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>Covered interval.</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>Ls, sandy conglomeratic, might better be called a limy sandstone, in places the sand grains predominate and in others they are merely held in a limestone matrix. Many angular limestone fragments are incorporated. Also many fossils. This ls. is based upon several fragments that may have floated down from an overlying limestone.</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>Covered interval.</td>
<td>0-1</td>
</tr>
<tr>
<td>5</td>
<td>Sandstone, fine grained, fossiliferous at top where it is vuggy due to only molds of fossils remaining; base not exposed.</td>
<td>3.5</td>
</tr>
<tr>
<td>6</td>
<td>Ls, white very fossiliferous, many of the fossils have been replaced by limonite. Weathers into a punky mass in some places. Usually weathers to smooth surface but in places may be cusped. Weathered surface in places shows very fine oolitic areas.</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Vally is in syncline and this limestone dips down to bottom of valley and forms stream bed to junctiohn with main stream.
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Limestone, thin to medium bedded, wavy bedded, light gray, many fossils and (oolites ?) or limonite. Shale interbedded with the wavy bedding. Very fossiliferous.</td>
<td>9.5</td>
</tr>
<tr>
<td>2</td>
<td>Limestone, hard, massive, all one bed, very fossiliferous, crinoid stems, brachs, mollusks, corals, and wavy, areas of limonite (ottomonsia?) light gray, limonitic.</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>Shaly interval.</td>
<td>0.1</td>
</tr>
<tr>
<td>4</td>
<td>Limestone, hard massive, as immediately above.</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>Poorly exposed interval but upper 3' is probably limestone</td>
<td>6.0</td>
</tr>
</tbody>
</table>

**Locality description**
Section in lime quarry on north part of Joe Studebaker farm.

**Measured by** H. C. Wagner  
**Date** 5/4/51

**Remarks**

Section along road just west of lime quarry. Section starts at top of lime of lime quarry and goes up.

1. Covered to Joe Studebaker's farm gate. Chert gravels last 14.0 10'. Some limestone but poorly exposed.
2. SS, medium grained, thin bedded, dark yellowish orange 10YR6/6, red where weathered badly.
3. Limestone, moderate yellowish brown, oolitic, oolites are limonite. Light gray, sandy, oolitic at top.
4. Covered interval. 5.0
5. Sandstone, dark yellowish orange 10YR6/6, medium grained, all subangular, well sorted quartz grains.
6. Limestone, thin to medium bedded, poorly exposed, light gray, many fossils, some as limonite.
## Locality description
Section in road cut on east side of road about 150' south of corner. Augered to limestone.

**Measured by**: H. C. Wagner  
**Date**: 5/21/51

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soil with a 6&quot; red sandstone bed, very fossiliferous,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>underlain by a very light olive gray (6YR/2) clay shale</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1'2&quot; thick, which is underlain by a dark yellowish orange</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(10YR6/6) clay shale 1' thick, followed by 2s.</td>
<td></td>
</tr>
</tbody>
</table>

This is presumably the shale between the South Bend and Stoner ls. It is the only place thus far that I have found it exposed.
State Geological Survey of Kansas

Sec. 1 Locality description

G-1 back sight for elevation to 54979

G-2 station at road that goes north to farm

G-3 point at base of Tonganoxie ss.

Measured by H. C. Richard Date 5/9/51

Remarks Section measured along 21 road between sections 21 and 26, measured going west. Section starts at road to farmhouse south of road at base of hill.

Bed No. Description Thickness

1. Sandstone, fine to medium grained well sorted in layers. 20.0
   Colors pale yellowish to grayish orange 10 YR 6/2-7/4.
   Quartz grains, subangular to angular, slightly micaceous.
   Some plant fragments and carbonaceous material.

2. Shale and SS, interbedded, shale predominates. Sandstone occurs as lenses and beds, thin to medium (4').

3. SS, fine grained, pale orange 10 YR 7/2, medium bedded. 4.0

4. Shale, clay, light gray N7, with thin interbedded sandstone. 1.3
   Beds about 1/4" thick. Becomes sandier toward the top with SS concretions. SS is very fine grained, micaceous, dusky yellow color 5Y 6/4.

5. SS, medium grained, well sorted subangular quartz grains about 2.7
   At base is a 3" zone that is broken with many ironstone fillings and some clay fragments. Massive bedded, 'Highly marked on upper surface. Strike N22E, dip 5 degrees NW.'

6. Shale, same as above. 1.0

7. Covered interval. Undoubtedly the same as above. 5.0

8. Shale, slightly silty, light gray N7 on fresh surface, pale yellowish brown 10 YR 6/2 where weathered, micaceous. Covered interval from here to creek to east is probably Weston shale also. 20.0
   This interval would cover about 35' of shale.
State Geological Survey of Kansas

T. 29 S., R. 14 E. County
Sec. 21

Locality description
G-4 station at intersection of roads 107
-5 Point 13.5' at base of
Conanoxie sandstone

Measured by H. C. Wipper

Remarks

Bed No. Description Thickness
1 Shale, slightly silty, micaceous. Has one very prominent 2
joint system trending N30E. Rock fractures along this joint
system into pencil type joint blocks. Another joint system
trending N56E but is not so prominent. Bedding in lower
portions is obscure (claystone) but becomes more prominent
upwards and upper 15' is well laminated. About 1' below
upper contact is an 8" layer of paper thin shales.
uppermost foot is almost pure clay and is plastic (almost).
Color varies from yellowish gray 5Y7/2 to moderate olive
brown 5Y4/4 with many ironstained beds interlaminated.

2 Concretionary sandstone at base followed
upward by medium grained sandstone with
layers containing angular ironstone concretionary bodies
interlaminated. A two foot thick bed of friable sandstone
containing large blebs of iron oxide, occurs about 3 and
1/2 feet above the base. Some (foot thick) fine grained
beds are interbedded. Bedding in places crumulated. Well
developed joint system trends N50E.

3 Shale, medium grained, thin to thick bedded, medium grained.

4 Concretionary sandstone at base followed
upward by medium grained sandstone with
layers containing angular ironstone concretionary bodies
interlaminated. A two foot thick bed of friable sandstone
containing large blebs of iron oxide, occurs about 3 and
1/2 feet above the base. Some (foot thick) fine grained
beds are interbedded. Bedding in places crumulated. Well
developed joint system trends N50E.
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SS, very fine grained, well sorted.</td>
<td>1-10</td>
</tr>
<tr>
<td>2</td>
<td>SS, limy, brick red to orange color.</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>LS, gray, sandy, slightly fossiliferous.</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>Covered interval, shale ?</td>
<td>2.0</td>
</tr>
<tr>
<td>5</td>
<td>LS, medium gray, very fossiliferous, sandy, osagia algal, fusulinids, crinoid</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>stem weathers into small, angular fragments.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Shale, as below.</td>
<td>2.0</td>
</tr>
<tr>
<td>7</td>
<td>LS, very fossiliferous, light-gray, largely large fusulinids</td>
<td>0.3</td>
</tr>
<tr>
<td>8</td>
<td>Shale, as below, non-extensive.</td>
<td>1.0</td>
</tr>
<tr>
<td>9</td>
<td>LS, very fossiliferous, appears to be lentilicul in nature and possibly is</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>not extensive.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Shale, light tan, becomes more silty toward top. Has two or three zones of</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ironstone concretions which are, apparently non-fossiliferous.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Shale, light tan, filled with fusulinids, thin beds of light tan limestone</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>interlaminated. These LS beds are silty and are pocky with fusulinids.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Also large neospiriferoid brachiopods. A zone of ironstone concretions lies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>about a foot above the thin limestones. The concretions show many fusulinids</td>
<td></td>
</tr>
<tr>
<td></td>
<td>either as cast or through their presence.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Shale, light gray with tan streaks and zones of ironstone</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>concretions.</td>
<td></td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

T. 27 S.R. 1/4  County: Wilson

Sec. 5

Locality description: Section starts at Y in road and goes north up the hill.

Measured by: H. C. Wagner  Date:  

Remarks:  

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SS, hard, massive, single bed</td>
<td>2.0</td>
</tr>
<tr>
<td>2</td>
<td>SS, same as below but thin bedded</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>SS, same as upper massive, medium grained sand, not micaceous</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
<td>SS, very fine grained, same as below but thin bedded and breaks into slope,</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>somewhat micaceous</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>SS, very fine grained, subrounded quartz grains, ripple marked, numerous</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>worm trails, medium bedded-bead being 2-3&quot; thick, dark yellowish orange 10YR6/6.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prominent joint system going N60E and N40W.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Shale, clay, pure clay in basal third, becomes silty towards middle, ironstone</td>
<td>38.0</td>
</tr>
<tr>
<td></td>
<td>concretions in zones and lenses throughout, Fossiliferous zone in upper half.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Color in lower portion is light olive brown 5Y5/2, in upper part is moderate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>olive brown 5Y4/4 with an orange cast. Poorly exposed. Clay basal portion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>appears almost black and breaks into paper thin laminae. Near contact with</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ireland ss shale becomes sandy and has light colored sandstone concretions in</td>
<td></td>
</tr>
<tr>
<td></td>
<td>it.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>SS, very fine grained, almost entirely subrounded quartz grains, single bed,</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>stratification line being thin and definite, iron stained along strat lines,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dark yellowish orange 10YR6/6.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Ls, very fine grained, dense, crystalline in part, very fossiliferous,</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>fusulinids in top, crinoid stems relatively abundant, brachiopods, ottonosia</td>
<td></td>
</tr>
<tr>
<td></td>
<td>not prominent, medium gray N5/5 on fresh surface, light olive gray 5Y5/2 on</td>
<td></td>
</tr>
<tr>
<td></td>
<td>weathered surface, Lower 6&quot; is relatively shaly.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Shale, limy, has lenses of fossils and concretions, brachiopods, crinoid</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>stems, no evidence of myalina, grayish orange 10YR7/4 in upper part, light</td>
<td></td>
</tr>
<tr>
<td></td>
<td>olive gray 5Y5/2 in lower.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ls, bed, full of fossil fragments, moderate to dark yellowish brown, 10YR5/4</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>to 10YR4/2.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Shale, unfossiliferous, clay, no silt, light olive gray 5Y5/2. No bedding</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>really a mudstone that breaks into siltish fragments.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Shale, clay, full of osacia alask and fusulinids.</td>
<td>0.5</td>
</tr>
</tbody>
</table>
### State Geological Survey of Kansas

#### Locality description

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Lg, composed largely of large osaria, single massive bed, weathered surface is generally very pale orange</td>
<td>3.0</td>
</tr>
<tr>
<td>14</td>
<td>Siltstone, limy, many limestone concretions and fossils</td>
<td>0.3</td>
</tr>
<tr>
<td>15</td>
<td>Siltstone, clayey, well bedded micaceous</td>
<td>9.2</td>
</tr>
<tr>
<td>16</td>
<td>Siltstone, very thin bedded, well bedded, micaceous, between 1.0 light and moderate olive brown 5Yr 4/4 to 5Yr 5/6 on fresh damp surface, Dries to lighter color, near dricky yellow 5Yr 4/4. This bed is exposed at the top of the covered interval at road crossing. It is probably representative of the material above the massive ss bed.</td>
<td>5.5</td>
</tr>
<tr>
<td>17</td>
<td>Covered interval</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>SS, massive bed, very fine grained, micaceous, between dark yellowish orange 10YR 6/6 and moderate yellowish brown 10YR 5/4, well developed joint system going NE and NW</td>
<td>0.6</td>
</tr>
<tr>
<td>19</td>
<td>Covered interval</td>
<td>6.0</td>
</tr>
<tr>
<td>20</td>
<td>SS, very fine grained, cross bedded, ripple marked, thin bedded micaceous, very pale orange 10YR 6/2 to pale yellowish orange 10YR 6/6 on weathered surface. Between dark yellowish orange 10YR 6/6 and pale yellowish orange 10YR 6/6 on fresh surface. Almost entirely surrounded quartz veins, some carbonaceous material along bedding planes.</td>
<td>2.0</td>
</tr>
<tr>
<td>21</td>
<td>Covered interval</td>
<td>8.0</td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td>Chert gravel—subangular chert pebbles ranging in size from 1/8 inch to 2 inches with a few subrounded to rounded sandstone pebbles. No gradation of pebbles is apparent but most frequent sizes are between 1/8 to 3/16 inch. Chert pebbles are grayish orange (10YR7/4) in color and a few had fossils in them (fusulinids and brachiopods). The sandstone pebbles are generally about light brown (5YR6/6) and are very fine grained. The pebbles are held in a light brown (5YR5/6) matrix of clay and silt with many scattered sand grains. The chert gravels sometimes make up the entire bed; in other places they occur as thin 1/2&quot; lenticular bodies in a light brown (5YR5/6) clayey siltstone.</td>
<td></td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

T. 29 S., R. 15E, County Wilson

Locality description: Section measured from bottom of stream on large exposure of Plattsburg Is. up hill to south to Capt. Creek Is. Measured by H. C. Wagner Date 4-30-52

Remarks

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ls., med. gr., pale yellowish brown (10YR 6/2) to dark brownish gray (5YR 3/1) on weathered surface, breaks to irregular grainy brownish gray (5YR 4/1) and dark gray (N3) fresh surface. At this exposure it is even-bedded and has eroded to a 40 X 300 ft. surface which is largely on the upper layer of the formation. This surface is smooth from a distance but at close range appears very irregular and lumpy on a small scale. The bedding planes are wavy bedded but on a much smaller scale than is exhibited in the Plattsmouth limestone member of the Creed fm. A very well developed joint system is evident at this exposure. The trends are N40W, N85E and N55E. This limestone is very fossiliferous. The uppermost 8&quot; layer consists largely of small crinoid fragments, small brachiopods and large fenestellate bryozoans. The fossil content of the rest of the bed, exposed here, consists of large pelecypods, large brachiopods, crinoid remains and fenestellate bryozoans. The uppermost 2 inches of the formation has a reddish cast and contains ?waln? valves.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shale fissile slightly silty, medium gray (N5) with a bluish cast. Contains three lenticular beds of yellowish orange (10YR 7/6) to dark yellowish brown (10YR 4/2) ironstone concretions, one near the base, one about 3' above the base and one about 5 feet above the base. This shale grades upward into a...</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Shale, fissile, slightly silty, light olive gray (5Y5/2) to yellowish gray (5Y 7/2) with ironstone concretions at the base and near the top. Grades upward into Claystone, slightly silty, light olive gray (5Y 5/2).</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Claystone, slightly silty, light olive gray (5Y 5/2).</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Covered interval. Apparently the claystone, but becomes more silty upward.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Siltstone, micaceous, between yellowish gray (5Y 7/2) and grayish yellow (5Y 8/4) in color. Cross bedded, ripple marked, and locally contains molds of pelecypods(?). Forms a distinct topographic bench.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Covered interval.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Shale, light olive gray (5Y 5/2).</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Ls., Algae, mostly Osagia but a few layer-like Cryptopora near the center. Made up mostly of Osagia with locally abundant crinoid stems and a few corals and brachiopod and pelecypod fragments. Weathered surface has many small olive gray (5Y4/1) bodies throughout, but the general color is yellowish gray (5Y 8/1). Fresh surface is very pale brown (5Y6/2) to light brownish gray (5YR, 818). Is bed caps the hill.</td>
<td></td>
</tr>
</tbody>
</table>
Locality description
On Hwy roadcut about 1 mile west of Altoma.
Measured from gully about 1 mile south to top of hill.

Measured by Holly C. Wagner
Remarks

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ls., lt. olive gray (5Y6/1), massive, poorly bedded, fragmental in Cenozoic (?) matrix.</td>
<td>1.1</td>
</tr>
<tr>
<td>2</td>
<td>Sh., yellowish gray (5Y8/1), unfossil., covered above basal 3', 35.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Shale, silty, medium olive gray (5Y5/1), unfossiliferous. Contains three 1&quot; layers of calcareous ironstone concretions in the upper 1/3 where it grades upward into Claystone.</td>
<td>8.0</td>
</tr>
<tr>
<td>4</td>
<td>Claystone, slightly, medium olive gray (5Y5/1) in basal 4', foot grading upward into moderate yellowish brown (10YR5/4) Claystone. Contains zone of pale yellowish orange calcareous ironstone concretions about 1 foot from top.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Shale, silty, yellowish gray (5Y7/2) to light olive gray (5Y5/2) with 6&quot; lenses of claystone colored moderate yellowish brown (10YR5/4) in lower 1/3. Claystone lenses contain aporadac, small calcareous ironstone concretions.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Shale, calcareous, slightly fossiliferous, grayish orange (10YR 5/6), very fossiliferous containing abundant crinoid stems, brachiopods, and corals.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Shale, calcareous, very fossiliferous. Poorly exposed but 610 appears to be light olive gray (5Y6/6) with many dusky yellowish brown (10YR2/2) coral streaks and chain shaped bodies.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>This shale grades upward into 1s. Also contains abundant crinoid stems and brachiopods.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ls., dark yellowish orange (10YR6/6) very fossiliferous containing abundant Crinoid stems, chain shaped bodies, brachiopod remains, and few productus spines and corals. Contains a few thin (2&quot;) olive gray (5YR4/1) limestone beds that are speckled with white crinoid stems and locally dark colored oolites (?) in the central and upper parts.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Upper 3' is very shaly.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Shale, dark yellowish gray (5Y7/1), largely covered but can be seen to contain ironstone concretions in the lower and upper parts. Upper part becomes silty and is capped by Siltstone, finely micaceous, yellowish gray (5Y7/2) to light olive gray (5Y5/2) which crops out as large fragments. Thin zone of ironstone concretions overlies it.</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Shale, poorly exposed, moderate olive brown (5Y4/6) on fresh surface &amp; dark yellowish gray (5Y7/1) on weathered surface.</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Ls., algae, shown only by concentration blocks at break in slopes.</td>
<td></td>
</tr>
</tbody>
</table>

(cont.)
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shale interval, poorly exposed.</td>
<td>6.0</td>
</tr>
<tr>
<td>2</td>
<td>Limestone, white, coarse grained, weathers to very cavernous or vuggy surface. Locally very fossiliferous or ironstained. Capt. Creek</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Locality description: On Hwv roadcut about 1 mile west of Altoona. Measured from gully about 1 mile south to top of hill.

Measured by Holly C. Wagner

Remarks

Sec. 18 & 20
State Geological Survey of Kansas
and Sec. 12 T29S., R15E

Locality description
Going South along road between sec. 7, T29S.,
R15E., and sec. 12, T29S., R15E. Starting at the base of
upper bed of Plattsburg.

Measured by Holly C. Wagner

Bed No. | Description | Thickness
--- | --- | ---
1 | Ls., moderate yellowish brown (10YR5/4) on weathered surface | 18.0
2 | Pale yellowish brown (10YR6/2) and medium gray (N6) on fresh surface. Very fossiliferous and clayey. Fossils weather out of the clayey areas and make collection of fairly good specimens relatively easy. Fossils consist mainly of crinoid stems, Girtyocoelea and brachiopods. Ls breaks or weathers into thin platy plates or ovoid shapes which cover the slope of the hillside. Becomes less clayey and thicker bedded near top. | 55.0
3 | Shale, medium light gray (N6), and very slightly silty in upper 10 ft. Grades downward into micaceous dark yellowish gray (5Y6/2) siltstone and ironstone concretions. Zone about 3" thick and downward into light olive gray (5Y5/2) very slightly silty shale that contains lenses of ironstone concretions locally. | 8.0
4 | Ls., not typically like Capt. Creek ls. elsewhere to the west. | At this exposure it is only sparingly algal (Oasia2) and weathers (and fresh, too) grayish orange (10YR7/4) although several light olive gray (5Y6/3) beds are incorporated. It is very fossiliferous, mainly crinoid stems & belemnoids. Appears to be a small fault cuts the bed, trending N76E & dip 85'N. May only be slumping along a joint plane. This ls. is very strongly jointed. Basal part is very clayey & apparently grades downward into the shale below. | 1.5
5 | Shale that grades laterally into shaly las. Shale color is pale yellowish brown (10YR6/2) to very pale orange (10YR6/2) fossils are mainly crinoid stems. Limestone beds interlaminated. | 4.0
6 | Ls., light olive gray (5Y6/2) to yellowish gray (5Y6/1) with many coarse grained seams running in irregular patterns across the faces. Very fossiliferous locally. To the west about 1 mile about 8' of reddish as overlies this bed. Contact is irregular & probably represents some local channeling. |
State Geological Survey of Kansas

T. 29 S., R. 16 E. County Wilson

Locality description: On east bank of Verdigris River about 1 mile S. of Barnhill Bridge. Section measured westward along river and then uphill to top of hill.

Measured by: H. C. Wagner
Date: 5-7-52

Bed No. Description Thickness

1. Ls., base not exposed. Bedding well developed locally and shows rather irregular large folds developed as shown in sketch. Light gray (N7) to very light brownish gray (5YR7/1) contains many interlaminated clay partings, irregularly distributed. Fossil content abundant throughout and fine specimens can be obtained from weathered clay partings. Fossils consist of very abundant crinoid columns throughout and locally abundant and well preserved, products, fenestellate bryozoans, oysters (?), and small pelecypods (?). This limestone has a very dirty appearance, weathers to a most irregular angular surface and locally has rale reddish brown (10R5/4) blotchy areas about 3 feet from the top. A 5" bed of dark gray (N3) very fine grained hard limestone occurs locally at the top but grades laterally into 6" to 17" of very fine grained hard, mottled dark gray (N3) and medium light gray (N6) limestone. This unit is less fossiliferous and much harder than most of this bed. The very irregular nature of this bed and its variable fossil content & lithology suggest biostromic accumulation to me. It is locally cross bedded. Shale beds become increasingly thick, but very lenticular in the upper 3 feet and in general the upper 2 feet is dark gray (N3) very calcareous shale. Very fossiliferous with irregular lenticular masses of limestone throughout. This shale weathers back to leave a sharp capping rock which is 3-5" resistant limestone, clayey and very fossiliferous. A small fault (1 ft. deep) breaks this ls. and drops the west side down. Later calcite has cemented the break N5°E, 80°w dip.

2. Shale, non-silty to very slightly silty, medium light gray (N6), weathers light olive gray (5Y6/1) overlies the ls. It is unfossiliferous and exposed for 8 ft in the river bank.

3. Covered interval 14.0

4. Claystone, yellowish gray (5Y7/2), unfossiliferous, breaks into angular fragments, in part shale, contains a few ironstone concretions. Very few apparent.

5. Covered interval 35.0

6. Ls., dark yellowish orange (10YR 6/6) to moderate yellowish Brown (10YR5/4) on weathered surface and olive gray (5Y4/1) to medium gray (N4) on fresh surface. Very fossiliferous with many Girtracocella and crinoid stems and local beds of brachiopods. Shaly zones throughout. No evidence of lower bed (Merriam) but base not well shown. No oolitic facies apparent.

822
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shale interval, very poorly exposed but apparently consists mainly of light olive gray (5Y5/2) shale with one or two 1&quot; lenses of calcareous ironstone concretions about 4 feet below the top.</td>
<td>23.0</td>
</tr>
<tr>
<td>2</td>
<td>Ls., quite variable in lithology and fossil content both vertically and laterally. The lower foot is light brownish gray, (5YR6/1) medium crystalline limestone that is studded with 1 inch brachiopods (?) many of whose shells are now geodes (lined with small crystals). The next 4&quot; consists of medium gray (N5) medium crystalline limestone which is either relatively unfossiliferous or consists almost completely of crinoid fragments, of Brownish gray (5YR4/1) medium grained very fossiliferous (many crinoid heads, stems and arms, and fenestrate bryozoans). A mottled Yellowish gray (5Y7/4) makes up the rest of the bed. It contains a zone of the same type of 1&quot; brachiopods (?) at the bottom but upward has many larger brachiopods with flat shells and ribs.</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>Shale, very fossiliferous, the fossils consisting of many crinoid fragments representing many different types of stems, many Girtyocelia bodies, and many irregular coral forms. Color medium light gray (N6).</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
<td>Ls., very fossiliferous and oolitic. Oolites about 2 mm in diam. Very variable in color but generally brownish gray (5YR4/1). Oolites commonly filled with limonite locally. Many crinoid stems and high brachiopods (?). Upper 6-8&quot; is full of Myalina (?) and fenestrate bryozoans and weather much more readily than does the lower massive part of the upper bed.</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>Shale, olive gray (5Y4/1) contains many lenses and beds of ironstone concretions in basal portion. Poorly exposed but general content remains the same until the upper 4' which is medium gray (N5).</td>
<td>100.0</td>
</tr>
<tr>
<td>6</td>
<td>Ls., very fine crystalline, hard, brittle, but apparently is very clayey. Medium gray (N5).</td>
<td>.33</td>
</tr>
<tr>
<td>7</td>
<td>Shale, medium gray (N5) fossiliferous, contains many limestone nodules and concretions in upper foot, the upper 5&quot; constituting a clayey limestone.</td>
<td>3.0</td>
</tr>
<tr>
<td>8</td>
<td>Ls., has the appearance of a fine colite, but these may be Osagia algae. They make up the entire rock for 1.5 feet. The base is very irregular and this bed varies in thickness from 1 to 2 feet. Has clayey Osagia (?) zone at base locally.</td>
<td>1.5</td>
</tr>
<tr>
<td>9</td>
<td>Sh., thin, calcareous variable in thickness.</td>
<td>0'1&quot;</td>
</tr>
<tr>
<td>10</td>
<td>Ls., basal 5&quot; contains many Osagia algae and is medium crystalline and yellow (5Y8/1) to grayish orange pink (cont.)</td>
<td>8.0</td>
</tr>
</tbody>
</table>
## State Geological Survey of Kansas

### Locality Description

<table>
<thead>
<tr>
<th>Sec. 30</th>
<th>Locality description</th>
<th>Stanton. Section starts at RR tracks where small ravine crosses it and proceeds east and then north up hill to lime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured by</td>
<td>H. C. Wagner</td>
<td>Date 5-12-74</td>
</tr>
</tbody>
</table>

### Remarks

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 (cont.)</td>
<td>It is overlain by yellowish gray (5Y8/1) fine crystalline, hard ls. that is seamed with irregularly shaped coarse calcite. The lower 3 feet weathers into 2&quot; regularly bedded layers but the upper part weathers to the pitted, wuggy irregular surface that is characteristic of the Capt. Creek ls.</td>
</tr>
</tbody>
</table>

### Bed No. | Thickness
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10 (cont.)</td>
<td>824</td>
</tr>
</tbody>
</table>

### Diagram

- **Posa:** Location of the survey point
- **Bed:** Number of the bed
- **Strat.:** Stratigraphic position of the bed

[Diagram of stratigraphic section]
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ls, poorly bedded, clayey breaks into thin flatish plates.</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Very fossiliferous consisting mainly of crinoid stems, brachiopod and penegeopy fragments, rhomboporous bryozoa, and many fusulinids. Feathers to dark yellowish orange (10YR6/6) and dark yellowish brown (10YR4/2). Fresh surface is medium gray (N5).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>In this locality there is a covered interval above this bed that is about 2.5' thick and then more is float on that. No outcrop.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shale, grayish orange (10YR7/4) and nearly white interbedded.</td>
<td>1.2</td>
</tr>
<tr>
<td>3</td>
<td>Slat, clayey, many plant fragments on bedding planes. Grayish orange (10YR7/4) poorly bedded. A few clay shales beds included.</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>Slat, clayey, medium bluish gray (5B5/1) poorly bedded.</td>
<td>1.2</td>
</tr>
<tr>
<td>5</td>
<td>Slat, well bedded, thin bedded-beds about ½ to 1 inch in thickness. Breaks into slabs. Yellowish gray (5Y7/2).</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Water
State Geological Survey of Kansas

Locality description:
Section measured from bottom of creek up the hill to the east-west road where it turns North down the hill.

Measured by Holly C. Wagner
Date 11-22-52

Remarks

Bed No.  Description       Thickness
1.    Lg. light gray (N7) when fresh, weathers to pale yellowish orange (10YR8/2). Very fossiliferous. Mainly small brachiopods. Top of hill.        1'
2.    Sandstone, very fine, angular grains, micaceous, strongly iron-stained dark yellowish orange (10YR6/2) to light brown (5YR5/6).        2.9'
3.    Lg. very sandy & micaceous. Very pale yellowish brown (10YR7/2) 1.4
      Unfossiliferous.
4.    Shale, very silty, micaceous, poorly bedded, stongly jointed. 1.7'
      Has thin clay layers in upper 8". Becomes very calcareous in upper 2". Yellowish gray (5T7/2) to pale yellowish orange (10YR8/6).
5.    Shale, fissile, dark gray (N3) breaks into large 3" thick plates. Contains zone (1" thick) of phosphatic (brown) nodules 11" above base.
6.    Lg., clayey & silty, dirty, very fossiliferous, many fusulinids. 1.4 light gray (N7). Locally iron stained. Upper 6" is limestone rubble.
7.    Coal.                                64"
8.    Claystone, medium dark gray (N4), carbonaceous, non-silty.          5'
9.    Coal                                 5'
10.  Claystone, medium dark gray (N4), carbonaceous, non-silty. 3.2'
11.  Coal-iron stained.                    1'
12.  Claystone, non-silty, purplish gray color near grayish purple (5P4/2) in upper 3/4 inch. Lower 2" ironstained badly.
13.  Shale, medium light gray (N6) to dark yellowish gray (5Y7/1). 81/2'
      Fissile, non-silty.
15.  Shale, medium light gray (N6) to dark yellowish gray (5Y7/1) 28.5'
      Fissile, non-silty.
16.  Lg. brownish gray (5YR6/1) to medium gray (N5) Medium 3.01 crystalline with many white specks throughout. Fossiliferous, fossils mainly Osagia (?) algae and small brachiopods. A few crinoid stems. Base not exposed. Joints N25E prominent.
State Geological Survey of Kansas

Locality description:

Measured from base of bridge across Hwy 47 eastward up south side of road to house.

SL 11-29-16

Measured by: H. C. Magner  Date: 11-23-52

Remarks:

Bed No. | Description |
--- | --- |
1 | 
| Ss, very fine grained, well sorted, subangular quartz grains and a few feldspar grains. Lica flakes abundant. Loaded with plant fossils (leaves) in good condition. Very finely sorted with limonite. Very pale orange (10YR 8/2). Bedding poor and variable in thickness both laterally and vertically and varies from 2" to 1 ½ feet in thickness. Silty layers common near base of exposure. |
| 5.8 |

2 | Ss, very fine grained, silicified, no plants, few mica flakes. Light gray (N7). |
| 1.2 |

3 | Ss, very fine grained, micaceous, very similar to lower sandstone below silicified bed, except massive. Uppermost 1" has fossils & grades upward into |
| 2.7 |

4 | Ls, very fossiliferous and hard, weathers to dark yellowish orange (10YR 6/6), grayish orange (10YR 7/4) on broken surface. Has local clayey areas that weather into pitted or vuggy surface near top. Fossils consist predominantly of crinoid stems and small brachiopods, but also contains fenestellate bryozoans, Ostrea?, horn corals, and a few large brachiopods. Very fine crystalline. |
| 1.8 |

5 | Shale, unfossiliferous, dark yellowish gray (5Y6/2), non silty grades upward into |
| 0.5 |

6 | Shale, calcareous, very fossiliferous (dark yellowish gray), mainly crinoid remains. Grades upward into |
| 3.0 |

7 | Ls, shaly, very fossiliferous, containing abundant crinoid remains; looks oolitic, yellowish gray (5Y7/2) |
| 0.3 |

8 | Shale, unfossiliferous, pale olive (10Y6/2) very slightly silty, poorly exposed |
| 1.04 |

9 | Gravel deposit to top of hill mostly of local origin consisting of a heterogeneous mixture of olive gray to brown sandstones, light gray fossiliferous limestone, ironstone concretions, subangular to subrounded and varying in size from 1/8" to 8-10". |
| 8.0 |
State Geological Survey of Kansas

T. 28 S.R. 16E County Wilson Altoona Quad.

Sec. 33 Locality description CL Measured from top of hill eastward to hwy. 75 and south to fence south of house on west side of highway. Measured by Holly C. Wagner Date 11/23/52

Remarks

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ls. yellowish gray (5Y8/1) and yellowish orange (10YR7/6) on weathered surface, and broken surface also. Very fossiliferous consisting of crinoid stems, sponges, (Amblysiphonella and Girtyococelis) fenestrate bryozoans, locally almost entirely small brachiopods and a few large brachiopods, Dirty, that is, clayey and ironstained limestone.</td>
<td>7.5&quot;</td>
<td></td>
</tr>
<tr>
<td>2. Sh. light olive gray (5Y5/2). Calcareous, fossiliferous, from which many sponges and crinoid stems weather. Poorly exposed.</td>
<td>6.5&quot;</td>
<td></td>
</tr>
<tr>
<td>3. Ls. very fine crystalline, light gray (N7) fresh, grayish orange (10YR7/4) weathered. Very fossiliferous algal, brachiopod fragments, crinoid stems, sponges.</td>
<td>0.5&quot;</td>
<td></td>
</tr>
<tr>
<td>4. Sh. silty, yellowish gray (5Y7/2) that contains a thin 1/2&quot; bed of ironstone concretions, (grayish yellow (5Y8/4) and pale yellowish orange (10YR8/6) below the top, and a 2&quot; bed 5.2&quot; below the top. The limestone bed is very fossiliferous, clayey, with crinoid stems, several spines of brachiopods, grayish orange (10YR7/4). A silty layer 1&quot; thick separate the upper yellowish gray shale from an olive gray (5Y4/1) very slightly silty shale. The siltstone layer contains plant fragments. Another siltstone layer 1&quot; thick occurs 24&quot; below the upper one. The shale between the two varies laterally in color between the yellowish gray and olive gray color. Covered to bottom of hill where Lola is in stream bed.</td>
<td>40&quot;</td>
<td></td>
</tr>
</tbody>
</table>
Locality description: Section starts in gully at 2 side of N-S road about 500' N of 3 Rounds School and goes North 14 mi. to top of hill, then back 2 mi. to Rd and N 7/8 mi. and north up to top of hill.

Measured by H. C. Wagner

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fine, grayish orange pink (5YR7/2) to grayish orange (10YR7/4). Poorly bedded, thin bedded, fragmental, consisting mainly of small crinoid stem fragments in a small Usagia matrix. Other fossils include crinoid stems and a few brachiopod fragments.</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td>Sh, yellowish gray (5Y8/1) to light olive gray (5Y6/1) fissile, very slightly silty. Lower 2 poorly exposed. Unfossiliferous. A few 1&quot; lenses of calcarcous concretions 7-10 below top.</td>
<td>98.0</td>
</tr>
<tr>
<td>3</td>
<td>La, hard, vertically jointed, light olive gray (5Y6/1) fresh. Usagia, horn corals. Upper 0.5' hard not so fossiliferous except locally is Usagia la., with pinkish cast.</td>
<td>1.1</td>
</tr>
<tr>
<td>4</td>
<td>Sh, yellowish gray (5Y6/1), calcarcous, very fossiliferous throughout. Two of three zones that are almost limestone beds included. These have very abundant fossils also, Neospirifer, Derbyia, fenestrate bryozoa, Haliospicion, Hustedia.</td>
<td>7.5</td>
</tr>
<tr>
<td>5</td>
<td>La, grayish orange (10YR7/4), clayey, impure, very poorly bedded, weathers into irregular shaped fragments of all sizes. Very fossiliferous, Neospirifer, crinoid stems, encrusting bryozoa, Hustedia, Composita, Heliospicion. Uppermost 4' light gray (N7) and little clay, very fossiliferous, medium crystalline, fenestrate bryozoan, Composita, brachiopods, crinoid stems, oolite?</td>
<td>23.2</td>
</tr>
<tr>
<td>6</td>
<td>Covered interval but slope suggests a clay or shale. This would be the Violas shale.</td>
<td>5.7</td>
</tr>
<tr>
<td>7</td>
<td>La, very light gray (N8) to pinkish gray (5Y8/1) weathered, thin bedded (2&quot;) in basal 3' and more massive above. Consists of a limestone coquina in apparently an algal matrix.</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Remarks:

Osagia?
State Geological Survey of Kansas

T. 28 S., R. 17 E., County Wilson

Sec. 28 & 33 Locality description

Measured by Date

Remarks

Bed No. Description Thickness
State Geological Survey of Kansas

Locality description Typical Exposure of the Vilas Shale. Measured from top of hill downward along west road ditch to point about 50 feet north of mailbox of 2nd farmhouse South.

Measured by Holly C. Wagner Date 6/25/54

Remarks Measured with hand level and 6-foot tape.

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6 ty</td>
<td>1.8, Light gray (077), hard, wavy &amp; irregularly banded, very thin 61+ bedded. Basal contact is gradational with underlying shale. Very fossiliferous including abundant Maksia locally that grade(?) laterally(?) into abundant small Osagia. The Osagia bed is about a foot and a half above the base at this locality. Typically very light gray (N6) vuggy, blotchy gray and white limestone with large areas of coarsely crystalline calcite occurs above these algal beds.</td>
<td></td>
</tr>
<tr>
<td>2.5 ft.</td>
<td>2. Sh, Light grayish orange (10YR8/1), calcareous, fossiliferous. 31/2 The upper inch contains fossils locally including small brachiopods, crinoid stems, and Tremadors-like gastropods.</td>
<td></td>
</tr>
<tr>
<td>3.6 ft.</td>
<td>3. Sh, nodular, medium gray (5N): weathers grayish orange (10YR7/1) 0.5 to pale yellowish brown (10YR5/2); slightly fossiliferous and of variable clay content. This bed occurs as a layer of unconnected roundish algal(?)-bodies that contain angular fragments of light olive-gray (5Y5/2) clay shale in their lower portions and a few fossils in other centers. Laterally they grade into a solid bed 0.61 thick that appears to consist, in the upper 2&quot; of small (.1-0.4&quot; diam.) algal pellets and Chonetia (?), Rustedia, Punctospirifer, crinoid stems, etc., most of which have an algal(?) coating. (There is a question in my mind whether the shale and algal limestone should not properly be placed in the Stanton limestone on an environmental basis -- but for mapability, the base of the Stanton should stop at the base of the Captain Creek as shown).</td>
<td></td>
</tr>
<tr>
<td>4.5 ft.</td>
<td>4. Sh, light olive gray (5Y5/2); non-silty, unfossiliferous, grades 81 downward into</td>
<td></td>
</tr>
<tr>
<td>5.5 ft.</td>
<td>5. Sh, dark bluish gray (5B3/1), non-silty, unfossiliferous, that 101 contains near its middle a 0.11 bed of lime gray (5B5/1) very clayey calcareous unfossiliferous concretionary bed seam-ed with black calcite and, at the top has a similar bed that is apparently not calcareous and about 0.11 thick. Grades downward into</td>
<td></td>
</tr>
<tr>
<td>6.5 ft.</td>
<td>6. Sh, light olive gray (5Y5/2), unfossiliferous, slightly silty, 851 finely micaceous locally. Contains several thin beds of ironstone concretions in the upper 60 feet and in the lower 151. Pencil jointing, trending N30E, occurs in the upper 251. The culvert on the north side of the E-W road 35 ft. above the base. Poorly exposed in the lower 15 feet. The Vilas Shale, including the beds 2, 3, 4 and 5, is 101 thick.</td>
<td></td>
</tr>
</tbody>
</table>
| 7.5 ft. | 7. Ia, grayish orange (10YR7/4) to dark yellowish orange (10YR6/6) 8.8
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.6h</td>
<td>Light gray (N7), light brownish gray (5Y6 1/1) and light olivine gray (5Y6 2/1), very fossiliferous and calcareous. The calcium carbonate content becomes excessive in two thin (3-12&quot;) zones about 3 and 6 feet above the base and vary fossiliferous shale goes laterally into nodular brownish gray limestones. The fossil content consists predominantly of crinoid stems, Helioponida and Girtyocella. Also included are fragments of crinoid heads and plates, ramose and fenestrate brachiopods, horn corals, Hustedia, a gastropod much like Tampoaspida, and other brachiopod fragments that look like parts of Marginifera, Neospirifer, and Compsacta. The shale is very thin banded, almost fossiliferous, but does not break into large plates but crumbles. The calcareous zones occur parallel to the bedding and some bedding planes contain many more fossils than others, although the fossil content is distributed throughout. Shale becomes increasingly calcareous near the upper contact.</td>
<td>8.21</td>
</tr>
<tr>
<td>9.1s</td>
<td>Grayish orange (10YR7 1/4) to dark yellowish orange (10YR6/4). A hard, very fossiliferous, weathers to a knobby surface, and rather platy locally, generally a single thin bed. Fossil content consists mainly of fragments of crinoid stems, fenestrate brachiopods, Girtyocella, Helioponida, horn corals, ramose brachiopods, encrusting brachiopods, and various brachiopod remains including Meekella, Hustedia. Also, some fairly well preserved crinoid calyces were noted.</td>
<td>5.1</td>
</tr>
</tbody>
</table>
**State Geological Survey of Kansas**

T. 30 S., R. 15E

**Locality description**
Section starts in stream cut 100' W of US 75 at road to oil well about 1/2 mi. south of junction of K-39 and US 75. Measurement was then carried to junction of K-39 & US 75 and thence westward about 3 mi. to top of hill.

**Remarks**
Measurements made by plane table and tape.

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6s (or ady 1s), weathers very pale orange (10YR8/2) but is grayish red (10R4/2) on fresh surface. Fine mica flakes moderately abundant; fizzes profusely with acid on fresh surfaces but not on weathered faces. Sand grains very fine to fine, well sorted locally, angular to subangular. Unfossiliferous except for carbonized wood locally abundant and worm (?) tracks. Bedding surfaces poor and irregular. No well-defined cross bedding or ripple marks. Clayey zone near center of exposure weathers inward and breaks into 1/4&quot; fragments. Uppermost 2&quot; is micaceous and very fossiliferous. The fossils consist mainly of small fragments of crinoid stems, ramose bryozoans, and brachiopods (Limonopodita ? and Neospirifer), and horn corals. It grades upward into 2 Ls, light gray (N7), dense, hard, moderately fossiliferous. Fossils consist of Cryptozoan, crinoid stems and plates, horn corals, ramose bryozoans, and a few fenestrate bryozoans. &amp; Osagia. The upper 3&quot; contains abundant Osagia and crinoid fragments and a few horn corals &amp; bellerophontids. Nothing else noted. Weathers into 1/4&quot; inch flaggy beds. At junction K-39 &amp; US 75 Ls is clayey &amp; hard &amp; weathers into 1-1/2&quot; hard, vertically jointed beds. Contains Marksia and Neospirifer. Measuring just on K-39. 4 Covered interval, apparently all shale. 44.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Sh, very pale orange (10YR8/2) to moderate yellowish brown (10YR5/4). Slightly calcareous. 1.6</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Ls, concretionary band; concretions 5-10&quot; thick; pale yellowish brown (10YR5/4) (fresh surface) yellowish orange (10YR7/6) on weathered surface. Unfossiliferous. 0.7</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Sh, slightly silty, yellowish gray (5Y7/2), weathers into flat 2.2 plates 1/8&quot; by 1/16&quot; by 1/8&quot;. 1.0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Ls, concretionary band, pale yellowish brown (10YR5/4). Unfossiliferous. 0.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Sh, yellowish gray (5Y7/2) to light olive gray (5Y6/1) very slightly silty, fissile, unfossiliferous. Has a few ironstone or iron-rich layers near the top. 25.7</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Ls, medium gray (N6) with limonite stains; hard in upper half, but lower half weathers into 1/2&quot; nodular masses which consist of fossil fragments and individual overgrown Osagia. This limestone is dominantly an Osagia limestone but contains also abundant brachiopod fragments (Neospirifer, Hustedia, Cioconita, Derbyia, fenestrated bryozoans, Gastrocoelia and Heliopora, and very abundant crinoid fragments. 1.1</td>
<td></td>
</tr>
</tbody>
</table>

(Cont.)
Sec. 25 & 26
Locality description
Section starts in stream cut 100' N of US 75 at oil well about 1/2 mi. S of junct. of K-39 and US 75. Measurements was then carried to junct. of K-39 & US 75 and thence westward about 1 mi. to foot of hill.
Measured by H. C. Wagner Date 7-11-53
Remarks Measurements made by plane table and tape.

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Bottom of stream</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Sh, light olive gray (5Y6/1), poorly bedded and very fossiliferous. Most abundant are crinoid stems, plates and spines, Girtyocoelia, Heliospongia, Encrusting bryozoans, Composita, Derbyia, Neospirifer, Punctospirifer. This is the thickest I have seen this shale. It contains three 4 in. to 8 in. thick nodule limestone beds within it. These beds are very fossiliferous and weathered 1/2&quot; fragments studded with fossils of the same varieties as listed above in the shale. Color of limestone is pale yellowish orange (10YR6/6) on surface.</td>
<td>20.2</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Ls, medium gray (N6) with limonite stains fresh, and pale yellowish orange (10YR6/6) weathered. Very impure. Weathers either into small rounded fragments or 1 foot wide slabs. Osagia profuse in lower part, less so upward. Fossils include Osagia, Girtyocoelia, Heliospongia, Derbyia, Neospirifer, Punctospirifer, Composita, many types of crinoid stems, plates and caps, fenestrate bryozoans. Many shaly streaks throughout the Ls from which the fossils weather.</td>
<td>28.2</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Ls, medium gray (N6) on fresh and weathered surfaces. Contains many 1/2 to 2&quot; angular bodies of limonitic material which have breccia appearance. Matrix is dense. No Girtyocoelia or Heliospongia noted. Cryptozoa and many crinoid remains commonest fossils.</td>
<td>30.6</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Ls, yellowish gray (5Y6/1) and medium dark gray (N4) noddled, dense, hard. Many crinoid stem fragments in a matrix of very fine (1/32 - 1/16&quot;) Osagia or oolites. Limonitic angular areas common. Irregularly bedded.</td>
<td>33.0</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Ls, medium dark gray (N4) fresh and light olive gray (5Y6/1) to weathered. Clastic limestone consisting primarily of fairly well sorted fragments of crinoid stems, brachiopods, ramose bryozoans, and Osagia or oolitic pellets about 1/32&quot; in size. Larger fragments common locally. Weathers to massive 2' beds locally and top usually forms bench.</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Covered interval-Augered and is very pale orange (10YR6/2) shale</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Ls, medium light gray (N6) fresh and yellowish gray (5Y7/2) to very pale orange (10YR6/2) weathered that is spaced very abundantly with thin dark sinuous algae (Karksia) locally the Karksia make up almost the entire rock and then they resemble cryptozoa. The uppermost layer is an in-crease in generally with some crinoid &amp; brachiopod fragments. A slope that appears to represent about 1 foot of shale separates this limestone from</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Ls, very light gray (N6) to white (N7), weathers to a gneiss or cavernous surface noddled hite and light gray and internally</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>17 (cont.)</td>
<td>is relatively porous and soft. Contains horn corals, crinoid stems &amp; Crystozoa in a sparsely to profusely usa matrix.</td>
<td>top of hill-end of section</td>
<td></td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Sh, silty, light olive-gray (5Y6/1) that contains thin (&quot;m) siltstone beds interbedded. Silt beds weather dark yellowish brown (10YR6/2) and are moderate yellowish brown (10YR6/4) on fresh surfaces. They are thinly laminated with light colored clay. Micaceous, ripple marked.</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Sh, very fine grained, micaceous, light olive gray (5Y5/2) weathered, yellowish gray (5Y7/2) fresh but iron stained to dark yellowish orange (10YR6/6). Grains are mostly well sorted subrounded quartz. Much carbonaceous material (finely broken) on bedding planes accompanied by very small white mica flakes. Cross bedded. Vertically jointed. Joints trend N70E &amp; N30W.</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Sh, silty, light olive gray (5Y6/1), fissile poorly ripple marked, contains a 6&quot; slat. bed at center.</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Sh, very fine grained, micaceous, light olive gray (5Y5/2) speckled with limonite, white (11)</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Sh, light gray (10Y) interbedded, fissile; becomes yellowish gray (5Y7/2) in upper 10 ft. Finely micaceous on bedding planes.</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ls, impure, grayish crand (10YR7/4) to pale yellowish orange (10YR6/6). Weathered readily into angular flat chips. No apparent bedding. Locally nodular and contains veins of calcite and dolomite. Also magnetite? Scarcely fossiliferous including Derbyia, Usalia, productid spines, crinoid stems. Hard, light gray (N7) to yellowish gray (5Y7/2) crystalline, limestone near upper contact (about 2&quot; thick). Overlain by impure fangy algae, fossiliferous ls. (2&quot;)</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Claystone, clean, olive-gray (5Y6/1) fresh, grayish yellow (5Y6/4) weathered. No bedding. Breaks into angular blocks 1&quot; or less in size. Contains a 3&quot; bed of Ptyllina and some crinoidal stems about 9' above the base.</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Ls, hard, brittle, vertically jointed HEOE, NA0, &amp; H1OE. Color medium dark gray (N4) fresh, yellowish gray (5Y7/2)weathered. Contains prominent Cryptozoon, and some Haccomifer crinoid stems, ramose bryozoans, productid spines; fusulinids scarce to moderate.</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Covered Interval. Two pronounced topographic benches occur 46&quot; 1/4&quot; and 52&quot; above the base. Represented by concentrations of 3s blocks.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Sh, very fine gr., pale reddish brown (10YR6/4) weathered and grayish orange (10YR7/4) fresh. Consists almost entirely of well-sorted, subangular parts. Trains. No slats. Blocks of iron oxide common. Jointed breaks into large blocks 2-3' thick.</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>
State Geological Survey of Kansas

Locality description: Section measured from bottom of creek about East of bridge upward up hill to the west and south to top hill.

Remarks

Bed No. | Description | Thickness
---|---|---
9 | | |
8 | | |
7 | | |
6 | | |
5 | | |
4 | | |
3 | | |
2 | | |
1 | | |
State Geological Survey of Kansas

T. 30 S., R. 14 E., County Wilson

Sec. 1-30-13

Locality description
Section starts at NE cor 17-30-14 and goes west along road to sec. 15-30-13.

Measured by H. W. Wagnor Date 7/5:

Bed No. Description Thickness

1 Sh, or claystone, yellowish gray (5Y7/2), nonsilty, calcareous 5.5
at upper contact. No fossils apparent. According to farmer Westphalia crops out in stream about 300' N of rd. in CS1
13-30-13 where Vinland 9' thick.

2 Ls, hard, brittle, vertically jointed E70E, N5E, yellowish gray (5Y7/4) weathered. Fossils consist of abundant Cryptozoan, and a few Juresania, Linoroductus, crinoid stems, Derbyia, Eeokula, fusulinids (s);
Covered-but apparently is sh, yellowish gray (5Y7/2)-Many 53.2
ironstone concretions.

3 Ss, very fine gr., white (5Y) at base and light olive gray (5Y7/2) fresh upwards. Fossils are yellowish orange (10YR8/6)
Well sorted subangular to subrounded quartz grains. Boulders of Iron oxide common. This is channel fill and fills channel in Robbins about 15 ft. and must cut out a limestone that cross out in RR cut 1 mile N of S Sec. 13-30-13. 4 he is in 1' thick beds, very impure, sandy and silty and micaceous, much ironstone replacement and many fossils including Juresania, Derbyia, Neosinifer, Ocaria, Dictyoclostus, echinoids, crinoid stems, Linoroductus. Overall thickness of Ls is 1.0'
Uppermost 1' bed is dark reddish brown (10R3/4) and lower part is yellowish gray (5Y7/2). Above the bed 2' is another thin Ls, very fossiliferous and above this there must be another that is almost solid fusulinids. I found float in several places but did not find it in place. the sandstone is in beds that average about 2' to 3' in thickness.
The fusulinid bed is about 2' below the base of the Ireland and 3'/4 above the other Ls.
<table>
<thead>
<tr>
<th>Sec.</th>
<th>Locality description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measured by</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**State Geological Survey of Kansas**

**3-30-15 and 34-20-9W and 35-29-15 S.**

**County** "Alison"

**Sec. 3, T. 30 S., R. 15 W.**

**Locality description** Section starts at A-28 and then jumps to A-22 and proceeds north and west up the hill.

**Measured by** H. C. Wagner  
**Date** 7/4

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sh, (actually a very slightly silty claystone that breaks into angular fragments). Weathers pale yellowish brown to light olive gray (5Y5/2) or light olive gray (5Y5/2) fresh. Contains a few thin beds of light bluish gray (5B7/1) claystone. Very slightly silty. Thin (1&quot;) beds or lenses of hard siltstone occur 2-5 ft. below the top. Form tracks are common on the siltstone.</td>
<td>15.0</td>
</tr>
<tr>
<td>2</td>
<td>Ls, hard, clayey, very fossiliferous, weathers pale yellowish orange (10YR8/6), fresh medium olive gray (5Y5/1). Fossiliferous containing crinoid stems, Heliospongia, Osagia, foraminifera? (white, hollow bodies about 1/16 - 1/32&quot; in size). Girtyocoelia and brachiopod fragments. A 2&quot; layer occurs near the base that is made up of small fragments of rhombohedral bryozoans, fenestrate bryozoans, productus spines, and small fragments of brachiopods.</td>
<td>1.2</td>
</tr>
<tr>
<td>3</td>
<td>Shale, very fossiliferous, slightly silty, light olive gray (5Y5/2) to olive gray (5Y3/2). Contains abundant Girtyocoelia, crinoid stems and heads, large Heliospongia, Dicryoclostus, Juresania, Composita, Hustedia, pelecypods.</td>
<td>13.8</td>
</tr>
<tr>
<td>4</td>
<td>Ls, thin bedded, irregular bedded very shaly and impure, very fossiliferous, medium light gray (5Y5/6) fresh, pale yellowish orange (10YR8/6) to pale yellowish brown (10YR6/2) weathered. Contains abundant crinoid stems, Girtyocoelia, Heliospongia, Juresania, fenestrate bryozoans, Cryptozoon common locally in upper half.</td>
<td>84.0</td>
</tr>
<tr>
<td>5</td>
<td>Covered interval-apparently gray to t.n. unifossiliferous shale.</td>
<td>14.0</td>
</tr>
<tr>
<td>6</td>
<td>Ls, hard, pale red (10R6/2) to grayish orange rank (10R8/2) fresh, yellowish gray (5Y6/1) weathered. An algae Ls made up almost entirely of Osagia but contains also a few brachiopod fragments.</td>
<td>1.6</td>
</tr>
<tr>
<td>7</td>
<td>Covered interval, apparently shale.</td>
<td>2.0</td>
</tr>
<tr>
<td>8</td>
<td>Ls, hard, very light gray (5B) with inkish cast on fresh surfaces, weathers white (N9). Weathers to irregular vuggy surface and in basal 3 ft. weathers to bruchiated appearance. Sparsely fossiliferous consisting predominantly of Cryptozoon and some brachiopod fragments and crinoid stems.</td>
<td>13.8</td>
</tr>
<tr>
<td>Bed No.</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Locality description:

Measured by: [Blank]
Date: [Blank]
Remarks: [Blank]
State Geological Survey of Kansas

T. 30 S., R. 15E County - Wilson

Sec. 33 Location: Section measured from stream bottom at T road under bridge north to top of hill.

Measured by H. C. Wagner Date 7/2

Remarks

Bed No. Description Thickness

1 Sh, grayish orange (10YR7/4), calcareous. 0.2
2 Ls, hard, vertically jointed lime. Moderately yellowish brown 1.2
(10YR7/4) to greenish gray (5Y6/1) fresh and grayish orange (10YR7/4) to very pale orange (10YR8/2) weathered. Fossiliferous, including crinoid stems, Girtyocoelia, Hustedia.
3 Sh, greenish gray (5Y6/1), calcareous, very fossiliferous. 2.1
Fossils are contained as single units in the shale, (especially in the lower part) but in many cases weather from impure limestone nodules and nodular beds (1-2" thick) throughout the shale. Fossils consist of crinoid remains, and a few Composita, Girtyocoelia, Heliogonelia, Tenestrate bryozoans, Hustedia.
4 Ls, very impure at base but harder at top, medium gray (5Y 5) fresh and grayish orange (10YR7/4) to very pale orange (10YR8/2) weathered. Very fossiliferous at base, less so at top. Ls is dense (very fine crystalline) with many calcite areas which are fossils. Fossils consist of crinoid remains, Girtyocoelia, Heliogonelia, Composita, Hustedia, Juracania, or Dictyonectes, many small (pinhead size) white hollow bodies- forams, and locally usadia and Parksia, fenestrate bryozoans, Crurithyris, Neogonifera, horn corals, encrusting bryozoa, Punctorstirifer.
5 Sh, yellowish gray (5Y7/2) to grayish yellow (5Y8/4) slightly silty, unfossiliferous except for a few plant fragments on bedding planes. Lower part finely exposed. 4.0
6 Ls, dk yellowish gray (5Y6/2), finely micaceous, slightly sandy. Apparently unfossiliferous. 5.0
7 Ls, medium light gray (5Y), silty, hard. Weathers to a single 0.9 massive bed. Unfossiliferous.
8 Sh, pale yellowish brown (10YR6/2), silty, unfossiliferous. 0.4
9 Ls, pale yellowish brown (10YR6/2), sandy (very fine gr. 0.1
etz.), a few carbonaceous fragments and small mica flakes. Unfossiliferous.
10 Sh, pale yellowish orange (10YR8/4), silty, Unfossiliferous. 0.3
11 Ls, pale yellowish brown (10YR6/2), silty to sandy slightly 0.2 micaceous. Contains a few small shell fragments.
12 Sh, yellowish gray (5Y7/2), calcareous, silty, unfossiliferous. 0.3
13 Ls, light olive gray (5Y6/1), silty or very fine sandy. Lo bs 0.1 like very fine sized Oasia throughout.
14 Sh, grayish orange (10YR7/4), very friable and calcareous. 1.6
15 Ls, medium dark gray (5Y), hard, very fossiliferous, matrix 0.9 Oasias and small oolites. Fulminating spar to moderate, throughout. Also cr. clays and few small attached brachiopods.
<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Ls, very light brownish gray (5YR7/1) hard Usagia algae matrix.</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Also profuse many small fusulinids and crinoid stems. Laterally Usagias</td>
<td></td>
</tr>
<tr>
<td></td>
<td>become very small and upper 0.1' becomes unfossiliferous, finely sandy and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>has carbonaceous material and small mica flakes.</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Sh, silty, micaceous, slightly fossiliferous, mostly objects</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Contains 4-5 1/4&quot; ripple-marked limestone beds that are micaceous but</td>
<td></td>
</tr>
<tr>
<td></td>
<td>contain many Usagia beans and fusulinids.</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Silt, moderate yellowish brown (10YR5/4) to dark yellowish orange (10YR6/6)</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Micaceous, cross bedded, ripple marks (trend NE to steep side shows</td>
<td></td>
</tr>
<tr>
<td></td>
<td>currents from S. and worm tracks.</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Covered Interval—shale apparently. But shows upper foot to be alternating</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>paper-thin plates, finely micaceous silt and shale interbedded. Yellowish</td>
<td></td>
</tr>
<tr>
<td></td>
<td>gray (5Y7/2).</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Silt, moderate yellowish brown (5YR5/4), finely cross bedded and ripple</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>marked. Weathers into 2&quot; beds.</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Sh, silty, yellowish gray (5Y7/2) that contains several thin light</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>bluish gray (5Y7/1) siltstone in lower portion some of which have trace</td>
<td></td>
</tr>
<tr>
<td></td>
<td>molds of crinoid stems, fusulinids and brittle stars.</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Ls, very clayey, light bluish gray (5Y7/1) nodular, fossiliferous but most</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>fossils have coating of CaCO₃ that precludes identification. Derb-is,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>crinoids. Weathers readily.</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Sh, yellowish gray (5Y7/2) weathered light gray (N7) fresh.</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Silty, micaceous, apparently unfossiliferous.</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Ls, about half clay in segregated units separated by Marksia.</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>Odd. Micaceous and silty also. Grayish orange (10YR7/4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Occurs in three beds separated by calcarneous silt, locally slightly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fossiliferous. Upward 0.3 Ls, 2.4 Sh, 0.5 Ls, 1.1 Sh, 1.6 Ls. Upper Ls is</td>
<td></td>
</tr>
<tr>
<td></td>
<td>hard and relatively massive. Thickness latemly downward to 3.8' thick.</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Sh, calcarneous apparently unfossil. grayish orange (10YR7/4).</td>
<td>0.1</td>
</tr>
<tr>
<td>26</td>
<td>Ls, massive, single bed, vuggy, cavernous. Nearly white in color. Much</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>secondary calcite in veinlets, soft, punky areas common. Usagia and Marksia</td>
<td></td>
</tr>
<tr>
<td></td>
<td>prominent locally.</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Ls, like below but apparently another thick bed.</td>
<td>6.0</td>
</tr>
<tr>
<td>28</td>
<td>Ls, about this much more overlies the 5.3 and 4' unless there is a rapid</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>dir change that I don't see.</td>
<td></td>
</tr>
</tbody>
</table>
# Locality Description

Section measured under west end of Bill Street Bridge, SE cor Neodesha.

<table>
<thead>
<tr>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured by H. C. Wagner Date 8-4-53</td>
</tr>
</tbody>
</table>

## Bed Description Table

<table>
<thead>
<tr>
<th>Bed No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td>Sh, light greenish gray (5GY6/1) to greenish gray (5GY6/1), fissile, slightly silty finely micaceous. Contains a thin bed of very fine grained sandstone. Concretions about 8&quot; below top. Upper part poorly exposed.</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>Clst, medium dark gray (N4), non-silty. Underclay</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>Coal, black, banded, more vitrain than dull. Bony in middle 1' and in upper 1&quot;.</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>Shale, variable in color but generally light greenish gray (5GY6/1) with many ironstone concretions in it. Thickness very variable as limestone fills scours cut into shale.</td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>Ls, medium light gray (N5), floogy and unfoss., where it fills 0.3-0.7 depressions but laterally grades into a medium light gray (N6) very calcareous micaceous siltstone, slightly fossiliferous includes crinoid stems and brach fragments.</td>
</tr>
<tr>
<td><strong>6</strong></td>
<td>Sh, calcareous or ls, very shaly, brownish gray (5YR4/1). Fossiliferous, mainly crinoidal remains.</td>
</tr>
<tr>
<td><strong>7</strong></td>
<td>Ls, hard, vertically jointed, medium gray (N5), dense, fossiliferous—crinoid stems, brachiod rod frogs, Cry toozoo.</td>
</tr>
<tr>
<td><strong>8</strong></td>
<td>Sh, light olive gray (5Y6/1), calcareous, micaceous, apparently unfoss.</td>
</tr>
<tr>
<td><strong>9</strong></td>
<td>Sh, grayish black (N2), fissile in lower 0.4'. Grades upward into olive gray (5Y4/1) micaceous siltstone (0.1'thick)</td>
</tr>
<tr>
<td><strong>10</strong></td>
<td>Ls, hard, olive gray (5Y2/1), carbonaceous and micaceous. Calcareous and contain s carbonate nodules (may be corals)</td>
</tr>
<tr>
<td><strong>11</strong></td>
<td>Sh, yellowish gray (5Y6/1), slightly silty, apparently unfoss. Contains limestone nodules.</td>
</tr>
<tr>
<td><strong>12</strong></td>
<td>Ls, irregular wavy bed, fossiliferous, mainly crinoids and brachiopods. Grayish orange (10YR7/4)</td>
</tr>
<tr>
<td><strong>13</strong></td>
<td>Sh, calcareous, fossiliferous, mainly crinoids and brach grayish orange (10YR7/4).</td>
</tr>
<tr>
<td><strong>14</strong></td>
<td>Ls, irregular, wavy bedded, grayish orange (10YR7/4) foss., crinoid and brach.</td>
</tr>
<tr>
<td><strong>15</strong></td>
<td>Sh, lenses out laterally, calcareous, fossil, yellowish gray (5Y8/1)</td>
</tr>
<tr>
<td><strong>16</strong></td>
<td>Ls, hard, medium bedded (0.2'-0.3' thick beds) grayish orange (10YR7/4) foss. Chonetes, Juracopia, Micrurifer, crinoid stems, fenestrate bryozoans, Hustadia, horn corals, ramose bryozoans.</td>
</tr>
<tr>
<td><strong>17</strong></td>
<td>Ls, shaly (and Sh, very calcareous,) light gray (11/2), finely algal, flaky, actually composed of fine sized fossil fragments of crinoids, brachiopods, ramose bryozoans, fenestrate bryozoans, in a fine vasia matrix.</td>
</tr>
</tbody>
</table>

**Whet gravels**
### Locality description

Section measured starting in bottom of small creek west of Hwy 37, thence east on 2nd W rd where good exposure are and touch up Hill Creek, a side of Hwy 37, then north on road for 1 mile south.

Measured by R. C. Wagner  Oude 9-27-53

### Bed No. |

<table>
<thead>
<tr>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ls, medium light gray (H6) weathered light olive gray (5Y5/2) 1.5 to yellowish gray (5Y7/2), hard, vertically jointed, dense. Fossiliferous, but not profusely so. Contains Larksia?, many brachiopods (large and small), crinoid stems.</td>
<td></td>
</tr>
<tr>
<td>2. Sh, dark yellowish brown (10YR4/2) to medium gray (H5), slightly silty, finely micaceous, fissile, a few &quot;ironstone concretions in beds throughout. Hi-grade marked in lower 2'.</td>
<td>0.1</td>
</tr>
<tr>
<td>3. Ls, medium light gray (H6) weathered dark yellowish orange (10YR6/6) to light olive gray (5Y6/1), hard, unfoossiliferous, non-marine.</td>
<td></td>
</tr>
<tr>
<td>4. Sh, yellowish gray (5Y7/2), fissile, micaceous.</td>
<td>0.2</td>
</tr>
<tr>
<td>5. Ls, light olive gray (5Y6/1), unfoossiliferous, grades upward into light olive gray (5Y6/1) massive micaceous silt in upper half.</td>
<td>0.4</td>
</tr>
<tr>
<td>6. Ssl, yellowish gray (5Y7/2), finely micaceous very thin bedded, several 1/4 - 1&quot; thin Ls (unfoossil.) platy beds in lower 2', thin shaly beds interlaminated. A few small ironstone concretions in upper 5 ft. Upper 2 ft. not visible but appear to be calcareous silt.</td>
<td>26.0</td>
</tr>
<tr>
<td>7. Ls, medium gray (N5), very fossiliferous. Usuaia, bryozoa, several genera of fenestrata bryozoans, encrusting bryozoans, crinoid stems galore, horn coral (canina) Hustedia, ramose bryozoans, and huge echinococcus, also a crinoid calyx (on eastern of these blocks). Also Syringocorala. Most fossils are in upper inch, but abundant throughout.</td>
<td></td>
</tr>
<tr>
<td>8. Sh, light gray (N7) to pale brown (5YR5/2) unfoossiliferous, very slightly silty.</td>
<td>20.0</td>
</tr>
<tr>
<td>9. Ls, marly, pale yellowish orange (10YR8/6) seamed with moderate yellowish brown (10YR5/4) limonite seams. Breaks or weathers into nodules. Unfoossiliferous.</td>
<td></td>
</tr>
<tr>
<td>10. Osl, olive gray (5YR1/1) very slightly silty, breaks into cuboidal fragments about 1/8&quot; in size.</td>
<td>3.0</td>
</tr>
<tr>
<td>11. Coal, weathered, much vitrinite, boney at center.</td>
<td>0.7</td>
</tr>
<tr>
<td>12. Ssl, yellowish gray (5YR1/1) generally very well bedded into beds 1/8 - 3/8&quot; thickness. A few beds up to 2&quot; in thickness but lenticular. Many plant fossils in bedding planes. Two beds (lower one very lenticular) up to 2&quot; thick locally, in upper half. Very finely micaceous and locally cross bedded. Uppermost part shaly.</td>
<td>12.7</td>
</tr>
<tr>
<td>13. Ss, grayish orange (10YR7/4) to grayish red (10R4/2), fine grained, fairly well sorted, subangular grains of quartz make up 95%. Also a few angular to well rounded shale fossils and a few limestone grains. Thin beds (1-2'). Iron stained. Finely micaceous, plant frags.</td>
<td>11.0</td>
</tr>
</tbody>
</table>
**State Geological Survey of Kansas**

**Locality description**
Measure in stream to west and up the bank to top of bench in back of barn.

**Measured by H. C. Wagner**
**Date 9/17/53**

### Remarks

- **Bed No.**
- **Description**
- **Thickness**

1. **Shale:**
   - Very light brownish gray (5YR 6/1) to grayish orange (10YR 7/4).
   - Hard, irregularly bedded, vertically jointed, joints running N18E. Finely oolitic locally. Very fossiliferous.
   - Contains *Myticella*, *Myalina*, and locally a concentration of about 90% small brachiopod valves; also large fenestrate bryozoans and crinoid stems. This shale is folded into a series of parallel trending small folds trending N18E with vertical amplitude of about 1' and 12-14' from crest to crest. I have found these same folds in gulleys both north and south of here—with the same general trend and amplitude, and have also noted similar irregularities in the lower Drum 1 mile east of Neodesha.

2. **Shale:**
   - Medium gray (N5) to light olive gray (5Y6/1) fissile throughout, unfossiliferous, one inch lenticular gray beds of calcareous segregations occur throughout, one every 2 to 3 feet. 2" unfoss. Shale 19' above base and many thin flaggy shale beds for next 2'.

3. **Shale:**
   - Medium gray (N5) to medium light gray (N6) very fossiliferous, fragmental, very abundant crinoid fragments, also ramose bryozoans, *Myalina?*, fenestrate bryozoans.
A SUMMARY OF THE GEOLOGY OF WILSON COUNTY, KANSAS

Holly C. Wagner

INTRODUCTION

Wilson County lies in southeastern Kansas; it is the second county north of the Kansas-Oklahoma boundary and the third county west of the Kansas-Missouri boundary. The altitude of the land surface ranges from 755 feet to 1,125 feet above sea level, and drainage is generally to the southeast through the Verdigris and Fall Rivers. The county falls within the Osage Cuestas subdivision of the Osage Plains section of the Central Lowland physiographic province. The topography is characterized by east-facing escarpments formed by resistant beds of Upper Pennsylvanian limestone and sandstone; intervening areas of less resistant shale form complementary dip slopes tilted gently westward. These Upper Pennsylvanian strata are in the Kansas City, Lansing, Pedee, Douglas, and Shawnee Groups of the Missourian and Virgilian Series (Fig. 1).

STRATIGRAPHY OF OUTCROPPING ROCKS

Pennsylvanian System, Missourian Series

Kansas City Group

Dennis Limestone

The oldest unit that crops out in Wilson County is tentatively correlated with the uppermost member of the Dennis Limestone, the Winterset Limestone Member. Only the upper 1 1/2 feet of the unit is exposed and consists of medium- to light-gray, fossiliferous limestone. Small oolites in local concentrations, as well as crinoid fragments, products of spines, ramose and fenestrate bryozoans, and small brachiopods.

Cherryvale Shale

The Cherryvale Shale consists of about 40 feet of yellowish-gray to dark-yellowish-brown clayey siltstone and silty shale. Several beds of light-gray to yellowish-orange unfossiliferous limestone, 1/4 inch to 9 inches thick, occur in the middle and upper parts of the formation. The Cherryvale crops out only in the southeasternmost part of the county (Fig. 1).

Drum Limestone

The Drum Limestone averages about 1 1/2 feet thick and generally is a single bed of hard, vertically jointed, medium-light-gray fossiliferous algal limestone. Oolites, algae and invertebrate fossils are locally concentrated in the upper half. The fossils include bryozoans; horn corals, and Syringopora; ramose, fenestrate, and encrusting bryozoans; crinoid stem segments and calyces; small bellerophontid and high-spired gastropods; Myalinia and small pelecypods; and locally abundant Osagia and Cryptozoon-like algae. In places the lower part of the Drum is a medium-gray, sparsely fossiliferous, finely crystalline limestone.

Chanute Shale

The Chanute Shale ranges in thickness from 40 to 90 feet and lies conformably on the Drum Limestone in the few places where the contact is exposed in the county. The lower part of the Chanute consists of an unnamed yellowish-gray, nesosity to very slightly silty shale about 30 feet thick. A distinctive unfossiliferous argillaceous limestone bed occurs about 25 feet above the base of this lower shale unit. A sequence of coal beds, termed the Thayer coal, separates the lower shale unit from the overlying Cottage Grove Sandstone Member. Incomplete exposures preclude accurate correlation and measurement of rock types in the Cottage Grove, but where thickest it is apparently composed of about 45

Publication authorized by the Director, U. S. Geological Survey.

The nomenclature and classification of the geologic units described in this report are those of the State Geological Survey of Kansas. They differ somewhat from the usage adopted by the U. S. Geological Survey.
feet of yellowish-gray, slightly micaceous, very fine grained, silty sandstone overlain by about 10 to 30 feet of platy sandy siltstone, which is overlain by 30 to 45 feet of grayish-red thin- to thick-bedded sandstones. The platy sandy siltstone has abundant plant remains on the bedding planes and locally contains dark-colored silicified wood. Coal beds a few inches thick occur between the different sandstone units of the Cottage Grove. Unconformities apparently occur locally within the Cottage Grove Sandstone Member.

**Jola Limestone**

The Jola Limestone unconformably overlies the Chanute Shale, and in the east wall of the Dunbar strip mine the basal member of the Jola rests upon the truncated ends of the uppermost siltstone beds of the Chanute at an angle of about 10 degrees. The Jola ranges in thickness from 6 to 10 feet and is lithologically divided into three members.

The Paola Limestone Member at the base is a medium-gray, hard, very finely crystalline, fossiliferous limestone that averages about 1 foot in thickness but locally thins to 1/2 foot or thickens to nearly 2 1/2 feet. It contains crinoid stems, fenestrate bryozoans, horn corals, and brachiopod fragments; and where thickest, fossils and shells are abundant in the upper part. The Paola weathers grayish orange, is vertically jointed, and, where it surrounds erosional remnants of the Cottage Grove Sandstone Member of the Chanute Shale, it is sandy.

The Muncie Creek Shale Member is 2 1/2 to 4 1/2 feet thick and typically consists of grayish-black very fissile shale and yellowish-gray shale. The black shale comprises the lower 1 1/4 to 2 1/2 feet of the member, weathers to paper-thin plates, and commonly contains oval-shaped, brownish-gray, phosphatic concretions that occur in layers about halfway between the top and bottom. The phosphatic concretions are one-half inch or more in diameter and contain a small amount of radioactive material. The black shale is conformably overlain by yellowish-gray to pale-yellowish-orange, unfossiliferous, silty to non-fissile shale that is locally calcareous in the uppermost few inches. Where calcareous the yellowish-gray shale is very fossiliferous and grades upward into the limestone of the Raytown member.

The Raytown Limestone Member commonly consists of 4 to 5 feet of clayey fossiliferous limestone but locally grades into very sandy limestone or very calcareous shale. It contains brachiopods, horn corals, and fragments of crinoid stems and corals. In places much of the member is made up of fragments of light-gray limestone incorporated in a matrix of grayish-yellow limestone and dolomite. The fragments range in size from 1/8 inch to 2 inches and many have serrated edges.

An exposure of light-gray limestone a few hundred feet west of Barnhill Bridge is at the approximate stratigraphic position of the Raytown and apparently represents a local bioclast. The arched beds are composed of the remains of bryozoans, crinoids, brachiopods, mollusks, and many unidentified shell fragments in a fine-grained elastic limestone matrix.

**Lane-Bonner Springs Shale**

The Lane-Bonner Springs Shale consists of 50 to 100 feet of yellowish-gray to light-olive-gray very slightly silty shale. It is 100 feet thick in the eastern half of the outcrop area, thins to about 50 feet near Altoona, and thickens to about 70 feet a few miles northwest of Altoona. Several thin layers of ironstone concretions are prominent in the lower half of the formation, and a thin fossiliferous limestone bed that apparently changes laterally to an unfossiliferous septarian-concretion zone occurs about 90 feet above the base. This limestone bed contains abundant crinoid stems and brachio­pods and fragments of light-gray limestone incorporated in a matrix of grayish-yellow limestone and dolomite. The fragments range in size from 1/8 inch to 2 inches and many have serrated edges.

**Lansing Group**

**Plattsburg Limestone**

The Plattsburg Limestone has a maximum thickness of almost 120 feet but thins locally to less than 1 foot. It characteristically contains the sponges *Girtyocoelia* and *Helioponechus* and typically consists of two limestone members separated by a calcareous shale member. Where the formation is thickest it poorly bedded, almost unfossiliferous, oolitic, algal limestone occurs at the top of the upper limestone member.

The Merriam Limestone Member at the base is 1 foot thick except northeast of Villas where it thins to less than 4 inches. The Merriam is generally a single vertically jointed very fossiliferous limestone bed that is light gray to light olive gray on fresh surfaces and grayish orange where weathered. It has a very finely crystalline to microcrystalline limestone matrix in which the remains of crinoids, sponges, brachiopods, and horn corals are interspersed.
The Hickory Creek Shale Member averages about 5 feet thick but is as much as 10 feet thick northwest of Altoona and apparently is absent northeast of Vilas. The shale is very finely micaceous, slightly silty, very calcareous and fossi
iliferous, and varies from medium light gray to yellowish gray. Thin silty beds locally contain plant fragments. The most common fossils are crinoid columnals and the sponges Girtyocoelia and Heliospongia. Other fossils include parts of crinoid heads, ramoses and fenestrate bryozoa, horn corals, and brachiopods. The Girtyocoelia specimens weather out as chains of small spherical-shaped bodies or as separated spheres.

The Spring Hill Limestone Member is the thickest member of the Plattsburg, averaging about 25 feet thick. It is apparently absent northeast of Vilas where the entire Plattsburg Limestone is about 6 inches thick. The Spring Hill consists generally of light-olive-gray to medium-light-gray, hard, clayey, very thin bedded and irregularly bedded, fossiliferous limestone. The sponges Heliospongia and Girtyocoelia are generally abundant, and crinoid fragments, brachiopods, horn corals, and encrusting and fenestrate bryozoa are common. Specimens of Osagia are locally abundant in the lower part, oolites in the upper part. Much of the Spring Hill is a detrital limestone in which many small fossil fragments are embedded in a silt-size calcareous matrix.

Where the Spring Hill is thickest the clayey, sponge-bearing limestone is overlain by sparsely fossiliferous algal limestone 10 to 50 feet thick. Irregularly shaped fragments of very finely crystalline medium-dark-gray limestone, 1/2 to 1 inch in length, are distributed in a matrix of light-olive-gray finely crystalline limestone and impart a brecciated appearance to the rock. Crinoid stem segments and algal growths resembling Cryptozoo are abundant in the light-olive-gray limestone matrix in some exposures. A brownish-gray bed of oolitic limestone 1 to 2 feet thick commonly is found at the top of the unit.

The Vilas Shale attains its maximum thickness of about 110 feet near Vilas and maintains this thickness between Vilas and Altoona. From Altoona it thins rapidly both east and west; about 4 miles to the east it is only 5 feet thick, and about 4 miles to the west it is only 8 feet thick.

Where thickest the lower 85 feet consists of light-olive-gray, unfossiliferous, slightly silty, locally micaceous shale that contains several thin beds of ironstone concretions in the lower and upper parts. The succeeding 18 feet is dark-bluish-gray to light-olive-gray nonsilty unfossiliferous shale that has near its center several thin beds of calcareous clayey concretions, some of which have welslots of black calcite. The uppermost 3 feet of the Vilas is light-grayish-orange fossiliferous calcareous shale containing crinoid columnals and sparse low-spired gastropods among fragments of brachiopod shells and bryozoa.

A medium-gray nodular limestone bed is present about 3 feet below the top of the Vilas over much of the outcrop area. This bed generally is 6 to 12 inches thick and is a mass of algae and oolites. In a few places, however, the limestone bed is made up of disconnected, flattish, algal? nodules or concretions.

Inasmuch as the thin limestone bed near the top of the Vilas is present throughout practically the entire area—even where the Vilas is less than 10 feet thick—most of the extreme variation in thickness of the Vilas must be due to relief on the pre-Vilas surface rather than to erosion at the end of Vilas time. Erosion, however, has occurred locally and is well shown in roadside 2 miles west of Altoona along Kansas Highway 47, where channels two feet or more deep were cut into the Vilas.

The Stanton Limestone crops out in a broad north-northeast-trending area across the middle of Wilson County (Fig. 1) and lies unconformably, at least locally, upon the Vilas Shale. It ranges in thickness from 15 to 75 feet and is divided into three limestone and two shale members.

The lowest member of the Stanton, the Captain Creek Limestone Member, in most places lies conformably upon the Vilas Shale but locally fills irregular steep-walled channels cut into the Vilas. At the base of the Captain Creek is a yellowish-gray finely crystalline algal and oolitic? limestone. Casts of large cephalopods filled with coralsely crys
talline calcite are locally common in this algal limestone. Above the basal algal limestone, but extending downward to the base of the formation where the algal limestone is absent, 10 to 14 feet of medium-gray cavernous limestone makes up the Captain Creek. This cavernous limestone unit forms escarpments, weathers almost white, and is deeply pitted with 1/2 to 1 inch holes. Fossils include crinoid columnals, fenestrate bryozoa, brachiopods, corals, and fusulinids. Vertical joints separate the rock into large blocks 3 to 20 feet across. Thin veinos of coarsely crystalline calcite form the medium-grained matrix.
The Eudora Shale Member is 2 to 5 feet thick and consists of light-greenish-gray very slightly silty calcareous shale that grades laterally into clayey limestone. In exposures 2 miles west of Altoona, and near the northeastern corner of Wilson County, grayish-black very fissile shale 1 to 3 feet thick is present near the middle of the Eudora. The black shale breaks into paper-thin plates on whose surfaces flattened orbiculoid brachiopods are locally abundant. In a few places thin-beded very argillaceous limestone containing the remains of large pelecypods comprises the lower 6 to 12 inches of the member. Other fossils, most abundant in the lower and upper parts of the Eudora, include crinoid columnals, horn corals, encrusting bryozoans, echinoid spines, and brachiopod and mollusk fragments.

The Stoner Limestone Member is 5 to 30 feet thick and consists of blotchy-appearing medium-gray and yellowish-gray thin- and wavy-bedded fossiliferous limestone. The Stoner characteristically is very fossiliferous, thin beds within it being composed of medium- to coarse-crystalline coquoidal limestone made up entirely of fenestrate bryozoans, or crinoid columnals and plates, or pelecypod and brachiopod fragments. Locally, relatively unfossiliferous very finely crystalline limestone predominates and much of the Stoner is a brecciated unit composed of angular light-brownish-gray to yellowish-gray limestone. Vugs and fractures filled with coarsely crystalline calcite are locally conspicuous. Where thickest, 5 to 9 feet of light-gray, irregularly bedded, sparsely oolitic, finely crystalline limestone occurs at the top of the Stoner.

The Rock Lake Shale Member is about 2 feet thick and very calcareous. It is distinguished with difficulty from the underlying and overlying limestone members but where recognized consists of light-olive-gray very calcareous fossiliferous shale in which echinoid plates and spines are abundant locally. Other fossils include crinoid columnals, ramose bryozoans, and brachiopod fragments.

The South Bend Limestone Member comprises 5 to 8 feet of olive-gray and dark-yellowish-orange sandy oolitic limestone. In a few exposures the lower part is conglomeratic and is made up largely of dark-yellowish-orange, subangular, very finely crystalline, unfolossiliferous, clayey limestone fragments in an olive-gray sandy-limestone matrix. In many exposures, however, the lower part is moderate-yellowish-brown sandy calcareous limestone. The oolitic facies of the South Bend Limestone Member weathers locally into large rounded boulder-like masses whose surfaces are pock-marked with closely spaced pin-size holes partly filled with limonite. The South Bend characteristically forms the reddish sandy soil that caps much of the surface of the Stanton cuesta. Fossils in the South Bend include fusulinids, crinoid columnals, corals, brachiopods, and unidentifiable small shell fragments.
In areas where the massive sandstone is absent, the lower part of the Tonganoxie consists of a 30-foot rhythmic sequence of alternating yellowish-gray to pale-orange siltstone and yellowish-brown very slightly silty claystone that grades downward, without any apparent depositional break, into the underlying Weston Shale. The upper 20 feet of the Tonganoxie consists of yellowish-gray clayey siltstone that contains several beds of micaceous very fine grained pale-grayish-orange sandstone.

The Westphalia Limestone Member is a pale-yellowish-brown algal limestone that is generally about 5 feet thick and is made up of two limestone beds separated by limestone rubble. At many places, however, it is a single bed about 3 feet thick. The lower part of the Westphalia consists of about 2 feet of pale-yellowish-brown locally sandy limestone that is made up predominantly of the alga Osagia and commonly has a few fusulinids and crinoid stems in the upper 10 inches. A foot of limestone rubble in a clayey limestone matrix overlies this unit and in turn is overlain by 3 feet of pale-yellowish-brown limestone that is made up almost entirely of Osagia. The uppermost part of the Westphalia locally contains abundant ostracode carapaces, gastropods, and brachiopods.

The Violand Shale Member is light-olive-gray to yellowish-gray slightly silty claystone that averages 6 feet thick. The upper foot is fossiliferous and characteristically contains large well-preserved Myalina valves.

The Haskell Limestone Member is less than 2 feet thick over most of its outcrop area but in places thickens to more than 8 feet. It is normally a thin hard single bed of finely crystalline, vertically jointed, medium-gray limestone but locally occurs as a series of 1 to 3 inch wavy-surfaced limestone plates. Fusulinids occur sparingly near the top of the member. A brecciated or mottled appearance, due to 1/8 to 1 inch angular areas of pale-yellowish-orange limestone in a matrix of very pale orange limestone, is prominently displayed on weathered surfaces at many outcrops.

The Robbins Shale Member is more than 120 feet thick in the southern part of the county but thins to 50 feet in the northern part, seemingly due to erosion prior to deposition of the Lawrence Shale. It is predominantly a light-olive-gray slightly silty shale that contains beds and lenses of small limonitic ironstone concretions. The concretions are moderate yellowish brown to dark yellowish orange and are most abundant near the center of the member. Fossiliferous zones occur near the middle and top of the Robbins.

**Lawrence Shale**

The Lawrence Shale, which is about 70 feet thick, consists of 3 to 5 sandstone beds separated by thick intervals of shale. The shales are lenticular but generally have an aggregate thickness greater than that of the sandstones. The basal bed, a thick channel-filling cross-bedded sandstone, is called the Ireland Sandstone Member. This cliff-forming unit is the most persistent sandstone bed in the Lawrence Shale. It is generally 5 to 20 feet thick but is as much as 60 feet thick in areas where the overlying shale beds are missing and the upper sandstone beds merge with the Ireland into a single unit. The sandstone is grayish orange to moderate brown and is medium to very fine grained. Small subrounded areas of limonite-stained subrounded quartz grains give the sandstone a marked speckled appearance. Mica flakes are sparse.

Unnamed shale and sandstone lenses comprise the interval between the Ireland and the thin discontinuous Amazonia Limestone Member, which occurs about 20 feet below the top of the Lawrence Shale. The sandstone beds above the Ireland Sandstone Member are generally from 1 to 4 feet thick, well bedded, locally ripple marked, speckled with small limonite-stained areas, and are unfossiliferous except for worm tracks. They are composed of well-sorted subrounded very fine quartz grains and are light colored, ranging from yellowish gray to very pale yellowish brown. Thin yellowish-gray siltstone layers and light-gray shale lenses are commonly interbedded.

The Amazonia Limestone Member is the only limestone in the Lawrence Shale and was found at only four places in the county. It consists of white very fossiliferous limestone, 7 inches thick, or light-gray to very pale yellowish-brown fossiliferous limestone, 18 inches thick. The fossils are mostly fragments of brachiopods, pelecypods, crinoids, and bryozoans.

Above the Amazonia is a red-shale unit that is made up predominantly of blotchy masses of dark-reddish-brown and pale-olive slightly silty claystone about 20 feet thick. The red-shale unit is overlain by light-gray to moderate-reddish-orange shale that grades upward into about one foot of dusky-blue claystone that immediately underlies a 2 to 4 inch bed of coal, the Williamsburg coal. The coal is overlain by about 2 feet of light-olive-gray shale that is un-fossiliferous except in areas where the contact with the Oread Limestone is apparently gradational. In those areas this uppermost shale is calcareous and contains abundant fusulinids.
Shawnee Group

Oread Limestone

The Oread Limestone lies conformably on the Lawrence Shale and is divided into seven members. In Wilson County it is about 70 feet thick but contains only three limestone and two shale members; the two additional members found elsewhere have been removed by erosion.

The Toronto Limestone Member at the base ranges in thickness from 2 to 7 feet; a massive lower part is apparently missing where the Toronto is thin. The lower part of the member is a 3-foot, light-gray, hard, irregularly bedded, fossiliferous limestone that in many places has a thin zone of fusulinid-bearing limestone in the lower part. The upper 2 to 4 feet of the member is generally very pale yellowish-brown fossiliferous limestone that has a decidedly mottled appearance consisting of small irregularly shaped areas of dark yellowish orange in a groundmass of very pale orange. The fossils consist mainly of fusulinids and fragments of brachiopods, fenestrate and ramose bryozoans, and crinoids.

The Snyderville Shale Member averages about 50 feet in thickness and is generally greenish-gray claystone in the lower part and dark-reddish-brown claystone in the upper part. Thin beds of pale-greenish-gray to yellowish-gray, very fine grained, locally calcareous, silty sandstone about 8 inches thick occur at the base and top of a 20-foot irregularly colored greenish-gray and reddish-brown claystone unit that composes the middle of the member. Many irregularly shaped calcareous concretions that are brown, red, green, or white within, but are stained reddish on their outer surfaces, weather from the upper half of the Snyderville.

The Leavenworth Limestone Member is a thin, hard, finely crystalline, medium-dark-gray, somewhat fossiliferous limestone. It is 14 to 16 inches thick, is vertically jointed, and breaks into rectangular blocks 6 inches to 5 feet across. Oblate concentric Cryptozoon-like masses that average about 3/8 inch wide and 5/8 inch long are locally abundant on the light-olive-gray weathered surfaces. An inch-thick oolitic zone at the base of the bed commonly contains large pelecypod valves, algae, and brachiopod fragments.

The Heebner Shale Member is about 6 feet thick and consists of about a foot of very fissile grayish-black shale that is overlain by 4 or 5 feet of light-olive-gray fossiliferous shale. The black shale weathers to paper-thin plates and contains abundant conodonts, scattered foraminifers and ostracodes, and the remains of bryozoans, crinoids, and brachiopods.

The Plattsmouth Limestone Member is the uppermost member of the Oread in Wilson County. It is 3 to 7 feet thick and locally forms the capping of ridges and dip-slopes. Its most distinctive feature is the wavy-bedded appearance displayed by the contacts between individual limestone beds along cliff-like exposures. The wavy beds are 2 to 4 inches thick and consist of light-gray fossiliferous limestone. Fossils are mainly fragments of brachiopods, pelecypods, crinoids, bryozoans, and fusulinids.

Cretaceous or Tertiary Intrusive Rocks

At the Silver City Dome in secs. 5 and 6, T. 27 S., R. 15 E., rocks of peridotite composition have intruded the Pennsylvanian strata as sill-like bodies in the subsurface. The sills do not crop out in Wilson County, but they are so near the surface that their metamorphic effects are seen in the outcropping rocks as color changes and sillification in limestone. The peridotite is exposed about half a mile north of Wilson County in the western half of sec. 31, T. 26 S., R. 15 E., where it crops out as weathered very micaceous grayish-yellow clay.

This section studies by E. W. Haelrich (unpublished report for K. K. Landes, Feb. 1948), Paul Franks (unpublished report for W. W. Hambleton, June 1953), Charles Milton (written communication, July 1955), and by the author indicate that the peridotite is fine- to medium-grained and was composed originally of olivine, biotite, diopsidic augite and relatively abundant feldspar. Most of the olivine has been altered to serpentine and phlogopite, the biotite to phlogopite and vermiculite, and the diopsidic augite to green chlorite. Weathering resulted in the formation of mixed-layer clay minerals, limonite, and magnetite.

Tertiary? and Quaternary Systems

Chert gravel and alluvium

Chert gravel deposits ranging in thickness from a few inches to 6 feet occur throughout the county but are not shown on the geologic map. The uppermost deposits may be Late Tertiary in age; the others are Pleistocene in age. The chert gravel deposits consist generally of subangular chert pebbles, ranging in size from 1/4 inch to 2 inches. The pebbles
are grayish orange and poorly sorted and are held in a light-brown sandy clayey siltstone matrix. In some places chert pebbles compose practically the entire deposit; in other places they are merely thin lenses in the siltstone matrix. Subangular pebbles of fine-grained reddish-brown sandstone are locally abundant amid the chert pebbles.

Quaternary alluvium, consisting of stream-laid deposits of gravel, sand, silt, and clay, as much as 45 feet thick, fills portions of the valleys of the Fall and Verdigris Rivers. Thinner deposits of local origin occur in the smaller stream valleys.

STRATIGRAPHY OF SUBSURFACE ROCKS

Exploratory wells drilled in Wilson County cut rocks of Precambrian to Pennsylvanian age. The lithology and thickness of the subsurface rocks are known from samples and electric logs of a few wells and from drillers logs of more than 6,000 wells drilled for oil and gas in Wilson County. Cuttings are available for only about 45 wells in the county, and electric and radioactivity logs are available for only about 60 wells.

Five wells in Wilson County bottomed in rock believed to be Precambrian in age. The rock was apparently granite in three of the wells and metamorphic rock in two.

Rocks of Late Cambrian age include the Lamotte Sandstone, which is 25 to 125 feet thick and consists of poorly sorted, coarse- to fine-grained sandstone, and the Biomeester Dolomite, which overlies the Lamotte and is a dark-gray to brown, finely crystalline, conspicuously glauconitic, noncherty, sandy dolomite 100 to 175 feet thick (Fig. 2).

Rocks of Early Ordovician age are correlated with the upper part of the Arbuckle Group and have a thickness of 650 to 850 feet. About 200 feet comprises the Van Den 100 to 175 feet thick (Fig. 2).

Rocks of Late Cambrian age include the Lamotte Sandstone, which is 25 to 125 feet thick and consists of poorly sorted, coarse- to fine-grained sandstone, and the Biomeester Dolomite, which overlies the Lamotte and is a dark-gray to brown, finely crystalline, conspicuously glauconitic, noncherty, sandy dolomite 100 to 175 feet thick (Fig. 2).

Rocks of Early Ordovician age are correlated with the upper part of the Arbuckle Group and have a thickness of 650 to 850 feet. About 200 feet comprises the Van Den 100 to 175 feet thick (Fig. 2).

Rocks of Late Cambrian age include the Lamotte Sandstone, which is 25 to 125 feet thick and consists of poorly sorted, coarse- to fine-grained sandstone, and the Biomeester Dolomite, which overlies the Lamotte and is a dark-gray to brown, finely crystalline, conspicuously glauconitic, noncherty, sandy dolomite 100 to 175 feet thick (Fig. 2).
Figure 2. — Generalized section of units occurring in the subsurface of Wilson County.
by the Kansas City Group. The lower three limestone formations (the Hertha, Swope, and Dennis Limestones) and two intervening shale formations (the Ladore and Galesburg Shales) of the Kansas City Group are about 200 feet in total thickness in the subsurface. The overlying strata of Pennsylvanian age crop out within the county and were described in the preceding section.

STRUCTURAL GEOLOGY

Wilson County lies within the Cherokee Basin, which is a northward extension into Kansas of the McAlester Basin of Oklahoma (Jewett, 1951, p. 126). The Cherokee Basin is bounded on the west by the Nemaha Uplift, on the east by the Ozark Uplift, and on the north by the Bourbon Arch.

The strata in Wilson County strike approximately N. 20° E. and dip westward at an average of about 25 feet per mile. In some places the dip flattens or changes to eastward, and it is on structures thus formed that many of the oil and gas fields of the county are located (Fig. 3).

The Fredonia Anticline is the most prominent structural feature entirely within Wilson County. It trends approximately N. 55° W. and a few miles east of Fredonia has a closure at the top of the Fort Scott Limestone of more than 100 feet. It is a composite elongate dome 6 to 10 miles long and 3 to 6 miles wide. The Fredonia Anticline apparently has been a positive structural element since Mississippian time; the thinning of sediments over the anticline indicates differential movement of nearly 300 feet during the Mississippian and Pennsylvanian Periods.

The Silver City Dome is a prominent topographic and structural feature at the northern border of Wilson County. Structural closure is approximately 175 feet and resulted mainly from sill-like intrusion of peridotite of Cretaceous or Tertiary age into the Pennsylvanian strata. About 40 feet of the uplift may reflect igneous intrusion into Mississippian strata.

Other folds in Wilson County are of small magnitude. A series of undulations in the Drum Limestone are exposed in the stream bed of Washington Branch about 3 miles east of Neodesha on Kansas Highway 37, and similar folds are exposed in the Dennis Limestone in the beds of tributaries of Dry Creek in the NE 1/4 sec. 9 and NE 1/4 sec. 30, T. 30 S., R. 17 E. The undulations in the Drum Limestone trend approximately N. 45° E. and have an amplitude of about 2 feet; those in the Dennis trend about N. 30° E. and have an amplitude of about 1 1/2 feet.

Six faults were observed in Wilson County; all are small and were seen only in creeks or roadcuts. The largest stratigraphic displacement is estimated at less than 5 feet. Vertical joint systems are conspicuous in many of the thick limestone and sandstone beds in the county. The joints fall into two general groups that trend about N. 50° E. and N. 35° W.

ECONOMIC GEOLOGY

The natural resources of Wilson County, such as petroleum, limestone, shale, and coal, furnish materials whose economic products are valued at about 7 million dollars annually. Petroleum has played a substantial role in the economy since 1893 when commercial quantities of oil and gas were discovered. Estimated total production to date (1962) from the 200 or more oil and gas pools (Fig. 3) amounts to more than 6 million barrels of oil and considerably more than 40 trillion cubic feet of gas.

The bulk of the oil production has been from the "Lower and Upper Bartlesville sands" and "Squirrel sand" of the Cherokee Group. Lesser oil production has come from the upper parts of rocks of Ordovician and Mississippian age, from the "Peru sand" of the Labette Shale, the "Weiser sand" of the Bandera Shale, the "New Albany sand" of the Chanute Shale, and from a local sandstone bed in the Vilas Shale (Fig. 2). The porosity of the producing sands averages about 17 percent and the permeability ranges from less than 0.01 to more than 300 millidarcies. The oil ranges in gravity from 15° to 35° A.P.I. Since 1937 repressuring by the water-flood method has been successful in several sands in the eastern part of the county, and to date about 25 secondary recovery projects have been operated. The currently active projects produce in excess of 100,000 barrels of oil yearly.

Twenty-two horizons, the deepest at 1,500 feet and the shallowest at about 200 feet, have produced gas. Underground storage projects are being operated east of Fredonia in the "New Albany sand" and southeast of Buffalo in the Iola Limestone by the Union Gas System. These projects have ultimate storage capacities of 380,000,000 cubic feet and 215,000,000 cubic feet respectively.

The oldest continuously operating oil refinery in the Midcontinent Region was built at Neodesha in 1897. To keep abreast of demands the capacity of the refinery has been progressively increased from the original 500 barrels to its present 30,000 barrels per day.
More than 750 thousand tons of limestone are utilized yearly in the production of Portland cement, crushed rock, and agricultural lime. The Stanton and Plattsburg Limestones furnish most of the raw material in these operations which include three major quarries located near Fredonia, Benedict, and Neodesha. The manufacture of rock wool may be of importance in the future.

The Weston Shale is utilized as a source of clay in two brick plants in Wilson County, one west of Buffalo and the other west of Fredonia. These plants have a combined capacity of more than 200,000 face and common bricks per day. Building tile and drain tile are minor products.
Coal occurs in two formations in the outcropping rocks of Wilson County and has been recorded in the Cherokee Group in the logs of several wells. Coal in the Chanute Shale is as much as 2 feet thick and has been mined locally where the thickness exceeds 10 inches. The coal averages more than 50 percent fixed carbon, has a heating value of more than 15,000 Btu per pound on a moisture and ash free basis, and is of bituminous rank. According to Schoewe (1944, table 7) a total of 18,661 tons of coal was mined between 1933 and 1942 in Wilson County. Most of this coal was from the Dunbar strip mine. Schoewe (1944, table 8) estimated the total production from the county as 271,875 tons. The other coal bed in the county is in the upper part of the Lawrence Shale but is not of mineable thickness.

Abundant chert gravel from deposits in many parts of Wilson County furnished road metal for most of the section-line roads. The thicker deposits have been exhausted and crushed rock has largely replaced the chert gravel.

REFERENCES


Schoewe, W. H., 1944, Coal resources of the Kansas City Group, Thayer bed, in eastern Kansas: Kansas Geol. Survey Bull. 52, pt. 2, p. 81-186.

U. S. Geological Survey, Menlo Park, California
Pennsylvania Megacyclothem of Wilson County, Kansas, and Speculations Concerning Their Depositional Environments

ABSTRACT

Sedimentation during Pennsylvanian time in Wilson County was cyclic. Approximately 15 separate but generally incomplete transgressions and regressions of the sea are represented in the limestone, shale, and sandstone strata. Cyclothems recorded in these rocks are parts of six larger cyclic repetitions, megacyclothem. Characteristic environments prevailed during each part of the megacycle and resulted in the formation of sedimentary rocks with clearly different lithologic and faunal attributes. Ten depositional stages composing each megacycle are categorized as follows: A, fluviatile continental; B, continental to marine transitional; C, argillaceous transgressive-regressive marine; D, continental margin; E, rapid-oscillation marine; F, stagnant-water marine; G, normal transgressive-regressive marine; H, nearshore argillaceous marine; I, nearshore clear-water marine; and J, nearshore regressive marine. The sedimentary rocks that formed during these stages are described, and speculations concerning their depositional environments are given.

INTRODUCTION

The Pennsylvanian System in Wilson County contains strata of 5 groups and 13 formations (Fig. 1). The system is characterized by sequences of limestone, shale, sandstone, and coal representing alternating marine and nonmarine depositional environments that were operative during successive advances and retreats of the Pennsylvanian sea. Each transgressive-regressive sequence defines a cycle of deposition, or cyclothem (Wanless and Weller, 1932, p. 1003), and several cyclothems are combined into larger cyclic sequences termed megacyclothem (Moore, 1936, p. 29, 30). The cyclic deposits of Pennsylvanian age in Kansas were thoroughly discussed by Moore (1936, 1949), who presented typical schemes of cyclic deposition for beds in different parts of the Kansas Pennsylvanian and Permian sequences. Although each distinctive rock type in the Pennsylvanian strata of Wilson County does not precisely fit into Moore's typical megacyclothem (1936, p. 30-34), most of the major rock units are present. Each rock type reflects deposition under different environmental conditions of water movement, water depth, water temperature, light abundance, salinity, hydrogen ion concentration, dissolved carbon dioxide, organic content, nutrient supply, abundance of land-derived matter, and other factors. On the basis of the lithologic and faunal characteristics of the strata exposed in Wilson County, 10 different sequential depositional environments, designated as stages, can be postulated as follows (Fig. 2): A, fluviatile continental; B, continental to marine transitional; C, argillaceous transgressive-regressive marine; D, continental margin; E, rapid-oscillation marine; F, stagnant-water marine; G, normal transgressive-regressive marine; H, nearshore argillaceous marine; I, nearshore clear-water marine; and J, nearshore regressive marine. Most of these 10 stages occur...
in each of the 6 megacycloths into which the Pennsylvanian strata of the county are herein grouped (Fig. 3).

The environmental significance of fossils and lithologies characteristic of the Pennsylvanian rocks of Wilson County are herein briefly discussed, the strata formed in each of the 10 stages are described, and their depositional environments reconstructed. In attempting reconstructions of the environments, a literature survey was made, and it was determined that opinions concerning the signifi-

<table>
<thead>
<tr>
<th>SERIES</th>
<th>GROUP</th>
<th>FORMATION</th>
<th>MEMBER</th>
<th>MEGA-CYCLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SHAWNEE</td>
<td>Oread Ls.</td>
<td>Plattsmouth Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heebner Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Leavenworth Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Snyderville Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Toronto Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lawrence Sh.</td>
<td>Unnamed Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Amazonia Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ireland Ss.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DOUGLAS</td>
<td>Stranger Fm.</td>
<td>Robbins Sh.</td>
<td>MEGACYCLE 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Haskell Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vinland Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Westphalia Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tonganoxie Ss.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PEDEE</td>
<td>Weston Sh.</td>
<td>South Bend Ls.</td>
<td>MEGACYCLE 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rock Lake Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stanton Ls.</td>
<td>Stoner Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Eudora Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LANSING</td>
<td>Vilas Sh.</td>
<td>Captain Creek Ls.</td>
<td>MEGACYCLE 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SUBGROUP</td>
<td>Plattsburg Ls.</td>
<td>Spring Hill Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ZARAH</td>
<td>Lane-Bonner Springs Sh.</td>
<td>Merriam Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LINN</td>
<td>Iola Ls.</td>
<td>Raytown Ls.</td>
<td>MEGACYCLE 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Muncie Creek Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Paola Ls.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chanute Sh.</td>
<td>Cottage Grove Ss.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unnamed Sh.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drum Ls.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEADSON</td>
<td>Cherryvale Sh.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dennis Ls.</td>
<td>Winterset Ls.</td>
<td>MEGACYCLE 1</td>
</tr>
</tbody>
</table>

Figure 1.—Nomenclature of exposed Pennsylvanian rocks of Wilson County.
### Table: Depositional Stages in Pennsylvanian Megacyclothsms of Wilson County

<table>
<thead>
<tr>
<th>Stage Symbol</th>
<th>Stage Designation</th>
<th>Lithology</th>
<th>Fauna and Flora</th>
<th>Relation to Shoreline</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>Nearshore regressive marine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Nearshore clear-water marine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Nearshore argillaceous marine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Normal transgressive-regressive marine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Stagnant-water marine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Rapid-oscillation marine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Continental margin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Argillaceous transgressive-regressive marine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Continental to marine transitional</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Fluvial continental</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Not to vertical scale.

### EXPLANATION

- **Limestone**
- **Muddy bedded limestone**
- **Oolitic limestone**
- **Sandstone**
- **Channel-fill sandstone**
- **Siltstone**
- **Gray shale**
- **Black shale** with phosphatic nodules
- **Red shale**
- **Ironstone concretions**
- **Coal**
- **Pelecypod**
- **Gastropod**
- **Brachiopod**
- **Bryozoa**
- **Crinoid**
- **Coral**
- **Fusulinid**
- **Alga**
- **Plant**

**Figure 2.—Depositional stages represented in Pennsylvanian megacyclothsms of Wilson County.**
cance to be attached to faunal and lithologic elements in rocks are many and varied.*

Space does not permit a comprehensive summation of these opinions, and I have therefore made an arbitrary selection of the opinions that I feel best account for the faunal and lithologic characteristics displayed in the Pennsylvanian rocks of Wilson County. Because of the emphasis placed on Kansas rocks in his writings, I have drawn heavily on the works of R. C. Moore and his associates.

Sediments of stages A, B, D, and J contain the fossil remains of land plants; those of stage B contain pelecypods, gastropods, brachiopods, bryozoans, crinoids, and corals; and those of stages C, E, and G contain fusulinids and algae in addition to forms enumerated for stage B. Ostracodes and conodonts were found in sediments of many of the stages, but particularly those of stage F. Calcareous sponges are common in stages E, F, and G of megacyclothem 3; and cephalopods are found in stage E of megacyclothem 4.

Pelecypods and gastropods are adapted to many sorts of environments, but the vast majority are bottom dwellers in shallow-marine water (Moore and others, 1952, p. 277, 398). Myalinids and particularly Myalina (Orthomyalina) are believed to have been sedentary forms, but they were not necessarily attached by a byssus (Mudge and Yochelson, 1962, p. 105). Newell (1942, p. 19) suggested that these myalinids lived in the shallow, turbid waters of the shore zone, and could tolerate an unusually great amount of variation in the salinity of the water. Brachiopods prefer shallow water—many forms prefer very shallow water with solid objects available for attachment, others prefer muddy bottoms, and still others prefer shallow water of subnormal salinity (Moore, 1929, p. 469). Walker (1957, p. 351) suggested that the orbiculoid brachiopods found in the fissile black shale probably were attached to seaweed.

Bryozoans live mostly in shallow clear water, fairly close to shore. Some are found in water constantly agitated by waves and strong currents, and colonies are most numer-

* The writer wishes at this point to express his appreciation for the constructive criticisms and suggestions given by T. A. Hendricks and E. E. Clark whereby the manuscript was considerably improved.
Figure 3—Megacycles represented in Pennsylvanian rocks of Wilson County.
suggest that they also lived in clayey and sandy environments, but the possibility should be considered that currents may have flushed the organisms into an unwholesome environment in which they died in great abundance. They were probably bottom dwellers and moved about on feeble pseudopodia; but late forms may have become adapted to a floating habit, the protoplasm in the inflated part of the shell having been distended by gaseous vacuoles (Dunbar, 1963, p. 30, 31, 41). The presence of algal incrustation in conjunction with fusulinids indicates that the water was less than 180 feet deep because below this depth photosynthetic processes essential for chlorophyll-containing algae are practically impossible, even in the clearest water (Elias, 1937, p. 425).

Ostracodes can be free swimming or bottom dwelling, and can live in foul, stagnant water as well as in water that is clear. Conodonts are apparently the remains of pelagic organisms—not bottom dwellers—and their greater abundance in shales rich in organic matter (Moore and others, 1952, p. 733) suggests life in an environment of unagitated, foul water, although the conodonts themselves may have lived near the surface where the water was better aerated (Moore, 1929, p. 672). Calcareous sponges live only in shallow water of full oceanic salinity and are most abundant at depths of less than 30 feet (deLahénfels, 1957, p. 1083). Cephalopods, using Nautilus as an example, live in normal sea water at depths of about 10 to 2,000 feet, but generally at shallower depths. At night they migrate from deeper into shallower water and come quite close to shore. Nautilus is not pelagic, living near or on the bottom, but swims freely (Stenzel, 1957, p. 1137). It is possible that the empty shells, rising to the surface after death of the animal, were widely distributed by winds and currents (Moore and others, 1962, p. 341).

Faunas interpreted by Moore (1949, p. 81) as representing very nearshore conditions include inarticulate brachiopods, certain types of calcarcous brachiopods (Derbya, Jarensia) in abundance, thick-shelled clams (especially Mytilus) and radially ribbed scallops (Aequipecten and other genera), more or less common snails (especially heteroconchs), and some bryozoa. He proposed also that offshore faunal assemblages are characterized by a varied group of marine invertebrates, particularly fusulinids, and that pre-dominance of algae indicates shallow-water deposition during the retreating phase of a marine inundation.

The environments in which these faunas and floras lived and were buried ranged from fluviatile to marine water. The water may have been rich in quartz sand, or have contained abundant clay or silt, or have been clear and very saline. Dapples (1947, p. 95-96) suggested that sandstone composed predominantly of quartz but also containing abundant muscovite on bedding planes accumulated chiefly in an environment associated with large alluviating rivers emptying into regions of extensive tidal flats.

Gries (1951, p. 231) summarized that red color in an argillaceous sediment probably is due to a supply of ferric iron oxide or hydroxide from the source area and to deposition in the absence of appreciable organic matter in an oxidizing environment where the higher state of oxidation could be preserved, or possibly to rapid burial under mild reducing conditions. Green, gray, or black shale probably formed under reducing conditions whereby the iron was changed to the ferrous state. Elias (1957, p. 426) concluded that red shale that separates marine phases of two neighboring cycles is a continental deposit and indicates emergence; he believed that green shale, which in places contains Lingula or which is mottled or interbedded with red shale, represents marine deposition within the zone of tides, the green color having formed through the reduction action of organic matter upon oxides of the original red silt (1937, p. 426-427). The development of ironstone concretions in shale may, in part, occur during lithification after a considerable time lapse (Krumbein and Sloss, 1951, p. 217). Moore (1929, p. 469) stated that black platy carbonaceous shale zones represent deposition in very shallow water that was acid because of accumulated humus and poor circulation. He suggested later (Moore, 1950, p. 15) that seaweeds may have furnished most of the carbonaceous material and have grown so thickly in this shallow water that distur-
bance of the bottom by wind and waves was nil. Weller (1957, p. 351) also suggested that the carbonaceous material in thin fissile black shale was derived from a prolific growth of seaweed which prevented circulation of the water and whose decaying remains exhausted the oxygen adjacent to the bottom. Phosphate in the black shale may have accumulated as a result of bacterial decomposition of organic debris (Barnes, 1957, p. 304-305).

Inorganic precipitates are formed when the solubility product of some substance is exceeded. Supersaturation may be induced by physical agencies such as temperature changes, it may be associated with the removal of carbon dioxide where photosynthesis occurs, or it may be related to changes in hydrogen-ion concentration or oxidation-reduction potential brought about by the organisms. In addition, precipitation may result from evaporation in isolated lagoons and seas (Sverdrup and others, 1942, p. 951).

Present-day oolites (forming in the Great Salt Lake, Utah; on the Great Bahama Bank, Florida; and at Laguna Madre, Texas) are restricted to areas of strongly agitated water near the shoreline or in tidal channels (Eardley, 1938, p. 1371; Illing, 1954, p. 43, 69; Freeman, 1962, p. 482). In the Bahamas the oolites are typically developed near the western ends of tidal channels and on the western beaches, where fresh oceanic water has been swept onto the shallow banks and has been sufficiently warmed and stirred up to become appreciably supersaturated with calcium carbonate (Illing, 1954, p. 43). Under the constant stirring movement induced by the tides and beach wavelets within the break-point, the calcium carbonate is precipitated as concentric oolitic sheaths of aragonite on sand grains (Illing, 1954, p. 69).

Twenhofel (1932, p. 860-862) pointed out that in epicontinental seas: (1) weak tidal action and tidal currents may lead to the presence of large areas of quiet water whose bottoms are covered with black mud rich in hydrogen sulfide; (2) shoreward the water may be so shallow as to destroy the erosional effectiveness of waves for distances of several miles from shore; (3) during times of large storms, the shallowness may allow the stirring up of previously deposited materials; and (4) bottoms adjacent to low shores without streams are apt to receive fine sediments, although some bottoms near such shores may have currents sufficiently strong to bring in coarse sediments. Moore (1946, p. 126) suggested that the marginal portions of very shallow advancing Pennsylvanian seas would be fresher than normal sea water by reason of the precipitation and runoff from the adjacent land and that the marginal portions of a retreating shallow sea may have had excess salinity because of evaporation in coastal lagoons and drainage of salt from connate water in the recently exposed salt-water sediments left behind by the retreating sea. Krumbein and Sloss (1951, p. 208) pointed out that the shoreline of a shallow advancing epicontinental sea becomes progressively submerged and that a sheet sand, which results from the sorting action of water in the zone between high and low tides, will develop without the production of a typical linear beach deposit.

The environmental data just presented have been arbitrarily selected, and it should be emphasized that other conditions of deposition have been proposed for each of these lithologic types and that more than one set of conditions may have operated during the deposition of any one rock type. However, I consider the factors cited above as those most likely to have been effective in the Pennsylvanian seas of Wilson County and have used them in speculating on the conditions under which the various rocks were deposited. The reader should keep in mind also that:

(1) The strata in which fossils are found do not necessarily indicate their environmental habitats, but may merely be their final resting places because as the animals and plants may have died in great abundance in the area as a result of a radical change in the environment, and the strata in which they are found would then indicate the new environmental conditions which brought about their death rather than those under which they lived and flourished.

(2) The lithologic continuity and constant thickness of a sequence of thin units over many hundreds of square miles indicate environmental changes of continental magnitude.
and are not the result of structural movement in a local area such as Wilson County but of movement of worldwide significance. Movement in Wilson County and adjacent area must have been generally downward, however, in order to allow accumulation of a continuous sequence of sedimentary rock 2,700 feet thick containing alternating marine and nonmarine sediments. Small-scale structural movements in Wilson County are known to have modified the depositional environments locally during certain megacyclic stages, but the effects were of small areal and temporal significance and are not considered herein.

(3) The fauna and flora are influenced by water or air temperature, by salinity, depth, movement, or clarity of water, or by the nutrient content in the environment, so that their significance with regard to any one factor is not clear; the thickness and lithology of the units provide a crude measure of the time involved in their deposition.

(4) The distance from, and elevation of, exposed land as the source of terrigenous contamination may have influenced the environment to a greater extent than depth of water. A similar conclusion was reached by Mudge and Yochelson (1962, p. 115).

DEPOSITIONAL STAGES

Because the strata of Pennsylvanian age in Wilson County are parts of repetitious sequences, members of different formations have had similar modes of origin and have the same or nearly the same lithologic and faunal characteristics. To describe each member or formation in detail would lead to much duplication. In the following sections, therefore, the stratigraphic unit that displays most completely the characteristics of each depositional stage is discussed in detail and any striking differences or similarities in thickness, lithology, or fauna displayed by correlative units are pointed out. The environment of deposition of the rocks deposited during each stage is reconstructed, and differences in the depositional environments of the correlative units are indicated.

A, FLUVIATE CONTINENTAL STAGE

In Wilson County, deposition during the fluviatile continental stage is represented by the lower parts of the Cottage Grove Sandstone Member of the Chanute Shale, Tonganoxie Sandstone Member of the Stranger Formation, and Ireland Sandstone Member of the Lawrence Shale (Fig. 3). The Ireland (megacyclothem 6) exhibits most completely the characteristics of the fluviatile continental stage and will be used as the example.

Physical Characteristics

Inasmuch as megacyclothemic deposition terminates with a general withdrawal of the sea, the oldest beds in a new megacyclothem—those constituting the fluviatile continental stage—commonly are deposited upon irregular erosion surfaces. Sandstone of the lower part of the Ireland fills channels cut as much as 60 feet into the underlying shale and commonly is strongly cross-bedded. The basal part of such a channel fill is well shown in a roadcut on Kansas Highway 96 about 6 miles northwest of Fredonia (Fig. 4). At this locality abundant fragments of light olive-gray shale from the underlying strata occur in the medium- to fine-grained sandstone of the lowermost 2 inches of the Ireland. Irregularly distributed elongate pods of siltstone and sandstone that contain much finely broken carbonaceous matter and Calamites occur in the lower 2 feet of sandstone in the exposure. The sandstone in the upper 12 feet in the roadcut is composed almost entirely of grains of subrounded, well-sorted, nearly equant, fine- to very fine grained quartz in beds that are both lenticular and truncated (Fig. 4). Correlation with adjacent outcrops indicates that as much as 50 feet of subaerially deposited fine- to medium-grained, slightly micaceous quartz-rich sandstone occurs above the sandstone of the roadcut. These continental deposits locally contain thin lenses of silty claystone and sandy siltstone and are overlain by sandstone that contains marine fossils in a few places.
The Tonganoxie Sandstone Member of the Stranger Formation and the Cottage Grove Sandstone Member of the Chanute Shale differ from the Ireland in a few characteristics that presumably reflect minor environmental modifications. The Tonganoxie differs in that the quartz grains are more angular and relatively poorly sorted, and small white mica flakes are abundant. The Tonganoxie, however, is a channel-filling sandstone as much as 60 feet thick, is coarsest at the base, and locally contains wood fragments. The Cottage Grove differs slightly in that the lower part consists of yellowish-gray, slightly micaceous, very fine grained silty sandstone that overlies strata containing a minable coal bed. The sandstone is about 45 feet thick, however, and generally is thin- and even-bedded; logs of exploratory wells suggest that the Cottage Grove fills channels cut 50 or more feet into the underlying shale.

Environment

In Ireland time in Wilson County, the initial phase of megacyclic deposition presumably began when streams that flowed across the county deposited material in largely subaerial channels cut 30 to 60 feet deep into the underlying soft strata of the preceding megacyclothem. The seaward parts of the streams probably occupied sinuous channels on tidal flats and on the adjacent submarine shelf. Delta building and reduction in stream grade or velocity apparently resulted in deposition in the lower parts of the channels of medium and fine sand containing a high proportion of plant debris, including Calamites. As the streams continued to meander and spread across the flood plains and delta areas, much fine sand was deposited in locally broad cross-beds, in plane-surfaced layers, or in thick unbedded units. Thirty to 50 feet of fine to medium sand and silt accumulated thusly, and the channels were mostly filled before the transgressing sea terminated the continental deposition.

During Tonganoxie and Cottage Grove times, previously cut channels were apparently also available for subaerial filling. Somewhat different source rocks, however, presumably furnished the more angular and less well sorted quartz grains and abundant small white mica flakes deposited during early Tonganoxie time. In early Cottage Grove time the source area for the materials transported by the streams must have been more distant, or the stream gradient less, so that only very fine
sand and silt were carried to the depositional environment.

II. CONTINENTAL TO MARINE TRANSITIONAL STAGE

The continental to marine transitional stage contains strata deposited under both nonmarine and marine conditions. The stage is represented by the upper part of the Ireland Sandstone Member and most of the strata in the overlying unnamed part of the Lawrence Shale, middle and upper parts of the Tonganoxie Sandstone Member of the Stranger Formation, and middle and upper parts of the Cottage Grove Sandstone Member of the Chanute Shale (Fig. 3). The Lawrence Shale (megacyclothem 6) will serve as the detailed example.

Physical Characteristics

The widespread sandstone beds of the upper part of the Ireland Sandstone Member of the Lawrence Shale are locally as much as 40 feet thick, but in many places they are separated into three units by two lenticular beds of shale 10 to 20 feet thick. These upper sandstone units of the Ireland are commonly grayish orange to moderate brown and are composed almost entirely of well-sorted, subrounded, very fine grained quartz. Small concentrations of limonite in many places cement the quartz grains and impart a speckled appearance to the rock; mica flakes are rare. The upper sandstone beds commonly have well developed ripple marks on which worm tracks are locally abundant. Casts of crinoid stems, low-spired gastropods (*Virgatilina*, *Nuculana*, *Schizodus*, and *Asiocleopetra*), and brachiopods (*Cucullites* and others) were found in a few places in the lower sandstone unit and locally in the upper sandstone beds. The intervening shale units generally are light olive gray, and silty or sandy.

The part of the Lawrence Shale above the sandstone consists of light-gray to light brownish-gray, medium-grained, sparsely fossiliferous, sandy, slightly micaceous limestone or very light gray to very pale yellowish-brown, very fossiliferous limestone. The sand grains in the sandy limestone are mostly moderately well sorted, subangular, nearly equant fine-grained quartz. Fossils in the Amazonia include crinoid stems and calyx parts; encrusting, ramose, and fenestrate bryozoans; productid and echinoid spines; small bivalves; brachiopods (*Cucullites, Derbyia*, and *Chonetes*); pelecypods (*Aviculopecten*); and many unidentified shell fragments. The Amazonia is overlain by about 6 feet of dark reddish-brown and moderate olive-gray slightly silty unfossiliferous claystone from which many small ironstone concretions weather. Above the concretionary claystone is a 4-foot dark reddish-brown claystone that has large irregular areas of pale-olive claystone throughout. Reddish-brown and nearly white calcareous nodules ⅛ inch to 6 inches in length, as well as small edaphic Stromatolites, weather from this unit. The next overlying 8 feet of claystone is mottled light gray and moderate reddish orange and also is unfossiliferous. Immediately above the unfossiliferous reddish-orange claystone is a dusky-blue claystone about 12 inches thick. Although no root systems were found in place, the claystone is unbedded, has a marked plasticity, and probably represents the deeply weathered material of an underclay. The underclay is overlain by 2 to 4 inches of coal that generally contains argillaceous layers at the middle and near the top. About one-third of the coal bed is vitrain and fusain, about one-third is attrital coal, and about one-third is argillaceous (bony) coal.

The middle and upper parts of the Tonganoxie Sandstone Member of the Stranger Formation consist of a sequence of alternating thin beds of ripple-marked micaceous siltstone and silty claystone. This sequence is missing in the southern part of the county and apparently is replaced by massive sandstone. Further north in Kansas several coal beds occur in the upper part of the Tonganoxie (Moore, 1936, p. 149). None is present in Wilson County, however.

The middle part of the Cottage Grove Sandstone Member of the Chanute Shale consists
of about 15 feet of very light gray, platy, carbonaceous siltstone in which the bedding locally dips northwest at about 10 degrees (Fig. 5). Many well-preserved fern leaves occur amid abundant small carbonized plant fragments on the finely micaceous bedding planes. The ripple-marked bedding surfaces and cross-bedding at a few localities suggest currents moving from south to north. Three sequences of coal beds occur in the Chanute Shale, one at the top of the platy carbonaceous siltstone and two below. Each coal sequence is of small areal extent and consists generally of two or three thin coals separated by three or more inches of carbonaceous claystone.

Environment

In late Ireland time the sea seems to have moved across Wilson County leaving in its wake a shoreline to shallow-water blanket sand that completely filled any remaining channels and overtopped the intervening areas. Brachiopods, gastropods, and pelecypods presumably grew in the nearshore marine water while offshore, beyond the influence of strong wave and current action, clay and silt apparently formed the base for growth of a crinoid community. A few crinoidal remains were carried shoreward during times of storms. Local reduction in wave action, current movement, or size of material furnished by streams resulted in the nearshore deposition in many places of relatively thick layers of clay and silt interbedded with and overlain by sand. In early late Lawrence time the preponderance of clay and silt furnished to the sea created conditions inhospitable to marine plant and animal life in much of the area. A layer of barren silty clay many feet thick accumulated over most of Wilson County. In shallow water where temperature, salinity, and other factors were satisfactory, however, faunas rich in bryozoans, echinoids, solitary corals, brachiopods and pelecypods thrived locally and their remains were concentrated by waves and currents into thin, discontinuous coquinaloidal limestone deposits. A very few organic remains were carried into carbonate-rich habitats lacking in nutrients, along with grains of fine quartz sand, and were enclosed in an iron-rich calcareous precipitate. As the sediments compacted, water highly charged with soluble iron moved through the silty clays along slightly more permeable zones, and the iron precipitated into beds and lenses of ironstone concretions.

Presumably the advance of the sea halted, and deeply weathered reddish silt and clay from the adjacent land area were spread subaerially across the broad coastal belt as the marine water withdrew from the county. Possibly some of the silt and clay that was then exposed upon poorly drained flats bordering the sea was subjected to considerable weathering and also developed a reddish color due to oxidation of the iron. Within the tidal zone in some places organic matter enclosed in the sediments presumably produced a reducing environment and small areas of greenish-colored muds formed. Water charged with calcium, sulfate, and carbonate ions provided materials that precipitated into crystals of gypsum and irregular nodules of limestone. The deeply weathered land surface underlain by these extremely fine-grained materials probably continued to be a nearly level plain on which grassy and reedy plants grew in profusion. Intermittently, streams overflowed their banks and flooded large shallow depressions on the floodplain surface. At times the streams carried large quantities of small branches and twigs of trees and much finely broken plant material into the low areas, where they settled into and covered thin accumulations of peaty matter derived from the indigenous vegetation. At other times clay and silt formed the chief constituents carried by the flooding streams. The clay and silt later became bony layers in coal, bark or small branches and twigs formed vitrain layers, and the finely broken plant material resulted in attrital coal. The fusain fragments possibly reflect oxidation in air prior to permanent submersion.

During late Tonganoxie time micaceous sand and silt accumulated on the shallow sea bottom adjacent to a low-lying land area, and gentle wave and current action time after time produced ripple-marked surfaces that were covered by thin accumulations of silty clay. Laterally, near the mouths of rivers, sand alone accumulated into thin deposits concurrently.
During middle Cottage Grove time, predominantly silt-size material was carried by sluggish streams to form broad deltas along a quiet shallow sea. The silt was spread laterally and formed into even-surfaced layers upon whose upper surfaces accumulated the finely broken remains of ferns and other plants that grew in profusion on the subaerial part of the delta and the adjacent coastal plain. During Cottage Grove time peat-filled swamps formed several times in local basins of small areal extent and relatively short duration. Each period of plant-debris accumulation was interrupted by an influx of clay from the adjacent land, possibly resulting from increased rainfall, from breaching of the basin border, or from both.

C, ARGILLACEOUS TRANSgressive-Regressive Marine Stage

Deposition during the argillaceous transgressive-regressive stage is represented by fossiliferous argillaceous and calcareous sedimentary rocks in the upper parts of the Lane-Bonner Springs and Vilas Shales, Westphalia Limestone Member of the Stranger Formation, uppermost part of the Lawrence Shale, and Toronto Limestone Member of the Oread Limestone. This marine sequence is exemplified by the Westphalia Limestone Member of the Stranger Formation (Fig. 3, megacyclothem 5).

Physical Characteristics

The lower 1 to 2 feet of the Westphalia Limestone Member of the Stranger Formation consists of pale yellowish-brown fossiliferous limestone that contains an appreciable amount of iron-rich detrital material in the calcareous matrix. Impurities of clay size are most common in outcrops in the northern part of the county; silt- and sand-size impurities are most abundant in outcrops in the southern part of the county. In a few localities the clay and sand constituents are predominant, and the rock is an algal mudstone or sandstone.

Both small and large bean-shaped algae (Osagia?) are very abundant in the lower part of the Westphalia. The multiple-layered coatings that compose the algae consist of about 2 to 20 thin irregularly crenulated layers of calcium carbonate around shell fragments, oolites, small fossils, and elongate iron-oxide cores. Angular silt-size grains of quartz are abundant throughout the limestone matrix.
and within the algal growths and the outer chambers of fusulinids. Insoluble residues of samples contain numerous sand-agglutinated foraminifers including *Tolypammina*, *Ammonovertella*, and *Hyperammina* amid limonite-cemented siltstone fragments, pitted grains of clear and cloudy quartz, and flakes of muscovite. Fossil fragments of echinoid spines and plates, ramose and fenestrate bryozoans, crinoid columnals, fusulinids, gastropods, pelecypods, and brachiopods locally form a large percentage of the lower part of the Westphalia. Identifiable forms include the brachiopods *Composita*, *Crurithyris*, *Hustedia*, *Neospirifer*, *Punctospirifer*, and *Juresania*; the pelecypods *Astartella*, *Aviculopecten*, and *Nuculana*; and the gastropods *Bellerophon* and *Worthenia*.

Six inches to 1 foot of limestone rubble, which consists of fragments of limestone covered with a white porous coating, locally separates the upper 2 to 3 feet of the Westphalia from the lower part. The upper part of the Westphalia is more widely distributed than the lower part and consists of moderate yellowish-brown impure fossiliferous limestone. Small *Osagia* and sparsely interspersed slender fusulinids (*Triticites*) show in relief on the moderate yellowish-orange weathered surface. The algal layers have formed around centers of echinoid spines and plates, ramose bryozoans, small shells and shell fragments, and quartz grains. Insoluble residues contain the foraminifers *Aminodiscus*, *Ammonovertella*, *Glomospira*, and *Tolypammina*, as well as quartz grains and a few mica flakes. This stage extended into earliest Vinland time as indicated by the fusulinid-algal-brachiopod fauna in the lowermost foot of the Vinland Shale.

Correlative strata in the overlying megacyclothem (No. 6) locally contain a somewhat higher percentage of clayey material in the lower part of the sequence. The uppermost part of the Lawrence Shale consists of about 2 to 3 feet of medium light-gray to light olive-gray, very calcareous, fossiliferous, nodular claystone. The lower 10 inches is only sparingly fossiliferous, but concentrations of pelecypods occur locally. In the overlying part of the unit are found the identifiable remains of the brachiopods *Chonetes* and *Dictyoclostus*, fragments of other brachiopods, ramose bryozoans, crinoids, corals, and echinoids. Fusulinids, together with a few foraminifers of the genus *Tetrataxis*, are extremely abundant in the uppermost part where the claystone grades upward into the Toronto Limestone Member of the Oread Limestone. The Toronto, in the lower part, is principally a fine- to medium-grained yellowish-gray argillaceous very fossiliferous limestone that weathers to wavy-bedded outcrop faces. Fossils occur throughout, but the fossil content varies in type and abundance both horizontally and vertically. This part of the Toronto is probably the lateral equivalent of the uppermost 5 feet of the Lawrence Shale, but exposures are too incomplete in the intervening area to provide proof of the equivalence. The fauna of the lower part of the Toronto contains pelecypods such as *Mytilina* (*Orthomytilina*), *Aviculopecten*, and *Astinolopitaum*; brachiopods such as *Chonetes, Composita, Crurithyris, Derbyia, Dictyoclostus, Hustedia, Juresania, Meekella, Neospirifer, Punctospirifer*, and *Rhipidomella*; ostracodes such as *Amphissites, Astartella, and Bellinella*; a lophophyllid coral and the coral *Syringopora*; high- and low-spired gastropods; fenestrate, ramose, and encrusting bryozoans; the ubiquitous crinoid stems; and abundant fusulinids.

In the uppermost part the Toronto has a brecciated appearance produced by angular fragments of dark yellowish-orange argillaceous limestone in a groundmass of very pale orange limestone. Cryptozoanlike algae surround crinoid columnals, horn corals, and fossil fragments.

In the rocks of megacyclothem 4, near the top of the Vila Shale, a series of limestone beds that are intercalated in gray shale possibly represent stage C. The lower limestone beds and underlying and overlying shale contain an assemblage of pelecypods, gastropods, brachiopods, algae, corals, crinoids, and scattered fusulinids. The upper limestone beds have a brecciated appearance due to grayish-orange limestone fragments surrounded by irregularly shaped seams of olive-gray calcite 1/25-inch thick.

Five to 10 feet below the top of the Lane-Bonner Springs Shale in Wilson County is a thin fossiliferous limestone bed that may rep-
recent an incomplete development of stage C in megacyclothem 3. The limestone bed and the overlying shale contain abundant crinoid stems and brachiopod fragments. These strata may, however, be representatives of other stages, for, farther north in Kansas, the Lane and Homer Springs Shales and the intervening Wyandotte Limestone apparently contain most of the elements of an entire megacyclothem (Moore, 1949, p. 78).

Environment

In early Westphalia time abundant sand, silt, and clay apparently entered the Wilson County area from a low-lying land area to the south as the sea transgressed and the water deepened. Much soluble iron was included in this terrigenous material as it accumulated in the carbonate-rich shallow sea. Pelecypods, gastropods, brachiopods, and other shallow-water forms flourished and were buried near the shore in the sandy lime mud in the southern part of the county area. Somewhat farther north the debris from an algal-fusulinid community formed a thin deposit on the near-level sea floor. Such a community suggests that the water deepened rapidly but was very clear and high in the nutrients needed to support such a population. Presumably, as the water shallowed, the progeny of the fusulinid population retreated seaward. Bean-shaped algae, however, continued to flourish in the warm, hypersaline water of late Westphalia time, and their remains accumulated to form a thin, widespread, calcareous stratum.

In late Lawrence time streams or marine water seem to have supplied clay-size material to the shallow sea bottom. Mollusks, brachiopods, and other life presumably grew abundantly in a slightly calcareous muddy habitat. As the sea rapidly deepened, a fusulinid community rapidly populated the area of Wilson County, and their remains accumulated abundantly on the sea floor during latest Lawrence and early Toronto time. In late Toronto time, the water shallowed and Cryptotheca algae became a part of the life-community. At times the calcareous mud containing the remains of these algae, as well as crinoids, solitary corals, and other animals, was sufficiently compacted, desiccated by exposure above sea level, or cemented to permit it to break into discrete fragments when subjected to the extreme action of storm waves. The fragments were almost immediately redeposited in lime mud of slightly different character so that the fragment boundaries are well displayed in the resulting rock. Similar conditions apparently prevailed in late Villas time. A partial oscillation of sea level may have occurred in Wilson County during Lane-Bonner Springs time, but the evidence is inconclusive.

D. Continental Margin Stage

Strata deposited at the continental margin are included in parts of the Villas Shale, Vinland Shale Member of the Stranger Formation, and Snyderville Shale Member of the Oread Limestone. The Snyderville best typifies deposits of the continental margin stage.

Physical Characteristics

The lower two-thirds of the Snyderville consists predominantly of dark reddish-brown claystone in the lower 10 feet and pale greenish-gray silty claystone in the upper 25 feet. However, large irregular greenish-gray areas occur in the lower part, and discontinuous lenses and irregular dark reddish-brown areas occur in the upper part. Two, locally three, lenticular sandstone beds occur 10 to 15 feet above the base of the Snyderville. The beds are yellowish gray, commonly finely micaceous and calcareous, 6 to 10 inches thick, and are composed mainly of well-sorted, very fine grained quartz. Ripple marks and worm tracks are locally common, and plant fragments were noted at one locality. About 35 and 45 feet above the base are other silty sandstone beds that are pale greenish gray to yellowish gray and very fine grained. The lower bed is locally 5 to 7 feet thick and is composed of well-sorted, very fine grained to silt size subangular quartz grains that are cemented with calcium carbonate in a few places. The upper bed is about 1 foot thick; its upper surface has markings that resemble mud cracks. Except for the uppermost foot, the upper 16 feet of the Snyderville consists predominantly of dark reddish-brown slightly silty claystone with lenticular interbeds of pale greenish-gray silty claystone.
yellowish-orange ironstone concretions, ½ to ¾ inch in diameter, are common in some exposures. Irregular-shaped calcareous nodules, which are usually stained reddish brown on their outer surfaces and are brown, red, green, or white within, weather out of the reddish-brown claystone in local abundance. The uppermost foot consists of light olive-gray calcareous shale that contains a nearshore marine fauna consisting of pelecypods (Astartella), ostracodes (Amphistephanus, Bairelia, Cavelina, and Holocystis), brachiopods (Chonetes and Dictyoclostus), foraminifers (Tetrataxis and Trifarina), algae (Oasia), gastropods, echinoid spines, crinoid columnals and plates, ramose bryozoan fragments, and unidentified conodont remains (Wagner and Harris, 1953).

The lower 2 to 14 feet of the Vinland Shale Member of the Stranger Formation consists predominantly of light olive-gray to yellowish-gray very slightly silty claystone. This part of the Vinland is unfossiliferous except for a few plant remains on bedding surfaces. The uppermost foot, however, is moderately calcareous and contains many large pelecypods of the genus Myalina (Orthomyalina) in conjunction with Chonetes and fragments of other small brachiopods, ramose bryozoans, corals, echinoid spines, crinoid columnals, and ostracodes.

The uppermost 3 feet of the Vilas Shale is light grayish-orange fossiliferous calcareous shale containing crinoid columnals and sparse low-spired gastropods amid fragments of brachiopods, pelecypods and bryozoans. At the base of this uppermost 3 feet is a 6- to 12-inch medium-gray nodular algal (Oasia?) oolitic limestone bed. No distinct representative of the continental margin stage was recognized in the megacyclothemic sequences that include the Lane-Bonner Springs Shale and the Chanute Shale.

Environment

As the sea shallowed and receded from Wilson County during early Snyderville time, deeply oxidized material derived from the erosion of weathered rocks of the low-lying coastal plain is thought to have accumulated as reddish silty clay upon the newly exposed land surface. Concentrations of plant remains brought about reducing conditions in small areas and the clay there became pale greenish-gray. Modification of the weather, possibly in the form of much greater rainfall, resulted in the spreading of relatively thin deposits of silt and very fine sand over the nearly level land surface, thus preserving the clay from further oxidation or reduction. Resumption of distribution of oxidized silty argillaceous material throughout Wilson County resulted in the accumulation of additional quantities of reddish clay. Again, where organic matter was concentrated, the reddish oxidized clay was reduced to a greenish color, and during short periods of excessive precipitation, layers of sand and silt were spread over the land. At times connate water saturated with calcium carbonate moved laterally through the more permeable beds, and the carbonate was precipitated in the form of calcareous nodules. Similarly, much soluble iron, which was subsequently deposited as oval-shaped ironstone concretions, may have been transported. Silty sandstone beds were cemented locally with calcite where percolating saline waters deposited their calcium carbonate between the quartz grains. Snyderville time closed with the Wilson County area again under water that prevented further oxidation or reduction of the iron in the clays and provided a habitat amenable to such shallow-water marine animals as the pelecypod Astartella and the brachiopods Chonetes and Dictyoclostus, as well as gastropods, echinoids, crinoids, and bryozoans.

During most of Vinland time the Wilson County area was possibly a coastal plain or tidal flat receiving fine silt and clay from streams draining the adjacent low-lying land area. Plant remains were brought into the area intermittently and in small quantity. Vinland time closed with the beginning of a general transgression of the sea and the establishment of a fauna consisting of large pelecypods, small brachiopods, solitary corals, echinoids, bryozoans, and ostracodes.

Land conditions apparently never prevailed during stage D in Vilas time. The sea was very shallow, however, and in latest Vilas time nearshore warm, continually agitated, relatively clear marine water made possible the growth and accumulation of abundant small oolites and Oasia? algae. Presumably the
water deepened to such an extent that the sea floor was below the realm of wave or strong current action. A thick layer of clay then covered the accumulated oolites and algae, and the stage was set for the introduction of a fauna composed of pelecypods, brachiopods, crinoids, and bryozoans.

E. Rapid-Oscillation Marine Stage

Five nearly identical limestone beds compose the representatives of the rapid-oscillation marine stage: the Paola Limestone Member of the Iola Limestone, Merriam Limestone Member of the Plattsburg Limestone, Captain Creek Limestone Member of the Stanton Limestone, Haskell Limestone Member of the Stranger Formation, and Leavenworth Limestone Member of the Oread Limestone. The Leavenworth exemplifies deposition during the stage.

Physical Characteristics

The basal 1 3/4 inches of the Leavenworth Limestone Member of the Oread Limestone consists of a fossiliferous granulite layer in which unbroken shells of brachiopods and large pelecypods are enclosed in a light brownish-gray matrix of subangular to rounded granules of limestone. Myalina (Orthomyalina) and Juresania are abundant in the matrix and are generally oriented concave side down. The remainder of the Leavenworth is medium dark-gray vertically jointed very finely crystalline fossiliferous limestone 1.2 to 1.6 feet thick (Fig. 6A). Fossil remains stick out in relief on the upper pale yellowish-brown weathered surface, and in many exposures the most distinctive feature of this surface is the presence of numerous dark oval-shaped algal bodies that range in length from 1/2 to 1 1/2 inches and in width from 1/4 inch to 1/2 inch. The algae consist of irregular concentric layers around brachiopod shell fragments, crinoid columnals, horn corals, and other shell fragments. Other fossils include echinoid spines and plates, gastropods, and brachiopods represented by the genera Marginifera, Derbyia, Composita, Juresania, and Linoproductus. Unbroken shells of small fusulinids (Trichites) are locally common in the middle and upper parts of the Leavenworth. Oolites, 1/50 to 1/10 inch in diameter, are also locally abundant near the top. The thin vertically jointed Haskell Limestone Member of the Stranger Formation is a dense, crystalline limestone (Fig. 6B) that also contains oolites, pelecypods such as Myalina (Orthomyalina), and fragments of brachiopods, fenestrate bryozoans, and crinoids in the lower part. In the upper part it is sparsely oolitic, dense, and crystalline and contains Cryptozoon? algae, brachiopod and other shell fragments, and long slender fusulinids. In the uppermost part is a veinlet-studded, brecciated-appearing, somewhat fossiliferous limestone. The entire Haskell is a single limestone bed that averages about 2 feet in thickness.

The Captain Creek Limestone Member of the Stanton Limestone consists of yellowish-gray finely crystalline algal (Oscagia) and oolitic vertically jointed very finely crystalline fossiliferous limestone in the lower 2 to 5 feet. Large nautiloid cephalopods are locally abundant. The remaining 5 to 10 feet of the Captain Creek is chiefly medium-gray, massive to thick-bedded cavernous limestone that weathers almost white, is deeply pitted with holes 1/2 inch to 2 inches in diameter (Fig. 7), and contains the locally abundant remains of crinoids, fenestrate bryozoans, brachiopods, corals, and fusulinids. At or near the top, the Captain Creek locally has an 8-inch zone of thin-bedded, somewhat argillaceous, red-blotched limestone that contains large pelecypods.

Both the Merriam Limestone Member of the Plattsburg Limestone and the Paola Limestone Member of the Iola Limestone contain shallow-water faunas in their upper and lower parts and are single beds about 1 foot thick. The Merriam, however, is very argillaceous limestone throughout and lacks fusulinids, which are found near the middle of the Paola.

Environment

In early Leavenworth time granules and oolites of calcium carbonate presumably were oscillated back and forth in relatively clear, shallow, carbonate-rich water inhabited by large pelecypods and nearshore-dwelling brachiopods. Very shallow water, and wave or current action sufficient to move the gran-
Wagner—Pennsylvanian Megacyclothsms, Kansas

Figures 6.—A, Leavenworth Limestone Member of Oread Limestone about 9 miles west of Fredonia, Wilson County. B, Haskell Limestone Member of Stranger Formation about 14 miles north of Fredonia, Wilson County.

ules were operative only long enough for a few inches of granulite to accumulate in the Wilson County area. Somewhat deeper water and more stable bottom conditions may have led to the introduction of a fauna containing brachiopods, gastropods, echinoids, crinoids, and solitary corals. Physicochemical conditions being optimum, the relatively shallow, clear water may have been warmed sufficiently to produce a gel-like calcareous precipitate on the sea floor. In such a precipitate collected the scattered remains of the indigenous animal and plant life throughout most of Leavenworth time. Calcareous algae, which formed multi-
pie layered coatings around broken fragments of the remains of crinoids and other animals, as well as small fusulinids that had apparently formed local colonies on the sea floor for a short period of time when the water was deepest, were among the remains of the different life-types that were enclosed in the cryptocrystalline calcareous precipitate. Leavenworth time closed as conditions necessary for this limestone deposition became inoperative.

Haskell time also opened with a shallow-water marine environment well suited to oolitic development and growth of large nearshore-dwelling pelecypods. Bryozoans, brachiopods, and crinoids soon became the dominant faunal elements, oolitic growth virtually halted, and a precipitate similar to that postulated for Leavenworth time formed. Fusulinids became locally abundant in the fauna in late Haskell time just prior to a general shallowing of the sea. Algae (Cryptozoon) became the most abundant life form, and conditions that led to the brecciation and redeposition of semilithified lime mud continued for a short time until Haskell deposition ended.

Captain Creek time also was a period during which the sea deepened and shallowed in a relatively short period of geologic time but probably over a somewhat longer time span and under more complex environmental conditions than operated during Leavenworth, Haskell, Merriam, or Paola times. The general deepening of the sea apparently started in late Vilas time, the water was highly charged with carbonate, was well lighted, and profuse small algae (Osagia) and oolites formed thin calcareous sediments. The algal-oolitic environment persisted, and in early Captain Creek time the unbroken shells of large nautiloid cephalopods were enclosed in a matrix of small oolites and Osagia. Laterally, in local depressions, highly charged carbonate-rich waters formed thick flocculating masses of calcium carbonate into which the remains of brachiopods, crinoids, bryozoans, corals, and fusulinids were carried and settled. Large pelecypods that apparently lived in a nearshore environment formed the major part of the fauna in the shallow water of late Captain Creek time.

Throughout Merriam time the sea water apparently contained a high content of argillaceous material in suspension and iron in
solution, and it is doubtful that the water ever attained much depth. Crinoids, sponges, brachiopods, horn corals, hyrozoans, echinoids, and small and large algae either lived in the somewhat muddy water or were brought in from the clearer water of adjacent areas. The physical aspects of the sea water were, however, very similar to those that operated during the fossiliferous calcareous deposition in stage K of megacycles 2, 4, 5, and 6, and a calcareous precipitate enclosed the remains of the Merriam life-community.

A marine environment well suited to invertebrate life existed in early Paola time, and hyrozoans, corals, crinoids, and brachiopods grew in profusion. The water presumably deepened throughout the Wilson County area and fusulinids abounded in conjunction with a few algae. In the east-central part of the county the water remained fairly deep until near the end of Paola time, and fusulinids continued to dominate the sea bottom; but in the southern part of the county algal life alone flourished in the hypersaline shallowing water of latest Paola time and furnished abundant remains to the upper part of the dense, gel-like mass of calcium carbonate that presumably blanketed the sea floor.

F. Stagnant-Water Marine Stage

Strata deposited under conditions of the stagnant-water marine stage (except for the Hickory Creek Shale Member of the Plattsburg Limestone) show the least lithologic variation of any rock type in the megacyclothem. Parts of the Heehner Shale Member of the Oread Limestone, Muneie Creek Shale Member of the Iola Limestone, Eudora Shale Member of the Stanton Limestone, and Robbins Shale Member of the Stranger Formation are typical of this stage.

Physical Characteristics

The lower 2 to 3 feet of the Heehner Shale Member of the Oread Limestone consists of nearly black fossiliferous conodont-bearing shale that breaks upon weathering into paper-thin laminae as much as 3 inches across. Finely comminuted plant remains are abundant on bedding planes in a few places. Small (1 to 2 inch) phosphatic concretions are found locally in the central part; the P04 content of the concretions is 32 percent (Runnels and others, 1953, p. 98). Conodonts identified by L. D. Harris (Wagner and Harris, 1953) from the Heehner in Wilson County and the immediately adjacent area include Cavusgnathus, Hindeodella, Ideognathodus, Lonchodas, Ozarkodina, Streptognathodus, and Trichognathus. Other microfossils identified are the foraminifers Ammodiscus, Crenulina, and Tetrataxis, and the ostracodes Bairdia and Cavellina. Unidentified small fragments of hyrozoans, brachiopods, and crinoids are present also.

The black shale part of the Muneie Creek Shale Member of the Iola Limestone is almost identical in character to the Heehner. It is 1 1/4 to 2 1/2 feet thick, is very fissile, breaks to paper-thin laminae, and contains abundant flattened, oval-shaped phosphatic concretions in the central part. The Eudora Shale Member of the Stanton Limestone locally contains 1 to 3 feet of almost black very fissile platy shale near the center. The black shale breaks to paper-thin laminae on whose surfaces flattened orthiculoid brachiopods are locally abundant. The lower few inches of the Robbins Shale Member of the Stranger Formation is dark gray and fissile and contains small phosphatic nodules in a few localities. The Hickory Creek Shale Member of the Plattsburg Limestone is yellowish-gray very fossiliferous calcareous shale in Wilson County; but farther north in Kansas the Hickory Creek has a thin carbonaceous platy shale in its lower part (Newell, 1933, p. 47).

Environment

The stagnant-water marine stage is thought to have been a time of poorly circulating, oxygen-poor sea water. Tidal or current movement was at a minimum, and the sea floor was a vast planar surface formed on the top of a thin layer of calcareous precipitate. Generally, little or no land-derived debris reached Wilson County. Seaweed, possibly the dominant life form, essentially filled the uppermost part of the shallow sea and probably had a dampening effect on wind-derived wave action. Abundant ostracodes and conodonts inhabited the water amid the seaweed, and small orthiculoid brachiopods were prob-
ably attached to the seaweed and drifted to the sea floor along with the seaweed remains, there to rest in a humus-filled anaerobic environment. Phosphate accumulated as a result of bacterial decomposition of this organic debris, to be concentrated into concretions either concurrently or later during diagenesis. The small broken remains of crinoids, bryozoans, and other invertebrate life were occasionally swept into the area by unusually strong currents.

G. Normal Transgressive-Regressive Marine Stage

Deposits formed during the normal transgressive-regressive marine stage include the Winterset Limestone Member of the Dennis Limestone, Raytown Limestone Member of the Iola Limestone, Spring Hill Limestone Member of the Plattsburg Limestone, Stoner Limestone Member of the Stanton Limestone, very fossiliferous beds in the Robbins Shale Member of the Stranger Formation, Plattsmouth Limestone Member of the Oread Limestone, and parts of subjacent shale members as well. The upper part of the Eudora Shale Member and Stoner Limestone Member of the Stanton Limestone are typical of this depositional sequence.

Physical Characteristics

The upper 3 feet of the Eudora Shale Member of the Stanton Limestone consists of light greenish-gray calcareous shale that grades laterally into clayey limestone. Fossils include crinoid columnals, horn corals, encrusting bryozoans, echinoid spines, and brachiopod and mollusk fragments. The lower part of the Stoner Limestone Member, next above and as much as 15 feet in thickness, consists principally of light-gray, wavy-bedded, calcareous, and locally cross-bedded fossiliferous limestone. In many places thin beds within the Stoner are medium to coarsely crystalline coquina made up entirely of crinoid columnals and plates (Fig. 8), echinoid plates, fenestrate bryozoans, or pelecypod and brachiopod fragments. Identifiable fossils include such genera as *Meekoporella*, *Composita*, *Iaresania*, *Neospirifer*, *Schizo-mphorius*, and *Syringopora*. In many places, relatively unfossiliferous very finely crystalline limestone predominates, and much of the Stoner is a brecciated-appearing rock consisting of angular areas of light brownish-gray in a matrix of yellowish-gray limestone. Fusulinids occur locally near the top of this part of the member, and sinuous bodies of coarse crystalline calcite, which closely resemble in form the algae *Cryptozoon*, are abundant in some areas. Vugs and fractures filled with sparry calcite are also conspicuous at many places.

The upper part of the Stoner is light-gray, wavy-bedded, sparsely oolitic, finely crystalline limestone 5 to 15 feet thick. It contains fusulinids only locally in the lower part. A fauna collected from this part of the Stoner by Newell (1933, p. 136) and others at the cement plant quarry at Fredonia contained abundant remains of brachiopods, pelecypods, gastropods, corals, and crinoids. The Plattsmouth Limestone Member of the Oread Limestone has a distinct wavy-bedded character (Fig. 9), contains brachiopods, pelecypods, gastropods, echinoid spines, and crinoid stems in the lower part, fusulinids in the upper part, and brecciated-appearing limestone in the uppermost part. The Spring Hill Limestone Member of the Plattsburg Limestone is irregularly bedded throughout and contains sponges (*Heliospongia* and *Girtyocoele*), brachiopods (*Neospirifer*, *Derbyia*, *Margitaffa*, *Curithyris*, *Echoiocomochus*, and *Composita*), solitary corals, bryozoans, and crinoids in the lower part, and *Cryptozoon* and blade-like algae in conjunction with a few fossil fragments, oolites, and fusulinids in the brecciated-appearing crystalline middle part. The limestone of the Raytown is clayey, fossiliferous, locally algal, and oolitic. Oolites, algae (*Osagia*), brachiopods, pelecypods, and gastropods are abundant in the Winterset. During Robbins time there apparently was too much clayey contamination or insufficient calcium carbonate in the sea water to form thick limestone beds. The fauna in the shale of this part of the Robbins, however, contains pelecypods, gastropods, brachiopods, corals, etc., most of the elements found in the wavy-bedded limestones.
**Environment**

The normal transgressive-regressive marine stage seems to have started in Eudora time with muddy carbonate-rich water covering the Wilson County area. Bottom-dwelling pelecypods as well as horn corals, bryozoans, echinoids, and brachiopods formed much of the fauna whose remains collected in the lime-rich mud that accumulated on the sea bottom. In early Stoner time the water deepened somewhat and became clearer, and some small depressions and possibly some reeflike areas well suited to one or a few particular types of invertebrate life developed. In certain small areas the remains of crinoids formed the only faunal element in the carbonate-charged lime mud; in other places the remains were entirely those of fenestrate bryozoans or of echinoids. Physicochemical conditions suitable to calcium carbonate precipitation presumably occurred during much of middle Stoner time and thin irregularly surfaced lenticular calcareous precipitates formed overlapping wedges upon the sea floor. Very thin concentrations of clay apparently were deposited on many of these surfaces, and after lithification and exposure to weathering, the wavy-bedded character becomes apparent. Deepening of the water was probably responsible for the entry of a locally abundant fusulinid fauna, but in late Stoner time the water shallowed and algal growth predominated as the life form in presumably hypersaline waters. Small particles were oscillated and oolites grew in the relatively shallow water in or near the habitat of a fauna consisting of pelecypods, gastropods, brachiopods, corals, and crinoids. Violent storm waves at times reached the sea floor and disrupted the semilithified bottom sediments which then settled as fragments into the unconsolidated calcareous mud that was being deposited.

The events recorded in Plattsmouth and Spring Hill times were very similar to those of Stoner time. During Raytown and Wintersett time, the sea presumably deepened and then shallowed, but without reaching the depth of fusulinid activity. Robbins time was apparently dominated by argillaceous debris from the land, but not to the exclusion of faunas whose habitats ranged from shallow to relatively deep water.
H, NEARSHORE ARGILLACEOUS MARINE STAGE

Nearshore argillaceous marine deposition is represented by strata of the Cherryvale Shale, lower part of the Lane-Bonner Springs Shale, Rock Lake Shale Member of the Stanton Limestone, and middle part of the Robbins Shale Member of the Stranger Formation. The Cherryvale Shale (Fig. 3, megacyclothem 1) is considered typical.

Physical Characteristics

The Cherryvale Shale consists of as much as 40 feet of yellowish-gray to medium-gray finely micaceous, thin-bedded clayey siltstone and silty claystone. A light olive-gray hard unfossiliferous limestone bed, 9 inches thick, occurs about 14 feet above the base, and several ¼ inch to ½ inch platy unfossiliferous limestone beds occur in the next overlying 2 feet. A few beds of small ironstone concretions occur below these limestone beds and also in the upper 5 feet. The lower 2 feet of the Cherryvale has current ripple marks locally.

The lower part of the Lane-Bonner Springs Shale consists of light olive-gray unfossiliferous silty claystone. Beds of unfossiliferous limestone concretions, 5 to 10 inches thick, are both underlain and overlain by claystone containing small moderately abundant ironstone concretions.

The Rock Lake Shale Member of the Stanton Limestone is poorly exposed in Wilson County but may represent this stage. It consists of locally calcareous claystone that is dark yellowish orange in the lower foot and very light olive gray in the upper foot. A marine fauna, consisting of several foraminifers and ostracodes as well as fragments of crinoids, bryozoans, echinoids, and brachiopods, was noted at a few localities.

The middle part of the Robbins Shale Member of the Stranger Formation consists of light olive-gray silty to sandy shale that characteristically contains abundant ironstone concretions. Two thin beds of moderate yellowish-brown very fine grained sandstone or sandy siltstone occur locally in this part of the Robbins.

Environment

In early Cherryvale time the Wilson County area was covered by a shallow sea whose water was presumably low in nutrients, was clouded by abundant clay and silt supplied by
erosion of a nearby low-lying land area, and apparently was inhospitable to marine animal or plant life. Current action locally developed ripple marks on the surfaces of the silt and clay layers. Near the middle of Cherryvale time, the calcium carbonate content and other physical characteristics of the sea water were such that limy gels collected on the bottoms of shallow depressions and precipitated as large discrete oval-shaped bodies or lenticular beds. Soluble iron became concentrated locally into ironstone concretions, possibly during dia genetic stages.

In Lane-Bonner Springs time almost identical conditions prevailed; but in middle Robbins time small amounts of sand-size detritus were distributed occasionally throughout the area and thin sandy beds accumulated upon the clayey mud. During Rock Lake time, physical and biological conditions remained locally suitable to marine life throughout this stage in the Wilson County area.

I. NEARSHORE CLEAR-WATER MARINE STAGE

Sediments of the nearshore clear-water marine stage are found in the Drum Limestone, Oolitic phase of the Spring Hill Limestone Member of the Plattsburg Limestone, South Bend Limestone Member of the Stanton Limestone, and limestone beds in the upper part of the Robbins Shale Member of the Stranger Formation.

Physical Characteristics

The lower 6 to 10 inches of the 18-inch Drum Limestone is composed of brownish-gray to medium-gray sparingly fossiliferous limestone. Broken crinoid stems are the dominant fossils and in conjunction with shell fragments of brachiopods, occur in a finely crystalline calcite matrix. The upper part is much more fossiliferous, generally is oolitic, and in the easternmost part of the county contains abundant Osagia and Cryptocystina-like algae. At a few localities the oolites, algae, and invertebrate fossil remains fill scours; small channel or large desiccation cracks that apparently formed in the lower part of the Drum prior to accumulation of the upper part. The oolites are much larger at the top of the bed than in the lower part and are concentrically banded; the outer rings in many are broken and striped back or folded, possibly as a result of partial desiccation. The fauna of the upper part of the Drum consists of the brachiopods Composite, Derbyia, Echinocnochus, Hustedia, Ixeasania, Marginifera, Neo spirifer, and Punctospirifer; horn corals and Syringopora; ramose, fenestrate, and encrusting bryozoans; crinoid stem segments and calyces; small helicospiriferid and high-spired gastropods; and Mystiina (Orthomyalina) and small pelecypods.

The uppermost few feet of the Spring Hill Limestone Member of the Plattsburg Limestone consists principally of oolites and algae Osagia that have diameters generally less than 1/2 inch but locally as much as 1/4 inch. The oolites are concentrated into pockets in a very finely crystalline limestone. In some of the oolites the concentric bands extend to the center of the oolite, but more commonly crinoid stem segments, shell fragments, or subangular microcrystalline limestone grains form the centers.

The South Bend Limestone Member of the Stanton Limestone is similar to the Drum and Spring Hill in being oolitic, but generally it is sandy, cross bedded, and contains a pelecypod-brachiopod fauna. It commonly contains brachiopods of the genera Rhipidomella, Punctospirifer, Hustedia, Meekella, Derbyia, Streptorhynchus, and Didasia; and the pelecypods Streblopecten, and Atriculopecten (Newell, 1933, Pl. 1, p. 140; 1937, p. 53). About 10 percent of the oolites have quartz grains at their centers. In a few areas, fusulinids were observed in the South Bend.

Three lenticular, locally developed limestone beds in the upper part of the Robbins Shale Member of the Stranger Formation consist primarily of the remains of Osagia and crinoid stem segments, numerous large and small brachiopods, pelecypods, and gastropods. Small fusulinids were abundant in a thin bed in one exposure.

Environment

Early in Drum time the shallow clear sea that covered the Wilson County area apparently was not particularly suitable for marine life because of low nutrient content, excessive salinity or temperature, or some other
important factor. Conditions for the precipitation of calcium carbonate, however, were apparently near optimum for a short period, and the remains of a scanty invertebrate fauna were enclosed in a viscous calcareous precipitate. In middle Drum time shallowing of the water may have brought this newly formed precipitate above low-tide level so that the upper surface became desiccated and was locally channeled by tidal-current action. Better conditions for marine life followed, as shown by the broken remains of bryozoans, corals, bryozoans, and crinoids that were carried into these desiccation cracks and tidal channels. There they were concentrated and, in conjunction with abundant oolites, were oscillated back and forth by small waves and shoreline tidal currents. Continued oscillation and accretion during most of late Drum time resulted in the formation of a thin accumulation of oolites and fossil fragments through-out the Wilson County area. Occasional temporary exposure above low-tide level allowed many of the oolites to become partly desiccated and flattened. They were subsequently incorporated in the calcareous sediments of latest Drum time.

In latest Spring Hill time a shallow-water marine environment also prevailed in which small oolites and algae (Osagia) were being oscillated back and forth in carbonate-rich water by current or wave action. Time was sufficient for the oolites to form a thin, widely distributed calcareous deposit on the flat or gently undulating surface.

During South Bend time many fine-size quartz grains were carried into the shallow clear sea, were oscillated in water highly charged with calcium carbonate, and formed the nuclei of many oolites. Wave and wind action concentrated the oolites and grains of lime sand into locally cross-bedded deposits. A brachiopod-pectenoid fauna inhabited the marine water and nearshore lime mud, and their shells were added to the deposits formed during South Bend time. Fusulinids may have lived in a few scattered places in the Wilson County area, or their remains may have been brought into the area by current action. During Robbins time, the calcareous remains of abundant marine plant and animal life formed a major part of several thin lenticular accumulations of lime mud on the shallow sea floor. Land-derived clay, however, was apparently the predominant material furnished to the sea and several times formed thick deposits upon which calcareous matter could accumulate.

J Nearshore Regressive Marine Stage

The nearshore regressive marine stage brought to an end the marine phase of each megacycle; the sea then receded from the Wilson County area and erosion cut channels as deep as 60 feet into the newly deposited strata. Sediments laid down by nearshore regressive deposition occur in the lower part of the Chanute Shale, middle part of the Lane-Bonner Springs Shale, lower part of the Vilas Shale, much of the Weston Shale, and upper part of the Robbins Shale Member of the Stranger Formation. The Weston Shale will serve as the typical example.

Physical Characteristics

The Weston Shale is composed mainly of medium olive-gray claystone that is silty in the upper part, where it incorporates several beds of grayish-orange very fine-grained micaceous thin-bedded sandstone. The sandstone beds are ¼ inch to 6 inches thick and contain finely broken plant fragments. The claystone is vertically jointed and fissile and breaks readily into small rectangular fragments. Ironstone concretions, one of which contained an unabraded marine gastropod, occur in lenticular beds and are separate oval bodies in the middle part of the Weston.

The upper 20 to 50 feet of the Robbins Shale Member of the Stranger Formation is light olive-gray silty to sandy shale that characteristically contains abundant dark yellowish-orange oval ironstone concretions. A thin sandstone bed or sandy concretionary bed is present locally.

The lower part of the Vilas Shale is light-olive-gray slightly silty claystone that locally contains thin yellowish-gray siltstone beds in the south-central part of Wilson County.

The middle part of the Lane-Bonner Springs Shale consists of medium olive-gray slightly
silty claystone that contains two thin (1-inch thick) finely micaceous siltstone layers with plant fragments. Small ironstone concretions generally occur abundantly above the siltstone beds.

The lower part of the Chanute Shale consists mainly of medium-gray unfossiliferous slightly silty claystone. Near the top of this part of the Chanute is a moderate yellowish-brown spongy unfossiliferous limestone bed that becomes soft and porous on weathering.

Environment

Most of Weston time was a period of quiet, shallow marine water unaffected by strong current action. Thin even beds of clay, without ripple marks or other sedimentary structures, were the main depositional result. Paucity of nutrim ent and freshening of the water due to greater rainfall may have contributed to the general disappearance of the previously abundant marine fauna. However, marine gastropods which later became the nuclei for concentration of iron carbonate were present in the muddy environment. In late Weston time the land area furnishing terrigenous debris presumably rose slightly and furnished silt and fine sand to the receding sea. An abundant land flora contributed small carbonaceous fragments to the sand and silt brought in by the rivers.

Very similar conditions probably prevailed during early Chanute time but an accumulation of iron-rich calcareous mud interrupted the clay deposition for a short period. Water and sediment conditions during parts of Lane-Bonner Springs, Vilas, and Robbins time were apparently very similar to those of Weston time.

SUMMARY

The 13 formations of Pennsylvanian age that crop out in Wilson County may be grouped into 6 major repetitive cycles of sedimentation (megacycles) that seemingly reflect deposition in a sequence composed of 10 distinct stages. This megacyclic pattern is not perfect and all 10 stages are not represented in each of the 6 megacycloths. Where complete, however, megacyclic deposition seems to have taken place under the conditions described below.

The megacycle began with stage A, in which fluvial sand was deposited in deep erosional channels cut during the major period of erosion between each succeeding megacycle.

During stage B a blanket sand with a small nearshore marine faunal assemblage was de-
posited as the sea transgressed upon the land. Slight fluctuations in water depth and the amount of nutrients and land-derived sediments may have been the factors that led to the successive deposition of barren marine muds, sandy lime muds with crinoidal and other shallow-water remains, and silty marine clays. A slight regression presumably left the clays bared to weathering processes and oxidation for a short period during which an abundant land flora furnished materials to form a thin bed of peat.

Stage C began with a major transgression of the sea, and the peat was covered with gray silt and clay, abundantly supplied by streams from the adjacent land. The shallow nearshore water must have teemed with organisms whose remains formed a large part of the iron-rich clayey calcareous mud that accumulated on the sea floor. Apparently the water deepened very rapidly, and the remains of a shallow-water community that consisted of gastropods, pelecypods, algae, brachiopods, bryozoans, crinoids, and corals became mixed with the remains of a deeper water fusulinid fauna. Fusulinids became less abundant as the water shallowed and algae and nearshore invertebrates again were the predominant life forms.

In stage D shoreline marine and dry land conditions prevailed for a short period of time. Weathered, oxidized red clay and fine-grained quartz sand from the adjacent low-lying land area formed the dominant depositional material.

As stage E began, the sea is presumed to have rapidly transgressed upon the land and covered it with a thin calcareous precipitate. This precipitate contained faunal elements that indicate a change from shallow water in which heavy-shelled pelecypods lived amid continually accreting calcareous granules and oolites, to locally fusulinid-rich deeper water, and then to shallow clear water of greater than normal salinity inhabited by abundant calcareous algae.

Stage F seems to have recorded a rather drastic change in the marine environment. Calm shallow water, which is presumed to have been low in oxygen and certain nutrients, covered the Wilson County area. Water motion was presumably reduced to a minimum by an extremely dense seaweed growth, and stagnant organic-rich bottom conditions appear to have resulted. As the seaweed died and fell to the bottom, an anaerobic resting place developed for the conodonts and ostracods that lived in the water.

As stage G began, the calm, poorly aerated water was again subjected to tidal and wave action and a normal transgressive-regressive cycle of the sea was initiated. A fauna composed mainly of mollusks, crinoids, brachiopods, bryozoans, and corals flourished at the beginning of the stage. At about the middle, this fauna was augmented and largely replaced by a profuse fusulinid fauna and sparse algal flora, and calcareous precipitates formed irregularly shaped deposits upon the sea floor. Small amounts of clay intermittently fell to the wave-surfaced top of the lime mud. Shortly, the water became shallower, algae became abundant, and the fauna changed again to corals, bryozoans, brachiopods, crinoids, and mollusks.

Stage H was a time of silty nearshore conditions, which, possibly as a result of very high rainfall and consequent freshening of the nearshore water, formed an environment inhospitable to marine life. Barren deposits of iron-rich clay and, locally, very calcareous silt and precipitated calcium carbonate accumulated in the shallow water.

During stage I saline water presumably drained from the compacting marine clay, adding its salt to that of the sea water; the nutrient content of the sea seemingly became higher than normal; and plant and invertebrate animal life again flourished in the Wilson County area. Brachiopod shells and crinoids, broken by strong wave action, accumulated in deposits rich in calcareous algae and oolites that formed in the continually agitated shallow water.

In stage J the megacycle closed with slight uplift in the land area and influx into the sea of sand and silt as well as clay. The marine population slowly migrated seaward, generation after generation, as its chosen habitat moved; the water shallowed and disappeared; and subaerial erosion cut deeply into the newly deposited clay as land conditions prevailed for the next protracted period in the Wilson County area.
REFERENCES


