Ordovician Graptolite Faunas and Stratigraphic Construction of the Martinsburg/Hamburg Foreland Segment, Central Appalachians, North America

By

George Robert Ganis BSc., MSc.
(Harrisburg, Pennsylvania, USA)

Thesis submitted for the degree of
Doctor of Philosophy
at the University of Leicester

University of Leicester
Department of Geology
University of Leicester
February 2004
ABSTRACT

Graptolite fossils provide a means for separating Late Ordovician autochthonous Martinsburg foreland basin strata (Appalachians, Pennsylvania, USA) from tectonically emplaced allochthonous Hamburg succession rocks. The youngest allochthonous rocks (Dauphin Formation) are Middle Ordovician, late Darriwilian 3 to 4a age, approximately two graptolite zones older than the foreland strata. Nineteen taxa described from the Dauphin Formation include Archiclimacograptus cf. A. riddellenis (Harris), Cryptograptus schaeferi Lapworth, Normalograptus antiquus (Ge), Pterograptus elegans Holm, Hustedograptus teretiusculus (Hisinger) ?, Pseudophyllograptus angustifolius s. l. (J. Hall), Haddingograptus oliveri (Bouček), Bergstroemograptus crawfordi (Harris), Tetrograptus cf. T. erectus Mu, Geh & Yin, and Kalpinograptus spp. (nov?). Newly described taxa are Pseudotrigonograptus ? ricardo sp. nov., and two (possibly more) reteograptids.

The initial allochthonous incursion (Unit H-1; = Cocalico Formation ?) into the foreland carried a synorogenic piggyback basin of mid-to-late Nemagraptus gracilis Zone turbidites (Unit M-1). Emplacement was upon the Hershey/Myerstown Formation deposited during earliest regional foreland subsidence. Emplacement of allochthonous Unit H-2 followed which was covered by foreland Unit M-2 (late Climacograptus bicornis Zone), containing allochthonous fragments. The foreland basin then spread laterally over the Jacksonburg Formation and equivalent “basal limestones” as Unit M-3 (Martinsburg Formation s.s.) during Dicranograptus clingani time.

The Hamburg succession (= Dauphin Formation) contains basin sediments deposited within the Octoraro Sea adjacent to the northern fringe of the microcontinent “Baltimoria”. Late Cambrian through Early Ordovician age rocks are composed of quartzofeldspathic, micaceous strata overlain by phosphorites, and covered by a black shale and quartzose-ribbon limestone package; lower to middle Arenig rocks are mostly starved clastic hemipelagites. After a biostratigraphic gap of 3-4 graptolite zones those rocks were incorporated into a Middle Ordovician, trench-origin olistostrome, formed as the Octoraro Sea closed, and co-occur with turbidites, distal pelagites and extrusive/ intrusive volcanics. Obduction of the Hamburg succession (part of the Westminster Terrane) onto southern Laurentia followed.
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>i</td>
</tr>
<tr>
<td>Table of contents</td>
<td>ii</td>
</tr>
<tr>
<td>List of figures</td>
<td>vi</td>
</tr>
<tr>
<td>List of tables</td>
<td>viii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>viii</td>
</tr>
<tr>
<td><strong>Introduction</strong></td>
<td>1</td>
</tr>
<tr>
<td>Statement of Problem</td>
<td>1</td>
</tr>
<tr>
<td>Study Objectives</td>
<td>2</td>
</tr>
<tr>
<td>Thesis Construction</td>
<td>3</td>
</tr>
<tr>
<td><strong>Chapter 1</strong></td>
<td>5</td>
</tr>
<tr>
<td><strong>Darriwilian graptolites of the Hamburg succession (Dauphin Formation), Pennsylvania and their geologic significance.</strong></td>
<td></td>
</tr>
<tr>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>Collecting localities</td>
<td>7</td>
</tr>
<tr>
<td>Study methods</td>
<td>7</td>
</tr>
<tr>
<td>Sedimentological and stratigraphical setting</td>
<td>8</td>
</tr>
<tr>
<td>The Darriwilian graptolite assemblage</td>
<td>9</td>
</tr>
<tr>
<td>Biostratigraphic analysis</td>
<td>11</td>
</tr>
<tr>
<td>Provincial analysis</td>
<td>13</td>
</tr>
<tr>
<td>Tectonic timing</td>
<td>14</td>
</tr>
<tr>
<td>Abbreviations for repositories</td>
<td>14</td>
</tr>
<tr>
<td>Systematic palaeontology</td>
<td>14</td>
</tr>
<tr>
<td>Order GRAPTOLOIDEA Lapworth, 1875</td>
<td>14</td>
</tr>
<tr>
<td>Suborder DIDYMGRAPTINA Lapworth, 1880</td>
<td>14</td>
</tr>
<tr>
<td>Family DICHOGRAPTIDAE Lapworth, 1873</td>
<td>14</td>
</tr>
<tr>
<td>Genus PSEUDOTRIGONOGRAPTUS Mu &amp; Lee, 1958</td>
<td>14</td>
</tr>
<tr>
<td><em>Pseudotrigonograptus ? ricardo sp. nov.</em></td>
<td>15</td>
</tr>
<tr>
<td>Genus PSEUDOPHYLLOGRAPTUS Cooper &amp; Fortey, 1982</td>
<td>19</td>
</tr>
<tr>
<td><strong>Genus</strong></td>
<td><strong>Reference</strong></td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td><em>Pseudophyllograptus angustifolius</em> s.l. (J. Hall, 1858)</td>
<td>19</td>
</tr>
<tr>
<td><em>Pterograptus elegans</em> Holm, 1881</td>
<td>21</td>
</tr>
<tr>
<td><em>Kinnegraptus</em> cf. <em>insuetus</em> (Keble &amp; Benson, 1928)</td>
<td>24</td>
</tr>
<tr>
<td><em>Acrograptus affinis</em> (Nicholson, 1869)</td>
<td>26</td>
</tr>
<tr>
<td><em>Cryptograptus schaeferi</em> Lapworth, 1880</td>
<td>29</td>
</tr>
<tr>
<td><em>Glossograptus</em> hincksii (Hopkinson, 1872)</td>
<td>35</td>
</tr>
<tr>
<td><em>Paraglossograptus</em> cf. <em>proteus</em> (Harris &amp; Thomas, 1935)</td>
<td>39</td>
</tr>
<tr>
<td><em>Kalpinograptus</em> spp. (nov?)</td>
<td>41</td>
</tr>
<tr>
<td><em>Kalpinograptus</em> ?</td>
<td>44</td>
</tr>
<tr>
<td><em>Hustedograptus</em> teretiusculus ? (Hisinger) sensu Jaanusson, 1960</td>
<td>46</td>
</tr>
<tr>
<td><em>Archiclimacograptus</em> cf. <em>A. riddellensis</em> (Harris, 1924)</td>
<td>49</td>
</tr>
<tr>
<td><em>Haddingtonograptus</em> Maletz, 1997</td>
<td>51</td>
</tr>
</tbody>
</table>
Chapter 2
Timing of allochthon emplacements and basin infilling for the Martinsburg/Hamburg foreland segment

Introduction 57
Biostratigraphic Considerations 62
  Biostratigraphic gap below *Nemagraptus gracilis* bearing rocks 62
  *Nemagraptus gracilis* (sensu Riva, 1969, 1974) Zone rocks: autochthonous or not? 65
  Province of graptolites and conodonts in allochthonous rock 66
Hamburg Allochthons Derived from the Westminster Terrane 67
Stratigraphy 69
  Transitional foreland units, Unit H-1 (= Cocalico ?), and Unit M-1 69
  Unit H-2 78
  Unit M-2 and pre- Martinsburg units bordering the M/HFS 79
  Unit M-3 and the ‘Swatara Gap Beds’ 86
Structural Considerations 88
Graptolite Occurrence Data, By Unit 91
  Unit M-1 91
  Unit M-2 95
  Unit M-3 and the Swatara Gap Beds 96
Palaeontological Notes 97
  *Amplexograptus leptotheca* (Bulman) 97
  *Corynoides calicularis* Nicholson 97
  *Climacograptus bicornis* (Hall) 101
  *Climacograptus meridionalis* (Ruedemann) 101
  *Climacograptus* (*Diplacanthograptus*) *spiniferus* Ruedemann 102
  *Cryptograptus* sp. aff. *tricornis* (Carruthers) 102
  *Cryptograptus tricornis* (Carruthers) 102
Chapter 3
Reconstructed stratigraphy of basin deposits adjacent to Baltimoria from allochthonous rocks of the Cambrian – Middle Ordovician Hamburg succession

Introduction
Stratigraphic Sections
  Cambrian Strata
  Ordovician Strata
    Tremadoc
    Arenig
Discussion
Conclusions
LIST OF FIGURES

Chapter 1
Darriwilian graptolites of the Hamburg succession (Dauphin Formation), Pennsylvania and their geologic significance.

Figure 1a: Location of the Martinsburg/Hamburg Foreland Segment and surrounding geology. 6
Figure 1b: Biostratigraphic position of the allochthonous Dauphin Formation its relationship to the Martinsburg/Hamburg Foreland Segment (M/H FS). 6
Figure 2: Pseudotrigonograptus ? ricardo sp. nov.; holotype and paratypes. 16
Figure 3: Pseudotrigonograptus ? ricardo sp. nov. 17
Figure 4: Pseudophyllograptus angustifolius s.l. (J. Hall, 1858) 20
Figure 5: Tetragraptus cf. T. erectus Mu, Geh & Yin (in Mu, Geh & Yin, 1962). 22
Figure 6: Pterograptus elegans Holm, 1881. 23
Figure 7: Kinnegraptus cf. K. insuetus (Keble & Benson, 1928). 25
Figure 8: Acrograptus affinis (Nicholson, 1869). 27
Figure 9: Bergstroemograptus crawfordi (Harris, 1926). 30
Figure 10: Cryptograptus shaferi Lapworth, 1880, juvenile forms. 30
Figure 11: Cryptograptus shaferi Lapworth, 1880. 31
Figure 12: Glossograptus hincksii (Hopkinson, 1872). 37
Figure 13: Paraglossograptus cf. P. proteus (Harris & Thomas, 1935). 40
Figure 14: Kalpinograptus spp. (nov?) & Kalpinograptus ?. 42
Figure 15: Reteograptus spp. (nov?). 45
Figure 16: Hustedograptus teretiusculus ? (Hisinger) sensu Jaanusson, 1960. 47
Figure 17: Archiclimacograptus cf. A. riddellensis (Harris, 1924). 50
Figure 18: Haddingograptus oliveri (Bouček, 1973). 52
Figure 19: Normalograptus antiquus (Ge, 1990). 56

Chapter 2
Timing of allochthon emplacements and basin infilling for the Martinsburg/Hamburg foreland segment.
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Geologic Setting of Martinsburg/Hamburg Foreland Segment</td>
<td>58</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Martinsburg Foreland Basin Correlation</td>
<td>60</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Correlation of Llanvirn and Caradoc Graptolite Zones</td>
<td>63</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Model for Development of the Western Half of the Martinsburg/</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hamburg Foreland Segment</td>
<td></td>
</tr>
<tr>
<td>Figure 5</td>
<td>Partial Map of Chronological Units, Western Martinsburg/</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hamburg Foreland Segment</td>
<td></td>
</tr>
<tr>
<td>Figure 6</td>
<td>Cross Sections Corresponding to Figure 5</td>
<td>71</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Unit M-1 at Locality G-44</td>
<td>75</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Early Foreland Basin Development</td>
<td>77</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Fissile Shales from Locality G-28, Unit M-2</td>
<td>80</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Unit M-2 at Locality G-38</td>
<td>80</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Detailed Biostratigraphy at Locality G-38</td>
<td>81</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Allochthonous Cobbles and Boulders Entrained in Unit M-2</td>
<td>82</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Undated Graywacke Sandstone Blocks in Unit M-2 Shales</td>
<td>89</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Overturned Lickdale Section</td>
<td>89</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Graptolite Faunal Distribution by Unit</td>
<td>92</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Graptolite Fauna, Unit M-1</td>
<td>99</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Graptolite Fauna, Units M-2 and M-3</td>
<td>100</td>
</tr>
</tbody>
</table>

**Chapter 3**

**Reconstructed stratigraphy of basin deposits adjacent to Baltimoria from allochthonous rocks of the Cambrian – Middle Ordovician Hamburg succession.**

| Figure 1 | Locations referenced in text                                                 | 112  |
| Figure 2 | Compilation of dated Hamburg succession sections                           |      |
| Figure 3 | Late Cambrian sections                                                       |      |
| Figure 4 | Coarse-grained and nodular phosphatic rock                                 | 115  |
| Figure 5 | Phosphatic-glaucconitic sandstone                                           | 115  |
| Figure 6 | Coarse phosphatic beds at the Route 22 section                             | 116  |
| Figure 7 | Spheroidal nodules of goethite after marcasite                              | 116  |
| Figure 8 | Ribbon-bedded limestone, Indiantown section                                | 119  |
| Figure 9 | Massive-bedded quartzose limestone, Indiantown section                      | 119  |
| Figure 10| Tremadoc section in the Gravel Hill Road olistolith                         | 121  |
| Figure 11| Pelagites, Unit H-1                                                         |      |
| Figure 12| Pelagic rocks, Lenhartsville section                                        | 124  |
| Figure 13| Ash bed (metabentonite) interbedded with shale and containing               |      |
carbonate nodules, Lenhartsville section 124

Figure 14: Manada Hill Member at Manada Hill 125
Figure 15: Chert/shale sets in the Manada Hill section 125
Figure 16: Shellsville Member hemipelagites 127
Figure 17: Soft sediment slumping in the Shellsville Member 127
Figure 18: Bouma A-B sequences, Nyes Road Member turbidites 128
Figure 19: Interbedded turbidites and red shales (pelagites), Nyes Road Member (type locality) 128

LIST OF TABLES

Chapter 1

Darriwilian graptolites of the Hamburg succession (Dauphin Formation), Pennsylvania and their geologic significance.

Table 1: Distribution of graptolite fauna by locality. 10
Table 2: Width of Cryptograptus schaeferi at thecae 2, 5 and 7. 34
Table 3: Comparative Measurements for A. riddellensis (Harris). 53
Table 4: Comparative Measurements of Haddingograptus oliveri (Bouček). 53

ACKNOWLEDGMENTS

I am indebted to a number of people who assisted, advised, and encouraged me during this research. I would first like to thank Prof. Richard Aldridge, Head of Geology Department, University of Leicester, for accepting me as a research student. My primary advisor, Dr. Jan Zalasiewicz, provided excellent support and encouragement; his guidance was key to my research. I also very much appreciate the critique and suggestions of Dr. Dickson Cunningham.

The first year of my research was largely spent at the Natural History Museum, London, where I was granted student status. For this I sincerely appreciate the support of my sponsor, Dr. Richard Fortey and to Dr. Norman McCleod, Keeper, Department of Palaeontology. The research at the NHM could not have been accomplished without the advice and help of Dr. Adrian Rushton (BGS, retired), whose guidance and friendship were invaluable. I am greatly indebted for his generosity of time and mentoring in graptolite taxonomy and biostratigraphy.
At critical intervals during the research synthesis I was materially assisted by the critique of Dr. Rodger Faill, Pennsylvania Geological Survey. His help in the field, and review of parts of the manuscript, with valuable suggestions, are gratefully acknowledged. Dr. John Repetski, U.S. Geological Survey, not only provided conodont ages for some important stratigraphic intervals, but also had a ready ear to sound out biostratigraphic issues on numerous occasions. Others who assisted in the field include Dr. John Taylor, Indiana University of Pennsylvania, and Dr. Nicholas Ratcliffe, U.S.G.S., who provided a critical response to the tectonic conclusions, and pointed out alternative solutions to some of the issues.

Lastly, I would like to thank Benjamin Ganis for his assistance in preparing the figures.
INTRODUCTION

STATEMENT OF PROBLEM

One of the more enigmatic terrains of the Central Appalachians lies within the outcrop belt of the Martinsburg Formation in the Great Valley Section of Eastern Pennsylvania, USA. The Martinsburg Formation is early Late Ordovician in age, but some of the rocks in that belt, roughly between the Susquehanna and Lehigh Rivers over a length of about 100 km, are, in part, older and lithologically different. Stose (1946) seized upon these facts and boldly proposed an overthrust upon the Martinsburg Formation that he named the Hamburg klippe, making a comparison with the Taconic Thrust of New York-Vermont.

Stose’s klippe proposal met with mixed response as subsequent discoveries indicated a more complex picture. Some of the rock within his klippe is unequivocally older than the Martinsburg Formation (some as old as Cambrian), and some (but, not all) rock is distinctly different from typical Martinsburg flysch. Early Ordovician conodonts in limestone slide blocks (Bergström et al., 1972) provided additional evidence of rocks older than the Martinsburg Formation in the belt. Platt et al. (1972) published a serious challenge to Stose’s Hamburg klippe in favour of allochthons within the Martinsburg Formation emplaced by gravitational tectonics. Both sides of the debate suffered from an insufficient distribution of dated rock from which to build a case. At the time there were only a few examples of rock unambiguously older than the Martinsburg Formation, and many graptolite assemblages suggest ages only slightly older, if at all, than Martinsburg, as the age of the latter was then assumed. By the late 1970’s, after much work by many people, the issue of the “klippe” remained in dispute and Root (1977, p.16) commented, “It is probable that the ultimate extent of the allochthonous strata and their sequence of incursion will only be determined by detailed palaeontologic studies of well-zoned microfossils [including graptolites]; structural studies and lithic assemblages are only a partial key to the deciphering of internal relations within this complex body of rock.”

During the 1980’s the study of the Hamburg klippe was resurrected within the paradigm of plate tectonics (but with very little new palaeontological data), and was greatly advanced by the work of Lash and Drake (1984). They provided ample evidence that the allochthons had indeed come from afar and had converged upon the Laurentian margin, and were among the workers that advocated an Iapetian microcontinent as the source of the Hamburg rocks. However, the issue as to whether the allochthonous rocks structurally overlay, or were contained within, the Martinsburg Formation remained a matter of debate.
A preliminary study of the graptolite faunas in the western half of Stose's "Hamburg klippe" was completed by Ganis et al. (2001). They showed that Late Ordovician Martinsburg age rocks were either interstratified or interleaved with older Middle Ordovician allochthonous rocks and, that the latter contained even older Late Cambrian to Early Ordovician olistoliths. Much of this thesis is a continuation of the work of Ganis et al. (2001) and, because of the integrated importance of that paper, a reprint is included in-pocket. That work was completed before the start of research studies at the University of Leicester. I was the principle author of the paper and completed most of the field work upon which the study was based. The co-authors provided assistance in graptolite and conodont taxonomy and biostratigraphic resolution.

As with many parts of the world, the Appalachians are viewed as a complex orogenic zone, "built largely upon the roots of an earlier, even wider orogenic region (the Grenville), and on various pieces from oceans and other continents" (Faill, 1997). Any model of the Hamburg rocks requires compatibility with this complex orogenesis.

This thesis continues the investigation of the Hamburg rocks with the aim of advancing the body of information necessary for understanding their geologic history. The need for much more palaeontological and biostratigraphic study formed the core of the work. The search for more fossiliferous rock, primarily with graptolites but with some conodonts, was moderately successful. This greater understanding of the distribution of dated rock led to a workable stratigraphy for both autochthonous and allochthonous units, a suggested structural configuration, and a proposed model for allochthon emplacement within the Martinsburg foreland basin. This study also attempts to integrate, by analogy, an analysis of ancient Martinsburg foreland basin development with studies of modern and geologically young foreland basins in other parts of the world. This analysis was particularly useful in explaining the likely geologic setting of rocks only marginally older than the Martinsburg Formation, sensu stricto.

This study draws upon the work of many previous investigators. Each chapter cites relevant work on the subject under discussion.

**STUDY OBJECTIVES**

The essential questions that this thesis attempts to answer are, (1) what are the biostratigraphic and palaeontological constraints that apply to the fossils of allochthonous versus autochthonous rocks, (2) what are the factors that affect the development of the Martinsburg foreland basin, and how does this basin accommodate allochthonous elements, (3) what was the origin and content (stratigraphy) of the Hamburg succession before it was
tectonically assembled as allochthons and structurally broken during emplacement and later deformation? The collage of answers to these questions, taken collectively, strongly leans toward the conclusion that the rocks of the Hamburg succession are not found in a structural klippe thrust over the Martinsburg Formation, but, rather, were emplaced within it and buried. The combined stratigraphy described here of autochthonous strata interstratified with allochthonous emplacements, and the regionally continuous Martinsburg age rocks above the allochthons, provides evidence against the overthrust model.

THESIS CONSTRUCTION

This thesis is composed of three chapters that closely follow the objectives set out above. The first chapter is a detailed discussion of the graptolite fossils within the Shellsville and Nyes Road Members of the Dauphin Formation, the youngest units that can be firmly established as allochthonous to the Martinsburg Formation and deposited within the Octoraro Sea. It was quite important to date the Dauphin Formation with the greatest precision possible because it marks the last depositional episode before the rocks were mobilized as allochthons. By the time these rocks came to rest in the Martinsburg foreland basin, a stratigraphic gap had elapsed which represents the time it took for this tectonic event to transpire.

The graptolites contained in these units are systematically described in chapter one, which is the formal treatment necessary to defend their attribution and assess their biostratigraphic significance. The systematic methodology also allows for the description of new taxa, for which there were some examples in the fauna. This effort proved to be useful in permitting a rather closely defined time for the deposition of these units.

Chapter two concerns with the development of the Martinsburg foreland basin in the area that received allochthons. This chapter is perhaps the most integrated in its analysis because of the amount of prior work that had been done on this geology, and the multitude of peripheral data that bear on the matter. For instance, the age of the basal Martinsburg Formation, and underlying units, within and bordering the study area was a critical point for analysis. Also, because these allochthons were detached from their original source, opinions regarding possible origins were weighed and considered. Much prior work has attributed large parts of the terrain to allochthonous status, where new fossil data, reported here, dispute that claim. The new data do not support Stose’s (1946) Hamburg klippe model. The fossil graptolite work helped map out “chronological units” that allowed a working stratigraphy to emerge for the autochthonous Martinsburg Formation, and revealed a sequence of allochthon emplacement events. A structural section with internal stratigraphy across the foreland, was also created for the first time.
The resulting effort led to a revised model for the development of the Martinsburg/Hamburg foreland segment, a name given here to this area. The research concluded that this basin segment was established earlier than adjacent foreland areas, as a result of local subsidence generated by the advancing allochthons.

Chapter three is a consolidation effort aimed at gathering up all prior reports of dated rock for the allochthonous Hamburg succession, combined with new data generated in this research. The result is a reconstructed stratigraphy developed from all the known scattered pieces of allochthonous rock found in the study area. This stratigraphy reveals the depositional history of basinal sedimentation adjacent to the microcontinent 'Baltimoria', believed to be the source of the Hamburg rocks. The stratigraphic record of the Hamburg succession supports that hypothesis, and contrasts with the palaeoenvironmental history of the Laurentian margin.
CHAPTER 1. DARRIWILIAN GRAPTOLOITES OF THE HAMBURG SUCCESSION (DAUPHIN FORMATION), PENNSYLVANIA AND THEIR GEOLOGIC SIGNIFICANCE.

INTRODUCTION

The graptolite biostratigraphy of the Hamburg "klippe" was initially addressed in Ganis et al. (2001). The area has often been described as a structural klippe (e.g. Stose, 1946; Lash & Drake, 1984), but an alternative explanation, preferred by the writer, is that of an allochthon complex emplaced within the Martinsburg foreland basin (Carswell et al., 1968; Platt et al., 1972; Root & MacLachlan, 1978; Faill, 1997; Ganis et al. 2001). The area will be described herein as the Martinsburg/Hamburg Foreland Segment (M/HFS), and the contained allochthons referred to as the Hamburg succession. Figure 1a illustrates the general geologic setting of the M/HFS.

A discussion of the stratigraphic content of the western half of the Hamburg succession (= Hamburg klippe of others) can be found in Ganis et al. (2001). They named the Dauphin Formation (see Fig. 1b) as comprising the allochthons and consisting of three members, the Shellsville hemipelagic olistostrome, the Nyes Road turbidites, and the Manada Hill pelagites. The Shellsville olistostromal member was dated with graptolites as Darriwilian (Da) 3 or 4 age (Whiterockian, Middle Ordovician) by Ganis et al. (2001), and contains olistoliths of older strata. The Nyes Road Member turbidites, also identified as Darriwilian 3 or 4, interfingers with the Shellsville Member. The Manada Hill Member pelagite was described as of Lower to Middle Ordovician age (Ganis et al. 2001).

The graptolite faunas reported in Ganis et al. (2001) were not treated systematically. A more complete description and analysis of the Middle Ordovician graptolites of the Hamburg succession was therefore undertaken to more thoroughly understand the biostratigraphic age of the unit, to systematically describe the fauna (including new taxa), and to compare and contrast the fauna to other Middle Ordovician sequences.

The Middle Ordovician Dauphin Formation represents the last depositional interval which incorporated older strata as olistoliths, before the entire Hamburg succession was structurally assembled and mobilized as a transported allochthon. This tectonic transport was part of the Taconic orogeny occurring during the early Late Ordovician. Thus, the difference in age between the youngest part of the Dauphin Formation and the strata enclosing the allochthons within the Martinsburg foreland is the time interval involved in this particular tectonic event. The graptolite faunas of the Dauphin Formation were studied in an effort to
Figure 1a. Location of the Martinsburg/Hamburg Foreland Segment and surrounding geology.

Figure 1b. Biostratigraphic position of the allochthonous Dauphin Formation and its relationship to the Martinsburg/Hamburg Foreland Segment (M/H FS).

<table>
<thead>
<tr>
<th>N. American</th>
<th>Graptolite Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>&quot;North America&quot;</td>
</tr>
<tr>
<td>Sweden</td>
<td></td>
</tr>
<tr>
<td>Maletz, 1995</td>
<td></td>
</tr>
<tr>
<td>Gi 1</td>
<td>Nemagrapthus graculus</td>
</tr>
<tr>
<td>Dauphin</td>
<td>H. teretiusculus</td>
</tr>
<tr>
<td>Dauphin</td>
<td>P. elegans</td>
</tr>
<tr>
<td>Dauphin</td>
<td>H. lentus</td>
</tr>
</tbody>
</table>

*Correlation to Australasian graptolite zones from Maletz, 1997.
Da = Darriwilian - Formal designation - Upper Stage of the Middle Ordovician Series
Gi = Grisbormian
more accurately fix the maximum age prior to this tectonic activity. The Hamburg succession has been hypothesized as a sedimentary sequence originally deposited adjacent to an Iapetian microcontinent at an unknown distance from the Laurentian margin (summarized in Ganis et al., 2001). The graptolite faunas described from the Hamburg succession by Ganis et al. (2001) are of the Pacific Faunal Province (consistent with Laurentia), but some new taxa are present.

COLLECTING LOCALITIES

Graptolites described in this study were collected at localities recorded in Ganis et al. (2001 p. 111; map of localities, p. 112), plus five additional locations. The alpha numeric locality identification system used by them, with longitude and latitude coordinates provided, is maintained herein, and the five new localities are added: G-31 (40°18′19″N, 76°50′47″W); G-34 (40°27′50″N, 76°22′38″W); G-40 (40°20′09″N, 76°43′32″W); G-43 (40°24′01″N, 76°35′50″W); G-49 (40°36′15″N, 75°52′25″W); skipped numbers represent localities not utilized, or those other than Middle Ordovician localities.

Twenty-one graptolite localities are dispersed throughout the western and central portions of the M/HFS over a strike distance of roughly 40 km and are within variable facies. One locality (G-49) is from the far eastern part of the M/HFS within the Dreibelbis Member of the Windsor Township Formation of Lash and Drake (1984). Most localities are roadcut exposures, but a few were from construction exposures; locality G-40 is a shallow excavation surrounding an electrical transformer, locality G-20 was from the foundation excavation for a small building that is mostly now built over, and G-17 is at the head of a small drainage ditch. The roadside localities should be available for future collecting, barring any major road construction modifications, although roadcuts can become overgrown.

STUDY METHODS

The specimens described below were collected by the writer. At some localities the graptolites were scarce and required many hours of work for few specimens, while other localities were rich in graptolites. The exposures available were isolated segments of a succession that is nowhere available in one complete exposure. The structural complexity of the terrain, which has not been mapped in detail, makes construction of reliable composite sections currently unfeasible.

The lack of a complete stratigraphic succession providing biostratigraphic control pre- and post-Darriwillian 3/4 was a hindrance to refining the biostratigraphic range of the overall Darriwilian section of the Hamburg sequence. However, as discussed more fully in
succeeding sections, the combined Darriwilian faunal assemblage for all localities was nearly complete at several individual localities, indicative of one biostratigraphic interval. No localities contained faunas prohibitively older or younger than the collective assemblage for all other localities (except for two locations with *Bergstroemograptus crawfordi*).

Most material consisted of flattened specimens on clastic rock, and was evaluated using a binocular microscope with a camera lucida attachment and a camera port. Generally, specimens were drawn and simultaneously photographed with a 35mm camera; specimens were usually wetted with alcohol. A calcareous bed from locality G-34 was etched with five percent acetic acid for 6 – 12 hours, which brought out the graptolites into 3D aspect and enhanced cross-sections. Unfortunately, no graptolitic rock was found suitable for full isolation of the fossils.

The collections were initially screened and trimmed in the United States, and the best and most representative material, including all taxa thought to be present, were shipped to the United Kingdom and repositioned in the collections of The Natural History Museum, London.

**SEDIMENTOLOGICAL AND STRATIGRAPHICAL SETTING**

The Dauphin Formation constitutes the Upper Cambrian and Lower to Middle Ordovician allochthonous components of the Martinsburg/Hamburg Foreland Segment. The Dauphin Formation is primarily a Middle Ordovician unit within which are older olistoliths ranging in age from Upper Cambrian to middle Arenig (Ganis *et al.*, 2001). The Dauphin Formation was structurally emplaced, possibly as gravity slides, into the Martinsburg foreland basin during the early Caradoc, as part of the Taconic event. The Darriwilian age Dauphin Formation is composed of complex off-shelf and deepwater facies, and was divided into three members (Ganis *et al.*, 2001). The Shellsville Member is a lower slope hemipelagite consisting mostly of shale, siltstone and fine sandstones. A few of the coarser intervals are calcareous. These clastic deposits have a variety of colour ranging from pale green to tan, brown, and black, often in thinly bedded packages. Thin silty to sandy turbidite layers showing sole- marks are locally interbedded in the sequence. Evidence of oxic conditions such as bioturbation alternates with anoxic indicators such as graptolitic black shale. In some exposures there are interbedded pelagic red and green shales and radiolarian-bearing cherts. Slumps and chaotic small-scale folding are evidence of pervasive soft sediment deformation from downslope gravity movement. Thirteen of the 21 graptolitic localities described herein are from this hemipelagite facies. It is within this sedimentological setting that much older olistoliths of various sizes, ranging from boulders to kilometre-size masses, were found (Ganis, *et al.* 2001). In some cases these olistoliths are distinctively different stratigraphic
packages, but others, particularly those of Arenig age, are sedimentologically indistinguishable from the Darriwilian hemipelagites.

The Nyes Road Member is a flysch composed of thick turbidites, typically showing multiple Bouma cycles. This facies represents submarine fan and channel fill/overbank deposits that cut through the lower slope hemipelagites and extended onto the abyssal plain. There they cover, and were covered by, red, tan and green pelagic shales and cherts of the Manada Hill Member. Seven of the 21 graptolite localities are within the Nyes Road Member facies. One locality (G-49) from the eastern end of the M/HFS is outside the area originally mapped for the Nyes Road Member by Ganis et al. (2001), and is within the Dreibelbis Member of the Windsor Township Formation of Lash and Drake (1984). The presence of Darriwilian (Da 4) graptolites in part of the Dreibelbis Member confirms its partial correlation with the Nyes Road Member, and the two units are physically very similar. Graptolites have been found associated with the red shale/chert facies of the Manada Hill Member where thin non-red hemipelagite intervals are interbedded. One locality (G-31) was collected from this setting.

All three members (= facies) are complexly interbedded and laterally gradational, making some exposures difficult to pigeonhole into a particular member. Recently, large and small Cambrian and Lower Ordovician olistoliths were found contained within the turbidite facies of the Nyes Road Member.

Many exposures show complex small-scale folding and faulting with multiple cleavages, and the rocks were structurally modified during transport as an allochthon into the Martinsburg foreland. The area was also affected by the waning effects of the Taconic orogeny, and again during the multiple pulses of Alleghenian tectonism. This has left the geology in a highly complex structural condition.

THE DARRIWILIAN GRAPTOLITE ASSEMBLAGE

A list of Darriwilian graptolites from the Dauphin Formation is found in Table 1. Nineteen taxa are listed, although only six can be characterized as common (found at 6 or more of the 21 localities). Six species are rare, occurring at only one or two localities.

The most common taxa are Archiclimacograptus riddellenis (Harris) and Cryptograptus schaeferi Lapworth which were recorded at 17 and 18 of 21 localities, respectively. Glossograptus hincksii (Hopkinson) was present at 12 of 21 localities, and Pterograptus elegans Holm and Hustedograptus teretiusculus? (Hisinger) were present at 9 and 10 locations, respectively. Pseudophyllograptus angustifolius s.l. (J. Hall) and Haddingograptus oliveri (Bouček) were each present at 6 of 21
Table 1. Distribution of graptolite fauna by locality (This study and Ganis et al. 2001).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pseudotrigonograptus ? ricardo sp. nov.</em></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pseudophytlograptus angustifolius</em></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetragraptus cf. T. erectus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pterograptus elegans</em></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Kinnegraptus cf. K. insuetus</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Acrograptus affinis</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*Janograptus ?<em>2</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Bergstroemograptus crawfordi</em></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryptograptus schaeferi</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Glossograptus hinoki</em></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Paraglossograptus cf. proteus</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Kalpinograptus ssp. (nov?)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Kalpinograptus ?</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Reteograptus ssp.</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hustedograptus teretiusculus ?</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Archidimacograptus cf. A. riddellianus</em></td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Haddingograptus olivieri</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Normalograptus antiquus</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Misc. dendroids</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total # taxa found</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>4</td>
<td>10</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>7</td>
<td>16</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

*1 - localities in turbidite facies; all other localities are within hemipelagic or pelagic facies
*2 - *Janograptus ?* sp. is provisionally listed because definitive examples are lacking, and could be distal stipe fragments of another taxon, such as *Acrograptus*.
*G* localities; see collecting localities in text.
localities. *Janograptus* is probably present, but was difficult to establish because of incomplete rhabdosomes, which can be confused with distal stipe fragments of *Acrograptus*. This situation may have led to the under-reporting of one or both genera because such stipe fragments are common. *Acrograptus affinis* (Nicholson) was positively identified, however.

Among the less common members of the fauna are *Pseudotrigonograptus? ricardo* sp. nov., the Kalpinographt, and at least two reteograptids. *Kalpinographt* was only found at three localities, two were where graptolites were abundant and collecting was extensive. *Kinnegrapht* cf. *K. insuetus* (Keble & Benson), *Tetragrapht* cf. *T. erectus* Mu, Geh & Yin and *Normalographt antiquus* (Ge) were each recorded at only one location, and *Bergstroemographt crawfordi* (Harris) was found at two locations.

**BIOSTRATIGRAPHIC ANALYSIS**

The suite of Darriwilian graptolites described from the Dauphin Formation by Ganis *et al.* (2001 p.121; fig.8) was classified as Darriwilian 3 to 4 age. The present study of the fauna, including additional material from five new localities, has narrowed the age range to late Da3 to early Da 4 (see Figure 1b).

Excluding new (and potentially new) taxa and dendroids, there is an assemblage of 13 species consistent with Da 4, although some forms range down into Da 3. Only one taxon, *Bergstroemographt crawfordi* (Harris), has been exclusively described from Da 3 or lower, which suggests a limited part of the Dauphin Formation may be within that zone. Other taxa consistent with early Da 4 are *Pseudophyllographt angustifolius*s.l. (J. Hall) and *Tetragrapht* cf. *erectus* Mu, Geh & Yin. The most common taxa in the assemblage, *Archiclimateographt riddellensis* (Harris), *Cryptographt schaeferi* Lapworth, *Glossographt hincksi*i (Hopkinson), *Pterographt elegans* (Holm), *Hustedographt teretiusculus* (Hisinger), *Haddingographt olivert*Bouček) and *Kalpinographt* comprise a classic Da 4 (*Pterographt elegans* Zone) suite. Of these, Maletz (1997) considered *A. riddellensis*, *H. teretiusculus*, *P. elegans*, as exclusively Da 4.

Taylor’s (1997) study of the Table Cove and Cape Cormorant – Black Cove formations in Newfoundland, described as in the Da 3 biozone, has many elements of the pandemic fauna that Maletz divided into a lower Da 3, *Nicholsonographt fasciculatus* Zone, and Da 4, *Pterographt elegans* Zone. Albani *et al.* (2001) subdivided the Cape Cormorant Formation into the *N. fasciculatus* and *P. elegans* zones. A number of the taxa recorded by Albani *et al.* (2001) in the *P. elegans* Zone of the Cape Cormorant Formation are also found in the Dauphin Formation (e.g. *P. elegans*, *C. schaeferi*, *H. olivert*, and *A. riddellensis*).
With the exception of *B. crawfordi*, the Dauphin Formation graptolite suite agrees with Maletz's Da 4 assemblage, with his exclusively pandemic Da 3 forms not present (e.g. *N. fasciculatus*, *Undulograptus* cf. *U. cumbrensis*, *Archiclimacograptus marathonensis*). Many of the taxa found only in the stratigraphically low Table Cove Formation in Newfoundland by Taylor (1997) (e.g. *Etagraptus hartii*, *Isograptus forcipiformis*, and *Pseudotrigrongraptus ensiformis*), have not been recorded in the Dauphin Formation. This suggests that the bulk of the Dauphin Formation correlates best with the stratigraphically higher Cape Cormorant Formation, which is also compatible with Maletz's (1997) concept of Da 4, as defined in the Oslo region.

The upper half of the Middle Ordovician has been described from other parts of the world to which the Dauphin Formation can be roughly correlated. In North America the Darriwilian 3 to 4 interval is contained within Berry's (1960) *Hallograptus etheridgei* (= *Paraglossograptus tentaculatus*) Zone in the Marathon Region of Texas and in Nevada (Ross and Berry, 1963). However, this interval includes much of the early Middle Ordovician, and is not sufficiently subdivided to allow a detailed comparison to just the middle to upper Middle Ordovician. Carter's (1989) list of fauna from the *Diplograptus* ? *decoratus* Zone of the Ledbetter Slate of Washington shares a number of common taxa with the Dauphin Formation (*C. schaeferi*, *P. elegans*, and *G. hincksii*) indicating a general correlation. In northwest Canada, Lenz & Jackson (1986) recognized the *D. ? decoratus* Zone with a Pacific Province fauna containing forms common in that zone as defined in Australasia, such as *C. schaeferi* and *Nicholsonograptus fasciculatus* and, according to Taylor (1997), possibly "*D." decoratus* and "*C." riddellensis."

The Ordovician graptolite sequence of Australasia, summarized by VandenBerg & Cooper (1992), contains the equivalent upper Middle Ordovician (their upper Lower Ordovician), which is the classical Darriwilian 3 and 4 zones. The Da 3, *Pseudoclimacograptus decoratus* Zone, contains a diverse assemblage in which *P. decoratus* is very abundant. The Da 4 *Pseudoclimacograptus* (*Archiaclimacograptus*) *riddellensis* zone, is defined by the first appearance of that species, and is subdivided into Da 4a, without *Dicellograptus* and *Dicranograptus*, and Da 4b, with those forms. Most of the Dauphin Formation is best correlated with the Australasian Da 4a based on the occurrence of *P. elegans*, *A. riddellensis* and the other taxa common in that zone, and the absence of *Dicellograptus* and *Dicranograptus*.

Ni (1991) subdivided the Middle Ordovician of the Jiangxi area of China into the *N. fasciculatus* and *P. elegans* zones, which Maletz (1997) correlated with the same zonation in Scandinavia. Of the nine species listed by Ni (p.103 & 104), including pendent
didymograptids (indicating the Atlantic Faunal realm), only \textit{P. elegans} and \textit{T. erectus} are shared with the Dauphin Formation.

**PROVINCIAL ANALYSIS**

The Darriwilian graptolite assemblage from the Dauphin Formation is characteristic of the Pacific Faunal Province, as noted in Ganis \textit{et al.} (2001). This assemblage is characterized by common pandemic forms, and a lack of pendent didymograptids (Bulman, 1971; Skevington, 1974). The causes and nature of Middle Ordovician graptolite provincialism were summarized in Maletz (1997), as related to Scandinavia (Baltica), and Taylor (1997) for Newfoundland (eastern Laurentia).

Because the Hamburg succession is allochthonous, and may have originated adjacent to a mid-Iapetus microcontinent (of Thomas, 1977; Lash \textit{et al.} 1984; Lash & Drake, 1984; Faill, 1997; and supported by Ganis \textit{et al.}, 2001), its provincial affinity is important with respect to the proposed microcontinent's palaeogeographic origins. During the Early to Middle Ordovician, the Appalachian fringe of Laurentia had a consistent orientation roughly parallel to the latitudinal meridians, with its southern margin (present day eastern margin) between the equator and 30 degrees south latitude (summarized in MacNiocaill \textit{et al.}, 1997). Between Laurentia and Baltica and peri-Gondwana lay the deep barrier of the Iapetus Ocean. If the Baltimore-Brandywine microcontinent (see Faill, 1997, p. 562-563 for summary discussion of the controversy surrounding the concept), and the presumed associated Hamburg succession, had ever been positioned close to Baltica or peri-Gondwana, before drifting toward Laurentia, its graptolite fauna might be expected to have an Atlantic Faunal Province signature, but it does not. This includes not only the Darriwilian graptolite fauna described herein, but also the Arenig faunas previously described in Ganis \textit{et al.} (2001). The graptolite faunal evidence, therefore, supports the supposition that the proposed Baltimore-Brandywine microcontinent, and the Hamburg rocks thought to have been deposited adjacent to it, were “peri-Laurentian”.

The Arenig portion of the Dauphin Formation, contained within olistoliths, described by Ganis \textit{et al.} (2001), contains no previously unknown fauna, and is very compatible with assemblages from equivalent zones in Newfoundland described by Williams & Stevens (1988), which are presumed to be from the Laurentian Margin. However, the Darriwilian portion of the Dauphin Formation apparently does contain some new graptolite taxa. The scarce taxon \textit{Pseudotrigonograptus} ? \textit{ricardo} sp. nov. (found at 4 of 20 localities), is so far unique to the Hamburg succession. The same may be true of the reteograptids. The rare
kalpinograpti are apparently not known elsewhere; however, most are represented by a single or just a few examples.

TECTORNIC TIMING

Estimating the Dauphin Formation as late Da 3 to early Da 4a provides a maximum age for the initiation of tectonic mobilization of the Hamburg succession as an allochthon. The earliest parts of the allochthon with a piggyback basin (the emplacement was by multiple events) arrived in the developing foreland during mid-to late *N. gracilis* to *C. bicornis* time, and was covered by autochthonous Martinsburg sediments during late *C. bicornis* time (Ganis *et al.*, 2001; and also discussed in Chapter 2). Using interpolation between radiometric dates on the chronological table of the Ordovician provided by Cooper (1999) gives an approximate duration of up to six million years ± 1 my for this event. During this interval the Hamburg allochthon was moved from an unknown distance in the Iapetus Ocean, separated from its underpinned crust, and obducted onto the Laurentian margin into the Martinsburg foreland basin. The present Laurentian margin is both compressed by Palaeozoic thrusting and folding and extended by Triassic-Jurassic rifting. The net distance that the Hamburg succession traveled since early Da 4a time has not been accurately calculated, but must have been hundreds of kilometres, at a minimum.

ABBREVIATIONS FOR REPOSITORIES

BU- Lapworth Museum, Birmingham University, Birmingham, U. K.;
GSC - Geological Survey of Canada, Ottawa
NHM - Natural History Museum, London
NMV - Natural Museum of Victoria, Melbourne

SYSTEMATIC PALAEOONTOLOGY

ORDER GRAPTOLOIDEA Lapworth, 1875
SUBORDER DIDYMOGRAPTINA Lapworth, 1880
FAMILY DICHOGRAPTIDAE Lapworth, 1873

Genus *PSEUDOTRIGONOGRAPTUS* Mu & Lee, 1958
TYPE SPECIES. *Pseudotrigonograptus uniformis* Mu & Lee, 1958; by original designation. Rickards (1973) stated that *P. uniformis* is a junior subjective synonym of *Graptolithus ensiformis* J. Hall, 1858 and, accordingly, lists the type species of *Pseudotrigonograptus* as *Graptolithus ensiformis* J. Hall, 1858, p.133 and as *Retiolites ensiformis*, J. Hall, 1865, p.114, Pl. 14, Figs 1-5. Rickards (1973) further assigned a ‘genolectotype’ as “Geol. Surv. Canada, 949g; figd. Hall, 1858, Pl. 14, Fig. 4, Quebec Group, near Point Levis.” Strictly speaking the concept of *Pseudotrigonograptus* continues to adhere to the holotype of *P. uniformis* Mu & Lee.

*Pseudotrigonograptus ? ricardo* sp. nov.; Figs 2 & 3

Holotype. USNM 509939, figured as *Pseudophyllograptus* sp. by Ganis et al. (2001:123, Fig. 10h); herein refigured as Figs 2-1a & 1b. Paratypes are designated as Figs 2-2a & 2b and 3a & 3b.

DERIVATION OF NAME. Named for Richard Fortey whose work on triserial graptolites was essential to the analysis of the new taxon herein described.

MATERIAL. About 30 flattened specimens. The holotype is greatly superior to the other examples. The holotype (Figs 2-1a & 1b) was subsequently broken, so the new figure differs slightly from that shown in Ganis et al. (2001).

REMARKS. The new taxon described is placed in the genus *Pseudotrigonograptus* with reservation. That genus is considered to include both triserial and quadriserial species (Rickards, 1973 and subsequent workers; see especially Williams & Stevens, 1988). *P. ? ricardo* sp. nov. is proposed as a much smaller triserial form, with fewer thecae, and a distinctly different appearance from the adults of other *Pseudotrigonograpti*. As *Pseudotrigonograptus* may take either triserial or quadriserial form it is questionable whether an exclusively triserial taxon, varying somewhat in other characteristics as well (see below), should also be included in that genus. However, the small mature rhabdosome of the triserial *Tristichograptus* described by Fortey from well preserved isolated material (1971: 191, text-fig. 3), and here redrawn (Fig. 2-4) as if flattened, compares well to the adult *P. ? ricardo* sp. nov. Therefore, the new taxon is tentatively assigned to *Pseudotrigonograptus*.

DIAGNOSIS. A small triserial rhabdosome, roughly 4.0 mm long and 2.5 mm wide, oval in broad outline, with deep thecal excavations. A medial line of apertures of the third stipe is seen in reverse view, while, in obverse view, a median septum is seen. Sicula and th1 pendent; usually 5 or 6 (up to 7) succeeding thecal pairs.

DESCRIPTION. In this triserial form the stipes comprise an a/b pair, as in a typical biserial diplograptid, with a third, or “c” stipe, which lies in a plane perpendicular to the flattened a/b pair. In *Tristichograptus (=Pseudotrigonograptus*, according to Rickards, 1973) Fortey
Figure 2. *Pseudotrigonograptus ? ricardo* sp. nov.; locality in brackets, all x12, 1 mm reference bar at 2a; holotype 1a & 1b, USNM 509939 [G-17]; paratypes 2a & 2b, NHM qq67 [G-6] and 3a & 3b, NHM qq 65 [G-34]; 4 is *Tristichograptus* (= *Pseudotrigonograptus*) redrawn from Fortey (1971: p.191, text-fig. 3).
Figure 3. *Pseudotrigonograptus* ? *ricardo* sp. nov.; locality in brackets, x15, 1 mm reference bar at 2a; 1a & 1b, NHNM qq 69 [G-6]; 2a & 2b, NHM qq 66 [G-6].
reconstructed a triserial form consisting of a symmetrical triad of stipes with a 120° interstipe angle. Without isolated material we do not know that \( P. \ ? \) \textit{ricardo} had a like form. The apertures of the c stipe are seen when they face the observer (as in the holotype, see Figs 2 1a & 1b) but, when viewed from the opposing side, the median septum is seen (as in the paratype; see Figs 2-2a & 2b). The identity and preservation of a third, or, in the case of quadririserial forms of \textit{Pseudotrigonograptus}, a fourth stipe, is commonly complicated by 'break-away'. This leaves a biserial appearance in flattened material (see Fortey, 1971; Rickards, 1973; Cooper, 1979; and Williams & Stevens, 1988) where the third or fourth stipe has separated from the rhabdosome along the median septum, and leaves a smooth-sided, cigar-shaped or 'leaf-like' form. No examples of \( P. \ ? \) \textit{ricardo} sp. nov. appear smooth-sided suggesting that 'break-away' did not take place and that the specimens may be triserial, with either the c stipe up, showing the apertures, or down, showing the median septum. Confirmation that \( P. \ ? \) \textit{ricardo} sp. nov. is indeed triserial, and not quadririserial, may rest on finding isolated specimens in the future. \( P. \ ? \) \textit{ricardo} sp. nov. has an oval outline with comparatively large thecae, triangular in outline with deep interthecal excavations. The thecal growth pattern of the a/b pair produces two pendent processes formed by the sicula and th1. This is followed by two pairs of declined thecae, usually one pair of horizontal thecae, and finally, two or three inclined thecal pairs. The sicula is mostly obscured and its length uncertain, though one paratype specimen (Figs 2-3a & 3b) shows a probable sicular outline 1.3 mm long. A short nema is seen in some specimens.

In the holotype the c stipe reveals a cluster of proximal apertures, followed by a progression of more distal apertures corresponding to the a/b stipe alignment. Some part of the proximal apertural cluster may represent a foramen comparable to that described by Fortey (1971, p.193) as the origin of the third stipe in \textit{Tristichograptus} (=\textit{Pseudotrigonograptus}). The size of the apertural ports on the c stipe are small compared to the side-view of the thecal apertures on the a/b stipes. This appears to be due to the c stipe being irregularly broken, giving cross-sections at relatively early-formed parts of the thecal tubes.

The interthecal septa are strongly developed. The longest thecae of the a/b stipe pair, which are the mid-rhabdosome horizontal pair, reach 1.0 mm in length where the total width across the rhabdosome is 2.5 mm. The two declined thecae (after the pendent sicula and th1) are 0.5 mm apart and succeeding thecae widen to approximately 0.75 mm apart.

DISCUSSION. It has been already noted that the small mature form of \textit{Tristichograptus} (Fortey, 1971; p.191, text Fig. 3) compares well to the fully adult form of \( P. \ ? \) \textit{ricardo} sp. nov., the former growing into a long, thin, cigar-shaped form, such as \textit{P. ensiformis}.
Furthermore, the c stipe of *P. ? ricardo* sp. nov. does not appear to completely break away along the median septum, as does sometimes occur in the *Pseudotrigonograptus*. It may be that *P. ? ricardo* sp. nov. is an arrested growth form derived from the *Pseudotrigonograptus* line.

Genus *PSEUDOPHYLLOGRAPTUS* Cooper & Fortey, 1982

**TYPE SPECIES.** *Phyllograptus angustifolius angustifolius* J. Hall, 1858, p. 172.

*Pseudophyllograptus angustifolius s.l.* (J. Hall, 1858); Fig. 4; Synonymy in Cooper & Fortey (1982).

**LECTOTYPE.** GSC 939 b, (Hall, 1865; Pl. 16, Fig. 21) designated and refigured by Cooper & Fortey (1982; Fig. 48f).

**MATERIAL.** Moderately common in the Shellsville Member, Dauphin Formation, but never abundant.

**DISCUSSION.** Although the two specimens figured herein (Fig.4) match well with the dimensions and shape of *P. angustifolius angustifolius* described by Cooper & Fortey (1982) none of these specimens here show details of the proximal structure sufficient for subspecific identification. Cooper & Fortey (1982) indicate maximum widths of 5.5 to 8.5 mm, while the two specimens described in this study are both 5.5 mm at the widest point. The thecal spacing for *P. a. angustifolius* is given by Cooper & Fortey (1982) as 8.5 – 12 in 10 mm in the middle third of the rhabdosome, whereas two specimens suitable for measurement in this study were 11 and 12 in 10 mm at a comparable level. Other comparable features of the study specimens to the description given for *P. a. angustifolius* by Cooper & Fortey (1982) include the denticulate appearance of the projecting ventral thecal margin, the parallel-sided nature of the rhabdosome, and the tapered appearance of the proximal and distal ends. Cooper & Fortey (1982) also describe the thecae of *P. a. angustifolius* as “moderately curved and highly inclined” from the proximal end to the widest point of the rhabdosome, then becoming progressively less inclined toward the distal portion, especially during the initial growth. The specimens in this study show the same thecal growth pattern.

*P. angustifolius s.l.* (J. Hall) is reported widely throughout the world in Arenig and Llanvirn strata (Cooper & Lindholm, 1990). Pseudophyllograptids become increasingly scarce in the upper Darriwilian, but reports of *P. angustifolius* at that level are widespread, i.e., Berry (1964, p.89; Norway), Taylor (1997, p.73; Newfoundland), Ni (1991, p.104; China), and VandenBerg & Cooper (1992, p.60; Australasia), and the taxon is pandemic.
Figure 4. *Pseudophyllograptus angustifolius* s.l. (J. Hall, 1858); locality in brackets, x5, 1 mm reference bar at 1a; 1a & 1b, NHM qq 71 [G-4]; 2, NHM qq 72 [G-2].
Genus *TETRAGRAPTUS* Salter, 1863

TYPE SPECIES. *Fucoides serra* Brongniart, 1828 (see discussion in Cooper & Fortey, 1982) *Tetragraptus cf. T. erectus* Mu, Geh & Yin (in Mu, Lee, Geh & Yin, 1962); Fig. 5.

1964 *Tetragraptus cf. erectus* Geh, p.401 (English text), Pl. 4, Fig. 13, text-Figs 8a, b

1997 *Tetragraptus sp. cf. Tetragraptus erectus* Mu, Geh & Yin; Maletz, p.26, text-Figs 8A-C, Pl. 1, Figs F, H

MATERIAL. One complete specimen (Fig. 5), flattened and faint, from the Shellsville Member, Dauphin Formation.

DESCRIPTION. A small openly reclined *Tetragraptus*, spanning 8.0 mm. Sicula at least 1.3 mm long, distal end indistinct; supradorsal height 0.6 mm with nema of equal length. Stipes widen from approximately 1.0 mm initially to 1.2 – 1.5 mm by the 4th theca. Thecae are deeply incised with strongly ‘denticulate’ margins, having apertural widths of about 0.5 mm, and spaced about 0.6 mm apart.

DISCUSSION. The openly inclined aspect of this specimen makes direct comparison with *T. erectus*, which is strongly inclined, problematic. However, the inclination of *Tetragraptus* stipes can vary widely (see, for example, the discussion on *T. bigsbyi/‘pseudobigsbyi’* in Williams & Stevens, 1988), and the open condition of this one specimen may or may not be typical of the taxon. The other dimensions of *T. erectus* compare well with those of this specimen. *Tetragraptus bigsbyi* (Hall), is strongly inclined, twice as wide initially, and thecae are not as incised.

*Tetragraptids* become scarce early in the *Pterograptus elegans* Zone where they are infrequently reported in low numbers, eg. Berry (1966, p.86), Carter (1989, p. 84), Maletz (1997, p. 26). Therefore, at generic level this taxon suggests an upper limit for the age of the Shellsville Member as low in the *P. elegans* Zone.

Genus *PTEROGRAPTUS* Holm, 1881

TYPE SPECIES. *Pterograptus elegans* Holm, 1881, p.71

*Pterograptus elegans* Holm, 1881; Fig. 6; Synonomy in Ni (1991) and Maletz (1997).

TYPE SPECIMEN. Hadding, 1911, p.493 stated that ‘original description (made by Holm, 1881) was based upon two Norwegian specimens’, and Berry (1964, p.82) commented further that the ‘genotype’ [sic] was described from 4αα2 beds within the city limits of Oslo. A specific type specimen was not designated (Taylor, 1997)
Figure 5. *Tetragraptus* cf. *Tetragraptus erectus* Mu, Geh & Yin (in Mu, Lee, Geh & Yin, 1962); locality in brackets, x10, 1 mm reference bar at 1a; 1a & 1b, NHM qq 73 [G-34].
Figure 6. *Pterograpthus elegans* Holm, 1881; locality in brackets, all x5, 1 mm reference bar at 1a; 1a & 1b, NHM qq 79 [G-31]; 2, NHM qq 80 [G-31]; 3a & 3b, NHM qq 76 [G-34]; 4, NHM qq 78 [G-34]; 5, NHM qq 81 [G-31].
MATERIAL. The species is common in the Shellsville and Nyes Road members of the Dauphin Formation, mostly as broken stipes. Five of the more complete specimens are figured herein (Fig. 6).

COMMENT. Berry (1964) provided a comprehensive description of the species and Maletz (1994) confirmed Berry’s conclusions concerning the proximal development and cladal branching of *Pterograptus* from isolated material.

DISCUSSION. The branching pattern, size and overall appearance of the specimens match well with those described for *P. elegans* by Holm (1881) and various subsequent authors. The length of the sicula measured on four specimens ranges from 0.5 – 0.7 mm. Secondary branching occurs at intervals of about 1.0 – 2.0 mm and the maximum stipe width varies from 0.4 to 0.5 mm. Proximal measurements of 2TRD on two specimens that had clear thecal definition were both 2.0 mm. The stipes are too mangled for confident measurements of distal 2TRD for any of the specimens.

*P. elegans* occurs exclusively in and throughout the *P. elegans* Zone in the middle Llanvirn and is a common pandemic species.

FAMILY SINOGRAPTIDAE Mu, 1957

SUBFAMILY SIGMAGRAPTINAE Cooper & Fortey, 1982

Genus *KINNEGAPTUS* Skoglund, 1961

TYPE SPECIES. *Kinnegraptus kinnekullensis* Skoglund, 1961, text-Fig. 2A

*Kinnegraptus cf. K. insuetus* (Keble & Benson, 1928); Fig. 7

*cf. 1928* *Tetragraptus (?) insuetus* n.s.p.: Keble & Benson, p.854-855, Pl. 104, Figs 11 a-c [Described from New Zealand].

*cf. 1962* *Tetragraptus insuetus* Keble & Benson; Skwarko, p.221-222, text-Fig. 4, Fig. A [Described from New Zealand].

TYPE MATERIAL. Keble & Benson (1928) figured three specimens, Pl. 104, Figs 11a-c which are listed (p.845) as “Type Fig. and two others”; therefore, since no type was specifically identified, they are collectively considered syntypes. Figures of these specimens were redrawn by Fons VandenBerg and kindly provided to the writer (Figs 7-1 & 2). The locality is 1231, Cobb Bed, northwest Nelson, New Zealand.

MATERIAL. A single weakly preserved, flattened specimen from the Dauphin Formation (Figs 7-4a & 4b), which is relatively complete, and some additional stipe fragments of questionable affinity. A second specimen (Figs 7-3a & 3b) with
Figure 7. *Kinnegraptus cf. insuetus* (Keble & Benson, 1928), locality in brackets, all x8, 1 mm reference bar at 1; 1 & 2 are redrawn specimens of Keble & Benson, 1928, pl. 104, 11a & 11b, respectively, by Fons Vandenberg, as *Tetragraptus (?) insuetus*; 3a & 3b, NHM qq 75 [G-31]; 4a & 4b NHM qq 74 [G-31].
Kinnegraptus - like thecae and a very curious “lyre” shape was also found in the same beds as the K. cf. insuetus specimen. It is probable that this specimen is incomplete and is only half the rhabdosome.

DESCRIPTION. The complete specimen (Figs 7-4a & 4b) has a small bell-shaped sicula 0.7 mm long, with a prominent rutellum of 0.3 mm. The specimen has a nema about the same length as the sicula. Three stipes are present, the initial pair developed approximately at the same level, and perpendicular to the sicula. One stipe branches after the first theca. The interthecal portion of the stipe is thin, ca 0.10 – 0.13 mm wide, but the stipe does not become as thin as some species of Kinnegraptus such as K. kinnekullensis. Relatively large triangular thecae grow perpendicular to the stipe. The thecae are about 0.6 mm long and are spaced at 14-16 in 10 mm. The 2TRD measured at the midpoint of the stipe is 1.4 mm.

A second incomplete ‘lyre-shaped’ specimen (Figs 7-3a & 3b) is distinctly symmetrical with relatively large triangular-shaped thecae emerging perpendicularly from initially thin stipes. Unfortunately, the sicula is not preserved. The initial stipe width is about 0.7 mm, which widens to 1.3 mm by the third theca. The thecae are spaced at a rate of 7.5 in 5 mm (2TRD = 1.3 mm). This incomplete specimen resembles the figured specimens of T. insuetus by Keble & Benson (1928), especially Pl. 104, Fig. 11b, but is slightly larger. The stipe width after the third thecae is 1.3 mm for the subject specimen and 1.0 mm for Keble & Benson’s specimens.

FAMILY UNCERTAIN

Genus ACROGRAPTUS Tzaj, 1969

TYPE SPECIES. Didymograpsus affinis Nicholson, 1869, Pl. XI, Fig. 20, by original designation.

Acrograptus affinis (Nicholson, 1869); Fig. 8; Synonomy in Strachan (1996, p.32)

TYPE MATERIAL. Lectotype; selected Elles & Wood (1901). They figured one of Nicholson’s specimens from one of his original localities. NHM Q3108, Tarn Moor Formation (Llanvirn) of Aik Beck (or “Eggbeck”), E. of Ullswater, English Lake District. Figured by Rushton (2000) as a syntype; also figured by Cooper & Fortey (1982, p.271; as “holotype”). Strachan (1996, p.32) listed it as a neotype and stated, “Elles and Wood selected the specimen which they figured as Pl.2, Fig. 1b”.

Figure 8. *Acrograptus affinis* (Nicholson, 1869); localities in brackets, 1-6, x5, 1 mm reference bar at la; 7, x2, with 10 mm vertical reference bar; (3-7 are either *Acrograptus* sp. or *Janograptus* sp.); 1a & 1b, NHM qq 82 [G-34]; 2, NHM qq 83 [G-34]; 3, NHM qq 86 [G-34]; 4, NHM qq 87 [G-34]; 5, NHM qq 85 [G-34]; 6, NHM qq 88 [G-34]; 7, NHM qq 84 [G-34].
MATERIAL. One complete specimen (Figs 8-1a & 1b), one partial specimen (Fig. 8-2), and numerous possible stipe fragments; all are flattened. Shellsville Member, Dauphin Formation.

DISCUSSION. *Acrograptus affinis* has a small sicula with a pair of barely declined thin stipes diverging from the sicula at slightly different elevations. The stipes are very long and widen only slightly. Nicholson (1869) describes the stipes as of uniform width from one-fiftieth to one-fortieth of an inch (0.5 to 0.6 mm) with “cellules” (= thecae) inclined to the axis (of the stipe) at 15 to 20°, occurring at a frequency of about 18 to the inch (= 7 in 10 mm), and having no overlap. The sicula of the syntype is simple and is ca 0.6 mm long. The width is 0.2 mm at th1 and 0.35 mm at th5. The ZTRD at theca 4-6 is 1.6 mm on one stipe and 1.9 mm on the opposing stipe at th5-7. Specimen NHM qq82 (Figs 8-1a & 1b) compares fairly well with the syntype described above. It has a sicula 0.6 mm long, is 0.5 mm wide at th4, and has a ZTRD of 1.8 mm at th4-6.

Distal stipe fragments withoutsiculae, that could be *A. affinis* (or other species of *Acrograptus*, or even other genera), are common throughout the Dauphin Formation. In many references (e.g. Erdtmann, 1971; Berry, 1964; Berry, 1960; Lemon & Cranswick, 1956; Ekström, 1937) such detached stipes are often referred to *Janograptus*. Ambiguously joined opposing stipe pairs without ‘conventional’ siculae may be referred to *Janograptus*, but none were found in this study. Whether or not *Janograptus* represents regenerated stipes from a variety of taxa has caused considerable debate (see Erdtmann, 1971 and Taylor, 1997 for a discussion of this issue). Some dichograptid stipe fragments of this type are figured herein.

*Acrograptus affinis* was first described by Nicholson (1869) from the Llanvirn of the Skiddaw Group. Berry (1964) reports the species from Norway in the *Didymograptus murchisoni* Zone, 4aa 2 unit. In North America it was recorded in the Llanvirn by Berry (1960) and Taylor (1997, p.11, as *Acrograptus* cf. *A. affinis*). Benson & Keble (1935) list it from New Zealand. Thus, the taxon appears to be pandemic, occurring in the stratigraphic equivalents, at least in part, of the Shellsville Member. However, as Maletz (1997, p.34) points out, “sufficient descriptions of most Llanvirn acrograptids do not exist.” This makes determination of a possible taxon’s range less precise, and subject to confusion with other species.

FAMILY GLOSSOGRAPTIDAE Lapworth, 1873

Genus *BERGSTROEMOGRAFTUS* Finney & Chen Xu 1984
TYPE SPECIES. *Bergstroemograptus crawfordi* (Harris, 1926); p.57, Pl. 1, Figs 5-7

*Bergstroemograptus crawfordi* (Harris, 1926); Fig. 9; Synonomy in Finney & Chen (1984)

HOLOTYPE. Harris (1926, Pl. 1, Fig. 5), NMV P13357

MATERIAL. The best preserved specimen is figured (Fig. 9); other less well-preserved specimens were found.

DISCUSSION. The specimens display the characteristic heart-shaped rhabdosome and pointed proximal end of *B. crawfordi* (Harris). Specimen NHM qq125 (Figs 9, 1a & 1b) is not well enough preserved to see a definitive monopleural thecal growth, but a frontal bulge is weakly developed. In all other respects, such as length (3.5 mm), width (2.5mm), and thecal spacing (0.4mm, proximally) it conforms to the characteristics shown by Finney & Chen (1984, Fig. 2) for *B. crawfordi* (Harris).

Finney & Chen (1984) state that *B. crawfordi* (Harris) ranges from the *Glyptograptus intersitus* (Da2) Zone to the *Diplograptus decoratus* (Da3) Zone in Australasia. In western Newfoundland it has been found in the *decoratus* Zone. The limited occurrence of *B. crawfordi* (Harris) in the Dauphin Formation suggests the earliest part of that unit may be within the Da3 interval, although no other exclusively Da3 elements were found.

Genus *CRYPTOGRAPTUS* Lapworth, 1880

TYPE SPECIES. *Diplograpsus tricornis* Carruthers, 1858; p.468, Fig. 2

*Cryptograptus schaeferi* Lapworth, 1880; Figs 10 & 11


1880  *Diplograptus* (Cystograptus) [sic] *tricornis*, Carr. var.*Schaeferi* Lapworth, Pl. 5, Figs 28a, b (recorded from southern Britain).

1908  *Cryptograptus tricornis* var. *Schaeferi* Lapworth; Elles & Wood, p.229, Pl. 32, Figs 13a-c; text-Figs 201 a, b.

1931  *Cryptograptus tricornis* var. *schaeferi* Lapworth; Bulman, Pl. 6, Figs 1-5; Pl. 7, Fig. 3, text-Figs 31a-c (recorded from Peru).

1933  *Cryptograptus schaeferi* Lapworth var. *latus* var. nov.; Bulman, p.352, Pl. 33, Figs 8a-c.

1937  *Cryptograptus tricornis* (Carruthers); Ekström, p.39, Pl. 9, Figs 1-5 (recorded from Sweden).
Figure 9. *Bergstroemograptus crawfordi* (Harris, 1926); localities in brackets, 1a & 1b, NHM qq 125 [G-3], x10 with 1 mm reference bar at 1a.

Figure 10. *Cryptograptus schaeferi* Lapworth, 1880, juvenile forms; localities in brackets, all x10 with 1 mm reference bar at 2a; 1a & 1b, NHM qq 102 [G-3]; 2a & 2b, qq 101 [G-34]; 3, NHM qq 100, [G-34].
Figure 11. Cryptograptus schaeferi Lapworth, 1880: localities in brackets 1a-5b, 7, 8 (complete specimen) & 9-12, x4 with 1 mm reference bars at 1a and above 8; 6a & 6b, x8 with 1 mm reference bar at 6a; enlarged proximal region of 8, x24 with 1 mm reference bar; 1a & 1b NHM qq 96 [G-34]; 2a & 2b, NHM qq 99 [G-4]; 3, NHM qq 98 [G-6]; 4a & 4b, NHM qq 89 [G-34]; 5a & 5b, NHM qq 95 [G-6]; 6a & 6b, NHM qq 91 [G-34]; 7, NHM qq 90 [G-34]; 8, BU 1323 (the lectotype); 9, NHM qq 94 [G-6]; 10a & 10b, NHM qq 97 [G-34]; 11, NHM qq 92 [G-34]; 12, NHM qq 93 [G-34].
<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1937</td>
<td><em>Cryptograptus tricornis</em> (Carruthers) var. <em>longispinus</em> var. nov.; Ekström, p.40, Pl. 8, Fig. 13.</td>
</tr>
<tr>
<td>1937</td>
<td><em>Cryptograptus lanceolatus</em> (Hadding); Ekström, p.40, Pl. 8, Figs 11, 12.</td>
</tr>
<tr>
<td>1956</td>
<td><em>Cryptograptus tricornis schaeferi</em> Lapworth; Lemon &amp; Cranswick, p.19, text-Fig. 4; K (recorded from Peru).</td>
</tr>
<tr>
<td>1960</td>
<td><em>Cryptograptus schaeferi</em> Lapworth; Berry, pp.69-70, Pl. 12, Figs 7, 8 (recorded from North America).</td>
</tr>
<tr>
<td>1963</td>
<td><em>Cryptograptus schaeferi</em> Lapworth; Ross &amp; Berry, pp.96-97, Pl. 5, Figs, 28, 29 (recorded from North America).</td>
</tr>
<tr>
<td>1964</td>
<td><em>Cryptograptus tricornis</em> (Carruthers); Berry, p.117, Pl. 9, Figs 1, 2a.</td>
</tr>
<tr>
<td>1964</td>
<td><em>Cryptograptus tricornis</em> var. <em>schaeferi</em> Lapworth; Berry, p.117, Pl. 11, Figs 7, 8 (recorded from Norway).</td>
</tr>
<tr>
<td>1970</td>
<td><em>Cryptograptus tricornis schaeferi</em> Lapworth; Skevington, p.418, Figs 6a-h, 7a-d.</td>
</tr>
<tr>
<td>1979</td>
<td><em>Cryptograptus schaeferi</em> Lapworth; Cooper, Pls 15d, jB; Fig. 63 (recorded from New Zealand).</td>
</tr>
<tr>
<td>1985</td>
<td><em>Cryptograptus schaeferi</em> Lapworth; Lenz &amp; Chen, Pl. 3, Fig. 2.</td>
</tr>
<tr>
<td>1986</td>
<td><em>Cryptograptus schaeferi</em> Lapworth; Strachan, p.25, pl. 3, Fig. 6, text-Fig. 21.</td>
</tr>
<tr>
<td>1987</td>
<td><em>Cryptograptus schaeferi</em> Lapworth; Xu, <em>et al</em>., p.103, Pl. 13, Fig 13.</td>
</tr>
<tr>
<td>1989</td>
<td><em>Cryptograptus schaeferi</em> Lapworth; Bjerreskov, Fig. 6a.</td>
</tr>
<tr>
<td>1990</td>
<td><em>Cryptograptus schaeferi</em> Lapworth; Ge, Zheng &amp; Li, p.107, Pl. 39, Figs 5, 9, 11-13.</td>
</tr>
<tr>
<td>1996</td>
<td><em>Cryptograptus schaeferi</em> Lapworth; Maletz &amp; Mitchell, p.647, Fig. 4 (11-15), p.648, Fig. 5.</td>
</tr>
</tbody>
</table>

**LECTOTYPE.** BU 1323; figured by Elles & Wood (1908), Pl. XXX11, Fig. 13a and noted as “typical specimen”, and from “Lapworth’s collection”. The locality given by Elles & Wood is Llandrindod Wells, Llandeilo, the same as listed by Lapworth. Strachan (1971) stated that BU 1323 is the “holotype” of *C. schaeferi* and commented that Elles & Wood (1908) figured it as a “typical specimen”. BU 1323 is refigured herein as Fig. 11-8. It is not entirely possible to reconcile figure 28a, b of Pl. V (Lapworth, 1880) with that of Elles & Wood cited above; therefore, their figure 13a, stated by Strachan (1996) as a ‘holotype’ should be regarded as a lectotype. It is difficult to ascertain if the discrepancy is due to an inaccurate drawing by Lapworth or if Elles & Wood figured a different specimen. Lapworth’s figure 28b is described as “proximal portion magn” with 28a “nat size”, but the proximal ends of the two figures appear different,
one with a single midspine (Fig. 28b) and one with two (Fig. 28a). This implies that Lapworth's 28a and b represent two different specimens.

MATERIAL. *Cryptograptus schaeferi* (Figs 10-11) is the most common species in the Darriwilian section of the Hamburg sequence. It is often found as abundant flattened specimens in dense swarms. These slabs show the considerable range of size, shape and proximal variation caused by preservation effects and taphonomic orientation.

DESCRIPTION. The rhabdosome is parallel-sided, usually straight, and most commonly preserved in biprofile (or lateral) aspect and occasionally in scalariform view. The complete sicula is seen in juveniles (Fig. 10), but in mature specimens usually only the bluntly pointed sicular rutellum, protruding from the base of the rhabdosome, is seen. The sicula, measured on three juvenile specimens and one adult was 1.9, 2.2, 2.3, and 2.2 mm in length respectively. The sicular rutellum is broad, bluntly pointed and about 0.4 – 0.7 mm in length. Thl grows down the sicula and also terminates in a spade-shaped rutellum (see Maletz & Mitchell, 1996, Fig. 4). This results in two similar proximal protrusions, which are seen in biprofile orientations. However, when the rhabdosome is rotated 90° only one of these rutella might be seen or the second may appear as less obvious. The lectotype can be interpreted in this manner with two long rutella, the shorter of which is partially hidden by the longer one in front (Figs 11-8). The proximal end also possesses two lateral spines, which may grow to 2 mm in length (Figs 11-12). The preservation of these spines in flattened material is also dependent upon orientation, which may show one, both or none. Initially the spines grow out and down at about 45° from the axis of the sicula; however, the longer mature spines on adults, which are not commonly preserved in biprofile aspect, show a more downward than outward growth (Fig. 11-2 a & b). Both of these spines are usually apparent when the rhabdosome is preserved in scalariform view (Figs 10, 11).

The apertural margins are straight or slightly concave and the thecae have a triangular outline between the thecal excavations. However, the thecae on some specimens may appear to droop downward rather than point outward, and it is not unusual for a single specimen to demonstrate both conditions (eg. Figs 11 – 1a &b, 10a & b). This situation makes measurements for 2TRD, overall thecal density, and width of rhabdosome, to some extent subjective. The rhabdosomes are typically 8-10 mm long, but range up to 30 mm within the population studied. The lectotype is 19.7 mm long. Table 2 represents the width of *C. schaeferi* sampled for this study, which shows a considerable range. After th1, *C. schaeferi* becomes parallel sided and individuals have a stable width. However, within a large population the individual width can vary considerably, some of which is taphonomic effect. The lectotype width is 1.67 mm at th7. The thecal density on 10 specimens averaged 14.3
Table 2. Width of Cryptograpthus schaeferi at thecae 2, 5 and 7. (* = width of type)
in 10 mm, and ranged between 11 and 16. The lectotype has 12 thecae in 10 mm. Measurements of 2TRD on nine specimens ranged from 1.13 to 1.76 mm, all taken in the lower half of the rhabdosome.

The rhabdosome possesses a conspicuous nema that sometimes develops a flat, spiral, multiple-lobed vane. It is occasionally preserved, especially on specimens in scalariform aspect and more rarely in biprofile view (Figs 11-6a & b). The biprofile specimen with a vane developed the structure after the 11th theca at 8 mm of growth, and the two in scalariform view had vane structures after 10 mm. These vanes appear to be thinly sclerotized and may be approximately as long as the rest of the rhabdosome.

DISCUSSION. Cryptograptus schaeferi is the commonly identified Cryptograptus species in the Dauphin Formation Darriwilian fauna. However, there has been a long and contentious debate over the differentiation of the various Cryptograptus taxa especially C. schaeferi (Lapworth), C. marcidus (Hall) and C. tricornis (Carruthers); see Skevington (1970) and Williams (1995). In 1858 Carruthers described Diplograptus tricornis, and Hall described Graptolithus marcidus in 1859. Carruthers (1868) claimed that Hall’s G. marcidus was identical to his D. tricornis, a view supported by Lapworth (1880, p.171-172). If that were the case, D. tricornis would be the senior synonym. In 1880 Lapworth described “Schaeferi” as a variety of D. tricornis. Finney (1978) stated Cryptograptus marcidus as a senior synonym for C. schaeferi. However, Williams (1995, p.65), noted that C. marcidus has a much smaller sicula than C. schaeferi (1.6mm vs. 2.5mm), so is likely to be a separate species from both C. schaeferi and C. tricornis. In the population studied here there is a preponderence of biprofile (or lateral) preservation typical of C. schaeferi, while C. tricornis is most often preserved in scalariform view (Williams, 1995); this difference in orientation reflects the shorter proximal thecal spines of C. schaeferi (Williams 1995). Williams noted that the sicula of C. tricornis is less sclerotized than that of C. schaeferi. Williams (1995) agrees with Hughes (1989) that C. schaeferi and C. tricornis are indistinguishable as regards to thecal count (but see Skevington, 1970). An earlier form, C. antennarius, possesses extremely long basal spines (Williams 1995). The range of C. schaeferi is shown by VandenBerg & Cooper (1992) as within the middle Darriwilian with C. tricornis ranging from the upper Darriwilian into the Gisbornian (Caradoc).

Genus GLOSSOGRAPTUS Emmons, 1855

*Glossograptus hincksii* (Hopkinson, 1872); Fig. 12; Synonymy for *G. hincksii* in Lemon & Cranswick (1956) and VandenBerg & Cooper (1992), to which is added: 1960 *Glossograptus hincksii* (Hopkinson), Berry, p.118, Pl. 4, Figs 3 & 4.

**TYPE SPECIMEN.** Not yet designated.

**MATERIAL.** The taxon is relatively common throughout the Dauphin Formation in the Shellsville and Nyes Road members. At least 50 specimens were collected from various localities.

**DISCUSSION.** The specimens collected are consistent with the figures and description of Hopkinson (1872), and also Lemon & Cranswick (1956) and Berry (1964). A variety of adult and associated juvenile specimens are represented. The adult forms were found in biprofile, subscalariform and scalariform orientation. The longest adult specimen is broken and incomplete. It is 16 mm long with a 10 mm vane attached to the distal portion of the rhabdosome. Widths of adult specimens are 2 – 3 mm (without spines; this measurement is somewhat arbitrary because the thecal tips grade into the spines). In biprofile aspect the thecae number 14 in 10 mm, the thecal spines are approximately 0.7 mm long, and the monopleural arrangement of the thecae is apparent. The lateral and dorsal spines measure up to 3 mm in length.

The biostratigraphic range of *G. hincksii* is generally given as upper Middle to lower Upper Ordovician, e.g. Berry (1960), Cooper & Lindholm (1990). However, varying opinion over species of *Glossograptus* such as *G. ciliatus* (recorded as a senior synonym of *G. hincksii* by VandenBerg & Cooper, 1992, p.78) and *G. holmi*, now referred to *Paraglossograptus holmi* (see Maletz & Mitchell, 1996, p.653) make assessment of the taxon's range problematical. Reported ranges of species very similar to *G. hincksii*, but identified as some other taxon, add to the confusion. The distinction of these species from *G. hincksii* requires a comprehensive analysis, which is beyond the scope of this study.

Genus *PARAGLOSSOGRAPTUS* Mu, Geh & Yin (in Mu, Lee, Geh & Yin, 1962)

**TYPE SPECIES.** *Paraglossograptus typicalis* Mu, Geh & Yin (in Mu, Lee, Geh & Yin, 1962)

**COMMENT.** The attribution of the genus *Paraglossograptus* has been somewhat confused since the name first appeared in Hsu (1959, p.187), who ascribed it to "Mu, MS., 1958",
Figure 12. *Glossograptus hincksii* (Hopkinson, 1872); localities in brackets, mature forms outside box x4 with 1 mm reference bar at 1a; juvenile forms within box, x8 with 1 mm reference bar at 7a; 1a & 1b, NHM qq 107 [G-34]; 2, NHM qq 106 [G-6]; 3a & 3b, NHM qq 105 [G-16c]; 4, NHM qq 108 [G-34]; 5, NHM qq 109 [G-2]; 6a & 6b, NHM qq 113 [G-34]; 7a & 7b, NHM qq 112 [G-3]; 8a & 8b, NHM qq 117 [G-34]; 9, NHM qq 114 [G-34]; 10, NHM qq 118 [G-34].
stating that Mu's paper had not then been published. Succeeding authors consistently referred the attribution of *Paraglossograptus* to Mu (in Hsu, 1959). However, as Rickards (1972) pointed out, the rules of the International Code of Zoological Nomenclature (ICZN; The Natural History Museum, London) Article 13.3, require that, after 1930, a type species must be designated for a new genus to be available. Although Hsu (1959) fully described the genus, and described three species, a generic type species was not designated. Therefore, according to the ICZN rules, the name *Paraglossograptus* was technically not available from Hsu's paper, and its attribution as Mu (in Hsu, 1959) is not valid.

In Mu & Lee (1960) *Paraglossograptus* was described, the authorship of the genus being credited to Mu (although as in Hsu, 1959), and *P. typicalis* was figured (p. 89, text-Fig. 127 & Pl. 1, Fig. 9), and designated as type species of the genus. However, *P. typicalis* was a new name, and the requirements of ICZN under Article 13.1, "Names published after 1930" specify that one of three options must accompany a new name: Art. 13.1.1, a description in words differentiating the taxon; or, Art. 13.1.2, "be accompanied by a bibliographic reference to such a published statement..."; or Art. 13.1.3, “be proposed expressly as a replacement name”. In Mu & Lee (1960), *P. typicalis* did not comply with the requirements of Article 13.1, and, thus, *Paraglossograptus* is not available from that date. Mu, Geh & Yin (in Mu, Lee, Geh & Yin, 1962) ascribe the attribution of *Paraglossograptus* to Mu (in Mu & Lee, 1960) with *P. typicalis* as the generic type species, which they also described, therefore fulfilling the requirements of Article 13.1.1. It would appear that Mu, Geh & Yin (in Mu, Lee, Geh & Yin, 1962) is the first technically correct introduction of *Paraglossograptus*, even though they attribute it to Mu (in Mu & Lee, 1960). Mu (1963) then inexplicably ascribed the attribution of *Paraglossograptus* to “Mu, in Hsu (1959)”, which, as explained above, is not valid. Mu (1963) further stated that *P. typicalis* is the type (which is correct), and figured it on page 364 (text-Fig. 15). This figured specimen, however, is not the specimen originally figured for *P. typicalis* by Mu, in Mu & Lee (1960, p.89, text-Fig. 127). However, Fig. 10, Pl. 18 in Mu, Lee, Geh & Yin (1962) does appear to be the same specimen as figured in Mu in Mu & Lee (1960, p.89, text-Fig.127) as the then assumed (it was not specifically stated as such) intended type specimen (?) for *P. typicalis*. This last point may assist future workers because Mu & Lee (1960) is difficult to locate, and I am indebted to the diligence of Isles Strachan, who found it listed in *Referativni Zhurnal Geologiya*, Moscow, (1960, ref. 22918), and then located a copy of the reference.

Hsu's (1959) description and discussion of *Paraglossograptus* specifically excluded synonymy with *Retiograptus tentaculatus* (Hall, 1865). Rickards (1972) disagreed with Hsu's analysis and considered *P. latus* and *P. typicalis* (not described by Hsu; it was first
figured by Mu, in Mu & Lee, 1960) to be junior synonyms of *R. tentaculatus*. Whatever the validity of Rickard’s analysis, the type species for *Paraglossograptus* is technically *P. typicalis* Mu, Geh & Yin (in Mu, Lee, Geh & Yin, 1962). In Berry (1966), *P. latus*, one of the three species described by Hsu (1959), was selected as the type species of the genus, since none was selected by Hsu. However, this is not valid because, as discussed above, *Paraglossograptus* is not available from Hsu (1959) and Mu & Lee (1960) clearly intended the type to be *P. typicalis*, even though they did not technically comply with the rules of the ICZN.

*Paraglossograptus* cf. *P. proteus* (Harris & Thomas, 1935); Fig. 13

- cf. 1935 *Lasiograptus (Hallograptus) proteus*, Harris & Thomas, p.305, Fig. 1, nos. 12 a-b; Fig. 2, nos. 30-33.
- cf. 1935 *Lasiograptus proteus*, Harris & Thomas, p.332 [listed]
- cf. 1960 *Lasiograptus (H.) proteus*, Harris & Thomas; Thomas, p.31, Pl. 6, Fig. 87.
- cf. 1962 *L. (Hallograptus) proteus*, Harris & Thomas; Mu, Geh & Yin in Mu et al., p.97.
- cf. 1966 *Paraglossograptus etheridgei* (Harris); Morris & Kay, text-Fig. 41 [schematic figure].
- cf. 1971 *Paraglossograptus* sp. Erdtmann, p.1514 [listed].
- cf. 1972 *Paraglossograptus proteus* (Harris & Thomas); Rickards; pp.110-111, Figs 2c, d.

**HOLOTYPE.** Harris & Thomas, 1935 Fig. 2, no. 30. Geological Survey of Victoria, Australia no. 37432.

**MATERIAL.** Three specimens from the Shellsville Member, Dauphin Formation.

**DISCUSSION.** None of the flattened specimens available for examination are very well preserved but sufficient critical features for comparison are present. These include the lacinial lattice that develops from the thecal margins outwards and upwards between the robust apertural spines. The detailed diagram of *Paraglossograptus* ? sp. (Whittington & Rickards, 1969, p.811), assigned to *P. proteus* by Rickards (1972), shows the appearance of the apertural spines which are large with respect to the thecal size and shape, and the lacinial growth. This figure is similar to the specimen shown in Figs 13-1a & 1b. The bent, compressed, and locally detached spines, which can originate from any of the four rectilinear sides of the rhabdosome, can be difficult to discriminate in flattened material. That, combined
Figure 13. Paraglossograptus cf. proteus (Harris & Thomas, 1935); localities in brackets, x5, 1 mm reference bar at 1a; 1a & 1b, NHM qq 127 [G-34]; 2, NHM qq 128 [G-34]; 3, NHM qq 129 [G-6].
with poorly preserved thecal apertures, makes an accurate thecal count difficult to determine. However, a 2TRD of approximately 1.4 mm at about 10 mm from the proximal end was determined (approximately 14 theca in 10 mm). Rickards (1972) describes the thecal density of *P. proteus* as 12-16 in 10 mm for the first few mm of growth, then 8-10 thereafter.

The rhabdosome width for *P. proteus* given by Rickards (1972) was 1.5-2.0 mm (exclusive of processes). The origin of the thecal tips for such measurements can be somewhat arbitrary in this type of spiny rhabdosome. The range in maximum width, excluding spines, measured for three specimens in this study is 1.5-2.3 mm. Rickards (1972) described *P. proteus* as half the width of *P. tentaculatus* and parallel-sided, whereas the latter as fusiform or parallel-sided. The specimens in this study are weakly fusiform but within the size-range of *P. proteus*. The closer-spaced thecae and fusiform appearance means that this material is similar to, but not identical with, *P. proteus*. The poor preservation of the specimens made determination of the extent of lacinial development uncertain. *Paraglossograptus holmi* (Bulman; transferred from *Glossograptus* to *Paraglossograptus* by Maletz & Mitchell, 1996) has lacinia only in the proximal part, but the examples included here appear to have lacinia more distally.

The form of *Paraglossograptus* to be expected in the upper Darriwilian is *P. proteus* rather than *P. tentaculatus* which is generally reported from lower stratigraphic levels. *P. proteus* is widely reported from the Pacific Faunal Province (see Rickards, 1972, p. 101), to which it is endemic.

**Genus KALPINOGRAPTUS** Jiao, 1977

**TYPE SPECIES.** *Kalpinograptus spiroptenus* Jiao, 1977

*Kalpinograptus* spp. (nov?) & *Kalpinograptus* ?; Fig. 14

**MATERIAL.** Six flattened specimens from the Shellsville Member, Dauphin Formation

**COMMENT.** None of the specimens found match any of the previously described species of *Kalpinograptus*, and up to four new morphologies, possibly representing species, could be present. However, with very few specimens of each taxon, none well preserved, they are left in open nomenclature.

*Kalpinograptus* specimen A; Figs 14-1a & 1b

**DESCRIPTION.** The specimen clearly shows the “Glossograptid bulge”, as described by Maletz and Mitchell (1996), formed from “the downward and outward curving and lateral overlapping of the proximal thecae”. At least two of the first-formed thecae initially show
Figure 14. Kalpinograptus spp. (nov?) & Kalpinograptus ?; localities in brackets, x8, 1 mm reference bar at 1a; Kalpinograptus spec. A, 1a & 1b, NHM qq 119 [G-34]; Kalpinograptus spec. B, 2a & 2b, NHM qq 121 [G-31]; Kalpinograptus spec. C, 3a & 3b, NHM qq 123 [G-31]; Kalpinograptus sp., 4 & 5, NHM qq 120 [G-31] & 122 [G-20], respectively; Kalpinograptus ?, 6a & 6b, NHM qq 124 [G-34].
downward growth, then curve upward and outwards, although the exact level within the bulge exposing the thecae is not clear.

The sicula is estimated at 2.4 mm long, the proximal tip being interpreted as the right spiny process; the supradorsal height is 0.4 mm. The two stipes initially diverge widely, but, over 3-4 mm curve up to form an angle of about 90°. The stipe width at thecae 4-6 is 1.5 mm, where the width of thecal apertures is 0.4-0.7 mm (a range influenced by preservational orientation). The thecae have conspicuous elongated processes, which Maletz & Mitchell (1996) described as 'rutelli', and which are typical of the genus. The 2TRD is 1.5 mm at thecae 4-5, where the overlap is about 50 percent.

DISCUSSION. This form compares somewhat to the examples of Kalpinograptus sp. shown in Maletz & Mitchell (1996, p.644, Figs 2, 1 & 2) but has more widely divergent stipes. Their specimen of Kalpinograptus was described from the American Tickle Formation of Newfoundland in the upper Darriwilian, which is roughly equivalent to the biostratigraphic level of the Shellsville Member.

Kalpinograptus specimen B; Figs 14 2a & 2b

cf. 2001 Kalpinograptus sp.; Ganis et al. p.118, Fig. 8G

DESCRIPTION. This specimen shows a slight distortion. The glossograptid bulge is poorly preserved and indistinct, and the number of curving thecae involved in it appears to be 3 or 4. The sicula is about 3.5 mm long, assuming that the shorter process within the tangle of proximal spines is the end of the sicula; the supradorsal height is 0.8 mm. The stipes diverge at about 45°, and are 1.5-2.0 mm wide at thecae 4-5. The 2TRD is 1.5 mm at thecae 4-5.

The specimen has large thecal processes, which resemble broad spines, almost as long as the rest of the stipe is wide.

Kalpinograptus sp. C; Figs 14 3a & 3b

cf. 2001 Kalpinograptus sp.; Ganis et al. p.118, Fig. 8F

DESCRIPTION. A single poorly preserved, slightly distorted, specimen was found. There is a suggestion of a glossograptid bulge, which could incorporate as many as 3 or 4 curved thecae, emerging at the periphery of the structure. The end of the sicula is not distinct among the spiny processes extending from the proximal end; therefore, the length of the sicula is only estimated at 2.4 mm; the supradorsal height is 0.7 mm. The stipes diverge at about 50°, and are 1.4 mm wide at thecae 3-5. The specimen clearly shows the thecae extending into long apertual processes (rutelli of Maletz & Mitchell, 1996). These thecal rutelli are about a third of the rest of the stipe width. The 2TRD at thecae 3-5 is 1.4 mm. Kalpinograptus specimen C has thicker stipes and shorter rutelli than K. specimen B.
*Kalpinograptus* sp.; Figs 14-4 and 14-5 are possible Kalpinograpti but appear distorted, and are not sufficiently preserved to compare with the other examples described here.

*Kalpinograptus* ?; Figs 14 6a & 6b

**DESCRIPTION.** A single, fairly well preserved, flattened specimen is present. Its affinity to *Kalpinograptus* is uncertain, but the specimen does appear to have long apertural processes characteristic of the genus. At least one theca appears to show a curved upwards and outwards growth, which could form the glossograptid bulge. The sicula is 1.8 mm long, and has a supradorsal height of 0.5 mm. The width of the thecal apertures is 0.45 mm, which is half of the stipe width of 0.90 mm, and the thecae are about 0.7 mm apart. The two stipes converge at an angle of 29°.

**REMARKS.** The *Kalpinograptus* material described from the Dauphin Formation differs from *K. spiroptenus* Jiao in general shape and the smaller proportion of the supradorsal area compared to the size of the rhabdosome. *K. spiroptenus* has a more ‘*Pseudisograptus*-like’ shape, (in silhouette) with a proportionally large supradorsal area, whereas the Dauphin material is more ‘*Isograptus*-like’ shaped, with a proportionally smaller supradorsal area. *K. spiroptenus* Jiao, has pronounced “s”- shaped thecae in the frontal bulge (glossograptid bulge of Maletz & Mitchell, 1996) with strong upward growth at the distal end, whereas, the Dauphin material appears to have a less pronounced final upward growth. *K. spiroptenus* Jiao was reported by Ni (1991) from the *G. teretiusculus siccatus* and *Nemagraptus gracilis* zones in China, higher stratigraphically than the Kalpinograpti described herein from the *P. elegans* zone. *K. ovatus* is much larger than any of the forms described herein.

**FAMILY ABROGRAPTIDAE** Mu, 1958

*Reteograptus* spp. (nov.?) Fig. 15

**COMMENT.** Finney (1980) included *Reteograptus* within the Abrograptidae. Maletz (1993 p. 328) questioned this, noting that the Abrograptidae have a sicular rutellum, as in dichograptids, whereas *Reteograptus* has a sicular virgella, as in diplograptids. The relationship of the abrograptid rutellum to the reteograptid virgella is unclear, and more study is needed to clarify the phylogenetic significance of these characters (J. Maletz, personal communication).

**MATERIAL.** Numerous flattened specimens; occasionally preserved with sicula but mostly only as scraps of meshwork. Fig. 10K of Ganis *et al.* (2001), Archiretiolitid sp. nov., is the
Figure 15. *Reteogaptus* spp. (nov.?); localities in brackets, x20; 1, NHM qq 157 [G-20]; 2, NHM qq 158 [G-31]; 3, NHM qq 156 [G-31]; 4, NHM qq 159 [G-31].
counterpart of NHM qq157, Fig. 15 (the photo in Ganis et al. (2001) is a mirror image which causes the part and counterpart to appear the same).

DISCUSSION. Minute skeletal reteograptids were common at three locations in the Shellsville member, but may be easily overlooked. The specimens show a fully sclerotized sicula, with virgella, but none of the specimens recovered show any sign of periderm. This lack of periderm reduced the strength of the rhabdosome during taphomony, resulting in local distortion of the original meshwork architecture. Specimens shown in Figs 15-1 and 15-3 preserve the best remnant meshwork organization, while Figs 15-2 and 15-4 show obvious distortion. The lengths of the siculae for the four specimens figured are 0.85, 0.80, 0.60 and 0.35 mm, suggesting two or more species. Finney's (1980) text-Fig. 16J of Reteograptus geinitzianus Hall, from an isolated early growth stage, bears some similarity to Fig. 15-2 shown herein. However, R. geinitzianus developed a periderm as it matured, whereas the material described here has not shown this. The material described here may all represent juvenile forms, even though it was found at multiple locations. Because of inadequate material and the uncertainty regarding the taxonomic maturity of the material described, they are left in open nomenclature.

SUBORDER DIPLOGRAPTINA Lapworth, 1873
FAMILY ORTHOGRAPTIDAE Mitchell, 1987

Genus HUSTEDOGRAPTUS Mitchell, 1987

TYPE SPECIES. Diplograptus uplandicus Wiman, 1895
Hustedograptus teretiusculus (?) (Hisinger) sensu Jaanusson, 1960; Fig. 16
Synonomy in Maletz (1997), to which can be added: v 1989 Glyptograptus teretiusculus (Hisinger); Hughes, p.65, Pl. 4, Fig. e; text-Figs 22f; 23d.

TYPE SPECIMEN. Hughes (1989, p.65) quoted information from Prof. Valdar Jaanusson that Hisinger's type material does not include any specimens that can be identified at the species level. Mitchell (1997, p.357) described specimen "CN 59886, Folkeslunda Limestone, Lasnamagi Stage (H. teretiusculus Zone), Sjostorp, Oland (Holm Collection)", as representative of the proximal development that he considered characteristic of H. teretiusculus, but he did not assign it as a lectotype and it has no formal status.

MATERIAL. H. teretiusculus (?) is common within the Dauphin Formation assemblage but never in high numbers at any one locality. Approximately 30 specimens were collected,
Figure 16. *Hustedograptus teretiusculus* ? (Hisinger) sensu Jaanusson, 1960; localities in brackets, 1a-3b, x10, 1 mm bar at 1a; 4-7, in box, x5, 1 mm bar at 4; 1a & 1b NHM qq 153 [G-34]; 2a & 2b, in NHM qq 150 [G-34]; 3a & 3b, NHM qq 147 [G-34]; 4, NHM qq 154 [G-1]; 5, NHM qq 146 [G-2]; 6, NHM qq 149 [G-34]; 7, NHM qq 151 [G-3].
mostly as incomplete flattened impressions. Nicely preserved specimens with full proximal
details are uncommon. The best specimens were partially dissolved from a calcareous bed
with 5 percent acetic acid that gave excellent cross-sectional details of the proximal region
(Figs 16-1a & 1b, 3a & 3b).

DISCUSSION. *H. teretiusculus* has been variously described in the literature. How much of
this variation is due to taphonomic or tectonic distortion, rather than intraspecific variation, is
uncertain. Mitchell (1987, p.356-357) provided a detailed diagram of the proximal
development, as did Maletz (1997, p.39). The essential elements of the taxon, as described by
Maletz (1997, p.39), are a strongly asymmetrical proximal end with three apertural spines, no
antivirgellar spines, a pattern A astogeny, and a rapidly widening rhabdosome. Some of the
critical measurements provided by Maletz are: proximal width 0.6-0.8 mm (not including
spines) at th1; width at th5, 1.3-1.7 mm; ultimate width, approximately 2.0-2.5 mm; and,
11.5-13 thecae in the first 10 mm (which converts to a 2TRD of 1.74-1.54 mm).
The specimens studied herein showed broadly similar parameters, but as the proximal ends
are poorly preserved, the assignment to *teretiusculus* is uncertain. The proximal
width (without spines) is 0.67-0.88 mm at th1; width at th5, 1.2-1.43 mm; maximum width of
longest specimen, 1.88 mm; 2TRD within the first 10 mm 1.78-1.35 mm. The proximal
development of the Dauphin specimens, where discernible, agrees well with that shown by
Mitchell (1987, text-Figs 2 L, M).

Maletz (1997) reports that *H. teretiusculus* (Hisinger) first appears near the base of the
*Pterograptus elegans* Zone. Reports of the taxon are widespread, well up into the Caradoc. It
was noted by Maletz (1998, p.363) that specimens described as *H. teretiusculus* (Hisinger) by
Rushton et al. (1996, Fig. 2g-i) from the *N. gracilis* Zone (Caradoc) have an antivirgellar
spine, and, therefore, are not *H. teretiusculus*. However, Rushton (2001) noted that Maletz
(1997, Pl. 7F, G) had figured *H. teretiusculus* (Hisinger; from Norway) with antivirgellar
spines from the Llanvirn. These Maletz figures do appear to show a minor antivirgellar
process, possibly a rutellum (Mitchell, 1987 described lappets on the dorsal margin of the
*G. teretiusculus* from the *C. bicornis* Zone (Caradoc) that does not have an antivirgellar spine,
but the thecal density is very high (20 in 10 mm) compared to *H. teretiusculus* described by
Maletz (1997) and this study (11.5-13 in 10 mm). A comprehensive analysis of forms
occurring in the Llanvirn versus those in the Caradoc needs to be undertaken to confirm that
the taxon is consistent, does indeed have such a long range, and whether the form with an
antivirgellar spine is a separate taxon.
FAMILY DIPLOGRAPTIDAE Lapworth, 1873

Genus ARCHICLIMACOGRAPTUS Mitchell, 1987

TYPE SPECIES. *Pseudoclimacograptus angulatus sebyensis* Jaanusson, 1960

*Archiclimacograptus cf. A. riddellensis* (Harris, 1924); Fig 17; Synonymy in Maletz (1997)

**TYPE SPECIMEN:** Harris (1924) described *Climacograptus riddellensis* from “an outcrop at the junction of Riddell’s and Jackson’s Creeks in the Gisborne district”, Victoria, Australia (location also designated as Ba 67 on Pl. VIII, p. 105). Pl. VIII, Fig. II is given as the holotype, “pres. Nat. Mus. Coll. (K1)”, and Fig. 12 as a paratype, “pres. Nat Mus. Coll. (K2)”.

**MATERIAL.** *A. riddellensis* (Harris) is moderately abundant within the Dauphin Formation (Ganis et al. 2001). They also identified some material as *Archiclimacograptus* sp. However, the marginally preserved specimens figured herein are designated *A. cf. A. riddellensis*. Most material is flattened and occurs in fair to poor preservational states. Occasionally, specimens are preserved in relief, and one calcareous bed treated with 5 percent acetic acid yielded well defined cross-sectional preservation. Many specimens were juveniles.

**DISCUSSION.** A comprehensive description of *A. riddellensis* (Harris) is found in Maletz (1997), which considerably elaborates upon the original description of Harris (1924). The species, as described by Berry (1966), is broadly in agreement with the concept of Maletz (1997) except that Berry describes the median septum as straight (p. 44) whereas Maletz describes it as zigzag throughout the rhabdosome (p.57). Neither the holotype nor paratype figured by Harris (1924) on Pl. VIII, Figs 11 & 12, respectively, show a median septum, so they are no help in resolving the issue. An examination of these specimens (if available) regarding that feature should be undertaken. Berry’s conclusions, however, were made from an examination of 55 topotypes from the original Harris (1924) locality housed at the National Museum of Victoria whereas Maletz described material from Oslo. Text-Fig. 25, p.54 of Maletz (1997) illustrates many specimens identified as *A. riddellensis* (Harris) for which the median septum shows a zigzag pattern to a slight to moderate degree. In some examples it is nearly straight, especially in the distal part of the rhabdosome. It seems unlikely there are two species, differing only in the aspect of the median septum being straight or zigzag, in the same provincial biozone, that are mutually exclusive for selective localities. The median septa of the Dauphin Formation specimens seem to be slightly zigzag or straight, but the feature is often difficult to discern, for specimens in other than good preservation. This feature is therefore thought to show much intraspecific astogenic variability.
Figure 17. *Archielimacograpthus* cf. *A. riddellensis* (Harris, 1924); localities in brackets, x20 in box, 1 mm reference bar at 1a; all others x10, 1 mm reference bar at 2; 1a & 1b, NHM qq 135 [G-16b]; 2, NHM qq 134 [G-34]; 3, NHM qq 138 [G-6]; 4, NHM qq 131 [G-3]; 5, NHM qq 137 [G-6]; 6, NHM qq 133 [G-6].
Comparison of basic parameters of the Dauphin material with those described by Harris (1924) and Maletz (1997), are given in Table 3. There is general agreement among the various authors that the taxon widens rapidly in the first few thecae and then becomes relatively straight-sided and long. Other common features include a prominent virgella and a spine on the first two thecae with slightly asymmetric proximal development. The thecae are strongly geniculate and bear no further spines after th1. Maletz (1997, p.51) provides an excellent diagram comparing *A. riddellensis* to similar species and only *A. angulatus* (Bulman) seems close enough to cause identification problems. According to Maletz (1997), *A. angulatus* is more slender than *A. riddellensis* and the proximal end is strongly asymmetrical. Hughes (1989) suggested that *Climacograptus ? (= Archiclimacograptus) riddelensis* [sic] is probably a senior synonym of *Pseudoclimacograptus angulatus sebyensis*.

*A. riddellensis* is a common pandemic species within Darriwilian faunas. There is a general agreement that the taxon ranges through the Da 4, but its first appearance is debatable. Hughes (1989) describes it from units of the Builth inlier of Wales, correlated with the upper *murchisoni* and lower *teretiusiculus* biozones. The taxon is also described from Australia (Harris, 1924), Norway (Berry, 1964; Maletz, 1997), North America (Carter, 1989; Ganis et al. 2001) and Estonia and Sweden (Janusson 1960), all roughly at the mid to upper Darriwilian level.

**Genus HADDINGOGRAPTUS** Maletz, 1997

**TYPE SPECIES.** *Pseudoclimacograptus (Pseudoclimacograptus) oliveri* Bouček, 1973.

**Haddingograptus oliveri** (Bouček, 1973); Fig. 18; Synonymy in Maletz (1997)

**HOLOTYPE.** Designated by Bouček (1973) as specimen 2539, figured by Bulman (1953) as *Climacograptus scharenbergi*, Rigshospitat, Oslo, 4 aa; Pl. 1, Fig. 3 and text-Fig. 1A, p.510, which is from the Holm collection at the Rijksmuseum, Stockholm.

**MATERIAL.** The taxon is common, but few specimens are well preserved. A few excellent specimens in relief are present and one calcareous bed contained specimens which, when etched with 5 percent acetic acid, yielded clear internal longitudinal sections showing the septa (Figs 17 la & 1b, 2a & 2b). Unfortunately, the specimens are fractured and not suitable for full isolation.

**DISCUSSION.** *Haddingograptus oliveri* was thoroughly described by Maletz (1997) from the Oslo region, Norway and by Taylor (1997) from Newfoundland, Canada. Parameters given by these authors, and those from the type specimen, are compared with those from the Dauphin material in Table 4. The Dauphin specimens match fairly well with *H. oliveri* as
Figure 18. *Haddingograptus oliveri* (Bouček, 1973); localities in brackets, x15 in box, 1 mm reference bar at 1a; all others x10, 1 mm reference bar at 3; 1a & 1b, NHM qq 144 [G-34]; 2a & 2b, NHM qq 141 [G-34]; 3, NHM qq 142 [G-6]; 4, NHM qq 139 [G-34]; 5, NHM qq 164 [G-34]; 6, NHM qq 143 [G-17]; 7, NHM qq 140 [G-34]; 8, NHM qq 145 [G-31].
Table 3. Comparative Measurements for *A. riddellensis* (Harris).

<table>
<thead>
<tr>
<th></th>
<th>Proximal width</th>
<th>Distal width</th>
<th>thecae in 10 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harris (1924)</td>
<td>0.7</td>
<td>1.4-1.7</td>
<td>10-11, rarely 13</td>
</tr>
<tr>
<td>Maletz (1997)</td>
<td>0.75-0.8</td>
<td>1.5-1.6</td>
<td>14-17 (p), 11-14 (d)</td>
</tr>
<tr>
<td>This study; <em>A. cf. riddell.</em></td>
<td>0.67-.88</td>
<td>1.25-1.50</td>
<td>10.6-13.5, after the 1st 5 mm, or a 2TRD of 1.88-1.48 mm</td>
</tr>
</tbody>
</table>

(d) distal  
(p) proximal

Table 4. Comparative Measurements of *Haddingograptus oliveri* (Bouček).

<table>
<thead>
<tr>
<th></th>
<th>Proximal width</th>
<th>distal width</th>
<th>2TRD th 2-4</th>
<th>thecal density (calculated for number in 10 mm)</th>
<th>length of prothecal septa</th>
</tr>
</thead>
<tbody>
<tr>
<td>type specimen</td>
<td>0.79</td>
<td>&gt;1.2?</td>
<td>N</td>
<td>N</td>
<td>0.18 - 0.22*3</td>
</tr>
<tr>
<td>Taylor (1997)</td>
<td>0.65 - 0.85</td>
<td>0.9 - 1.35</td>
<td>0.85 - 1.2</td>
<td>18 - 23</td>
<td>0.15 - 0.20*4</td>
</tr>
<tr>
<td>Maletz (1997)</td>
<td>0.6 - 0.9</td>
<td>1.1 - 1.8</td>
<td>0.75 - 1.1*1</td>
<td>15 - 20 (p)*2 14-16 (d) *2</td>
<td>0.15 - 0.30</td>
</tr>
<tr>
<td>this study</td>
<td>0.5 - 1.0</td>
<td>0.95 - 1.43</td>
<td>0.88 - 1.30</td>
<td>12 - 18</td>
<td>0.13 - 0.32</td>
</tr>
</tbody>
</table>

*1 measured from Maletz's text Fig. 30, p.65  
*2 Maletz gave 7.5 - 10 in first 5 mm; 7 - 8 distally in 5 mm.  
*3 measured from type figure  
*4 measured from Taylor's Fig. 20, p.141  
N = Not recorded or possible to measure from Figs  
all measurements in millimetres  
(d) = distal  
(p) = proximal
described, the Dauphin material also showing a full-length zigzag median septum; a virgellar spine; strongly geniculate and sigmoidal thecae, with th1 and 1 strongly u-shaped and reaching down to the base of the sicular aperture. These characteristics are typical of the taxon. Mitchell (1987) stated that *H. oliveri* has a type c proximal development.

The biostratigraphic range of *H. oliveri* is uncertain because of its potential conflation with similar pseudoclimacograptids such as *P. scharenbergi* as discussed by Maletz (1997). It is a common form in the zones of *Nicholsonograptus fasciculatus* and *Pterograptus elegans* in Norway (Maletz, 1997) and at a similar biostratigraphic level in Newfoundland (Taylor, 1997) from the Black Cove and Table Cove formations.

**FAMILY MONOGRAPTIDAE** Lapworth, 1873
(emended Mitchell, 1987)

Genus *NORMALOGRAPTUS* Legrand, 1987
(emended Melchin & Mitchell, 1991)

(Objective synonym: *Scalarigraptus* Riva, 1988)

**TYPE SPECIES.** *Climacograptus scalaris normalis* Lapworth, 1877

*Normalograptus antiquus* (Ge, 1990 in Ge, Zheng & Li); Fig. 19
1990 *Orthograptus antiquus* n. sp. Ge, Zheng & Li; p.127, pl. 44, Figs 3,4; 11,13 [not seen; *fide* Maletz 1997].
1997 *Normalograptus antiquus* (Ge in Ge, Zheng & Li); Maletz, p. 72-73, Text-Fig 35 A-H, Pl. 6, Figs A,C-E; Pl.7, Figs A, B.

**MATERIAL.** A single fairly well preserved flattened specimen from the Dauphin Formation (Winsor Township Formation of Lash, 1987).

**DISCUSSION.** The single specimen is preserved in obverse aspect and conforms to the comprehensive description provided by Maletz (1995). The rhabdosome is quite distinctive having a *Normalograptus* proximal development (pattern H astogeny of Mitchell, 1987), and glyptograptid-like succeeding thecae. The exposed part of the sicula is about 0.6 mm long with a 0.24 mm wide aperture, and a virgella 0.6 mm in length. The virgella is the only spine.

The width across the initial thecae at the apertures is 0.5 mm, and the rhabdosome gradually widens concurrent with increasing thecal size; the width at th6 is 1.08 mm. The specimen has 7 thecae in the first 5 mm, which is slightly higher than the 6 in 5 mm reported by Maletz (1995). The specimen has a median septum originating in the th2 level, which extends the length of the rhabdosome.
*Normalograptus antiquus* was initially reported (Ge, *et al.*, 1990) from Ningxia, China in the *Pterograptus elegans* Zone. The occurrence reported here is the first for North America. *N. antiquus* (Ge) is unrelated to *Climacograptus antiquus* Lapworth.
Figure 19. *Normalograptus antiquus* (Ge, 1990); locality in brackets, x20, 1 mm reference bar; 1a & 1b, NHM qq 126 [G-49].
CHAPTER 2. TIMING OF ALLOCHTHON EMPLACEMENTS AND BASIN INFILLING FOR THE MARTINSBURG/HAMBURG FORELAND SEGMENT.

INTRODUCTION

This paper addresses the infilling of the Martinsburg foreland basin in the Appalachian area of central Pennsylvania, USA (Fig. 1), where it contains embedded allochthons of Taconian (Mid-to-Late Ordovician) orogenic affinity. The timing and order of allochthon emplacements and autochthonous basin infilling have been dated primarily with graptolites and some conodonts. This belt of rock lies within the northern portion of the Great Valley Section of the Ridge and Valley Physiographic Province. The relationship of this area to the wholly autochthonous Martinsburg Formation to the southwest and northeast is also reviewed.

The Martinsburg foreland basin formed in the early Caradoc (early Late Ordovician) in response to tectonic loading from island arc and microcontinent obduction upon the southeastern (present orientation) Laurentian margin (summary in Faill, 1997). The Taconic allochthons of Pennsylvania most likely originated from sediment deposited in the Octoraro sea lying between Laurentia and the off-shore Baltimore-Brandywine microcontinent (Faill, 1997; Ganis et al., 2001); other Taconic allochthons in North America have a Laurentian slope origin (Stanley and Ratcliffe, 1985). Comparison of this Ordovician terrain to modern and geologically young foreland basin systems involving allochthon emplacement helps clarify some long-standing, and disputed, structural/stratigraphic relationships. This analysis provides evidence in favour of the suggestion by Ganis et al. (2001) that the allochthon-bearing area of the Martinsburg foreland basin developed earlier than adjacent areas of the basin.

Rocks of the Great Valley clastics outcrop, roughly between the Susquehanna and Lehigh Rivers, were characterized as the “Hamburg klippe” by Stose (1946; see Fig. 1 herein), and compared to the classic Taconic allochthons of New York and Vermont. That part of the Great Valley contains fossils older than the Martinsburg Formation proper, and bodies of rock uncharacteristic of typical Martinsburg flysch such as red and green shale and chert, deep-water limestones and black shale, and pillow basalts and diabase dykes. The klippe interpretation requires an overthrust upon the Martinsburg Formation and was supported by some workers (e.g., Epstein et al., 1972; Wright and Stephens, 1978; Wood and Maclachlan, 1978; Wright et al., 1979; Lash & Drake, 1984; and, Horton et al., 1989, who called it the Hamburg Terrane). The alternative interpretation of allochthonous elements within the Martinsburg Formation can be found in MacLachlan (1967), Carswell
Figure 1. Geologic Setting of Martinsburg/Hamburg Foreland Segment (Hamburg klippe of Stose, 1946), modified after Faill (1997), Ganis et al. (2001); location of Hershey/Myerstown Formation after O’Neill (1964), and Meisler and Beecher (1971); location of Yellow Breeches Thrust after Gray and Root (1979).

Legend

- YBT - Yellow Breeches Thrust
- H/MY - Hershey/Myerstown Formation
- C - Carlisle
- HG - Harrisburg Gap
- SG - Swatara Gap
- SR - Shochary Ridge
- LG - Lehigh Gap

Shading indicates thrust-faulted boundary.
et al. (1968), Platt et al. (1972), Root (1977), Root and MacLachlan, (1978), MacLachlan (1979), Stephens et al. (1982), Faill (1995), and Ganis et al. (2001).

The use of the term “klippe” by Stose (1946), in the sense of a remnant, erosionally isolated, overthrust was expanded by some of these workers to include gravity-emplaced allochthons within the foreland basin that co-mingled with autochthonous Martinsburg. In this regard, the term “Hamburg klippe” has sometimes been used as a terrane definition, where “klippe” departs from the classical definition (a practice I consider misleading). In this paper that area will be called the Martinsburg/Hamburg Foreland Segment (M/HFS). The strata in the western half of this area were investigated in some detail with respect to their graptolite fauna, and the relationship between the autochthonous Martinsburg Formation and the allochthonous Hamburg succession (Dauphin Formation of Ganis et al., 2001) is discussed. Fig. 2 summarizes the results of this study and proposes a correlation of the units within and bordering the M/HFS.

It is well documented that parts of the M/HFS contain graptolites and conodonts much older than the Martinsburg Formation (Willard, 1943; Stose, 1946; Carswell et al., 1968; Platt et al., 1972; Raring and Ganis, 1973; Wright & Stephens, 1978; Epstein et al., 1972; Repetski, 1984a, 1984b; Lash et al., 1984; Lash & Drake, 1984; and, Ganis et al., 2001). However, the relationship of the older rocks to the younger Martinsburg Formation has long been a controversial topic. After Stose (1946) proposed that the “Hamburg klippe” was structurally emplaced over the Martinsburg Formation, a debate over its validity soon ensued (see, for example, the discussions in Gray and Willard, 1955 and Platt et al., 1972).

The graptolite evidence for an older klippe thrust over the Martinsburg Formation given by Stose (1946) consisted of two data sets. Very restricted strata from Susquehanna Gap at Harrisburg, PA, near the western edge of the proposed klippe, have graptolites unequivocally older than the Martinsburg Formation (described by Willard, 1943) of “Deepkill” (effectively Arenig) age. Other strata, from a number of places throughout the M/HFS, have N. gracilis (sensu Elles & Wood, 1913), or possibly C. bicornis Zone age faunas, referred to as “Normanskill” age, that are only slightly older than Martinsburg, as the age was understood at the time. Indeed, it was recognized that some of the graptolite faunas from the latter data set ranged into early Martinsburg age (Gray and Willard, 1955). Biostratigraphic proof that the older rocks were embedded allochthons within the Martinsburg Formation, rather than an overthrusted klippe, required finding undoubted Martinsburg age fossils as a matrix around them. In 2001, Ganis et al. reported finding Martinsburg age graptolites in such a context within the M/HFS surrounding allochthon masses containing older graptolites.
<table>
<thead>
<tr>
<th>System</th>
<th>Series/Stage</th>
<th>E. N. A.</th>
<th>Carlisle</th>
<th>Western M/HFS</th>
<th>Eastern M/HFS</th>
<th>Lehigh Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>CINCINNATIAN</td>
<td>EDENIAN</td>
<td>C. loricata</td>
<td>G. SF</td>
<td>Upper Sandstone G</td>
<td>Unit 4 SF</td>
<td></td>
</tr>
<tr>
<td>C. linearis</td>
<td>Upper Shale G</td>
<td>Unit 3 SF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. PENNSYLVANIAN</td>
<td>TRENTONIAN</td>
<td>C. parviparti</td>
<td>Lower Sandstone G</td>
<td>Unit 2 G SF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. bicornis</td>
<td>Lower Shale G</td>
<td>Unit 1 G</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. H. F. S.</td>
<td>not differentiated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: G - graptolites; C - conodonts; © - conodonts, permissive age; SF - shelly fauna; ♂ - Taconic thrust

Figure 2. Martinsburg foreland basin correlation.

*1 Unit H-1 deposited in E. to M. Ord.; thrusted into position shown
*2 Unit M-1 deposited in N. gracilis (sensu Riva) time as a wedge-top basin; thrusted into position shown atop Unit H-1
*3 Unit H-2 deposited in M. Ord. (Da 4a) time, thrusted into position shown
Ganis et al. (2001) described Martinsburg age graptolites as part of an early Caradoc fauna (Late Ordovician) in strata both younger and older than the age of the base of the regional Martinsburg bordering the M/HFS. They did not subdivide this Caradoc section, but did recognize a final *Climacograptus spiniferus* age cover above the allochthons(s), which comprises the Swatara Gap beds immediately below the Silurian unconformity. The map and description provided by Ganis et al. (2001; fig 3) showed undivided belts of Martinsburg Formation interleaved or interstatified with older allochthonous bodies. The Caradoc graptolite beds interspersed with the allochthon slices, below the final *C. spiniferus* Zone fill, were specified as *Climacograptus bicornis* to *Corynoides americanus* (= *Dicranograptus clingani*) Zone in age. The structural relationship between these belts, whether repeated by faulting or infolding, was left open for future study.

This paper shows that the Caradoc strata in the Martinsburg foreland basin can be subdivided concurrent with Taconian allochthon emplacements. An early foreland turbiditic flysch unit of *Nemagracilis gracilis* Zone (or possibly early *Climacograptus bicornis* Zone) age was deposited in a piggyback basin above allochthonous rock; this was followed by further allochthon emplacement, and then deposition of late *C. bicornis* through *C. spiniferus* Zone age strata. Figure 2 is the stratigraphy of the western portion of the M/HFS suggesting a correlation with the Martinsburg foreland units to the southwest and northeast.

The area studied in detail is roughly the western half of the M/HFS where the lithostratigraphy and biostratigraphy were investigated. Applying the stratigraphic scheme developed for the western part of the terrain to the eastern part remains to be comprehensively evaluated, but preliminary reconnaissance and literature review reveals similar units of equivalent age and characteristics. This study demonstrated that close biostratigraphic control was needed to be certain of a lithostratigraphic unit’s age. For example, there are parts of four turbiditic flysch units in different graptolite zones, both allochthonous and autochthonous, that are practically indistinguishable in the field. This situation made it difficult to project turbiditic units over any significant distance lacking exposure and/or fossils. It also complicates the correlation of turbiditic units from the western part of the terrain, where biostratigraphic control is moderately good, with similar units described by others in the eastern part, where such control is scant.

Post-foreland deposition faulting, shearing and cleavage formation, and folding has created a complicated structural overprint upon the geology. A large- scale overturned antiform is proposed as a prominent structure in the central part of the western portion of the M/HFS.
**BIOSTRATIGRAPHIC CONSIDERATIONS**

A persistent problem in separating allochthonous from autochthonous rock within the M/HFS has long existed. This study clarifies this problem through recognition of a biostratigraphic gap between the two successions, and determining that the early units deposited in the foreland where allochthons are present are older than the base of the Martinsburg occurring elsewhere. The following section discusses this biostratigraphic gap and the need to assess its duration from graptolite successions occurring outside North America.

**Biostratigraphic gap below *Nemagraptus gracilis*-bearing rocks; for discussion below and graptolite zonation in the Llanvirn (Darriwilian) and Caradoc see figure 3.**

The widely distributed allochthonous strata of Late Darriwilian (Da) 3 to early Da 4a age (Ganis *et al.*, 2001) within the M/HFS are separated from the *N. gracilis*-bearing strata by about two graptolite zones. Using the the zonation of Maletz (1995, 1997) that interval includes the late *Pterograptus elegans*, *Pseudamplexograptus distichus*, (restricted to the peri- Gondwana region and Scandinavia; Maletz, 1995) and *Hustedograptus teretiusculus* zones. Some workers equate the *Hustedograptus teretiusculus* (= Da 4b; formerly *Glyptograptus* cf. *G. teretiusculus*) Zone, which is basically the Llandeilian interval of Britian, with both the Da 4a and 4b intervals (eg. Cooper, 1979; Cooper & Lindholm, 1990; Vandenberg and Cooper, 1992; Cooper, 1999; Fortey, *et al.*, 2000, Fig. 34). However, the *H. teretiusculus* Zone (= Da 4b only) is characterized by the first appearance of small dicellograptids and dicranograptids and early nemagraptids lacking lateral branches (Finney & Bergstrom, 1986), prior to the first appearance of *N. gracilis*. Maletz (1995) correlates the *P. elegans* Zone (Da 4a) of Scania, Sweden with the upper part of the Aberediddian below the Llandeilian.

Although the *H. teretiusculus* Zone interval is well established in many areas of the world (Cooper, 1979, Finney & Bergström, 1986), its definition in North America is less well documented. Carter and Churkin (1977) had a very sparse fauna through that interval in Idaho and referred it to the *Glossograptus hincksii* Zone. Cooper (1979, p.46-47) commented that Berry’s (1960) work in the Marathon, Texas area failed to discriminate the first appearance of *Dicellograptus* and *Dicranograptus* from the first appearance of *N. gracilis*, and that they may well occur in the same order as they do in Australia and New Zealand. Berry (1960) identified the *G. cf. G. teretiusculus* Zone as his Zone 10 and commented (p.8), “[the zone] is characterized by the widespread development of *G. cf. G. teretiusculus* and *Amplexograptus confertus*. *Phyllograptus* makes its last appearance here”. He further stated that multiramous
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Caradoc</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Nemagraptus gracilis</td>
<td>Gi 1</td>
<td>N. gracilis</td>
<td>N. gracilis</td>
</tr>
<tr>
<td>Llanvirn</td>
<td>Hustedograptus teretiusculus</td>
<td>Da 4b</td>
<td>*</td>
<td>H. teretiusculus</td>
</tr>
<tr>
<td></td>
<td>Pseudimplexograptus distichus</td>
<td>Da 4a</td>
<td>No fauna known</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pterograptus elegans</td>
<td>Da 4a</td>
<td>P. elegans</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nicholsonograptus fasciculatus</td>
<td>Da 3</td>
<td>N. fasciculatus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Holmograptus lentus</td>
<td></td>
<td>H. lentus</td>
<td></td>
</tr>
<tr>
<td>Arenig</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Correlation to Australasian graptolite zones from Maletz, 1997.

**Figure 3. Correlation of Llanvirn and Caradoc Graptolite Zones.**
dichograptids and tetragraptids make their last appearance in the previous Zone 9. Bergström (1978) reexamined the Marathon section and described the Woods Hollow Shale through the G. cf. G. teretiusculus interval stating, "The graptolite fauna of Zone 10 is improverished... [and] early forms of Dicellograptus and Nemagraptus, as well as other characteristic forms present in the G. teretiusculus Zone in Scandinavia, have not been found...".

Finney and Bergström (1986) identified an interval below the first appearance of N. gracilis (thus, below the N. gracilis Zone) at Calera, Alabama, with Dicellograptus, Dicranograptus, and Azygograptus, which is in the H. teretiusculus Zone. They also state (p.56) that the upper range of Pterograptus is below the first appearance of Dicellograptus and Dicranograptus in the Victorian succession. That defines a graptolite interval later than Pterograptus and most dichograptids, and pre- N. gracilis, which includes the H. teretiusculus Zone. Therefore, the total Da 4 interval, which contains Pterograptus and other dichograptids in the Da 4a Subzone, is not equivalent to just the H. teretiusculus Zone as commonly used in Europe and North America. This was recognized by Maletz (1995, 1997) who places the H. teretiusculus Zone (=Da 4b) above Da 4a in Norway and Sweden. Berry (1964; also Norway) defined the H. teretiusculus Zone by the first appearance of dicellograptids and dicranograptids without dichograptids except for Janograptus. However, in North America, there is no adequate continuous succession sufficient to resolve the zonation between the last appearance of P. elegans, and most dichograptids, and the first appearance of N. gracilis. Maletz and Mitchell (1995; see Fig. 3) show a poorly constrained gap between the P. elegans and upper H. teretiusculus zones in North America.

In the M/HFS none of the strata containing P. elegans, with other dichograptids, have Dicellograptus or Dicranograptus. Furthermore, the Darriwilian interval there was established as late Da3 to early Da 4a. The missing interval in the M/HFS can be estimated as probably the upper part of Da 4a, all of Da 4b (= H. teretiusculus Zone), and probably the lower part of the N. gracilis Zone. However, it is not firmly established how far into the N. gracilis Zone the missing interval extends, and it is possible that it reaches to low in the C. bicornis Zone.

Therefore, there is a gap of approximately two graptolite zones between the unquestionably allochthonous Darriwilian strata and the N. gracilis-bearing strata. It appears clear that the Darriwilian age and older strata of the allochthon are not in unbroken depositional continuity with N. gracilis-bearing and younger age strata. Had the allochthonous Hamburg rocks been mobilized as an allochthon after N. gracilis Zone time there should be a continuity of deposition connecting that age strata with the Darriwilian strata. The missing time between the two sequences suggests a hiatus related to the Hamburg rocks becoming
assembled as an allochthon prior to the appearance of *N. gracilis*. That also suggests the *N.gracilis*-bearing strata were deposited in a developing foreland setting and the time gap represents the interval of allochthon transport.

*Nemagraptus gracilis (sensu Riva, 1969, 1974) Zone rocks: autochthonous or not?*

Here I argue that the *N. gracilis* Zone (*sensu* Riva, 1968, 1974; henceforth referred as just ‘*sensu* Riva’) strata in the M/HFS are not allochthonous in the sense that pre-*N. gracilis* rocks are. The basal Martinsburg Formation southwest of the M/HFS, beyond where the Hamburg allochthons are embedded in the foreland basin, was reported by Stephens and Wright (1981) as of *Diplograptus multidens* Zone age (Riva, 1968, 1974; = *C. bicornis* Zone of Berry, 1960 or Williams, 1995). Northeast of the M/HFS the basal Martinsburg Formation is reported as very uppermost *C. bicornis* Zone by Epstein and Berry (1973). There are strata (Unit M-2 described below) in the M/HFS that are partly as young as those adjacent basal Martinsburg successions, but extend downward to lower stratigraphic levels within the *C. bicornis* Zone. This is part of the evidence that the foreland developed earlier where the allochthons entered the basin. A mid-*N. gracilis* to early *C. bicornis* (= Chazyan to Blackriveran) Zone age of pre-M Martinsburg transitional platform rocks below the allochthons (discussed more fully below), as compared to a *D. multidens* age for similar transition rocks outside the area of allochthon emplacement, further supports this hypothesis.

The discovery of widely distributed clastic rocks of pre-*N. gracilis* Llanvirn age (late Da 3 = *N. fasciculatus* Zone to early Da 4a = lower *P. elegans* Subzone; work-in-progress) within the M/HFS (Ganis et al., 2001), that are unambiguously allochthonous, and which contain even older Arenig, Tremadoc, and Late Cambrian olistoliths, is cause for reevaluation of the allochthonous status previously given to *N. gracilis* Zone (*sensu* Riva) age strata by Stose (1946) and subsequent workers. The interval separating the lower *P. elegans* Subzone strata from the *N. gracilis*-bearing strata is missing in the M/HFS, as discussed above, indicating a structural event activating the former as an allochthon into a developing foreland basin containing the latter.

Prior to Ganis *et al.* (2001, see p.110-111 for review) the clastic portion of the allochthons was widely reported as of *N. gracilis* Zone age. Complicating the analysis of the status of *N. gracilis* Zone age rocks is the differing opinion of the length of that zone. Specifically, the *N. gracilis* Zone of Riva (1969, 1974) includes a longer time span than the same zone of Berry (1960) or Williams (1995). The range of the *N. gracilis* Zone of Riva is essentially the range of that taxon which is followed by his *D. multidens* Zone. Many biostratigraphers (e.g., Berry, 1960; Finney, 1986; Williams, 1995) have concluded that *C.
bicornis first appears in the mid-part of Riva’s N. gracilis Zone, defining a C. bicornis Zone above a N. gracilis Zone, which extends up to include the equivalent interval of Riva’s D. multidens Zone. (the continued use of N. gracilis Zone in the text following will be in that limited sense, unless indicated otherwise). There are only a few taxa that define the lower parts of either the N. gracilis or C. bicornis zones, and many taxa range through both zones or have disputed ranges. This often makes it difficult to determine the stratigraphic position of limited faunas in either of these zones.

N. gracilis age rock previously assumed to be strictly allochthonous is more likely related to synorogenic deposition within the developing Martinsburg foreland. Allochthonous rock derived from a distant non-Laurentian source adjacent to Baltimoria (an informal name for the Baltimore- Brandywine microcontinent of Thomas, 1977; Lash and Drake, 1984; and, Faill, 1997) is older than the N. gracilis Zone and can be distinctly defined biostratigraphically. Turbiditic rocks of probable N. gracilis Zone (sensu Riva) age (Unit M-1 described below, containing N. gracilis and associated Dicellograptus fauna, but apparently lacking C. bicornis) are found below autochthonous Unit M-2 (also described below), but are separated from it by an allochthonous unit occurring in between. Thus the question arises whether these N. gracilis Zone (sensu Riva) age strata are also allochthonous? Modern analysis of geologically young foreland basins, discussed below, provides an analog to the Martinsburg foreland basin infilling involving allochthon emplacements. Those models, discussed below, show synorogenic wedge-top or piggyback basins formed on top of an incoming allochthon, which is proposed as the origin of the N. gracilis Zone age strata in the M/HFS.

It is not strictly defensible to say that N. gracilis Zone (sensu Riva) age rocks within the M/HFS are too old to be Martinsburg proper because the base of the Martinsburg strata is younger bordering that area. Where the top of pre- Martinsburg strata are permissive for a N. gracilis Zone age, such as below the M/HFS in the Hersey/Myerstown Formation (Fig. 2), the earliest foreland basin units above could be roughly the same age, albeit slightly younger, especially in the context of synorogenic deposition.

Province of graptolites and conodonts in allochthonous rock

The allochthonous masses of Hamburg succession rock embedded in the Martinsburg Formation have been dated with graptolites and conodonts (see Ganis et al., 2001 for summary). Bergström, Epstein and Epstein (1972) discovered that conodonts from these rocks represent the Baltoscandic realm associated with deep, cool water conditions. Repetski and Ganis (2001) reviewed the Baltoscandian conodont zones present in these rocks and
commented on the absence of conodonts from the North American Midcontinent realm. Even in the deep basinal setting it is common to find a trace representation of shallow platform elements resulting from “overwash”. If the Hamburg succession had been deposited adjacent to the Laurentian margin, finding an occasional platform-derived Midcontinent conodont element would be expected. From this it can be inferred that the original site of deposition for the Hamburg succession was likely removed from the Midcontinent province. Epstein et al. (1972) discussed this situation and concluded that, “the faunal barrier was a water body of considerable size, perhaps oceanic in magnitude”. This supports (but does not prove) the idea that the Hamburg succession was deposited on the flank of Baltimoria removed from Laurentia.

There are numerous examples of carbonate and non-carbonate rocks containing only cold-water conodont faunas without accidental Laurentian overwash. However, there is one example where carbonate conglomerate cobbles have been found in the Martinsburg shale (Unit M-2 discussed below) that yielded not only Lower Ordovician Laurentian (Midcontinent) conodonts (J. Repetski, personal communication, 2001), but Laurentian (?) trilobites (J. Taylor, personal communication, 2001), all within a shelf derived lithology. This is the only reported occurrence of this kind in the H/MFS. The origin of these carbonate cobbles may be from the erosion of upscraped Laurentian shelf-debris, caught up and carried forward in the thrusting of the Hamburg succession onto the platform.

HAMBURG ALLOCHTHONS DERIVED FROM THE WESTMINSTER TERRANE

The text discussion will be easier to follow from this point if the reader refers to Figure 4 (in pocket). The argument favouring an earlier formed foreland basin where the Martinsburg Formation contains allochthons also suggests a forward advance along the Taconic front at that paleoposition (see panel F’ on Figure 4; in pocket). The Taconic orogeny was a diachronous event over the extent of the orogen (Rodgers, 1970) and the earlier formed M/HFS is merely a regional detail. If the Hamburg allochthons are detachments from the Westminster Terrane, as advocated by Faill (1995), then that terrane would have been the master allochthon first obducted upon the Laurentian margin. The origin of the Westminster Terrane (originally named by Rodgers, 1970) is attributed to sediment deposited in the Octoraro Sea between Laurentia and Baltimoria by Faill (1997). Its position is largely coincident with the Hamburg allochthons, only further outboard in the Piedmont (see Horton et al., 1989, fig. 1 inset, p.217; also Fig. 1 herein).
Although Ganis et al. (2001, p. 126), and Horton et al. (1989, p. 220) argued that the Hamburg allochthons do not match the rocks of the Westminster Terrane, it should be pointed out that the oldest Hamburg strata found, thus far, are Late Cambrian in age (Lash and Drake, Jr., 1984; Ganis et al., 2001). If the rocks preserved in the Westminster terrane are older than Late Cambrian, then the Hamburg allochthons could have detached from above that level to become embedded in the foreland basin (the writer wishes to acknowledge discussions with Rodger Faill concerning this hypothesis). A complication of this proposal is the Late Cambrian through Early Ordovician strata in the M/HFS occurring as olistoliths in a Middle Ordovician matrix (Ganis et al., 2001) rather than as a discrete package below younger strata. However, the tectonic process by which the olistostrome formed, and the incompleteness of the event to the exclusion of rocks older than Late Cambrian, is poorly understood.

The Westminster Terrane consists of sediment deposited in the Octoraro Sea from both a Laurentian and a Baltimorian provenance; however, the Hamburg rocks may have originated only from the Baltimorian direction (see Ganis et al. 2001). The Hamburg rocks from the Baltimorian side also may have been first imbricated over the Laurentian-source rocks during the closure of the Octoraro Sea. Muller et al. (1989; Fig. 10B, p. 130), illustrated such a history for the Westminster Terrane, although they identified “Baltimoria” not as a microcontinent but, rather, as, “[a] distended edge of [the Laurentian] continent”, and referred to it as the Towson Terrane. Later, if only part of the elevated Hamburg rocks became allochthonous into the Martinsburg foreland basin (as a direct result of the Martic thrust according to Faill, 1997), then the remaining pile of Westminster rocks would consist of all the Laurentian side, and possibly, the Hamburg strata below the level of the Late Cambrian. Because the Westminster terrane has not yielded fossils, the credibility of this hypothesis has not been tested. The large scale structural movements during the Taconian and Alleghanian orogenies involving the Westminster Terrane, and consequent metamorphism, further complicate the assessment of this hypothesis.

In fairness, it should be pointed out that the Baltimore-Brandywine massifs and the Glenarm Series cover rocks are not universally accepted as a former microcontinent(s). Thus, the depositional site of the Westminster terrane as partly non-Laurentian, derived from “Baltimoria”, is challenged by some. Evidence favouring the microcontinent scenario is summarized in Horton et al. (1989, p. 220-221) and Faill (1997). The evidence relates to the lithic differences between the Baltimore-Brandywine terranes and Laurentian basement, as well as the absence of dykes of Blue Ridge affinity in the former that are present in the latter. Evidence against the microcontinent senario (see also Horton et al., p. 220) relates to a proposed correlation between the Loch Raven schist of the Glenarm and the Manhattan schist.
Unit A (Laurentian basement cover). However, Horton et al. (1989, p. 220) rejected this correlation on lithologic grounds.

The part of the Martinsburg foreland basin that was infilled with early emplaced allochthons and piggyback units, and then covered with mid to late C. bicornis and younger flysch, resulted in a thicker accumulation of strata compared to the foreland basin not affected by allochthon emplacements. This additional thickness of sediment appears to manifest itself as a wider outcrop pattern in the M/HFS (even though the southern boundary is overthrusted), which is apparent on the Pennsylvania state geologic map (Berg, et al., 1980).

STRATIGRAPHY

The M/HFS contains autochthonous strata of the Martinsburg Formation and embedded Taconic allochthons on many scales. Ganis et al. (2001) named the Dauphin Formation, with three members, as the collective unit for all allochthonous components at a mappable scale (excepting boulder-sized masses). The stratigraphy discussed below consolidates the large Dauphin Formation rock masses, and the recognizable levels of the Martinsburg Formation, into a unified 'stratigraphic' order of allochthonous levels, designated with the prefix “H” (for Hamburg) and “M” (for Martinsburg). The “H” units are not traditional stratigraphic intervals, but assume the position of an interval, and displace sediment after emplacement. As the allochthonous masses occur at many scales, only the very largest of the allochthons are recognizable as a “Unit”. Neither the “H” or “M” units are formal stratigraphic designations. The stratigraphy discussed below is shown on Figure 2.

Transitional foreland units, Unit H-1 (= Cocalico ?), and Unit M-1

The stable Cambro-Ordovician carbonate platform of southern Laurentia subsided under tectonic loading from island arc and microcontinent obduction during the late Mid-to early Late Ordovician Taconic event (see summary discussion in Faill, 1997). The platform carbonate deposition was replaced by ever increasing clastic input as a foreland basin was created. This is the classic signature of foreland basin subsidence that is discussed in Ettensohn (1991, p.216); and the use of the term “foreland basin” conforms to the description therein. The transitional foreland sediment, above the subsiding platform sequence associated with the M/HFS, is the Hershey/Myerstown Formation (Prouty, 1959), consisting mostly of black argillaceous impure carbonate, and carbonate conglomerates within the Hershey Formation portion. The distribution of the Hershey/Myerstown Formation is entirely coincident with the Taconic Hamburg rocks. These impure carbonates were deposited on the inner foreland ramp. The earliest allochthon(s) of the Hamburg succession, emplaced within
the newly forming foreland basin, would have been thrusted (or slid by gravity) above the 
Hershey/Myerstown strata (fig. 4, panel C; in pocket).

Along the southern fringe of the M/HFS in Dauphin and western Lebanon Counties, 
the Hershey/Myerstown Formation with “Martinsburg shale” lies within the overturned limb 
of the Lebanon Valley nappe. The nappe moved northward on the Yellow Breeches thrust 
(MacLachlan, 1967; Root and MacLachlan, 1978) over the M/HFS (see Figs 5 and 6). The 
inclusion of the “Martinsburg Shale” within the Lebanon Valley nappe as the lowest structural 
unit (highest stratigraphically) was proposed by MacLachlan (1967). Further east, the entire 
southern boundary of the M/HFS has been overridden by a series of crystalline-cored nappes 
(well figured in Gray and Root, 1999, p. 259, Fig. 18-2) resulting in a very complicated thrust 
array. I have not evaluated the extent to which “Martinsburg” (or Hamburg) clastics have 
been incorporated into these nappes; however, Gray and Root (1999) show slivers of 
“Martinsburg” rock within the thrusted blocks. The generality of the entire southern boundary 
of the M/HFS being overthrust is shown by Horton et al. (1989, Fig. 1 inset, p.217), and 
was called the Yellow Breeches thrust.

The transitional units below the M/HFS are not exposed north of the Yellow Breeches 
thrust and are inferred to be the Hershey/Myerstown Formation. North of the Yellow 
Breeches thrust the rocks are in normal stratigraphic position (see cross section A-A’, Fig. 6). 
Although the basal unit (stratigraphic top) below the Hershey/Myerstown, above the sole of 
the Yellow Breeches thrust, was called the Martinsburg Formation (e.g. MacLachlan, 1967), 
the writer believes these rocks are the earliest allochthonously emplaced unit. These clastic 
units, some of which are tan and pink phyllitic shales, bear little resemblance to 
autochthonous Martinsburg. Furthermore, these phyllitic strata appear similar to the rocks of 
the Cocalico segment (see Fig. 1), an area that is most likely a detached portion of the 
Hamburg succession, which lies south of the M/HFS.

Brecciated organic fragments recovered from the Annville and Myerstown formations 
(platform units below the Hershey/Myerstown Formation), within the transported overturned 
nappe limb, in Lebanon County by Hower, et al. (1999) indicate a greenschist metamorphic 
grade. The rocks of the M/HFS north of the nappe sole are of diagenetic to low anchizone 
grade (J. Hower, personal communication, 2002). MacLachlan (1967, p.75) concluded that 
the Yellow Breeches thrust is a post-Taconian structure since it truncates Taconian rocks.
Figure 5. Partial Map of Chronological Units, Western Martinsburg/Hamburg Foreland Segment.

Index to graptolite locations:
Localities 1-6, 7, 10-30 from Ganis et al. 2001; therein described with a “G” prefix.
Localities 1-4, 6, 9, 13-17, 19-21, 24, 27, 31, 34, 40, 43, 49; Ganis, work-in-progress; therein described with a “G” prefix; some overlap with Ganis et al. 2001.
Localities 10-12, 26, 28, 36, 38, 39, 41, 42, 44-48; described herein with a “G” prefix; some overlap with Ganis et al. 2001.
Locality 35, no published record; Arenig age

* See figure 2 for unit identification.
Figure 6. Cross Sections Corresponding to Figure 5.
There is no detailed stratigraphic assessment of the Cocalico Terrane, but preliminary comparison by Stose (1946) to some of the rocks in his "Hamburg klippe" (= M/HFS herein) is probably correct. Root and Maclachlan (1978, p.1516) also inferred that the Cocalico "includes rocks of Taconic affinity". It is probable that rocks of Martinsburg age and affinity are intermingled within the Cocalico Terrane. Provisional graptolite ages reported by Stose (1946) for the Cocalico as well as a conodont age reported by Repetski and Ganis (2001) confirm that at least part of the Cocalico is of Ordovician age. The main outcrop of the Cocalico Formation in Lancaster County has been mapped stratigraphically above the Myerstown Formation (Meisler & Becher, 1971). I agree with MacLachlan (1967, p.63) that the Hershey Formation, as distinguished from the Myerstown, may be a facies variation, which limits the former to areas in Dauphin County (to which can be added Lebanon County).

North of the Yellow Breeches thrust is an additional fault (Paxtang thrust of MacLachlan, 1967) in the western end of the M/HFS that brings the carbonate platform rocks of the Cumberland Valley Sequence up against rocks of the M/HFS (see Fig. 5 and cross-section, Fig. 6). This provides evidence that the Cumberland Valley Sequence underlies at least the western part of the H/MFS, which was indicated by MacLachlan (1967).

The lowest 'stratigraphic' unit within the western portion of the M/HFS foreland basin, north of the Yellow Breeches and Paxtang faults, is believed to be the allochthonous slice Unit H-1. I here propose that Unit H-1, the Cocalico-like rocks above the Yellow Breeches thrust, and at least part of the Cocalico segment rocks are stratigraphic correlatives. Unit H-1 is composed of red, tan, and green pelagic shales and radiolarian-bearing chert, with occasional thin carbonate turbidites. Lash et al. (1984, p.14-15) discussed the origin of these rocks as comparable to of modern pelagic sediments in the deep ocean. The allochthonous Unit H-1 was named the Manada Hill Member by Ganis et al. (2001), and has been dated with conodonts as Mid-Ordovician in depositional age. Although only pelagic facies rocks have been identified in Unit H-1 thus far, other facies could be present (other allochthons comprise multiple facies; see below). Its position as the lowest allochthonous unit north of the Yellow Breeches thrust is speculative since its base is concealed, and the nature of the contact with the transitional carbonate units above the platform is uncertain. If the Cocalico (or part thereof) and the Cocalico-like rocks above the Yellow Breeches thrust, resting on the Hershey/Myerstown, are indeed correlative with the H-1 slice north of the Yellow Breeches thrust, then that speculation is reduced.

The general character of the H-1 slice, or Manada Hill Member, does share some attributes with the Cocalico rocks as described by Stose (1946). Both are dominantly pelitic and contain either red or purple units, occasionally green. The Cocalico is also partly grey
and black (Meisler & Becher, 1971). Repetski and Ganis (2001) described a disrupted carbonate bed in a dark phyllitic shale in the Cocalico Formation from Lancaster County from which Ordovician conodonts were recovered. Given that the Cocalico is of a higher metamorphic grade than Unit H-1 described above, and that the earliest allochthon(s) could have been composed of multiple facies, a correlation of the two units seems plausible.

At Manada Hill, Unit M-1 can be seen stratigraphically above a thick exposure of the Manada Hill Member (the type section) in a hillside cut north of Interstate 81, which forms the southeastern boundary of a large parking area for a trucking depot. Unit M-1 is the lower part of the Martinsburg foreland strata within the M/HFS, and is of either *Nemagraptus gracilis* or low *Climacograptus bicornis* Zone age (both these intervals are equivalent to the *N. gracilis* Zone sensu Riva), depending on the interpretation of the fauna. This is older than Martinsburg Formation outside the M/HFS to the southwest and northeast. Some exposures are composed of turbidites with well-defined Bouma cycles (Figure 7). The biostratigraphic content of the total section was determined from a composite assembly of isolated exposures (discussed under Graptolite Occurrence Data, By Unit) that are believed to be in relative stratigraphic order. Although not specifically recognized, Unit M-1 may have a hemipelagite facies, which is commonly associated with turbidites.

Unit M-1 primarily occurs in the north central portion of the M/HFS with younger beds on either side, suggesting an overall antiform, where the northern limb is overturned (see Fig. 5 and accompanying section, Fig. 6). This antiform feature is generally discernable in the central western part of the M/HFS that was investigated, but its continuity to the east and west is not clear, and faulting, especially thrusting, has probably affected the structure (discussed more fully below under Structural Considerations). Nonetheless, the presumed stratigraphic position of graptolitic sections in Unit M-1 is based on this approximately defined fold scenario. To the south and north of the suggested central antiform other smaller folds are developed. For instance, a younger core of *C. americanus* Zone strata with older *Climacograptus bicornis* Zone strata on either side, suggesting a synform, (in Unit M-2; discussed below) occurs north of the Paxtang thrust in the Rutherford Heights area (see Fig. 6; cross-section). The thickness of Unit M-1 is estimated to be approximately 1400 m.

Assigning an autochthonous status to Unit M-1 could be a point of debate. If it is of *N. gracilis* rather than *C. bicornis* age, not only would that make it considerably older than any demonstratable autochthonous Martinsburg outside the M/HFS, but it would apparently be of the same approximate age as part (or possibly all) the Hershey/Myerstown Formation, which developed within the foreland as the carbonate bank foundered under tectonic loading.
Figure 7. Unit M-1 at Locality G-44. Massive graywacke interbedded with thinly bedded siltstone/shale; rock hammer in centre of photo for scale.
However, the age of the latest Hershey/Myerstown Formation is not precisely known (long-ranging conodonts recovered from the Hershey are permissive from the Chazyan to the lower Blackriveran interval; J.R. Repetski, personal communication), and there remains a slight possibility that an \textit{N. gracilis} Zone age Unit M-1 could be younger than that sequence. That scenario would require that all the Hershey/Myerstown plus an allochthonous slice emplaced over it, and the deposition of Unit M-1 above that, all occurred before the end of the Chazyan (\textit{N. gracilis} Zone), which seems unlikely. Assuming the earliest allochthonous elements were thrust (or slid by gravity) into the inner foreland ramp on top of the Hershey/Myerstown (see also Drake \textit{et al.}, 1989, p.110), a possible resolution to the dilemma of an \textit{N. gracilis} Zone age Unit M-1 would be a condition where deposition occurred on the earliest allochthon as a piggyback basin while it was advancing into the foreland basin it was creating.

Synorogenic piggyback (or wedge-top) deposition is common in the proximal parts of active foreland basin systems (Horton & DeCelles, 1997). Tropeono \textit{et al.} (2002) describe the emplacement of an allochthon into the Bradanic Trough of the Apulian Foreland of southern Italy (Pliocene-Pleistocene) with a wedge-top basin that also provides an analogy to the Hamburg allochthon emplacement with an \textit{N. gracilis} age Unit M-1 deposited in-transit and on top. The wedge-top or piggyback basin atop the allochthon emplaced in the Bradanic Trough is described by Tropeono \textit{et al.} (2002) as composed of hemipelagites, which pass upwards into a thick pile of turbidites. If the Unit M-1 turbidites (and hemipelagites?) were deposited in this manner they could conceivably be the same age as the earliest foreland units (Hershey/Myerstown) that the allochthon, complete with piggyback basin Unit M-1, came to rest upon via thrusting (or gravity emplacement). This can be generally visualized as an allochthon (Unit H-1) entering the subsiding Laurentian slope, and creating the foreland basin, carrying a piggyback basin (Unit M-1) in active synorogenic deposition during mid-to-upper \textit{N. gracilis} time (T$_1$). This is diagrammatically illustrated by annotating figure 2b of Tropeono \textit{et al.} (2002) as Figure 8 (and panel C, fig. 4; in pocket) herein (Unit H-2, discussed below, is also identified). At T$_2$ (early \textit{C. bicornis} time) the allochthon, with Unit M-1 on top, was emplaced upon the Hershey/Myerstown that was deposited on the foreland ramp ahead of the allochthon, also during \textit{N. gracilis} time.

Opinions will vary on whether a \textit{N. gracilis} Zone age Unit M-1 should be included with the Martinsburg Formation, but it has the sedimentological characteristics of that formation (turbiditic flysch), and was deposited within the newly forming Martinsburg foreland basin. This contrasts markedly with the much older allochthons deposited outside the foreland in a separate depocentre, possibly adjacent to Baltimoria.
Figure 8. Early Foreland Basin Development. (Modified after Tropeano et al., 2002, Figure 2b; image inverted); Approximate *N. gracilis* Zone time (sensu Riva 1969, 1974) annotated to show analogous units in the Martinsburg/Hamburg Foreland Segment. The allochthon units were originally deposited adjacent to Baltimoria.
The graptolite assemblages of Unit M-1 are more consistent with a *N. gracilis* age than a *C. bicornis* age, but the latter cannot be precluded. This is due to long-ranging species and an absence of exclusively *C. bicornis* taxa (see Biostratigraphic Data below). But, if Unit M-1 is *C. bicornis* age then it could easily be autochthonous, and deposited directly above the early-emplaced Unit H-1 allochthon. It is also possible that part of Unit M-1 was formed as a piggyback basin, and part after the allochthon carrying those strata was emplaced. Further recovery of graptolites from Unit M-1 may clarify its precise biostratigraphic position.

**Unit H-2**

An allochthonous Unit H-2 was emplaced above Unit M-1 (Fig. 4, panels D&E; in pocket). Unit H-2 consists of proximal turbidites, with some interbedded red pelagic shales and associated lithologies (Nyes Road Member of Ganis *et al.*, 2001), and olistrostromal hemipelagites (Shellsville Member of Ganis *et al.*, 2001) and turbidites. At least part of the Windsor Township Formation of Lash and Drake, Jr. (1984) is physically comparable and correlates with the Nyes Road Member of Ganis *et al.* (2001), especially where red siliceous shales are interbedded with turbidites. Darriwilian graptolites (*Normalograptus antiquus* (Ge) and *Cryptograptus schaeferi* Lapworth; see Chapter One) were recovered from the Dreibelbis Member, Windsor Township Formation south of Kempton. Other parts of the Windsor Township Formation are reported to contain graptolites of the *N. gracilis* Zone (e.g. Weisenberg Member; Lash & Drake, Jr. 1984, p.13), and the preliminary conclusion is that the Windsor Township Formation consists of units of multiple ages and different origins.

The discovery of metre to kilometre-sized olistoliths in the turbiditic facies of the Nyes Road Member of the Dauphin Formation is newly reported here. Associated with this complex is a large debris deposit with boulder-size fragments of deep-water carbonates, chert, and shale in a matrix of scaly mudstone located just east of Locality 43 (see Fig. 3). Unit H-2 was dated as Darriwilian 3/4 (Middle Ordovician) by Ganis *et al.*, (2001), and more precisely as early Darriwilian 4a (Ganis, work-in-progress). It was formed in a diverse lower slope and abyssal environment resulting from submarine channels and fans, debris flows and basal plain deposits of turbiditic, hemipelagic, and pelagic character. Presumably, this is a trench setting that reincorporated an earlier formed and uplifted (?) Late Cambrian through Early-Ordovician stratigraphy as fragmented olistoliths (Ganis *et al.*, 2001).

The concept of uniform terrane-wide episodes of allochthon emplacement is an oversimplification of a much more complex phenomenon. Although it is apparent that the gross ‘stratigraphic’ position of allochthons H-1 and H-2 can be established, it is by no means certain that they are everywhere present in the M/HFS at the same precise interval, or that the
emplacement episode was not a fragmentary process. Root and MacLachlan (1978) described a complex structural history of allochthon emplacement at the western limit of the M/HFS, where multiple, identifiable allochthon masses are interspersed in autochthonous rocks. Their Enola and Summerdale allochthons are strike projections of Unit H-2 that occur west of the Susquehanna River.

The stratigraphic position of allochthonous elements may not be entirely consistent, nor the dimensions of allochthons constant. There may be places where the emplacement event is not recorded and replaced by autochthonous Martinsburg. Even so, the precision of graptolite zonation might not be sufficient to recognize an intermediate age between Units M-1 and M-2 (see below) where the allochthon might be absent. The abrupt termination of allochthons H-1 or H-2 might be faults, or the end of an allochthonous submarine block.

The Jonestown Volcanic Complex of spilitic, amygdaloidal pillow basalts may also have erupted concurrent with the deposition of Unit H-2 (Ganis et al., 2001; p.126). The evidence for this is circumstantial however, consisting mainly of limestone blocks in contact with basalt which have been thermally metamorphosed at the margins (Stose & Jonas, 1927; reconfirmed by Ganis, 1997). The deep-water limestone blocks are olistoliths, and the unit that contains similar masses can be seen to the west, and appears to be part of the Shellsville olistostrome (Ganis et al., 2001), which is part of Unit H-2. The uncertainty in this conclusion lies with the sparse outcrop available to connect the two areas. Other limestone blocks near the baked fringe examples yielded Lower Ordovician conodonts of late Tremadoc to early Arenig age (Lash, 1984), which is consistent with the age of the limestone olistoliths in the Shellsville Member. Thus, the preliminary conclusion is that the basaltic magma intruded Unit H-2, which is late Da3 to early Da 4a age (Llanvirn). The Jonestown Volcanic Complex also contains diabase dykes that cut greywacke turbidites at some locations.

**Unit M-2 and pre-Martinsburg units bordering the M/HFS**

The H-2 allochthon(s) is overlain by Unit M-2 (Fig. 4, panel F, in pocket) which is dominated by dark grey and olive shales and siltstones. The lower to mid-part of Unit M-2 has been dated as of mid to high *C. bicornis* Zone age with graptolites at various levels over a wide area, which is mostly older than the Martinsburg outside the M/HFS. However, the unit extends upwards into strata containing *Corynoides americanus* (= *Dicranograptus clingani*) Zone graptolites (Figs. 9, 10 and 11) which correlate with lower Martinsburg age strata elsewhere. The autochthonous nature of Unit M-2 is indicated by the graptolite (see below) age of its upper part, which contains the transition from upper *C. bicornis* Zone into the *C. americanus* Zone (see Figs. 12 and 13). This is equivalent to the basal Martinsburg age
Figure 9. Fissile shales from locality G-28, Unit M-2; Greywacke is also present in the exposure; contains graptolites from the Corynoides americanus Zone. Compare with exposure shown on Figure 10.

Figure 10. Unit M-2 at locality G-38. Transition from Climacograptus bicornis Zone shales (above 10 cm diameter white circle in centre upper part of photo) to C. americanus Zone below (the sequence is overturned). Shale slabs were excavated from a trench illustrated on Figure 11.
Locality G-38

Base of Martinsburg Form.
bordering the Martinsburg/
Hamburg Foreland Segment

C. americanus Zone (= D. clingani Zone):
Orthograptus quadrimucronatus
O. amplexicaulis
Climacograptus sp. (large)

Figure 11. Detailed Biostratigraphy at Locality G-38 Roadcut.
Figure 12. Allochthonous cobbles and boulders entrained in Unit M-2
described by Epstein & Berry (1973) northeast of the M/HFS at Lehigh Gap and the base of the Martinsburg Formation southwest of the M/HFS described by Stephens and Wright (1981). However, a considerable portion of Unit M-2 extends well below the uppermost \textit{C. bicornis} beds, all of which is older than the basal Martinsburg Formation bordering the M/HFS.

Relatively small allochthonous masses, some no larger than small boulders, are present within Unit M-2 and possibly also in Unit M-3. Unit M-2 has numerous places where carbonate and clastic boulders and slab-like fragments, metres long and/or thick, have been entrained. An example occurs at graptolite Locality G-42 (located on Nyes Road near the junction of Hunters Run Road). Here boulders of polymictic conglomerate contain clastic clasts and limestone conglomerate clasts, and are found in highly sheared and cleaved Martinsburg shale (Figure 12) dated by graptolites. Some of the limestone conglomerate clasts contain trilobite-bearing, shelf-derived carbonate that was dated as Lower Ordovician with conodonts (J. Repetski, personal communication). This is good evidence that allochthonous elements are erratically distributed on many scales, and only the very largest of these masses are ‘stratigraphically’ discernable on a regional basis, such as Units H-1 and H-2. Another example occurs at Locality G-30 where greywacke blocks occur within a turbiditic greywacke/shale flysch (Figure 13). Here the shale matrix yielded Martinsburg-age graptolites, but the greywacke blocks did not yield fossils. It is not clear whether these blocks are allochthonous in the same sense as above, or have a syndepositional origin as intraclasts.

This lower part of Unit M-2 contains a \textit{C. bicornis} Zone fauna including \textit{C. bicornis} (J. Hall), \textit{Orthograptus ex.gr. calcaratus} (Lapworth), \textit{Corynoides calicularis} Nicholson, \textit{Pseudoclimacograptus scharenbergi} (Lapworth), and \textit{Pseudoclimacograptus stenostoma} (Bulman). \textit{P. scharenbergi} (Lapworth) was found within this \textit{C. bicornis} Zone portion of Unit M-2, but was not found in the transition beds into the \textit{C. americanus} (= \textit{D. clingani}) Zone above containing \textit{Orthograptus quadrimucronatus} J. Hall. The upper range of \textit{P. scharenbergi} ends before the top of the \textit{Climacograptus wilsoni} Zone in Scotland (Williams, 1994), a level equivalent to the very top of the \textit{C. bicornis} Zone in North America. Riva (1972) listed \textit{P. scharenbergi} only as high as the \textit{D. multidens} Zone in Quebec and Williams (1995) shows its range through the equivalent \textit{C. bicornis} Zone in Newfoundland. The base of the Martinsburg Formation bordering the M/HFS, being just barely below or within the lowest \textit{C. americanis} Zone, is above the range of \textit{P. scharenbergi} and that taxon has not been reported there. \textit{P. stenostoma} is also restricted to the pre- \textit{C. americanus} Zone. Ganis et al. (2001) attributed the occurrence of these two species in the M/HFS as an indication of earlier syntectonic Martinsburg flysch deposition. Therefore, the lower age of Unit M-2
demonstrates that Martinsburg deposition began earlier within the M/HFS than outside that area. Unit M-2 covers the allochthonous slice Unit H-2, which occupied space in the Martinsburg foreland after emplacement. It appears that some of the C. bicornis Zone strata were depositionally displaced by the allochthon, because, below them is Unit M-1, which is upper N. gracilis (or possibly lower C. bicornis) in age at its top.

The concept of an earlier-formed foreland basin in the M/HFS is supported by the overall age of Unit M-2, which spans the age of the earliest Martinsburg Formation bordering that foreland segment (see figure 2). An earlier-formed foreland basin also accomodated the emplacement of the earliest allochthon (Unit H-1) with piggyback Unit M-1. However, this concept must be reconciled with the age of the pre-Martinsburg units to the northeast and southwest of the M/HFS, as compared to the age of the pre-allochthon emplacement Hershey/Myerstown Formation.

East of the M/HFS the Martinsburg Formation is gradational with the underlying Jacksonburg Formation (Stephens & Wright, 1981). The lower Jacksonburg Formation is grey, massive bedded, crystalline limestone, which is overlain by black argillaceous limestone (O’Neill, 1964). Towards the top of the formation the calcium carbonate content drops dramatically and is replaced by shale of the Martinsburg Formation. Beneath the Jacksonburg is the Black River unconformity, which is an erosional surface that cut into a crustal (peripheral) bulge of upwarped Lower to Mid-Ordovician-age Beekmantown Group shelf carbonates created as tectonic loading approached the Laurentian margin (discussed and referenced in Faill, 1997; p.594). Bordering this bulge to the southwest (present-day orientation) would have been a sag, which can be inferred to have guided the trajectory of the advancing Hamburg allochthon(s). The pre-Jacksonburg erosion of the bulge would have supplied the limestone clasts found in the Hershey Formation conglomerates, which were deposited within the low area flanking the bulge. The erosion of an upwarped Beekmantown terrain as a source of the Hershey Conglomerate was suggested by Prouty (1959), and attributed to faulting. It follows that, until the bulge was reduced to the point where it could be onlapped with further subsidence, the Jacksonburg limestone could not have been deposited. Furthermore, the age of the lower to mid-Myerstown portion of the Hershey/Myerstown Formation beneath the H/MFS is demonstrably older than all of the Jacksonburg Formation (conodont ages; J.R. Repetski, personal communication; see also Ross et al., 1982). Although the age of the top of the Hershey/Myerstown Formation in Dauphin and Lebanon counties below the M/HFS has not been accurately determined, it also follows that it is most likely older than the base of the Jacksonburg Formation in Lehigh County to the northeast.
Drake et al. (1989) described the Hershey depositional environment as euxinic, and identified the limestone clasts in its upper conglomerate as Beekmantown Group rocks. This source was generated by the erosion on the Black River unconformity upon which the Jacksonburg Formation was later deposited. He further stated (p. 110) that, “The limestone conglomerate suggests that faulting began here slightly earlier than in that part of the foreland basin now underlain by rocks of the Schuylkill and Lehigh Valley sequences” (northeast of the M/HFS).

Southwest of the M/HFS the Martinsburg Formation is underlain by black argillaceous carbonate, which Dyson (1967) assigned to the Hershey Formation. However, Root (1977, p.14) doubted the Hershey correlation and assigned the strata to “basal limestones” of the Martinsburg Formation. There is no unconformity (or peripheral bulge) described below this unit, and it is gradational from the Chambersburg Formation below (Stephens & Wright, 1981). The lower age of the “basal limestones” should correspond to the regional subsidence from tectonic loading, which is about early to mid-Blackriveran, if compatible with the allochthons arrival at that time. The graptolites reported near the base of the Martinsburg Formation above the “basal limestones”, by Aldrich (1966), *Dicranograptus nicholsoni* Hopkinson [sic], *cf. var. parangulus* Gurley; *Glyptograptus cf. euglyphus* Lapworth; *Diplograptus multidens* Elies & Wood; *Orthograptus calcaratus, cf. var. alabamensis* Ruedemann; and, *Climacograptus* sp. (tiny form), are compatible with a *D. multidens* Zone age. Stephens & Wright (1981) show the basal Martinsburg west of the M/HFS as within the *Diplograptus multidens* Zone (= *C. bicornis* Zone).

The euxinic (shallow, anoxic) black shale and impure carbonate of the Hershey/Myerstown Formation suggest that the early tectonic subsidence of the foreland was minimal at any time, and steadily progressive. As the allochthon entered the inner foreland ramp, and was emplaced, the subsidence spread laterally to form the shallow basin environment for the Jacksonburg Formation to the east of the M/HFS and the “basal limestones” to the west (Fig. 4., panels F' & F"; in pocket). From west to east the distinction (mainly as decreasing magnesium content) between the Hershey/Myerstown Formation and the Jacksonburg Formation becomes less apparent (O’Neill, 1964), and the relationship is likely diachronous.

Stratigraphic field relationships show that Unit M-2 is autochthonous, and was deposited upon and after the emplacement of allochthon(s) H-2 (Shellsville & Nyes Road Member of Ganis et al. (2001). If Unit M-2 was allochthonous, neither its base or its top would have a conformable contact. The base of Unit M-2 has not been found exposed, however, and the top, with a *C. americanus* Zone age, appears to be in depositional
conformity with younger units (Unit M-3) all the way up to the top of the Martinsburg Formation at Swatara Gap. Unit M-2 is widely distributed in the southern and northern portions of the western M/HFS (see Fig. 5), and helps define the broad fold geometry (see Fig. 6) discussed above. Most of the unit does not exhibit the well-defined turbiditic Bouma cycles or have conspicuous sole or tool marks as seen in Unit M-1. Some aspects of quasi-turbidite origin are present, such as graded bedding, but, overall, the unit may be partially the result of hemipelagite deposition or represents distal mud turbidite facies (outer fan). Layers of pale shale mudstone are interbedded with dark silty shale, siltstone, and sandstone. There are minor parts, however, where turbidite deposition is evident, with recognizable Bouma sequences, such as Locality G-28.

A curious feature of Unit M-2 is the amount of shearing and cleavage development in the southern versus the northern belt (as opposing fold limbs). Unit M-2 in the southern part of the M/HFS is badly sheared and highly cleaved, which may be due to much later thrusting (Alleghanian? age) affecting that portion of the terrane.

Unit M-3 and the ‘Swatara Gap Beds’

Above Unit M-2 is a gradational change to proximal turbidites of Unit M-3 with multiple Bouma sequences (Fig. 4, panel G; in pocket). This unit is poorly exposed, as much of its outcrop is covered by Silurian Tuscarora quartzite talus from Blue Mountain; therefore, only generalities of its composition are known. It lies between the dark grey shales, siltstones and finer sandstones of Unit M-2 below and the uppermost shales and siltstones of the “Swatara Gap Beds” at the top of the Martinsburg, which contain *C. spiniferus* Zone graptolites (Wright et al., 1979) and an Eden age shelly fauna (see Stose, 1930, p.643 & p.686, where he commented that the age of the fauna at Swatara Gap “is the same age as that which occurs elsewhere in the lower part of the typical Martinsburg”. This comment seems inexplicable, as the fauna is the age of the upper Martinsburg, as Stose surely would have understood at the time). The “Swatara Gap” strata are interpreted as forming in a shallow marine environment by Lehman (1988); therefore, the Martinsburg basin shoaled up from a deep to a shallow environment between the deposition of Unit M-2 and the “Swatara Gap Beds”.

Some greywacke beds of Unit M-3 also contain a shelly fauna (locality G-46) with *C. spiniferus* and other sparsely occurring graptolites. These shelly beds are newly discovered (first reported here), and have not been described; however, the graptolites provide a *C. spiniferus* Zone age. The shelly fossils, dominated by brachiopods, bivalves, and pelmatozoans, are remarkably well preserved, and some do not appear to have suffered
transport abrasion. However, the association with apparent turbidites is an unexpected
environment for that quality of preservation. The transition upsection into a deltaic environment
signals a general shallowing within the basin, and the sediments at location G-46 may be only
marginally classified as turbidites. Poor exposure in this area hinders a more detailed
sedimentological analysis.

North of the eastern terminus of the M/HFS (see Fig. 1; = “Hamburg klippe” of
others) Wright and Stephens (1978) described the Shochary Ridge strata in a synclinal
structure. Here, they delineated four fossiliferous units of *N. gracilis* Zone to *C. spiniferus*
Zone age. An Upper Barneveldian (= lower Eden) age shelly fauna occurs at the top of the
sequence. The graptolite fauna listed by Wright and Stephens (1978) for their lower Unit 1
are: *Leptograptus flaccidus trentonensis* Ruedemann, *Dicranograptus “nicholsoni”
parvangulus* Gurley, *Climacograptus bicornis* (Hall), *Orthograptus calcaratus* Lapworth,
*Pseudoclimacograptus scharenbergi* (Lapworth), and *Climacograptus bicornis tridentatus*
Lapworth. This fauna, although referred to the *N. gracilis* Zone by Wright and Stephens
(1978), could easily range into the *D. multidens* (upper *C. bicornis*) Zone. This would place
it, without a biostratigraphic gap, just below their Unit 2 containing *Diplograptus multidens*
Elles & Wood, *Corynoides americanus* Hopkinson, *Orthograptus amplexicaulis* (Hall), and
*Glyptograptus cf. euglyphus* [sic] Lapworth, a fauna compatible with the transition from the
*D. multidens* to *C. americanus* zones. They characterized the total sequence as a transition
from a deep water to a deltaic environment, which correlates with Units M-2, M-3, and the
“Swatara Gap Beds”. Wright and Stephens (1978) considered the Shochary Ridge beds to be
either partly (lower unit excluded) or all autochthonous Martinsburg.

Wright *et al.* (1979) were able to trace the *D. multidens* age shales of the Shochary Ridge
syncline eastward into the Bushkill Member (of Drake and Epstein, 1967) of the
Martinsburg Formation, “with no change in either lithology or faunal age”. Considerable
debate has centred around the relationship of the Shochary Ridge sequence to the ‘slate belt’
Martinsburg to the east. Although the Shochary Ridge strata may be thrust to their current
position, as advocated by Lyttle *et al.* (1987), their relationship with the ‘slate belt’
Martinsburg to the east is most likely a facies difference.

Stose (1946) proposed a two-member subdivision of the Martinsburg Formation east
of the M/HFS in a synclinal structure, while Drake and Epstein (1967) supported a three-
member scenario with no syncline. The difference in interpretation is based on the nature of
Drake and Epstein’s (1987) Pen Argyl Member along the northern part of the Martinsburg
outcrop belt, which they contended is older and distinctly different from their Ramseyburg
and Bushkill members to the south. Wright, *et al.* (1979) supported Stose’s interpretation and
argued that the Bushkill Member is repeated through a syncline and is equivalent to the Pen Argyll Member, based on faunal evidence. Further discussion on this issue can be found in Wright et al. (1979, pp.1182-1183) and Lash et al. (1984 pp. 2-3 & 80-81).

Rocks with Eden age shelly faunas, similar to those occurring in the Shochary Ridge strata and Swatara Gap, were reported by Stose (1930) from Susquehanna Gap near the western terminus of the M/HFS, and by Willard (1943) five miles east of Swatara Gap immediately beneath the Silurian unconformity. Thus, a band of autochthonous Martinsburg, containing shelly fauna and C. spiniferus Zone graptolites, occurs across the northern portion of the M/HFS, extending southwestward, through an area that has been frequently mapped as allochthonous “Hamburg klippe” (eg. Stose, 1946; Root and MacLachlan, 1978; Lash et al., 1984; Lash and Drake, Jr., 1984; Horton et al., 1989). The Shochary Ridge strata are not unique, but can be traced southwestward to the Swatara Gap locale (recognized by Drake et al., 1989, p.110) and correlated with Units M-2 and M-3 up to and including the “Swatara Gap Beds”; and, hence west to Susquehanna Gap near the western edge of the M/HFS.

STRUCTURAL CONSIDERATIONS

A partial map showing the distribution of chronological units, where graptolite age control is good (Fig. 5), includes multiple lithofacies within most units. For instance, Unit H-2 is composed of hemipelagites, turbidities and debris flow deposits, and also contains some very large older olistoliths. Units H-1 and H-2 are allochthon slices, but are treated as stratigraphic units, although their relative position in the stratigraphy could vary, and the ‘unit’ may be fragmented or even absent, in part. It was recognized by Ganis et al. (2001), and in this study, that some of the allochthonous rock, especially the hemipelagite and pelagite facies, was deformed prior to and/or during transport as an allochthon. Exposures of this rock commonly display evidence of soft sediment deformation (Lash et al., 1984; Lash and Drake, 1984; Ganis et al, 2001). Root and MacLachlan (1978, p.1519) commented, “these rocks frequently contain multiple cleavages, a distinctive folding style that serves to distinguish them structurally from autochthonous rocks, and fauna older than the Martinsburg”.

As the foreland basin geometry continually changed, and allochthons were emplaced, the strata had the potential for early deformation. Even given these reservations, the mapped pattern of chronological unit distribution, although incomplete, suggests a fold history. I have constructed a cross-section (Fig. 6) using the chronological unit distribution map (Fig. 5) suggesting a central antiform, with a northern overturned limb, and smaller adjacent and internal folds. The cross-section line for the southern limb (right side up) is offset along strike from the northern limb (overturned; see figure 14) by roughly 18 kilometres, which
Figure 13. Undated graywacke blocks in Unit M-2 shales.

Figure 14. Overturned Lickdale Section; approximate contact lines artificially enhanced; corresponds to part of B-B' on Figure 6.
creates a level of uncertainty regarding the continuity and the structure between the two parts. However, the consistent pattern of *C. bicornis* through *C. spiniferus* Zone strata occupying the northern part of the western half of the M/HFS, dipping south and younging north (indicating inversion) strongly suggests the main structural element in this part of the Great Valley is a large-scale overturned anticline. Later faulting has disrupted the continuity of the basic anticline pattern, so the cross-section analysis may be only an approximation of the actual fold geometry.

The age of this fold pattern can only be speculated. If the folding is late Taconic then the Silurian unconformity would truncate it, and the strata would have been, presumably, refolded during the Alleghanian Orogeny. If this is the case, the fold pattern suggested by the cross-section (Fig. 6) would be more complicated than portrayed. The only evidence of Taconic folding provided by the data here is the suggestion of a large, north-trending, dextral strike-slip fault northeast of Harrisburg. There Units H-1, M-2, and H-2 are offset to the north from their trend coming west, which appears to cut the southern fold limb (displacing it northwards), but not displacing the Silurian unconformity boundary. The nature and position of faulting in this area has not been sufficiently investigated to confirm these conclusions, and they are offered only a possibility at this time.

If the fold pattern shown on Figure 6 is Alleghanian, then its basic geometry, as portrayed on the cross-section, is more likely to be approximately correct, ignoring the small scale folding that is undoubtedly also present. As stated above, the northward movement of "Cocalico" terrane within the Lebanon Valley nappe, on the Yellow Breeches thrust, onto the southern M/HFS is an Alleghanian event (MacLachlan, 1967).

Deep, ramping-up Alleghanian detachments and imbricate stacking are usually portrayed on large-scale cross-sections from the Piedmont through the Great Valley (Martinsburg foreland basin), and into the post-Ordovician folded Appalachians (e.g. Berg *et al.*, 1980). This thrusting and detachment results in the entire regional geology being characterized as 'para autochthonous' and these types of structures are likely below the section portrayed in Figure 6, and could emerge within it. That the platform sequence does not emerge at the surface near the antiform axis could signal that imbricate stacks within the foreland basin strata increased the thickness above the carbonate horizon.

Lash *et al.* (1984) and Lash and Drake, Jr. (1984) described the "Hamburg klippe" as thrust over the Martinsburg Formation, following the model put forth by Stose (1946). They also subdivided their "klippe" into two slices; an older Late Cambrian to Early Ordovician age Richmond slice, composed of the Virginville Formation, thrust over a younger *N. gracilis* Zone age Greenwich slice, composed of the Windsor Township Formation; all sourced from a
rifted microplate (= Baltimoria). Many workers since Stose (1946) have favoured a competing model involving allochthonous slices within the Martinsburg Formation (see discussion in Introduction). However, new biostratigraphic data (Ganis et al. 2001, and this study) contradicts Lash et al. (1984) and Lash and Drake, Jr. (1984). Much of the area within their “allochthonous” Windsor Township slice contains strata with autochthonous Martinsburg age graptolites or Eden age shelly fauna. The *N. gracilis* Zone *(sensu* Riva) age strata have been reassessed (discussed above) as synorogenic within the Martinsburg foreland basin, and the Late Cambrian through Early Ordovician strata are contained as olistoliths, some quite large up to kilometre size, within a Middle Ordovician olistostrome (Ganis et al., 2001). A location in the Dreibelbis Member of the Windsor Township Formation yielded Middle Ordovician graptolites (see Chapter One). These conditions would preclude the possibility of the two slice, internally consistent, allochthonous scenario proposed by Lash et al. (1984) and Lash and Drake, Jr. (1984). The last point above regarding the olistostrome was based on work restricted to the western part of M/HFS, and it cannot be precluded at this time that very large slices of Late Cambrian to Early Ordovician rock are thrusted as stacked slices with the Middle Ordovician (early Da 4a) age strata somewhere within the terrain, in a manner different from the olistolithic nature previously described.

**GRAPTOLITE OCCURRENCE DATA, BY UNIT**

The deposition within the Martinsburg foreland in the M/HFS was complicated by emplacements of slices and debris from a Taconic allochthon, the limits of which defines the boundaries of the foreland segment. The general biostratigraphic content of the Martinsburg Formation and allochthonous slices is discussed in Ganis et al. (2001). Additional graptolite biostratigraphic data concerning the Martinsburg portion is presented here. This new data has resulted in a proposed stratigraphic subdivision of the Martinsburg Formation within the M/HFS (see Fig. 2). A chart of the graptolite fauna reported from each unit described below can be found in figure 15. Individual graptolite species are described under Palaeontological Notes.

**Unit M-1**

The beds below Unit M-1 are allochthonous pelagites (Manada Hill Member of Ganis et al., 2001; also identified herein as Unit H-1). The exposure of the Manada Hill Member type section is overlain by Unit M-1, where the basal fauna were recovered from Locality G-41 (40°21' 12" N, 76°43' 34"N; USGS Hershey Quad.; see Fig. 5). The following graptolites have been identified from G-41:
Figure 15. Graptolite Faunal Distribution by Unit.

<table>
<thead>
<tr>
<th>Graptolite Zone</th>
<th>N. gracilis (sensu Riva 1969, 1974)</th>
<th>D. multidens (C. bicornis)</th>
<th>C. americanus (D. clingani)</th>
<th>C. spiniferus (D. clingani)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>H-1 allochthon; with older faunas</td>
<td>M-1 basal</td>
<td>M-1 mid</td>
<td>M-1 top</td>
</tr>
<tr>
<td>Glossograptus sp. aff. hincksii</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nemagrapthus gracilis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudoclimacograptus modestus</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reticograptus geinitzianus</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corynoides calicularis</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicellograptus intortus</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicellograptus brevicaulis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryptograptus tricornis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicellograptus salopiensis</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudoclimacograptus scharenbergi</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Ensigraptus caudatus</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Cryptograptus sp. aff. tricornis (small)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normalograptus cf. brevis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climacograptus meridionalis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicellograptus cambriensis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicellograptus alabamensis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudoclimacograptus stenostoma</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glyptograptus sp. indet</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudoclimacograptus isknos</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diplograptus ? foliaceus</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplexograptus cf. leptotheca</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climacograptus bicornis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dicranograptus nicholsoni</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthograptus ex. gr. calcaranus</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Orthograptus quadrimucronatus</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectograptus amplexicaulis</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Climacograptus (Diplacanthograptus) spiniferus</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Glossograptus sp. aff. hincksiii (Hopkinson)

Dicellograptus sp. Hopkinson

Nemagraptus sp. cf. N. gracilis

Pseudoclimacograptus sp.

Reteograptus geinitzianus J. Hall

Corynoides calicularis Nicholson; not common

This fauna is consistent with the N. gracilis Zone; however, the first appearance of C. calicularis has been indicated near the base of the C. bicorns Zone by some workers (e.g. Williams, S.H., 1995; Williams, et al., in press). The accumulated fauna throughout the remainder of Unit M-1 is compatible with a mid to upper N. gracilis or, possibly, a low C. bicorns Zone succession.

The mid portion of Unit M-1 is poorly exposed in small isolated outcrops and has yielded graptolites at three localities, G-12, G-26, and G-44. The graptolites found at Localities G-12 and G-26 were described (with coordinates) by Ganis et al. (2001).

Locality G-12:

*Dicellograptus salopiensis* Elles & Wood

*D. intortus* Lapworth

*Climacograptus antiquus* Lapworth

*Reteograptus geinitzianus* J. Hall

Locality G-26:

*Corynoides* sp. cf. *C. calicularis* Nicholson; not figured from this location

*Cryptograptus tricornis* (Carruthers); not figured from this location

*Glossograptus* sp.

*R. geinitzianus* J. Hall

The middle portion of the M-1 unit was also found to be graptolitic at Locality G-44 (40° 21’ 12”N, 76° 43’ 54”W; USGS Hershey Quad.; see Fig. 5) where the following graptolites were recovered from a flaggy-bedded greywacke:

*R. geinitzianus* J. Hall

*Pseudoclimacograptus scharenbergii* (Lapworth)

*Pseudoclimacograptus modestus* (Ruedemann)

*Corynoides* cf. *calicularis* Nicholson; sparse

*D. cf. D. salopiensis* Elles & Wood

*Nemagraptus gracilis* (J. Hall)

*Dicranograptus brevicaulis* Elles & Wood
This fauna is consistent with the *N. gracilis* or *C. bicornis* Zone but, no younger than mid-*C. bicornis* Zone, the upper range of *N. gracilis* and *D. brevicaulis* (Williams, *et al.*, in-press).

The upper part of Unit M-1 is found in the Lickdale section (see Figs 5 & 14) along Interstate 81 S, at locality G-39. The nature of the contact above Unit M-1 is covered and not certain. The stratum above is an allochthonous slice (Unit H-2) which is part of the Shellsville Member of Ganis *et al.* 2001. However, the Unit H-2 slice at the Lickdale Section (see Fig. 6 & 14) is quite thin compared to other locations suggesting the possibility that the upper Unit M-1 contact is thrust against it, truncating part of the section. If that is the case, part of Unit M-1 may also be truncated, and it may not be the very top of the unit. Alternately, Unit H-2 may be thrust against Unit M-2, also resulting in partial truncation (as shown in Fig. 6) but the contact is not exposed. If there is no fault between Units M-1 and H-2 or Units H-2 and M-2 then Unit H-2 is the tapered edge of an allochthonous slice. This is a tantalizing possibility, which would reveal the fragmentary and/or irregular dimensions of the allochthonous slices. The following graptolites were recovered at Locality G-39 (40° 26' 35" N, 76° 31' 00" W; USGS Indiantown Gap Quad.; see Fig. 5 & 14):

- *R. geinitzianus* J. Hall
- *Cryptograptus aff. tricornis* (Carruthers)
- *Normalograptus? brevis* (Elles & Wood)
- *Dicellograptus alabamensis* Ruedemann
- *Dicellograptus cambriensis* Hughes
- *Pseudoclimacograptus scharenbergi* (Lapworth)
- *P. modestus* (Ruedemann)
- *Glyptograptus* sp. Lapworth
- *Corynoides calicularis* Nicholson; sparse

Of this fauna, *D. alabamensis* is generally regarded as restricted to the *N. gracilis* Zone (e.g. Williams, 1995; Hughes, 1989) but *C. calicularis* is regarded as a *C. bicornis* Zone or higher taxon (Williams1995 & Williams, *et al.*, in-press). The other fauna are consistent with both the *N. gracilis* and *C. bicornis* zones.

Locality G-47 (40° 28' 08" N, 76° 20' 26" W; USGS Bethel Quad.; see Fig. 5) cannot be specifically positioned stratigraphically, but appears likely to be upper Unit M-1 from its lithologic characteristics and limited fauna of the *N. gracilis* Zone (*sensu* Riva) including:

- *Cryptograptus aff. tricornis* (Carruthers)
- *Corynoides calicularis* Nicholson
- *Dicellograptus* sp
Unit M-2

Unit M-2 is included in the undivided Caradoc sequence of Ganis et al. (2001) as part of the Martinsburg foreland basin fill. As separated from younger Caradoc units (Unit M-1) herein, the localities (with coordinates) and graptolite faunas of Ganis et al. (2001) now considered exclusively part of Unit M-2 are as follows:

Locality G-10
*Diplograptus* ? sp. cf. *D. foliaceus* (Murchison)
*Climacograptus bicornis* (J. Hall)

Locality G-28
*Corynoides calicularis* Nicholson; abundant
*Orthograptus* ex. gr. *calcaratus* (Lapworth)
*O. quadrimucronatus* (J. Hall)

Locality G-30
*Dicranograptus* sp. cf. *D. ramosus spinifer* Elles & Wood; reassigned herein to *D. cf. nicholsoni* Hopkinson

New localities and fauna for Unit M-2 are as follows:

Locality G-11 (40° 28' 18"N, 76° 20' 50"W; USGS Bethel Quad.; see Fig. 5)
*Orthograptus* ex. gr. *calcaratus* (Lapworth)
*Pseudoclimacograptus scharenbergi* (Lapworth)
*Amplexograptus leptotheca* (Bulman)

Locality G-36 (40° 17' 12"N, 76° 48' 17"W; USGS Harrisburg East Quad; see Fig. 5)
*Orthograptus* ex. gr. *calcaratus* (Lapworth)
*Ensigraptus* cf. *caudatus* (Lapworth)

Locality G-38
lower stratigraphic portion (40° 26' 53"N, 76° 30' 59"W; USGS Indiantown Quad; see Figs 5, 10, & 11)
*Climacograptus bicornis* (J. Hall)
*Pseudoclimacograptus scharenbergi* (Lapworth)
upper stratigraphic portion (same coordinates and Figures)

*Climacograptus* sp.

*Orthograptus* cf. *O. amplexicaulis* (J. Hall)

*O. quadrimucronatus* (J. Hall); common

Locality G-42 (40° 18' 41"N, 76° 45' 54"W; USGS Harrisburg East Quad.; see Fig. 5)
*Corynoides calicularis* Nicholson, common

Locality G-45 (40° 17' 33"N, 76° 52' 50"W; USGS Harrisburg West Quad; see Fig. 5)

*Orthograptus* ex. gr. *calcaratus* Lapworth

Locality G-48 (40° 23' 20"N, 76° 40' 05"W; USGS Grantville Quad; see Fig. 5)
*Pseudoclimacograptus isknos* Zalasiewicz

Of the localities listed above G-10, G-11, G-38, G-42 and G-38 (lower stratigraphic portion) contain a *C. bicornis* Zone fauna; and, localities G-28, G-30, G-36, and G-38 (upper stratigraphic portion) contain a *C. americanus* (= *D. clingani*) Zone fauna. Locality G-42, with only *C. calicularis*, could be *C. bicornis*, or *D. clingani* age. The general pattern of graptolite localities in Unit M-2 is low diversity, which may be a condition of the *C. bicornis* to *C. americanus* transition. The equivalent biostratigraphic position in southern Scotland, the *Climacograptus wilsoni* Zone and transition into the *D. clingani* Zone above, was found to be of low diversity by Williams (1994).

**Unit M-3 and the Swatara Gap Beds.**

The marginally to non-turbiditic basin-fill shales, siltstones, and minor sandstones of Unit M-2 pass upward into proximal turbidites with distinctive Bouma beds, which is Unit M-3. The first available exposure of the M-3 unit is well above Unit M-2 and the character of the transition is not known. The uppermost available exposures of the M-2 unit are within the low *C. americanus* Zone (= *D. clingani* Zone; just above *C. bicornis*-bearing beds), and the M-3 unit at Locality G-46 (40° 27' 10"N, 76° 32' 10"N; USGS Indiantown Gap Quad; see Fig.5) contains *Climacograptus (Diplacanthograptus) spiniferus* Ruedemann (and a newly discovered shelly fauna) indicating the upper *D. clingani* to low *Pleurograptus linearis* Zone. Presumably the sequence is unbroken between the two points as the basin shallowed and filled. This shallowing continues upsection into the deltaic units containing the famous Swatara Gap shelly fauna (Lehmann, 1988) of Eden age.
The presence of Eden age (± C. spiniferus Zone) shelly fauna at various points along the northern portion of the M/HFS, from Shocary Ridge to Harrisburg Gap, allows a general correlation of autochthonous Martinsburg age strata across the entire region.

**PALAEONTOLOGICAL NOTES**

All graptolites discussed below (see Figs. 16 and 17) are flattened impressions collected during this study and those reported by Ganis et al., (2001). Graptolites are generally scarce in the Caradoc rocks of the M/HFS, and occur in widely separated and restricted sections. The comments regarding abundance, i.e. common, rare, refer only to beds where graptolites do occur.

*Amplexograptus leptotheca* (Bulman); Fig. 17H.

The basal part of Unit M-2 contains a scarce *Amplexograptus* at one location (G-11). It has a virgella spine with a horizontally directed antivirgellar spine (only a slight tip on the specimen shown) and a prominent spine at th1. The thecal style modifies from strongly geniculate in the proximal region to thecae with highly rounded supragenicular walls distally. The 2 TRD measured at thecae 3-5 is 0.9 mm and the rhabdosome is 1.1 mm wide across the proximal end. This matches fairly well with Hughes' (1989) description for *A. leptotheca*.

*Corynoides calicularis* Nicholson; Figs 16A-N.

The specimens collected in this study compare favourably in shape to the lectotype and other specimens from the lectotype block figured in the Atlas of Graptolite Type Specimens (Zalasiewicz et al., 2000). From the lectotype and accompanying specimens it can be seen that the rhabdosome is relatively long compared to its width, and is slightly curved to nearly straight. The long sicula has a large rutellum, and two additional thecae grow downward along its side in parallel position, also with rutelli. According to Williams (1995) the aperatures of these later thecae do not reach the full level of the sicular aperture, and flare outwardly. This results in a proximal end that appears to have an assortment of knobbly protrusions, as the rhabdosome is flattened in various ways. A third smaller theca sometimes develops as an outwardly directed bud near the distal end. The taxon also has a long nema.

The lectotype and associated mature specimens have a proximal width, across the rutelli, of 1.0 to 1.3 mm and a mid- rhabdosome width of about 0.6 mm. These specimens are also 10.1 to 13.4 mm long, not considering the curvature of the specimens and exclusive of nema. The specimens in this study are smaller, being 0.2 to 0.7 mm wide proximally and only slightly smaller mid-rhabdosome, and are 2.0 to 8.5 mm long. The specimens of this taxon
Figure Captions for Figures 16 and 17


Figure 16. Graptolite Fauna, Unit M-1.
Figure 17. Graptolite Fauna, Units M-2 and M-3.
figured by Williams (1995, text-fig. 15 A-L; p. 60) of juveniles and mature examples from Newfoundland ranged from 0.2 to 1.0 mm wide proximally, 0.2 mm to 0.6 mm at midpoint, and ranged from 4.0 to 12.0 mm long. The rhabdosome width is obviously dependent upon the development stage of the second and third thecae, determining which requires the preservation of the interthecal septae and/or the proximal end definition. Preservation orientation also affects measurement accuracy. The mature specimens figured by Ganis et al. (2001, Fig. 9m-n, p. 120) for Unit M-2 show the interthecal septae and have dimensions comparable to the lectotype. These specimens are preserved on shaly siltstone. The flattened specimens figured for this study are from a lower stratum (Unit M-1), and are preserved on greywacke. These examples are draped along the contours of sand grains making physical measurements less precise. The specimens are also poorly preserved, lacking good definition of either the interthecal septae or the proximal end, which made it difficult to assess the level of maturity. Even so, their assignment to *C. calicularis* is justified based on the overall long and thin dimensions, which can be distinguished from other, more squat species, such as *C. americanus*, which occurs at a higher biostratigraphic level. *Corynoides curtus* Lapworth was described as a smaller form; however, Riva (1974) determined that there is a continuous gradation from smaller to larger specimens, concluding that they may be referred to *C. calicularis*.

*Climacograptus bicornis* (Hall); Figs 17W-Y.

This species was found sparingly in Unit M-2, but was abundant in the beds just below the transition to the *C. americanus* Zone (= *D. clingani* Zone) above. The climacograptid thecal form with pronounced, wide, and subhorizontally-directed proximal spines and sometimes a long thickened virgella (previously referred to *C. bicornis tridentatus* Lapworth), makes this a readily recognizable species. The size of the proximal spines is highly variable, and mature specimens can include examples thickened with a membranous growth (see Riva and Ketner, 1989). This species was also recorded by Ganis *et al.* (2001, Fig. 9L, p. 120) for the same unit. The largest specimen found measured 31 mm in length, with a proximal width of 0.78 mm and a distal width of 2.0 mm. For a typical specimen the 2TRD between th3-5 was 1.4 mm.

*Climacograptus meridionalis* (Ruedemann); Figs 16A'-B'.

Two specimens of this taxon were found in the upper beds of Unit M-1. As pointed out by Riva and Ketner (1989, p.77, Fig. 5), it may be distinguished from *P. modestus* by its
archiclimacograptid-like thecae and large size. The virgella of this species can attain considerable length.

**Climacograptus (Diplacanthograptus) spiniferus** Ruedemann; Figs 17I-J.

This species was common within greywacke beds also containing a well preserved shelly fauna in Unit M-3. The species has a superficial resemblance to *C. bicornis*; however, the smaller proximal spines are asymmetrically aligned, thinner and needle-shaped. The largest specimen found is 11.7 mm long, 0.5 mm wide, proximally (where the first pair of thecae are noticeably narrower than the subsequent ones), and 1.3 mm wide, distally. The 2 TRD measured at about 1/3 of the length of the rhabdosome is 1.6 mm. Williams (1995) commented that the thecal excavations of this species only occupy 1/5 of the total rhabdosome width. This feature for the specimens in this study varied between 1/5 and 1/3 of the rhabdosome width, a condition probably subject to preservational orientation.

**Cryptograptus sp. aff. tricornis** (Carruthers); Figs 16O-R.

A small form of *Cryptograptus* is present in the upper beds of Unit M-1. The specimens are juveniles with distinctive basal spines and rutellum, and are arrowhead-shaped. The specimens are only about 0.33 mm wide at the proximal end, which is roughly half the width of *C. tricornis* and even less than that of *C. schaeferi*. The material is similar in form to *C. tricornis*, only smaller.

**Cryptograptus tricornis** (Carruthers).

This species was reported but not figured by Ganis *et al.* (2001, p.123) from early Caradoc strata, equivalent to Unit M-1 herein.

**Dicellograptus intortus** (Lapworth).

This species was recorded by Ganis *et al.* (2001, p.120, Figs 19A-C) from what is now determined as Unit M-1. It is recognizable by its small axillary angle (Lapworth, 1880) which was described by Hughes (1989) as 10- 15°. No additional specimens were found in this study at the new locations listed.

**Dicellograptus salopiensis** Elles and Wood; Figs 16U-V.

This species was found during the present study in the mid and upper parts of Unit M-1, and also reported by Ganis *et al.* (2001, Figs 9 D-E, p.120) from the same beds. Elles and Wood (1904, p.145) described this species (their *D. divaricatus* Var *salopiensis*) as
characterized by slender stipes with a uniform width of 0.5 mm. Williams (1995, p.43) noted that it lacked spines, other than in the proximal region. The specimens found in this study match those characteristics. Williams (1995, pp.43-45) also discusses the considerable problem of other species possibly being synonymous with *D. salopiensis*, such as *D. vagus*, *D. gurleyi*, and *D. sextans exilis* (see also discussion in Hughes, 1989, p.45).

**Dicellograptus cambriensis** (Hughes); Figs 16S-T.

Several specimens meeting the description of *D. cambriensis* (Hughes, 1989, pp.38-39) were found in the upper beds of Unit M-1. Notable in this diagnosis is the sicula, which is always skewed toward th2 and fused against the dorsal stipe wall. The two specimens illustrated here clearly show this feature. The axillary angle for these specimens was 23° which falls within the range of 20- 70° given by Hughes (1989, p. 39). The specimens also match the proximal stipe width, style of thecae, and character of spines present provided by Hughes (1989). He described the combined sicula and nema length reaching 1.8 mm, commonly 1.1 to 1.5 mm, and in the specimens figured here these values range from 1.4 to 2.1 mm. The 2TRD between thecae 3-5 is given by Hughes (1989) as 1.12- 1.37 mm. Neither specimen here had sufficient thecal definition at thecae 3-5, but a measurement of the 2TRD at thecae 2-4 was 1.33 mm.

**Dicellograptus alabamensis** Ruedemann; Fig. 16W.

A single incomplete specimen was found in the upper part of Unit M-1. The summary description of this species given by Rushton (2001, p.49) proved most useful, which also clarified the unpublished conclusion of S. Finney regarding its synonymy with *D. smithi*. The specimen has highly introverted thecal apertures and mesial spines up to at least theca 5. The 2TRD at th3-5 is 1.25 mm and the width at theca 5 is 0.6 mm. These characteristics fit the description of *D. alabamensis* given by Rushton (2001).

**Dicranograptus brevicaulis** Elles and Wood; Figs 16R'-U'.

This species is common at one location in Unit M-1 but was not seen elsewhere. The specimens conform to the description of the species by Elles and Wood (1904, p. 168) quite well. Most specimens had 4-5 spinose thecae in the biserial portion, which falls within the range of 3-5 given, but is also within the range of *D. rectus* Hopkinson with 4-6 biserial thecae. The similarity of the two species was discussed by Elles and Wood (1904), Hughes (1989), and Williams (1995). Hughes grouped the two species together and remarked that the type of *D. rectus* cannot be traced, and thus cannot be adequately compared to *D. brevicaulis*. 
The uniserial portion of *D. brevicaulis* does not have spines. The examples collected in this study have an axillary angle between 30–43°, while Elies and Wood (1904) noted a figure of 30° for the taxon.

**Dicranograptus cf. nicholsoni** Hopkinson.

Figured in Ganis *et al.* (2001, Fig. 9F, p.120) as *D. sp. cf. D. ramosus spinifer* Elles and Wood; however, that species has a much higher number of thecal pairs in the biserial portion than the specimen shown. The specimen figured has 10 spinose biserial thecal pairs compared to 30 described by Elies and Wood (1904, p.176) for *D. ramosus spinifer*. Williams (1995) described *D. ramosus spinifer* from Newfoundland with 17 biserial thecal pairs. The specimen figured by Ganis *et al.* (2001) has a biserial portion that is 10 mm long, far less than the 25-30 mm given for *D. ramosus spinifer* by Elies and Wood (1904). Unfortunately, the specimen was broken off just after the bifurcation to the uniserial stipes. The specimen is considered closer to *D. nicholsoni* which Elies and Wood (1904) described as having about 8 thecal pairs in the biseral part of 5-8 mm in length. Williams (1995, p.34) described Newfoundland examples of *D. nicholsoni* with a biserial portion of 5-10 thecal pairs and a maximum length of 1.5 cm.

**Diplograptus ? sp. cf. D. foliaceous** (Murchison).

Figured in Ganis *et al.* (2001, Fig.9I, p. 120). A single specimen is associated with *C. bicornis* in Unit M-2. No additional specimens were found during this study. It appears similar to the Hughes (1989, Fig 23a) example from the type slab, and that figured by Elles and Wood (1907, Fig. 178, p.261). Hughes' (1989) emendment of *D. multidens* to *D. foliaceous* is followed without critical review.

**Ensigraptus caudatus** (Lapworth) ? ; Fig. 17V.

Riva (1989, p.89) emended *Climacograptus caudatus* to *Ensigraptus*. Two specimens figured by Ganis *et al.* (2001, Figs 9Q-R, p.120) as *C. antiquus* Lapworth do not show proximal spines other than a virgella, and are provisionally revised to *C. caudatus*, thus to *Ensigraptus caudatus*, per Riva.; *C. antiquus* has two proximal spines plus a virgella (Lapworth, 1873, p.134; Elies and Wood, 1906, p. 200). In many other respects, such as thecal density, size of rhabdosome, and length of robust virgella with parasicula, the two species are very similar. The proximal end development of the two species differs, however, as elucidated by Riva (1989). An additional specimen of *E. caudatus* ? was found during this
study. It was not possible to ascertain the proximal end details for any of these specimens, and
the species referral is uncertain and based only on the general characteristics of the material.

*Glossograptus* sp. aff. *G. hincksii* (Hopkinson); Figs 16X-Y.

This genus is common in the lower part of Unit M-2; also recorded by Ganis *et al.* (2001, Fig. 11C, p.123). Examples from this study were identified as *G. sp. aff. G. hinckii* because of the similarity in general characteristics to that taxon. One distinctive feature of some specimens is thickened stake-like distal spines about 0.12 mm wide that do not terminate in a point, which is possibly a variation from *G. hincksii* s.s.. The specimens have a proximal width, less spines, of 1.0 mm and a distal width, less spines, of 2.0 mm, with spines up to 2.5 mm long. The thecal density in biprofile aspect is about 7 in 5 mm. These dimensions are consistent with those of *G. hincksii* (Hopkinson).

*Glyptograptus* ? sp.; Fig. 16Z.

A single specimen that can be identified only as *Glyptograptus* ? sp. was found in the upper beds of unit M-1. It has a highly asymmetric proximal end with a short virgella and one other short spine.

*Nemagraptus gracilis* (J.Hall); Figs 16G'-I'.

The taxon is scarce in low to mid- Unit M-1 and was found at two locations. Ganis *et al.* (2001) did not report finding the species. Only one mature specimen was seen with lateral branching. The more common juveniles are less confidently identified, but do match the early proximal development shown by Finney (1985). A sicula measured from a juvenile specimen is 1.0 mm long.

*Normalograptus* ? cf. *N. brevis* (Elles and Wood); Fig. 16C.

A specimen of this taxon was found in the upper beds of Unit M-1. The first two thecae show a strong upward growth from an asymmetric proximal end with no lateral spines. The sicula is about 0.8 mm long with a thickened virgella. The second and third thecae are of climacograptid form with apparent horizontal apertures. The specimen is 0.5 mm wide at the proximal end compared to 0.64 mm shown for the lectotype by Hughes (2000).

*Orthograptus* ex. gr. *calcaratus* (Lapworth); Figs 17K-O.

This is a common taxon in Unit M-2. It was recorded by Ganis *et al.* (2001; Figs J-K, p.120). Williams (1982) discusses the problem of great variation in size and overall form
attributed to this species (and subspecies), and the need for additional work to sort it out. With one notable exception (Fig 16K) the specimens were small to moderate-sized 0.8 to 1.2 mm wide proximally and 1.0 to 1.6 mm wide by th4. The specimen figured as 16K is huge compared to the rest of the population being 2.0 mm wide proximally and reaching a distal width of 3.0 mm.

**Orthograptus quadrimucronatus** (J.Hall); Figs 17P-U.

This taxon is common, first appearing at the base of the *C. americanus* (= *D. clingani*) Zone, in Unit M-2. It was reported by Ganis et al. (2001, 9O-P, p.120) from this level co-occurring with *O. ex.gr. calcaratus*. It can be distinguished from the latter by the presence of apertural spines throughout the rhabdosome and a denser thecal spacing. Goldman (1995) redescribed the species and clarified the status of numerous subspecies and synonyms. The specimens found in this study generally agree with the morphometrics of this species given by Goldman (1995).

**Pseudoclimacograptus modestus** (Reudemann); Figs 16J'-P'.

This small form of *Pseudoclimacograptus* is common in Unit M-1. According to Hughes (1989, pp.71-72) it can be differentiated from *P. scharenbergi*, which also occurs at this level, by a smaller 2TRD, and having conspicuous spines on both th1^1 and th1^2 plus a modest virgella. The specimens identified as *P. modestus* have a 2TRD of 0.76 to 1.1 mm, within the range described by Hughes (1989), and/or a pair of th1 spines. The zigzag median septum is usually apparent, but often only faintly preserved.

**P. scharenbergi** (Lapworth); Figs 16Q' and 17A-B.

The type specimen is unknown but assumed by Pribyl (1947) to have come from the *C. wilsoni* Zone at Dob's Linn, Scotland (Hughes, 1989, p.72). Thus, the exact morphology is open to speculation. Hughes stated that the distal and proximal 2TRD is higher for *P. scharenbergi* than for *P. modestus*. The specimens illustrated on Figure 16, identified as the former, had a proximal 2TRD of 1.3 and 1.4mm, consistent with the range of *P. scharenbergi* given by Hughes (1989, p.73). These specimens have only small apertural denticles suggestive of proximal spines, and a relatively long virgella. Ganis et al. (2001, Fig 9G, p.120) also recorded this species. It was found in Units M-1 and M-2 through the *N. gracilis* and *C. bicornis* zones.
P. stenostoma (Bulman).

This taxon is one of the more easily recognized pseudoclimacograptids. The narrow slit-like thecal apertures are distinct. It was reported from a level equivalent to Unit M-1 by Ganis et al. (2001, Fig 9H, p.120). No additional specimens were found during this study.

P. isknos Zalasiewicz; Figs 17C-F.

Numerous specimens of this small distinctive graptolite were found at one locality within Unit M-2. P. isknos had previously been found only from the Upper Serw Formation, Wales in the lower multidens Biozone (Zalasiewicz, 1992). Finding this species in North America at the same approximate level suggests that this taxon has biostratigraphic value.

As described by Zalasiewicz (1992) this graptolite is densely thecate with 20 to 18 thecae/10 mm, and has a blunt, square proximal end with an obliquely growing sicula and additional spine. The proximal width was given as 0.5 to 0.8 mm, increasing distally to 0.7 to 1.15 mm.

Two adult specimens were found with 2 TRD’s at thecae 2-4 of 0.9 mm (22 thecae in 10 mm); were 0.57 and 0.49 mm wide at th1; and, 0.80 mm wide by thecae th5. The median septum, although indistinct, was wrinkled and offset, suggestive of zig-zag form, confirming its assignment to Pseudoclimacograptus by Zalasiewicz. The sicula is strikingly curved and one juvenile showed the additional spine also growing obliquely. It could not be determined if the second spine is an antivirgellar spine or has emerged from th1.

Rectograptus amplexicaulis (J.Hall); Fig.17G.

This taxon was rare in the beds containing O. quadrimucronatus in Unit M-2. The specimen figured is quite similar to Orthograptus amplexicaulis shown by Williams (1995) from Newfoundland and generally matches the figures in Ruedemann (1947, including Hall’s figures reproduced).

Reteograptus geinitzianus J. Hall; Fig. 16D’-F’.

This is a common species throughout Unit M-1. It was also recorded by Ganis et al. (2001, Fig. 9S, p.120) at this level. The preservation of the periderm over the meshwork varied considerably from absent to very complete. A sicula preserved on one specimen measured 0.5 mm long, and the most complete specimen has 6 thecae in 5 mm. The longest
specimen found is 8.5 mm long and 1.9 mm wide at the mid-point of the rhabdosome. These measurements match the lectotype described by Finney (1980).

CONCLUSIONS

1. The allochthonous Hamburg succession, including olistostromal units, is embedded as large ‘stratigraphic’ slices and smaller masses within the Martinsburg Formation, and is early Darriwilian (Da) 4a Zone and older in depositional age. The part of the Martinsburg foreland basin containing allochthons is named the Martinsburg/Hamburg Foreland Segment (M/HFS).

2. The stratigraphic gap between the allochthonous rock and the Martinsburg foreland basin deposits is only approximately known, and appears to be a portion of the Da 4a Subzone, the Da 4b Subzone (= H. teretiusculus Zone) and probably the lower part of the N. gracilis Zone.

3. The transitional stratum deposited above the carbonate platform during the early development of the foreland, where the allochthons entered, is the euxinic Hershey/Myerstown Formation. It is older than comparable units (Jacksonburg Formation, northeast of the H/MFS and 'basal limestones' southwest of the M/HFS) of the foreland bordering the area where the allochthons were emplaced.

4. It is proposed that the earliest foreland deposits in the M/HFS, designated Unit M-1, were deposited as synorogenic flysch during N. gracilis Zone (sensu Riva) time in a piggyback basin on top of the initially emplaced allochthon(s), Unit H-1.

5. It is proposed that allochthonous Unit H-1, north of the Yellow Breeches thrust, correlates with the Cocalico-like rocks above the Yellow Breeches thrust, and at least part of the rocks of the Cocalico Formation to the south. The Unit M-1 (= Cocalico) package was emplaced above the Hershey/Myerstown Formation in the developing foreland basin.

6. The Hamburg allochthons, emplaced during the early development of the foreland basin, derived from an advance along the diachronous Taconic front. These allochthons probably detached from an initially obducted Westminster terrane composed of sediment deposited in the Octoraro Sea between Laurentia and the Baltimoria microcontinent.

7. Allochthon Unit H-2 was emplaced above the synorogenic foreland basin Unit M-1 during C. bicornis Zone time.
8. After emplacement of allochthonous Unit H-2 the foreland basin infilling continued and developed laterally as Unit M-2, primarily as distal turbidites, during late C. bicornis Zone time. Foreland basin deposition now occurred northeast and southwest of the M/HFS. Minor sized allochthonous debris continued to enter Unit M-2.

9. Conditions in the foreland shallowed from deep turbiditic to deltaic between C. americanus and C. spiniferus Zone time.

10. The Martinsburg age stratigraphy at Shochary Ridge in the eastern M/HFS can be correlated with the stratigraphy from Swatara Gap through the Lickdale section, and projected westward to Susquehanna Gap at Harrisburg.

11. The northern portion of the western half of the H/MFS is the overturned northern limb of a large inverted antiform which repeats as an upright limb in the southern portion.
CHAPTER 3. RECONSTRUCTED STRATIGRAPHY OF BASIN DEPOSITS ADJACENT TO BALTIMORIA FROM ALLOCHTHONOUS ROCKS OF THE CAMBRIAN - MIDDLE ORDOVICIAN HAMBURG SUCCESSION.

INTRODUCTION

The Hamburg succession is the stratigraphic record of allochthonous rocks within Stose’s (1946) Hamburg klippe. I prefer the alternative interpretation of Platt et al. (1972) that the allochthonous rocks were emplaced within the Martinsburg foreland basin. Ganis et al. (2001) named the Dauphin Formation as the inclusive unit for the rocks comprising the allochthonous strata. Scattered allochthons and olistoliths of the Hamburg succession record a depositional history for basinal sedimentation that probably occurred adjacent to Baltimoria (an informal name for the Baltimore–Brandywine microcontinent(s) of Thomas, 1977; Lash and Drake, 1984; and Faill, 1997) during the Late Cambrian to Middle Ordovician. The controversy over whether the Baltimore – Brandywine terrane represents a microcontinent(s), or merely a rifted portion of Laurentia is summarized in Horton et al. (1989) and Faill (1997). The stratigraphy of the allochthonous Hamburg succession appears to demonstrate a distinctly non–Laurentian character, representing sediment deposited within the Octoraro Sea (of Faill, 1997; figs 11 and 12) derived from Baltimoria. As such, these rocks would have once been part of the Westminster terrane (sensu Faill, 1997), the collective name for the sediments deposited within the Octoraro Sea.

The Hamburg succession contains only basinal sediments, including lime turbidites, and no shallow shelf–deposited strata have been noted. The carbonate shelf sediment deposited contiguous to Baltimoria is believed to be the Cockeysville marble of the Glenarm Series (of Knopf & Jonas, 1923; as explained in Faill, 1997, p. 563), but no discernible trace of this succession has been found as allochthons in the Martinsburg foreland, nor has any part of the crystalline basement of Baltimoria been found there. The structural separation of the Hamburg allochthons appears to have excluded both the crystalline rocks comprising the microcontinent(s) and most, if not all, its shelf sediment cover.

The basinal sediments of the Hamburg succession range in depositional age from Late Cambrian to Middle Ordovician (late Darriwilian 3 to early Darriwilian 4a; see Chapter One). The absence of rocks older than late Cambrian may reflect the detachment level within the Westminster Terrane for allochthons that moved northwestwards (present-day orientation). The record of sedimentation between the Late Cambrian and Mid-Ordovician for the Hamburg succession is incomplete, fragmented, and scattered, and strata representing the late
Arenig through early Middle Ordovician have not been found. Rocks from this missing interval may yet be discovered, but it might be speculated that their absence is related to the structural history of the Octoraro Sea closure.

The work by Ganis et al. (2001) identified Late Cambrian (?) – early Arenig olistoliths within a Middle Ordovician matrix in the western half of the Martinsburg/Hamburg foreland segment (M/HFS; a name applied to that part of the Martinsburg foreland containing the Hamburg allochthons). Both the olistoliths and the olistostromal matrix were dated with graptolites or conodonts. Although the existence of rocks older than the Martinsburg Formation in the M/HFS has been known since the 1940’s (reviewed in Ganis et al., 2001, p.110), their structural and stratigraphic relationships were poorly known and speculative.

This study combines the available information in the literature with new field data reported here, to construct a stratigraphy from the scattered allochthonous rock found in the M/HFS. The rocks used to construct this stratigraphy are restricted to strata associated with datable fossils. Parts of the succession are unfossiliferous and, therefore, cannot be placed within a coherent stratigraphy. It is also apparent that much of the mid-to-lower slope and basin plain deposits were quite variable in facies. This means that the stratigraphic character for any particular time interval at one location might appear as a different facies at some other removed location. Nonetheless, this exercise of compiling a stratigraphic column from disjointed parts is useful as a guide to the overall sedimentological conditions and facies variations in deposits contiguous to Baltimoria through time.

This reconstructed stratigraphy also records the geologic history of Baltimoria, as reflected in its sedimentological derivatives. Clues to the palaeoposition, palaeoclimatology, eustatic level, tectonic history, and bioprovincial association of Baltimoria may be found in this record.

**STRATIGRAPHIC SECTIONS**

The localities mentioned below can be found on Figure 1. A composite stratigraphic column (Fig. 2, in pocket) has been constructed for the allochthonous rocks of the Hamburg succession from a variety of published and new data presented here. These allochthonous rocks are scattered throughout the M/HFS as structural slices and/or olistoliths in younger matrix.

**Cambrian Strata**

Carbonate beds (mostly limestone), commonly associated with black shale, are widely distributed throughout the M/HFS. Some exposures have been dated with conodonts as Late Cambrian (Trempealeauan). Stratigraphically below the carbonate/black shale
Geology near Harper Tavern

Locations referenced in text.

FIGURE 1. Locations referenced in text and geology near Harper Tavern
association are non-carbonate successions of micaceous, feldspathic siliciclastic rocks which are dominantly sandstone with lesser siltstones and minor shales. This lower siliciclastic portion has not been dated, but it is no younger than Trempealeauan.

Lash and Drake (1984) named the lower siliciclastic succession the Sacony Member of their Virginville Formation. A distinctive feature of this member is the high plagioclase feldspar content of the coarser lithologies. The feldspar content (plagioclase greatly exceeds K-feldspar) of the Sacony Member sandstones from their Richmond slice (though I do not advocate the existence of the Richmond slice as a coherent lithotectonic unit) in the eastern half of the M/HFS was reported by Lash and Bembia (1984, p.107) to range between 40 – 52 percent. They also report that the plagioclase is dominantly albite and oligoclase and that heavy minerals include biotite, euhedral zircon, apatite, tourmaline, hornblende, and opaques. Lash and Drake (1984, p.17) and Lash and Bembia (1984 p. 105) recorded a minimum thickness of the Sacony Member to be 245 m.

I have identified a succession very similar to the Sacony Member of Lash and Drake (1984) and Lash and Bembia (1984) in the western half of the M/HFS. The exposures of the Sacony-like strata are found near Harper Tavern, PA (see Fig. 1) as large structurally disconnected masses that appear to be regionally contained within younger Middle Ordovician flysch (Nyes Road Member of Ganis et al., 2001) in a manner similar to the olistoliths of the Shellsville Member described by Ganis et al. (2001). However, the largest of these “olistoliths” in the Harper Tavern area, the Indiantown section, is on the order of 1.5 km long and 126 m thick, which might be interpreted by some as a structural slice interleaved with the younger surrounding strata rather than contained within it as a sedimentological olistolith. However, whatever the preferred terminology, the older strata are broken and stratigraphically discontinuous from other correlative rock sections, and the widespread, stratigraphically continuous, country rock is a consistently younger flysch which does contain demonstrable olistoliths to the west (see Ganis et al., 2001).

The stratigraphic sections comprising the Sacony-like strata found near Harper Tavern are shown on Figure 3 (in pocket). Lash and Drake (1984) and Lash and Bembia (1984) do not provide detailed stratigraphic sections of the Sacony Member, but do describe its general make-up. In Figure 3 (in pocket), I attempt to correlate their general descriptions of the Sacony Member with the Indiantown section and the Route 22 section near Harper Tavern. Thin sections from the basal micaceous sandstones at these two sections are comparable to the petrology of the Sacony Member provided by Lash and Bembia (1984). Like the Sacony Member, the basal sandstones of the Indiantown and Route 22 sections are poorly sorted and highly feldspathic (plagioclase dominant) with mostly angular quartz. Micaceous siltstones
interbedded with the Sacony Member described by Lash and Drake (1984) were also found in the Indiantown and Route 22 sections.

Lash and Drake (1984) also reported interbedded greyish-green to pale blue-green micaceous shale and mudstone within the Sacony Member. A minor amount of black (highly carbonaceous) mudstone was found in the Sacony-like part of the Indiantown and Route 22 sections, but no green or blue-green shale or mudstone was noted. However, the thicker Sacony-like part of the Indiantown section is only 55 m thick, and has some unexposed portions, compared with the 245 m reported for the Sacony Member by Lash and Drake (1984). The lesser thickness of the Sacony-like strata in the Indiantown section probably indicates a less complete section than the Sacony Member strata described by Lash and Drake (1984). They also described (p.17) minor amounts of chert with highly cleaved black, grey, and light green thinly laminated silicified shale, interbedded with the sandstone and siltstone in the Sacony Member. I did not field check this observation in their study area, but, to the extent Lash and Drake (1984) felt these units were distinct from the other lithologies in the Sacony succession, it can be speculated that they may be younger Middle Ordovician units enclosing Sacony fragments as olistoliths. Fossil evidence could verify or refute such a conjecture, but the description of these rocks seems to fit the Middle Ordovician Shellsville Member strata containing olistoliths described by Ganis et al. (2001).

Presumed allochthonous Hamburg succession rocks were described by Root and MacLachlan (1978) at the western edge of the M/HFS as discrete allochthons within the Martinsburg foreland. Their Enola allochthon contains a variety of rock units, among which are “greenish-grey to greyish green, coarsely micaceous mudstones and siltstones”. Although undated, these strata may correlate with the Sacony Member.

At the Indiantown and Route 22 sections, at what I interpret as the top of the Sacony-like strata, a distinctive phosphatic interval occurs. The most P₂O₅-rich lithology is coarse-grained and fragmental, containing black phosphatic nodules (Figure 4), but mixed phosphatic-glauconitic sandstones are also present (Figure 5). The coarse-grained lithologies comprise an interval about 5m thick, which locally have an algal bloom on weathered surfaces resulting from a “fertilizer-like” decomposition of the rock (Figure 6). Some of the coarse fragmental rock contains masses of marcasite and spheroidal nodules of radial goethite pseudomorphs after marcasite (?) (Figure 7). A grab sample from the phosphate-glauconite sandstone lithology has a P₂O₅ content of about 6 percent and the black shale just above contains 1.5 percent P₂O₅. The P₂O₅ content of the thicker black shale strata above that interval was not investigated. A small amount of minute authigenic euhedral barite was also
Figure 4. Coarse-grained and nodular phosphatic rock.

Figure 5. Phosphatic-glaucnitical sandstone.
Figure 6. Coarse phosphatic beds at the Route 22 section.

Figure 7. Spheroidal nodules of goethite after marcasite. The spheres are broken in half to show a hemisphere with internal radial structure; complete spheres are preserved on some specimens.
seen in a microprobe scan of the phosphatic rock. This scan also revealed that the composition of the phosphate mineral(s) present is consistent with apatite. No macrofossils have been seen in the phosphatic rock but fossil fragments were seen in thin section.

The phosphatic section occurs at the top of a siliciclastic interval which was probably deposited rapidly, and just below a significant transition to dominantly carbonate turbidite deposition. Phosphatic accumulation requires slow depositional conditions and contrast with periods of high terrigenous input (Slansky, 1986). The interbedded laminated black shale with glauconitic sandstone and coarse fragmental phosphatic rock fits the general description of the "Zone D" facies of transported hemipelagic phosphorite described by Föllmi (1990: see his fig. 5, p. 244). Föllmi (p. 237) commented, "Condensed phosphatic sediments form in marine enviroments, characterized both by lowered net sediment-accumulation rates and episodic sediment remobilization, and by (bio-) chemical conditions suitable for phosphogenesis". O'Brien et al. (1990) stated that, "Apatite and glauconite formation are favoured by periods of high sea-level and low current velocities...", so the phosphatic interval in the Hamburg succession records a radical transition of basinal deposition, and may reflect a marked change in sea level, shelf enviroment, and climatic conditions experienced on the western (present-day orientation; the palaeo-orientation would have been north) margin of Baltimoria. No such record is seen on the eastern margin of Laurentia where conditions at the time reflected a stable carbonate platform. Baltimoria is believed to be a microcontinent that first rifted/drifted away from Laurentia during the Cambrian and early Ordovician, and then migrated westward toward Laurentia during the closure of the Iapetus Ocean and the Octoraro Sea in the Mid-Ordovician (see discussion in Faill, 1997). The climatic conditions, depositional characteristics and apparent eustastic levels recorded in the Hamburg stratigraphy are likely a reflection of the unique conditions, including, probably, tectonically induced changes in water depth, experienced by the migrating microcontinent rather than hemispheric or global conditions.

Above the Sacony Member, and the phosphatic interval at its top, Lash and Drake (1984) recorded and named the Onyx Cave Member. Interestingly, they did not describe a phosphate interval, but, because that is only about 5 m thick in the Indiantown and Route 22 sections, it could have been easily overlooked, and the moderately elevated phosphatic content of the black shale is only discernible with chemical analyses. Lash and Bembia (1984) summarized the content of the Onyx Cave Member as, "black shale and thinly laminated limestone at the base that grades into thin-to-thick-bedded ribbon limestone, and limestone clast conglomerate at the top". That succession indicates a deep water environment with facies variations reflecting turbiditic carbonate grain flow input and channeling into an
environment where carbonaceous mud steadily accumulated (see also discussions of sedimentology in Lash and Bembia, 1984, and Lash and Drake, 1984).

Strata matching the general description of the Onyx Cave Member occur, in the same stratigraphic order, at the Indiantown and Vesle Run sections near Harper Tavern, PA (see Fig 1), and elsewhere in the eastern half of the M/HFS (i.e. Root & MacLachlan, 1978, p. 1521; Berkheiser, 1984, discussed below). A correlation of these sections with the Onyx Cave Member is proposed and shown on Figure 3 (in pocket). Lash et al. (1984) report that the Onyx Cave Member is Late Cambrian in depositional age from recovered conodonts. Late Cambrian conodonts were also recovered from a limestone unit containing abundant well-rounded and frosted sand grains at the Vesle Run section. Lash et al. (1984) and Lash and Drake (1984) noted the same type of well-rounded sand grains as a distinctive feature of the Onyx Cave Member. The presence of well-rounded, frosted sand grains suggests an arid environment on the western fringe of Baltimoria at this time. Like the Onyx Cave Member, the Indiantown and Vesle Run sections also contain ribbon limestone (Figure 8), limestone conglomerate, and massive bedded quartzose limestone (Figure 9).

Berkheiser (1984) described a thick black shale/limestone succession with sections containing nodular barite in western Berks County, which is roughly the centre of the M/HFS. The black shales associated with the barite nodule deposits also have a low P$_2$O$_5$ content ranging from 0.2 to 1.0 percent, and one pyritic sample was 5.9 percent P$_2$O$_5$. Samples of the limestone from the Bohn Farm location of Berkheiser (1984) yielded a Late Cambrian conodont age (J.R. Repetski, U.S.G.S., personal communication, 2001). It would appear that this succession, at least partially, correlates with the phosphatic transition and black shales of the Onyx Cave (Lash and Drake, 1984) and similar rocks at the Indiantown and Route 22 sections. However, Berkheiser (1984, p. 39) indicated that this section is roughly 470 m thick, which far exceeds the 90 m for the Onyx Cave Member of Lash and Drake (1984) or the 76 m of correlative Onyx Cave-like plus phosphatic beds for the Indiantown section. Possibly, the Berkheiser section may be affected by structural thickening. Within his broad area of black shale outcrop, near the village of Hamlin, a thin (± 5 cm) metabentonite was found in a small borrow pit (since filled in). There is no known correlation to this ash bed, but the island arc south (paleo-orientation) of Baltimoria in the Iapetus is a possible source. There are no reported Late Cambrian ash beds in the Laurentian carbonate succession.

Ordovician Strata

TREMADOC

The Late Cambrian limestone and black shale association comprising the Onyx Cave Member in the eastern half of the M/HFS and correlative sections near Harper Tavern in the
Figure 8. Ribbon-bedded limestone, Indiantown Section. 5 cm black lens cap for scale.

Figure 9. Massive-bedded quartzose limestone, Indiantown Section. 2 m measuring staff for scale.
western half, continue into the Early Ordovician Tremadoc (early Ibexian), found as an olistolith described by Ganis et al. (2001). Here the olistolithic nature of the rock is more certain, as Middle Ordovician (Llanvirn) matrix (the Shellsville Member of the Dauphin Formation) can be found as a widespread background unit, which also contains other olistoliths of Arenig age. The strata comprising the Early Ordovician (Tremadoc) section found in the Gravel Hill Road olistolith occur at the junction of Rt. 22 and the Dauphin/Lebanon County line (Ganis et al., 2001; their fig. 5). That section is reproduced here as Figure 10, and is indicated on the compilation succession shown on Figure 3 (in pocket). The Tremadoc strata of the Gravel Hill Road olistolith commence with a few metres of thick-bedded limestone, with shaly partings, in the lowest part of the section. Above that is mostly fissile shale, grey-green in the lower part and black above. This section marks a transition from dominantly carbonate/black shale facies to mostly fine siliciclastic deposits.

A few large carbonate cobbles from polymict carbonate/clastic conglomerate (olistoliths) have been found, contained within the early Martinsburg Formation 0.7 km north of locality G-25 of Ganis et al. (2001, p.112), These carbonate clasts differ from the Cambro-Ordovician, deep-water origin carbonates of the Hamburg succession in yielding macrofossils as well as mid-continent province conodonts which are Early Ordovician in age (J. Repetski, personal communication, 2001). One cobble of bioclastic, intraclastic grainstone yielded a small collection of well-preserved trilobites in which at least five Early Ordovician genera are present. They include a leiostegiid, an asaphid, a remopleurid, and a bathyurid (J. Taylor, personal communication, 2003). Both the lithology and the fauna (especially the presence of a bathyurid) suggest a Laurentian platform environment. A possible origin for these conglomerate clasts is from eroded fragments of upscraped platform debris, generated during overthrusting of the Hamburg rocks onto the Laurentian margin and carried forward with the allochthons.

A 2.2 m section of ribbon limestone in the Gravel Hill olistolith, at the Tremadoc/Arenig boundary, is one of the stratigraphically higher carbonate units in the Hamburg succession. Other than an occasional calcareous siltstone, the carbonate input appears to have waned early in the Arenig. This is a preliminary conclusion because most of the carbonate rock is turbidite-derived, and so, can be erratically distributed. Epstein et al. (1972) described a limestone turbidite block, enclosed within green mudstone, which was dated with conodonts as early Arenig age, in the eastern part of the M/HFS. Sedimentation during the Tremadoc was also slow as the entire series, representing approximately 11my (Cooper, 1999), is contained within only 161.5 m (Ganis et al., 2001).
Figure 10. Tremadoc Section in the Gravel Hill Road Olistolith. Copied from Ganis, et al. (2001, Fig. 5, p.114).
ARENIG

Higher in the Ordovician, other olistoliths described by Ganis et al. (2001), dated with graptolites, represent strata of the lower Arenig Series. They described three Arenig age olistoliths in eastern Dauphin and western Lebanon counties as individual exposures surrounded by Middle Ordovician (Llanvirn) Shellsville Member matrix. These olistoliths are composed of clastic hemipelagites of variegated, thin to platey-bedded, shales and siltstones. The graptolites are mostly found in thin anoxic black shale interbeds, but not exclusively. In addition to these Arenig age olistoliths, an exposure of Arenig age (Didymograptus bifidus Zone) black shale was found just west of the Lebanon- Berks county line in the embankment cut of the ramp from Interstate 78 to Route 22. A large exposure of variegated shales and siltstones on Interstate 78 (west-bound lane) right at the county line nearby is the same Llanvirn age and lithology as the Shellsville Member. Thus, the pattern of older fragments (olistoliths) associated with an olistostrome matrix, consistently of Middle Ordovician age, occurs over a large part of the M/HFS.

Willard (1943) described two beds containing Arenig age graptolites (he referred to them as Deepkill age) from Susquehanna Gap (location on Fig. 1). The site of these localities appears to have been lost due to subsequent road construction. These localities were the original discovery of rocks older than the Martinsburg Formation found within the belt of that formation that prompted Stose (1946) to propose the Hamburg klippe.

Collectively, the Arenig age fragments are restricted to the lower half of that series and no Arenig strata above the Isograptus victoriae lunatus Zone have been reported. The next reported record of sedimentation in the succession is low (?) to middle Llanvirn, representing a gap of three to four graptolite zones. The Arenig section is also apparently quite condensed with individual fragments never amounting to more than a few tens of metres (Ganis et al., 2001; and data this study), although it is not possible to know how much of the original succession is missing.

The stratigraphic gap in the Hamburg succession above rocks younger than the Arenig Isograptus victoriae lunatus Zone ends in the mid-Llanvirn (late Darriwilian 3 to early Darriwilian 4a) for non-pelagic facies rocks where sedimentation resumed with hemipelagites and clastic turbidites. The earliest pelagic sedimentation is recorded in strata for which the biostratigraphic position is less precisely known and can only be restricted to early to middle Llanvirn. It was during this time that thick sections of pelagic sedimentary rock were deposited, consisting of red, green, and tan shale, sometimes with chert or siliceous shale, and occasionally with thin carbonate turbidite layers recorded. Although minor red or green shale, possibly representing interfingering of pelagic facies, occurs sparingly in other hemipelagite
and turbidite facies units elsewhere in the succession, the thicker (greater than 10 m),
dominantly pelagite facies, represent a distinct stratigraphic subdivision (i.e. Manada Hill
Member of Ganis et al., 2001). Sections of red and green shale, with accessory lithologies
described above, have been noted in the Hamburg succession by many prior workers (e.g.
Root and Maclachlan, 1978, as part of their Enola allochthon). The presence of these non-
Martinsburg strata supports the Hamburg klippe model and/or the concept of allochthons in
the Martinsburg foreland. Wright and Feeley (1979) determined that red shales had a higher
$\text{Fe}_2\text{O}_3 / \text{FeO}$ ratio relative to green shales. They agreed with Ziegler and McKerrow (1975)
that oxidized iron compounds, eroded from pre-land plant sources, would have been plentiful,
and would subsequently be reduced to greenish grey marine sediment in the presence of
adequate organic matter, but would be red where organic matter was insufficient. Lash et al.
(1984) discussed the pelagic aspect of these rocks, comparing them with radiolaria-bearing
cherts, and red pelagic clay accumulations in modern deep ocean environments.

The pelagic rocks have been dated with conodonts which occur as internal moulds or,
rarely, in thin lag siltstones in high concentrations. Several of the thicker sections of pelagites
have been dated but, for the most part, these rocks, which are widely distributed throughout
the M/HFS, have not been biostratigraphically investigated. Therefore, their distribution in the
stratigraphy described here should be considered preliminary. Two of these sections, which
were dated with conodonts, are summarized on Figure 11 (in pocket). The Lenhartsville
section has been dated with conodonts as Darrwilian 2-4 (J. Repetski, personal
communication, 2003), and was erroneously reported as early Arenig age by Ganis (1997).
This 40 m section is a series of red and green slates and shales (Figure 12) and contains 4 thin
($\pm$ 5 cm) ash (metabentonite) beds (Ganis, 1997). The footwall of the exposure has the lowest
ash bed within a shale unit containing carbonate nodules (Figure 13). No ash beds of similar
age have been record in the Laurentian margin succession.

The Manada Hill section (Figure 14) is the type locality for the Manada Hill Member
of Ganis et al. (2001) and is about 370 m thick. The lower, approximately 20 m is reddish
(maroon) shales with chert. The chert layers are 10 – 15 cm thick that form sets with 2 – 6 cm
of shale with sharp contacts (Figure 15). Similar rhythmic chert/shale sets were described by
Nisbet and Price (1974) from the Neraida cherts of the Othris Mountains, Greece and
attributed to low density turbidity currents near a mid – ocean ridge. The remainder of the
section is alternating red (maroon) and tan shales with minor chert or siliceous shale.
Conodont data (J. Repetski, personal communication, 2003) indicate that the Lenhartsville
and Manada Hill sections are of Darrwilian 2-4 and Darrwilian 3-4 depositional ages,
Figure 12. Pelagic rocks, Lenhartsville Section (40°34'23" N, 75°52'35" W). Height of face in background approximately 10 m.

Figure 13. Ash bed (metabentonite) interbedded with shale and containing carbonate nodules, Lenhartsville Section.
Figure 14. Manada Hill Member at Manada Hill. Height of face approximately 10 m.

Figure 15. Chert/Shale sets in the Manada Hill Section. Pen is 15 cm long.
respectively (= early to mid- Llanvirn). However, at Manada Hill there is an unconformity at the top of the pelagites above which are Caradoc turbidites. The interpretation of this sequence is that the pelagites are part of an allochthon (Unit H-1) that moved into the Martinsburg foreland basin with turbidites deposited above in a syntectonic piggyback basin (see Chapter Two). Such turbidite deposition is most likely to have occurred following the deposition of the allochthon strata; therefore, the Lenhartsville pelagite section probably represents an older phase of sedimentation than the Manada Hill pelagite section.

During late Darriwilian 3 to early Darriwilian 4a time (see Chapter One) the mid-Arenig and older non-pelagic strata were reincorporated as olistoliths into younger units. The evidence for this cannibalizing event, which formed the Shellsville olistostrome, was described in Ganis et al. (2001). The extent to which the olistostrome contains olistoliths of wholly pelagic facies rocks (other than minor interbeds within hemipelagites and turbidites) is not known, but no wholly pelagic-facies rocks have been identified to date. However, black shale/limestone packages and other lithologies resembling the Onyx Cave Member strata (described above), as well as Arenig age hemipelagites, have been recorded as olistoliths. The matrix of the olistostrome comprises both hemipelagites, consisting of variegated, thin-to-platey-bedded shales and siltstones (Figure 16), as well as clastic turbidites and debris flow deposits. Some exposures show soft sediment slumping (Figure 17). The Jonestown volcanic suite of pillow basalts and diabase appears to have been extruded onto the Shellsville olistostrome and intruded into the Nyes Road turbidites (see Chapter Two).

The late Darriwilian 3 to early Darriwilian 4a interval is also when the Hamburg succession records the first large-scale clastic Bouma turbidites (Figures 18 & 19; Nyes Road Member). These turbidite events formed submarine fans at the base of slope and cut through or covered other hemipelagites and pelagites. Although only some Darriwilian turbidite exposures show interbedding with red shale pelagic facies (Figure 19), this feature is a key indicator of strata of this time. These successions may be contrasted with later Caradoc turbidites formed in the Martinsburg foreland basin, which are never interbedded with red shale pelagites. The localized beds of red shale pelagites within the thick Bouma successions of the Nyes Road Member probably record slow, deep ocean sedimentation on top of turbiditic fans, which were, in turn, covered by later turbiditic events. It is worth noting that the younger Caradoc turbidites of Nemagraptus gracilis age in the M/HFS were interpreted by most prior workers as allochthonous and not part of the Martinsburg Formation. I interpret these younger turbidites as a piggyback basin deposited atop incoming allochthons within the early development of the Martinsburg foreland basin, and not part of the Hamburg succession, sensu stricto, which formed in the Octoraro Sea (see Chapter Two).
Figure 16. Shellsville Member hemipelagites. Hammer against face near centre for scale.

Figure 17. Soft sediment slumping in the Shellsville Member. Exposure near Figure 16, but now removed by excavation. U.S. 25 cent piece for scale.
Figure 18. Bouma A-B sequences, Nyes Road Member turbidites. Rock hammer in centre for scale.

Figure 19. Interbedded turbidites and red shales (pelagites), Nyes Road Member (type locality).
DISCUSSION

The stratigraphy of the Hamburg succession reconstructed herein is undoubtedly incomplete, but does allow for some preliminary and general comments about the geologic history of the western (present orientation) Baltimoria basin. These basinal deposits, now found in the Hamburg allochthons, were probably deposited within the Octoraro Sea (sensu Faill, 1997). As such, their content reflects the history of microcontinental migration, which gives the Hamburg succession a distinct character, differing from the history of the Laurentian margin during the same time. The following is a summary account of the strata deposited in that basin, and recorded in the Hamburg allochthons.

The earliest record of deposition in the Hamburg succession is clastic sediment of the Sacony Member of Lash and Drake (1984) and similar strata reported as olistoliths by Ganis et al. (2001). The unit above the Sacony strata is the Onyx Cave Member of Lash and Drake (1984), which also has olistolithic counterparts described by Ganis et al. (2001). The Onyx Cave strata have been dated with conodonts as Late Cambrian and the Sacony sections are probably of similar age. The Sacony strata are composed of poorly sorted, quartzose, plagioclase-rich, micaceous sandstones with micaceous siltstones above. That reflects an environment characterized by rather rapid sedimentation. Lash and Drake (1984) referred to Basu (1976) in noting that plagioclase is not stable in a humid climate, which might indicate an arid environment source for the Sacony depositional interval.

Lash and Bembia (1984) described the source of the Sacony strata as igneous and metamorphic cratonic rocks of high relief that they attributed to horsts of Laurentian basement. The Baltimore and Brandywine massifs, believed to be the remnants of Baltimoria, have a composition different from native Laurentian basement and do not have late Proterozoic “Blue Ridge” dykes as found in Laurentian Grenvillian rocks (see discussion in Horton et al., 1989 and Faill, 1997). For these reasons a microcontinent as a source for the Sacony strata is preferred over Laurentian horst. This preference of source for the quartzofeldspathic, Sacony units of the late Cambrian Hamburg succession, is not related to the Late Proterozoic-Early Cambrian Iapetian rift basin of Valentino and Gates (1994) proposed for the origin of the Peters Creek Formation. The Peters Creek is an Octoraro Sea deposit (Faill, 1997, p. 569), but its proximity to Laurentia during deposition is only loosely constrained. The Peters Creek Formation is rich in K-feldspar, whereas the Sacony strata are plagioclase-rich, so they are not obviously related. This illustrates a possible difference between Laurentian-sourced (Peters Creek) versus microcontinent-sourced Sacony petrology.

At the top of the Sacony strata, reported herein, a major change in the sedimentological regime occurred. As noted above, a redeposited phosphorite unit occurs
above the Sacony strata and just below the Onyx Cave strata. Lash and Bembia (1984) make the following statement regarding the transition from Sacony facies to Onyx Cave facies; 

"The change from quartzofeldspathic to black shale sedimentation in the Late Cambrian (Fig. 5b) tells of rapid subsidence in which (1) the quartzofeldspathic source was no longer contributing sediment and (2) basin subsidence exceeded sedimentation rate". The effects of subsidence as the cause of the loss of source relief is speculative, and was made by Lash and Bembia (1984) in the context of off-Laurentia fault blocks, as opposed to a microcontinent source. It is possible that the microcontinent’s relief (adjacent to its edge facing the Octoraro Sea) was gradually reduced by base level erosion, as deduced from the sandstone to siltstone transition in the stratigraphy. That succession was then covered by the phosphorites during a period of very slow sedimentation.

However, the black shale/ limestone turbidite deposition comprising the Onyx Cave strata could have been initiated by basin subsidence. The phosphorite deposition found just below the Onyx Cave, reported herein, is favoured by high sea level, perhaps caused by subsidence of Baltimoria facing the Octoraro Sea rather than by eustatic sea level rise. The Onyx Cave deposition continued through the end of the Cambrian and into the Early Ordovician; however, some sections (e.g., the Gravel Hill olistolith, Ganis et al., 2001) show that the carbonate grainflow input was diminishing through Tremadoc time. There are still some carbonate turbidites in the earliest Arenig (Tetragraptus approximatus Zone) succession but, after that time, the carbonate input all but ceased, and was replaced by clastic hemipelagites. However, the record of Arenig deposition comes from small, isolated and widely distributed olistoliths, representing an incomplete section. The youngest Arenig example found is the Hill Drive olistolith, which has a graptolite fauna from the Isograptus victoriae lunatus Zone at its western end (Ganis et al., 2001). The Onyx Cave Member of Lash and Drake (1984) does not include rocks like the Arenig age olistoliths above the T. approximatus Zone level. The Arenig hemipelagites are lower slope deposits consistent with sedimentation adjacent to an accretionary prism.

No strata of late Arenig age have yet been found in the Hamburg succession. Pelagic sedimentation may be represented just above the highest part of the Arenig succession (= Darriwilian 2), but the conodonts found in those strata are long-ranging and could be as young as late Llanviri (Darriwilian 4). For hemipelagite and turbidite deposition the stratigraphic gap above the I. v. lunatus Zone extends to the late Darriwilian 3 to early Darriwilian 4a Zone where both facies resume. The existence of this stratigraphic gap is somewhat speculative because rocks of this missing interval might only be represented as rare olistoliths of highly condensed strata that simply have not been found in the poorly exposed geology.
However, the existence of a possible gap in the stratigraphic record, which resumes with the earlier strata reincorporated into an olistostrome (Ganis et al., 2001) of one narrow biostratigraphic interval (late Darriwilian 3 to early Darriwilian 4a), may have tectonic significance. These circumstances suggest that the early Arenig and older deposits were uplifted during the time of the stratigraphic gap, which positioned the strata to slide or erode into a subsequent trench. The convergence of Baltimoria toward Laurentia during the early Middle Ordovician is a probable mechanism for stacking (and thickening) of the pre-convergence strata formed at the microcontinent’s margin. The subduction of Laurentia beneath the converging Baltimoria block (shown diagrammatically as fig. 11c of Faill, 1997) would generate a trench, and the olistostrome is consistent with a trench fill deposit. The thick clastic turbidites (Nyes Road Member of Ganis et al., 2001) deposited during this same interval are a coarsening-up succession that is characteristic of plate movement towards a trench (Moore and Karig, 1976; as suggested for the Hamburg succession by Lash, 1985).

The long history (Cambrian through Middle Ordovician) of Baltimoria first rifting/drifting away from Laurentia, and then converging towards the continent (Faill, 1997) would, presumably, allow a long period of potential pelagic sedimentation in the Octoraro Sea. However, pelagites have only been recorded in the Hamburg succession in Middle Ordovician deposits over an interval that can only be restricted to Darriwilian 2-4, based on the conodonts recovered. The apparent incomplete record of pelagic sedimentation (most of the pelagite deposits have not been dated) in the Hamburg succession might be related to deep burial of sediment in a trench, structural dislocation, or their distal position relative to the construction of the Hamburg strata into incipient allochthons.

However, in Darriwilian age successions, distinct sections of pelagic facies rocks are preserved in allochthons of the Hamburg rocks. Minor pelagites are also found interbedded with clastic turbidites.

The final history of the Hamburg succession is entirely structural. The biostratigraphic evidence (see Chapter One) supports a model whereby no strata younger than early Darriwilian 4a were deposited in the Octoraro Sea and convergence trench before obduction of the Hamburg succession occurred on to the Laurentian margin initiating the Martinsburg foreland basin across the divide. Fragments of allochthons on many scales, derived from the rising hinterland, slid or were thrust into the foreland starting in the Nemagraptus gracilis (or possibly low C. bicornis) Zone times during the early Caradoc (lowest Late Ordovician).
CONCLUSIONS

1. Basin sediments deposited adjacent to the Baltimoria microcontinent within the southern portion of the Octoraro Sea (*sensu* Faill, 1997) are recorded in the Hamburg succession (Dauphin Formation of Ganis *et al.*, 2001).

2. Rocks of the Hamburg succession are found as dislocated allochthons within the Martinsburg/Hamburg Foreland Segment (M/HFS). The Late Cambrian through Early Ordovician rocks are found as olistoliths within a Middle Ordovician matrix in at least the western half of the terrain.

3. The oldest rocks yet found in the Hamburg succession are the Late Cambrian Sacony strata (the Sacony Member of Lash and Drake, 1984 and similar olistolithic bodies of rock in the western M/HFS). The Sacony strata are dominantly composed of quartzofeldspathic (plagioclase-rich) sandstones grading upwards to micaceous siltstones.

4. The Sacony strata record a period of coarse siliclastic input derived from the igneous-metamorphic bedrock of the microcontinent source-rocks. The plagioclase content of the "Sacony" contrasts with Laurentian-sourced Cambrian age (?) microcline-rich sandstones of the Peters Creek Formation of the Westminster Terrane.

5. There is a transported phosphatic/glauconitic interval approximately 5 m thick above the Sacony strata, representing a period of low sedimentation rate and/or high sea level.

6. The Onyx Cave strata (the Onyx Cave Member of Lash and Drake, 1984 and similar olistolithic rock bodies in the western M/HFS, Ganis *et al.*, 2001, and this study) are a thick accumulation (hundreds of metres in some sections) of black shale and limestone above the phosphatic interval. The limestone is both ribbon-bedded and thickly-bedded, and commonly contains well-rounded quartz sand grains. This interval probably records basinal subsidence. Late Cambrian conodonts have been found from several locations within these rocks.

7. The Early Ordovician Tremadoc rocks, a continuation of the Onyx Cave strata, are found in a relatively condensed section 161.5 metres thick in the Gravel Hill Road olistolith (Ganis *et al.*, 2001). Minor limestone beds are found at the base and top of the succession with graptolitic shales, siltstones, and minor chert comprising most of the section.

8. The Early Arenig is represented by clastic hemipelagites found as olistoliths.
9. No Late Arenig (post *Isograptus victoriae lunatus* Zone) through Early Llanvirn (Darriwilian 1? - 3?) rocks have been located. This may be an interval when the older rocks were structurally stacked as the microcontinent converged towards Laurentia.

10. The Laurentian margin subducted beneath the approaching microcontinent (see Faill, 1997, fig. 11c), resulting in a trench. In this setting, the older stacked rocks of the Hamburg succession were reincorporated into a Middle Ordovician (late Darriwilian 3 to Early Darriwilian 4a) olistostromal complex (Shellsville and Nyes Road members of Ganis et al., 2001). The Jonestown volcanic complex was probably intruded/extruded at this time.

11. Distal pelagites (Manada Hill Member of Ganis et al., 2001) are recorded in the Hamburg succession only in Middle Ordovician (Llanvirn) strata, which are loosely dated as Darriwilian 2-4. Some sections have volcanic ash beds.

12. Collectively, the rocks of the Hamburg succession appear to have a unique history, separate from that of the Laurentian margin.
THESIS CONCLUSIONS

Part of the Late Ordovician, Appalachian Martinsburg foreland basin contains allochthonous elements of the Hamburg succession (Dauphin Formation of Ganis et al., 2001). This area lies roughly between the Susquehanna and Lehigh Rivers in the Great Valley Physiographic Section of Pennsylvania. Stose (1946) proposed the Hamburg klippe to explain this geology, but an alternative model is supported here, basically following the concept of Platt et al. (1972), that the allochthonous rocks were emplaced within the Martinsburg Formation.

The Hamburg succession was deposited in the Octoraro Sea (sensu Faill, 1997) which existed between Laurentia and the microcontinent(s) Baltimoria during the early Palaeozoic. During the medial Ordovician Taconic orogeny, Baltimoria converged toward Laurentia, which subducted beneath the microcontinent(s). The contents of the Octoraro Sea, the Westminster Terrane, obducted on to the Laurentian margin upon a carbonate platform.

The youngest allochthonous rocks are the Shellsville and Nyes Road Members of the Dauphin Formation which were extensively collected for graptolites. The fauna recovered includes: *Pseudotrigonograptus? riciano* sp. nov., *Pseudophyllograptus angustifolius* s.l. (J. Hall), *Tetragraptus* cf. *T. erectus* Mu, Geh, & Yin, *Pterograptus elegans* Holm, *Kinnegraptus* cf. *insuetus* (Keble & Benson), *Acrograptus affinis* (Nicholson), *Bergstroemograptus crawfordi* (Harris), *Cryptograptus schaefleri* Lapworth, *Glossograptus hincksii* (Hopkinson), *Paraglossograptus* cf. *P. proteus* (Harris & Thomas), *Kalpinograptus* spp. (nov?), *Kalpinograptus?*, *Reteograptus* spp (nov?), *Hustedograptus teretiusculus?* (Hisinger), *Archi Climacograptus* cf. *A. riddellensis* (Harris), *Haddingograptus oliveri* (Bouček), and *Normalograptus antiquus* (Ge). This assemblage suggests the age of these units is late Darriwilian 3 to early Darriwilian 4a. This is about two graptolite zones older than the youngest foreland basin deposits, which represents the interval of tectonic obduction for the Hamburg succession.

The Hamburg allochthons broke away from the Westminster Terrane during obduction (Faill, 1997), probably at a level within Late Cambrian strata, the oldest units known in the succession. These rocks thrust forward creating a subsidence sag, the Martinsburg/Hamburg foreland segment (M/HFS), much earlier than bordering areas of the future enlarged basin. As the foreland subsidence began the carbonate platform transformed to a clastic basin, signalled by the Hershey/Myerstown Formation transitional strata (impure carbonates). A peripheral bulge formed at the leading edge of the subsidence, the erosion of
which provided carbonate pebbles to the Hershey facies. Based on work completed in the
western part of the M/HFS, the following geologic history is proposed:

The initial allochthonous emplacement was upon the Hershey/Myerstown Formation,
which is represented by the Cocalico Formation within the Lebanon Valley nappe. The
Cocalico, stratigraphically above the Hershey/Myerstown Formation within the nappe, was
faulted against the Martinsburg/Hamburg rocks of the Great valley Section during the
Alleghanian orogeny (terminal Palaeozoic) by the Yellow Breeches thrust. North of that
thrust the allochthonous Unit H-1 (Manada Hill Member, Dauphin Formation) is believed to
be correlative to the Cocalico Formation, as it is lithologically similar to it. However, the base
of Unit H-1 is not exposed and cannot, at this time, be confirmed as resting on the Hershey/
Myerstown Formation. Unit H-1 contains Middle Ordovician conodonts and is composed of
pelagites of red, green and tan shales and radiolarian cherts.

Unconformably overlying Unit H-1 are late *N. gracilis* (possibly early *C. bicornis*)
Zone (Late Ordovician) clastic turbidites, which constitute Unit M-1. It is the same age as
part of the Hershey/Myerstown Formation, and is proposed as a piggyback basin deposited
atop allochthonous Unit H-1 as it was emplaced, creating the formative foreland basin.

Above Unit M-1 is another allochthon emplacement, Unit H-2, composed of Middle
Ordovician olistostromal hemipelagites (Shellsville Member) and turbidites (Nyes Road
Member) containing Lower Ordovician olistoliths. The Unit H-2 matrix is the youngest
allochthonous strata found in the Hamburg succession. The emplacement of Unit H-2 was a
discrete allochthonous event, but may not have been wholly contiguous or coherent. Parts of
the unit can be mapped over large areas, but it is possible that the emplacement was
fragmentary, and that concurrent sedimentation within the foreland was also occurring. The
emplacement of Unit H-2 probably occurred during early to mid-*C. bicornis* time because
covering it is autochthonous Unit M-2, which has late *C. bicornis* age graptolites at its base.

Unit M-2 contains scattered allochthonous debris, such as boulders and large slabs,
and is composed of mostly distal turbidites. Near the top of Unit M-2 is the transition from the
*C. bicornis* (= *D. multidens*) to the *C. americanus* (= low *D. clingani*) Zone. This is the age of
the basal Martinsburg Formation *s. s.* to the east, which covers the transitional Jacksonburg
Formation, and to the west covering the transitional "basal limestones". This indicates that the
Martinsburg foreland basin had now enlarged to include those regions.

Martinsburg deposition continued as Unit M-3 within the foreland basin throughout
the *D. clingani* Zone and shoaled up from turbidites to deltaic facies. The Martinsburg
Formation can be correlated across the northern portion of the M/HFS from Shochary Ridge
to Susquehanna Gap. Plotting of 'Chronological Units', both autochthonous and allochthonous, in the western half of the M/HFS reveals a large-scale overturned anticline.

The stratigraphic history of the Hamburg succession can be reconstructed from the allochthonous rocks. The oldest rocks in this succession are Late Cambrian through Early Ordovician and are found as olistoliths in a Middle Ordovician olistostrome. The Late Cambrian Sacony strata (the Sacony Member of Lash and Drake, 1984, and similar rocks in the western H/MFS) are composed of quartzofeldspathic (plagioclase-rich), micaceous sandstones grading upward to more silty strata. These rocks record the gradual erosion of an igneous-metamorphic high relief terrain (Lash and Bembia, 1984) of northern (palaeo-orientation) Baltimoria. The Sacony strata, in the western M/HFS, are capped by transported phosphorite indicating an interval of slow sedimentation and high sea level. Above this are the Onyx Cave strata (the Onyx Cave Member of Lash and Drake, 1984) and similar rocks in the western H/MFS, a thick interval of black shale interbedded with traction-generated ribbon and massive-bedded, quartzose limestones. These strata probably resulted from tectonically induced basin subsidence.

The Early Ordovician Tremadoc and early to mid-Arenig age olistoliths were described by Ganis et al. (2001), and are more shale-rich at the base, with less limestone, than the Onyx Cave strata, and are clastic hemipelagites in their younger parts. These olistoliths are contained in a Middle Ordovician clastic hemipelagic (Shellsville Member) and turbiditic (Nyes Road Member) olistostrome that is three to four graptolite zones younger than the youngest olistolith. This stratigraphic gap may be the result of structural stacking during closure of the Octoraro Sea. As the microcontinent and the contents of the Octoraro Sea (the Westminster terrane) converged north (palaeodirection) the Laurentian margin was subducted, and the olistostome and turbidites formed in a trench with concurrent deposition of distal pelagites. The Jonestown volcanics were most likely intruded/extruded into this trench at this time. The Westminster terrane was then obducted on to the Laurentian margin and was structurally separated from the crystalline microcontinent(s).
SUGGESTIONS FOR FURTHER WORK

The results of this thesis do not preclude the need for further work on the palaeontology and geology of the Hamburg/Martinsburg foreland segment. The composition and relative abundance of the graptolite fauna are somewhat different from other examples at the same biostratigraphic level worldwide. Notable in this regard is the unusual abundance of Cryptograptus schaferi and the rare occurrence of Kalinograptus. The ecological, provincial, and/or environmental factors controlling the characteristics of the graptolite fauna would be an interesting follow-up study. The newly discovered occurrence of well preserved shelly fauna associated with asphalitic granules in a turbidite sediment association needs to be investigated. The potential for finding significant palaeontological specimens would appear to be high. This could greatly assist a refinement of the biostratigraphic position of the interval. A study of the taphonomy and ecology of the occurrence is also needed.

The necessity and feasibility of acquiring fossil-age control of strata for geologic mapping in this complex terrain was well demonstrated in this thesis. However, much mapping remains to be done, not only in the western half of the terrain addressed in the thesis, but in the eastern half as well. If this fossil-assisted mapping is accomplished, a more complete and accurate understanding of the structural geology will be forthcoming.

The evolution of the allochthonous Hamburg succession included the deposition of coarse turbidite facies (greywackes), presumably derived from a microcontinent source. Later turbidites are suspected to have been deposited as a piggyback basin on an incoming allochthon, with structurally higher positioned allochthons parasitised as a source. These two turbidite successions were then emplaced into the Martinsburg foreland basin and covered by turbiditic sediment. It would be very interesting to determine if these different turbiditic rocks have distinctive mineralogic or geochemical signatures reflecting their individual geologic histories.


Strachan, I. 1996. *A bibliographic index of British graptolites (Graptoloidea), Part 1*.

Palaeontographical Society, Publication No. 600, 40 pp.

Taylor, R.S. 1997. *Taxonomy and biostratigraphy of Middle Ordovician (Llanvirn) graptolites from the Table Cove and Black Cove formations, western Newfoundland*.

Unpublished masters thesis, Department of Earth Sciences, Memorial University of Newfoundland, 258 pp.


Williams, H., compiler. 1978. Tectonic lithofacies map of the Appalachian orogen. Memorial University of Newfoundland, St. John's, scale 1:1 000 000.


New biostratigraphic information from the western part of the Hamburg klippe, Pennsylvania, and its significance for interpreting the depositional and tectonic history of the klippe

G. Robert Ganis*
Consulting geologist, P.O. Box 6128, Harrisburg, Pennsylvania 17112, USA

S. Henry Williams†
Department of Earth Sciences, Memorial University of Newfoundland, St. John’s, Newfoundland A1B 3XB, Canada

John E. Repetski
U.S. Geological Survey, 926A National Center, Reston, Virginia 20192, USA

ABSTRACT

Biostratigraphic investigation of the graptolite and conodont faunas of the western part of the Hamburg klippe of eastern Pennsylvania permits a revised stratigraphic framework and new conclusions regarding its likely tectonic setting. Graptolite and conodont data reveal an almost complete Lower to lower Upper Ordovician zonal section. No Cambrian strata appear to be present, with the possible exception of the uppermost part.

During Early to early Middle Ordovician time, medium- to fine-grained siliciclastics and minor carbonate sediments were deposited in a lower slope and rise setting. These sediments were consolidated and incorporated as olistoliths in an olistostrome, possibly as a trench-fill complex, during the Middle Ordovician (Darriwilian 3/4). This olistostrome, which contains large Lower and lower Middle Ordovician fragments within a matrix of shales, siltstones, and sandstones of Da 3/4 age, is herein named the Shellsville Member of the Dauphin Formation. Turbidites, here assigned to the Nyes Road Member of the Dauphin Formation, were also deposited during Da 3/4 time. These rocks interfinger with red beds of the here-named Manada Hill Member of the Dauphin Formation. The red shales, cherts, and associated rocks of the Manada Hill Member are pelagic deposits that range in age from at least early Arenig through middle Llanvirn time. These allochthonous rocks were emplaced as a gravity-generated klippe into the Martinsburg foreland basin during late Climacograptus bicornis or early Dicranograptus clingani time. These three members compose the Dauphin Formation (new) in the western part of the klippe area. Prior to emplacement of the allochthon, syntectonic flysch and scattered wildflysch of the Martinsburg Formation were deposited. Some graptolite faunas from the Martinsburg Formation, where contiguous with the klippe, may be slightly older than those known from areas farther from the klippe. This could indicate an earlier start of deposition in the Martinsburg foreland basin in advance of the allochthon.

The klippe occupied a large space in the Martinsburg foreland basin and it diverted deposition in this area until it was finally covered by late Martinsburg age sediment. The Dauphin Formation is now structurally interleaved and folded with the Martinsburg Formation as a result of late Taconian and later Alleghanian tectonism.

Keywords: conodonts, graptolites, Hamburg klippe, Martinsburg Formation, Ordovician.

INTRODUCTION

Our work describes a large number of new graptolite and conodont localities throughout the western end of the Hamburg klippe terrane. This new biostratigraphic information was used to delineate allochthonous from allochthonous rocks in the region.

Many of the graptolite and conodont zones and successions described are new for the Hamburg klippe. The allochthon in this part of the terrane is shown to be a Middle Ordovician olistostromal unit containing Lower Ordovician olistoliths. Graptolite evidence confirms that the Martinsburg foreland (Martinsburg Formation) was the host for the gravity-emplaced allochthonous components composing the Hamburg klippe.

The Hamburg klippe is within the belt of Ordovician pelitic rocks of the Great Valley (Fig. 1) of eastern Pennsylvania. The parautochthonous Martinsburg Formation (Upper Ordovician) is southwest and northeast of the klippe boundary. Earlier workers, including Rogers (1858), Stose and Jonas (1927), and Kay (1941), recognized rocks in the area now included within the klippe that were different from those of the Martinsburg Formation. In addition, Willard (1943) reported graptolite faunas from this area that are older than those of the Martinsburg Formation. Stose (1946) also reported graptolites too old for the Martinsburg Formation in the same area and contrasted the dissimilar klippe rocks, which included cherts, carbonates, volcanic rocks, and...
red and green shales, with those of the Martinsburg. The concept of a Taconic-type klippe, having similarities to the classic Taconics of New York and New England, was introduced by Stose (1946). Stose’s map (Stose, 1946) shows a band of the Martinsburg Formation north of the klippe, as well as slices of Martinsburg to the south. The Hamburg klippe is now recognized as the southernmost of the train of Taconic allochthons obducted onto the Laurentian margin (see Fig. 2) during Middle to Late Ordovician time.

Both the Martinsburg Formation and the Hamburg klippe contain flyschoid rocks (graywacke and/or shale), which caused some workers (e.g., Gray and Willard, 1955; McBride, 1962) to include strata within the klippe in the Martinsburg Formation. Platt (in Carswell et al., 1968) recognized the highly discontinuous nature of the stratigraphy within the klippe sequence and proposed that the older allochthonous materials had been delivered to and included within the Martinsburg basin via gravity sliding. This concept differed from an entirely allochthonous klippe above the Martinsburg Formation (Stose, 1946). The structural and stratigraphic relationship of the older allochthonous rocks of the Hamburg sequence to the younger Martinsburg Formation has been a point of debate since the klippe interpretation was proposed. Part of the problem is in determining the age of the basal Martinsburg Formation bordering the allochthon. Berry (1970), Epstein and Berry (1973), Stephens et al. (1982), Parris and Cruikshank (1992), and Finney et al. (1996) clarified the age of the basal Martinsburg Formation near and adjacent to the Hamburg klippe. Further confusion arose from distinguishing tectonically induced sediments formed as a result of the allochthon transport into the Martinsburg foreland from the contents of the much older allochthon.

On the basis of their work on the western end of the Hamburg klippe, Root and MacLachlan (1978) proposed that large discrete allochthons were delivered into the Martinsburg basin by a combination of gravity sliding and thrusting. Root (1977) mapped a probable mixed terrain unit containing autochthonous Martinsburg Formation and allochthonous strata in the U.S. Geological Survey Harrisburg West quadrangle. The Hamburg klippe was the theme of two formal field trips (Stephens et al., 1982; Lash et al., 1984), but both dealt chiefly with the eastern part of the klippe. Lash and Drake (1984) described the eastern part of the klippe in considerable detail and proposed a stratigraphy within the context of an accretionary complex developed in a convergent margin. They also proposed large structurally distinct slices within the eastern part of the klippe.

**AGE OF HAMBURG SEQUENCE:**

**PRIOR BIOSTRATIGRAPHIC EVIDENCE**

The initial evidence supporting a Taconic-type klippe in eastern Pennsylvania was based upon graptolite faunas of Early and Middle Ordovician age found in the western part of the allochthon (Willard, 1943; Stose, 1946). This discovery prompted Stose (1946) to recognize a distinct teectonostratigraphic division known as the Hamburg klippe thrust over the younger (Late Ordovician) Martinsburg Formation. Willard (1943) reported graptolite faunas from what was thought to be the Martinsburg Formation in Dauphin County, Pennsylvania, of Normanskill (early Late Ordovician) age. Fossils from various localities reported by Willard (1943) suggest Arenig, Llanvirn, and early Caradoc ages. Stose (1946) confirmed and added to Willard’s Normanskill and Deepkill discoveries. Carswell et al.
NEW BIOSTRATIGRAPHIC INFORMATION FROM THE WESTERN PART OF THE HAMBURG KLIPPE

**Table 1. Fossil Locality Coordinates**

| Locality number | Location  
|-----------------|-----------
| G-1             | 40°21'03'' 76°40'54'' |
| G-2             | 40°21'43'' 76°40'22'' |
| G-3             | 40°21'40'' 76°40'19'' |
| G-4             | 40°21'45'' 76°40'04'' |
| G-5             | 40°21'52'' 76°39'53'' |
| G-6             | 40°22'16'' 76°39'06'' |
| G-7 south       | 40°22'33'' 76°39'17'' |
| G-7 north       | 40°22'36'' 76°39'17'' |
| G-8 (west of study area) |               |
| G-9 (west of study area) |               |
| G-10            | 40°16'05'' 76°48'55'' |
| G-11 (east of study area) |           |
| G-12            | 40°22'07'' 76°40'54'' |
| G-13            | 40°19'47'' 76°45'22'' |
| G-14            | 40°20'28'' 76°41'07'' |
| G-15            | 40°21'49'' 76°41'14'' |
| G-16 A, D, E    | 40°22'32'' 76°38'36'' |
| G-16 B, C       | 40°22'33'' 76°38'35'' |
| G-17            | 40°22'42'' 76°38'44'' |
| G-18            | 40°22'37'' 76°38'17'' |
| G-19            | 40°22'58'' 76°37'56'' |
| G-19 east       | 40°22'59'' 76°37'56'' |
| G-19 west       | 40°22'55'' 76°38'00'' |
| G-20            | 40°22'18'' 76°39'01'' |
| G-21            | 40°21'53'' 76°39'50'' |
| G-22            | 40°22'35'' 76°38'15'' |
| G-23            | 40°22'50'' 76°38'05'' |
| G-24            | 40°18'41'' 76°46'19'' |
| G-25            | 40°17'44'' 76°45'53'' |
| G-26            | 40°21'51'' 76°40'44'' |
| G-27            | 40°19'03'' 76°44'45'' |
| G-28            | 40°16'20'' 76°48'50'' |
| G-29            | 40°16'16'' 76°48'55'' |
| G-30            | 40°18'08'' 76°43'43'' |
| LP-24 (west of study area) | see Platt, (1972) |

*Appears without "G" prefix in Figure 3.

Figure 2. Appalachian allochthonous terranes of Taconic affinity. Modified after Williams, 1978 (in Bosworth, 1989).

(1968) reported new pre-Martinsburg graptolites from the western part of the klippe (identified by J. Riva) and a single occurrence of abundant Dictyonema sp. with no other forms, which led Riva (in Carswell et al., 1968) to suggest an Early Ordovician age (Tremadoc). This "Dictyonema" collection was reexamined and determined to be rooted dendroids of no stratigraphic significance. Platt et al. (1972) reviewed the accumulated graptolite data from the Hamburg klippe and reported on several new collections of Middle and late Middle Ordovician age (which are now considered Late Ordovician) from the Harrisburg area. An account of graptolites from the western part of the Hamburg klippe was also provided by Root and MacLachlan (1978), who reported assemblages (identified by J. Riva) indicating the Nemagraptus gracilis Zone (early Caradoc) and Didymograptus bifidus Zone (middle Arenig) in two beds only 15 m apart at a single locality.

Graptolite faunas from the Hamburg klippe, summarized in Stephens et al. (1982), Lash et al. (1984), and Lash and Drake (1984), have consistently been referred to as indicating the Nemagraptus gracilis Zone (Riva, 1972, 1974) and possibly the older Hustedograptus (formerly Glyptograptus) teretiusculus Zone. In all of these summaries, literature reports of graptolite ages older than N. gracilis were not mentioned, except for Stephens et al. (1982), who acknowledged the report of Dictyonema sp. mentioned here. Previous reports of conodonts from the Hamburg klippe were all from localities in the eastern part of the klippe. Raring and Ganis (1973) reported several genera of Middle Ordovician conodonts from limestones near Lebanonville, Berks County, Pennsylvania. This locality was resampled in 1997; it consists of carbonate nodules that form a discontinuous bed within a thick section of red and green shale that also has thin volcanic ash interbeds (Ganis, 1997). The conodonts recovered are of early Arenig age and are of North Atlantic province affinity. Bergström et al. (1972) and Epstein et al. (1972) reported and discussed additional conodont collections from the Lebanonville area in strata subsequently assigned to the Windsor Township Formation by Lash and Drake (1984). They compared these faunas, which represent the Prioniodus elegans Zone, to known coeval early Arenig faunas of the North American and North Atlantic faunal realms. Combined with sedimentological and structural evidence, they concluded that these strata had a southern or southeastward source rather than Laurentia. Repetski (1984a, 1984b)
Figure 3. Generalized geologic map and proposed stratigraphic subdivision of the Hamburg klippe (Dauphin Formation) and associated Martinsburg Formation in eastern Dauphin County, Pennsylvania.

reported additional Lower Ordovician conodonts from deeper water carbonate flysch deposits of the Windsor Township Formation and from clasts of similar lithologies incorporated into the probable Upper Ordovician Spitzenburg Conglomerate located ~3 km northeast of Lenhartsville. The conodonts indicate the *P. elegans* and probably the *Oepikodus evae* zones (early to middle Arenig). Repetski (in Lash et al., 1984; Lash and Drake, 1984) also recovered a few sparse Late Cambrian and Early Ordovician conodont faunules from the Virginville Formation ~6.5 km south-southwest of Lenhartsville. The single Late Cambrian collection, from the Onyx Cave Member of the Virginville Formation, is the oldest, and thus far the only unequivocal Cambrian, locality dated from the Hamburg klippe. Lower Ordovician conodonts were recovered from a limestone unit intruded by the Jonestown basalts (Löfgren et al., 1999; Lash, 1984; Ganis, 1997).

**STRATIGRAPHIC SUMMARY**

In this study the western part of the Hamburg klippe east of Harrisburg, Dauphin County, Pennsylvania, and just into westernmost Lebanon County (see Fig. 1), was searched for graptolites. We found 30 graptolite-bearing sections and spot localities (see Fig. 3); 5 of them also yielded conodonts. Fossils from these localities span the Lower through lower Upper Ordovician, from the Tremadoc (possibly uppermost Cambrian) to the Caradoc (*D. clingani* Zone), permitting a documentation of the stratigraphy for the western half of the klippe (Fig. 4). The apparent absence of most or all of the Cambrian section is puzzling because the depositional history of the Octoraro sea would seem to have provided for it during its Late Proterozoic through Cambrian development (e.g., Thomas, 1977; Lash et al., 1984; Lash and Drake, 1984; Faill, 1997). All of the other Taconide sequences in the Appalachians, with the possible exception of the Jutland and Peapack klippen in New Jersey, contain Cambrian rocks. We speculate that any missing Cambrian rocks, assuming they ever existed, were removed tectonically from the rest of the sequence, or possibly consumed during subduction once convergence began, during the Early to Middle Ordovician.

The older allochthonous sequence, comprising the western part of the Hamburg klippe, is herein named the Dauphin Formation, and is divided into three members. The name Dauphin beds was used by Willard (1943) to describe the Normanskill and Deepkill graptolite...
NEW BIOSTRATIGRAPHIC INFORMATION FROM THE WESTERN PART OF THE HAMBURG KLIPPE

Figure 4. Stratigraphy of the western part of the Hamburg klippe.

The Shellsville Member (herein proposed) is composed of a starved, deep-water facies suite of variegated shales and siltstones, mudstones, thin limy layers, cherts, and pelagic red and green shales of Da 3/4 age (D. decoratus through lower Hustedograptus teretiusculus zones). The Shellsville Member is named for a series of exposures along U.S. Route 22 in Dauphin and western Lebanon Counties near the town of Shellsville. A few good outcrops of this unit display highly contorted and slumped beds resulting from soft-sediment deformation. This Middle Ordovician Shellsville Member is an olistostome containing olistoliths of Lower Ordovician strata. The older olistoliths appear to have been emplaced in the matrix as coherent lithified bodies. Structural dislocation during the emplacement of the klippe and later faulting transformed the olistostome into an olistostromal melange. It is very difficult to estimate the true thickness of the Shellsville Member (the outcrop width is 1.0 km) because of its convoluted nature and the randomly distributed olistoliths within it.

We found three Arenig age olistoliths in the Shellsville Member. These olistoliths are lithologically similar to the surrounding matrix. Without fossils, these rocks would be difficult, if not impossible, to differentiate. Rocks of the County Line olistolith (Figs. 3 and 5) contain graptolites of the lower D. bifidus Zone and the Isograptus victoriae lunatus Zone. The exposure is poor and faulted and extends over a few tens of meters; it has a thickness of a few meters. The Hill Drive olistolith (Fig. 3) is ~0.3 km long, and has an estimated thickness of a few tens of meters. It contains graptolites of the lower D. bifidus Zone and the Isograptus victoriae lunatus Zone. The exposure is poor and faulted and extends over a few tens of meters; it has a thickness of a few meters. The Shellsville Member is poorly exposed in a
between turbidite sequences. It has been rec-
ognized west of the 5.5-km-long olistostrome (the mapped portion of the Shellsville Mem-
ber), and continues westward for at least 8 km (Fig. 3). In addition, exposures are found along Manada Creek south of U.S. Route 22 in Dauphin County. This member is also of Da 3/4 age, and together with the Shellsville Member, constitutes a belt of rock within the same limited range of graptolite zones across all of Dauphin County.

In addition to the thin (<10 m) interbeds of red shale in the Nyes Road Member, much thicker and extensive exposures of red shale and radiolarian chert, locally interbedded with tan, green, or purple shale, minor interbeds of limestone or dolomite, and sparse volcanic ash layers (discussed in Ganis, 1997), occupy prominent ridges that can be traced for many kilometers. Where such sections exceed 10 m in thickness they can be mapped and are here-in assigned to the Manada Hill Member of the Dauphin Formation. The Manada Hill Member is named for exposures underlying the Manada Hill (spelled Manadahill on the U.S. Geological Survey topographic quadrangle map) area in eastern Dauphin County in road cuts and shale pits. Overall, this unit compares well with Member B, mapped in Dauphin County by Carswell et al. (1968) as variegated red and dark shale, mudstone, and chert. Collectively, this lithofacies constitutes a large temporal range of distal, deep-water deposits that was broken and interleaved into other lower slope components during the initial pro-
grading sedimentation and during transport of the klippe and subsequent structural defor-
mation. Exposures of this lithofacies in a shale pit at Lenhartsville, Pennsylvania (east of the study area), contain ash beds and associated layers of carbonate nodules that were dated as Early Ordovician (early Arenig) by conodonts (Repetski, in Ganis, 1997). Stephens et al. (1982) reported *N. gracilis* Zone (Riva, 1972, 1974) graptolites from red shale in the eastern part of the klippe.

There is no evidence that rocks were de-
posited between late Da 4 through late *N. gracilis* to early *C. bicornis* Zone time, i.e.,
the interval between deposition of the Daup-
phin Formation (the allochthon) and that of the earliest Martinsburg foreland deposits de-
scribed below. We suggest that deposition was interrupted during the obduction of the Ham-
burg sequence on the Laurentian margin dur-
ing that tim e.

There is no evidence that rocks were de-
posited between late Da 4 through late *N. gracilis* to early *C. bicornis* Zone time, i.e.,
the interval between deposition of the Daup-
phin Formation (the allochthon) and that of the earliest Martinsburg foreland deposits de-
scribed below. We suggest that deposition was interrupted during the obduction of the Ham-
burg sequence on the Laurentian margin dur-
ing that tim e.

Within the mapped limits of the Hamburg klippe are belts of turbiditic flysch and wild-
flysch deposits that have yielded graptolites of the upper *C. bicornis* Zone (*D. multidentis*
Zone of Riva, 1969, 1974) through the youn-\nger *D. clingani* Zone (*C. americana* Zone of Riva, 1969, 1974; Berry, 1960, 1970, 1971) that should be retained within the Martinsburg Formation. A *C. bicornis* Zone age (sensu Berry, 1960; Williams, 1995) was recorded by Wright et al. (1979; ascribed to the *D. multiden-
tis* Zone therein) and Finney et al. (1996) for the oldest Martinsburg bordering the Ham-
burg klippe to the southwest. Epstein and Ber-
ry (1973) and Parris and Cruickshank (1992) estimated the basal Martinsburg Formation in eastern Pennsylvania to be of similar age. Figure 3 shows the belts of the Martinsburg For-
formation as they relate to the members of the allochthonous Dauphin Formation within the study area. The presence of *Pseudoclinoeca-
grapthus stenostoma* and *P. scharenbergi* in some of the Martinsburg localities contiguous with the allochthonous klippe strata may in-
dicate that syntectonic Martinsburg flysch de-
position began earlier, in advance of the allochthon, because these taxa are not present elsewhere in the Martinsburg Formation out-
side the klippe boundary.

Stose (1946) showed a thin band of Mar-
tingsburg Formation extending across the northern part of the klippe on its western part. This map pattern was retained by some later workers (e.g., Platt et al., 1972; Root and MacLachlan, 1978; Faill, 1997), but not by others (e.g., Stephens et al., 1982; Lash et al., 1984; Lash and Drake, 1984). Stose (1946) also indicated small slivers of Martinsburg south of the klippe. Our study shows that much more of the area traditionally mapped as the Hamburg klippe should be retained within the Martinsburg Formation, not as fringes to the north and south, but as inter-
leaved belts with the older allochthonous components. The structural relationship of these belts has not been determined. The al-
ternating belts of the Martinsburg and Daup-
in Formation may connect as folds or re-
peat from faulting. Alternately, the allochthon may have slid into the Martinsburg foreland in pieces, as suggested by Carswell et al. (1968), rather than as one mass, as suggested by Wright and Stephens (1978) and Wright et al. (1979).

Another characteristic of the Martinsburg Formation, where it is contiguous with the al-
lochthonous components, is the presence of
Figure 6. Tremadoc graptolites from the Hamburg klippe. All figured specimens are reposited in type collections of the Department of Paleobiology, U.S. National Museum of Natural History (USNM), Washington, D.C. Locality is indicated by brackets. (A–D) _Rhabdinopora flabelliformis parabola_ (Bulman), 44 m level, Gravel Hill Road (north) [G-7]. A, B, ×10; C, D, ×5; USNM 509823–826, respectively. (E, F, J, K–M) _Rhabdinopora flabelliformis_ subsp. cf. _R. f. anglica_ (Bulman), [G-19]. L, ×2.5, M, ×10, others, ×5 (L is also in Fig. 11D); USNM 509827–832, respectively. (G–I) _Anisograptus matanensis_ Ruedemann, [G-19], ×5; USNM 509833–835, respectively. (N–R) _Adelograptus tenellus_ (Linnaeus), 135–145 m level, Gravel Hill Road [G-7], ×10; USNM 509836–840, respectively. (S, T) _Kiaerograptus bulmani_ (Thomas), 157 and 161 m levels, Gravel Hill Road [G-7], ×10; USNM 509841 and 509842, respectively.
Figure 7. Arenig graptolites from the Hamburg klippe. All figured specimens are reposited in type collections of the Department of Paleobiology, U.S. National Museum of Natural History (USNM), Washington, D.C. Locality is indicated by brackets. (A, B) Pendeograptus sp. cf. P. pendens (Elles), 164.3 m level, Gravel Hill Road [G-7], ×5; USNM 509843 and 509844. (C, D) Tetrograptus approximatus approximatus (Nicholson), 164.3 m level, Gravel Hill Road [G-7], ×5; USNM 509845 and 509846, respectively. (E-G) Pendeograptus fruticosus (J. Hall), ×5. E, [G-5 west], F, G, [G-16A]; USNM 509847–849, respectively. (H) Pseudotrigonograptus ensiformis (J. Hall), [G-16D], ×5; USNM 509850. (I-L) Didymograptus (Didymograptellus) bifidus (J. Hall), [G-16A], ×5; USNM 509851, respectively. (M, N) Keblograptus bidens (Keble), [G-16D], ×5; USNM 509855 and 509856, respectively. (O-R) Didymograptus (Expansograptus) constrictus (J. Hall), [G-5 west], ×5; USNM 509861 and 509862, respectively. (U-X) Didymograptus (Expansograptus) abdita Williams and Stevens, [G-5 east], ×5; USNM 509863–866, respectively. (Y-B’) Xiphograptus svalbardensis (Archer and Fortey), [G-5 east], ×5; USNM 509867–870, respectively. (C’) Acerograptus sp. cf. A. gracilis (Törnquist), [G-18], ×5; USNM 509871. (D’, E’) Goniatograptus thureaui (M’Coy), [G-5 east], ×5; USNM 509872 and 509873, respectively. (F’–K’) Isograptus victoriae victoriae Harris, [G-5 east], ×5; USNM 509874–879, respectively.
Figure 8. Darriwillian (middle Llanvirn) graptolites from the Hamburg klippe. All figured specimens are reposited in type collections of the Department of Paleobiology, U.S. National Museum of Natural History (USNM), Washington, D.C. Locality is indicated by brackets. (A–C) Pterograptus elegans Holm, ×5. A, [G-16c], B, [G-2], C, [G-21]; USNM 509880–882, respectively. (D) Pseudophyllograptus sp., [G-3], ×2.5; USNM 509833. (Caption continued on p. 119.)
scattered boulder conglomerates (wildflysch). The matrix shale at one of these exposures (G-7; Table 1) has early Caradoc graptolites. This matrix encloses both angular graywacke blocks and soft-sediment deformed irregular masses. Root and MacLachlan (1978) mapped the "Conodoguinnet wildflysch" near the northwestern edge of the allochthon, which they described as allochthonous graywacke in autochthonous shale. Stephens et al. (1982) reported graptolites from that sequence as belonging to the D. multidentis or C. americanus Zone (C. bicornis to D. clingani zones of Williams, 1995). Lash and Drake (1984) described similar but undated deposits in the eastern part of the Hamburg klippe. These boulder conglomerates of the Martinsburg Formation may be analogous to the blocks-in-shale of the Snake Hill Formation (Normalization of some authors) of the classic Taconic region of New York (Landing, 1986; Berry, 1962) and are about the same age. This scenario also appears comparable to the Pawlet to Austin Glen Formation transition described by Zen (1968) in the New York Taconic Mountains. The transition from syntectonic (and possibly allochthonous) flysch to autochthonous Martinsburg is gradational and appears to have occurred within the upper C. bicornis to lower D. clingani zones.

**BIOSTRATIGRAPHY**

Graptolite faunas (Figs. 6–11) ranging in age from early Tremadoc to Caradoc from a number of graptolitic intervals have been recognized. They can be matched closely with sequences elsewhere in the Appalachians, particularly western Newfoundland (Cooper et al., 1998; Williams and Stevens, 1988, 1991), Quebec (Maletz, 1997a), and the southeastern United States (e.g., Finney, in Ross et al., 1982). A relatively complete succession is present from the early Tremadoc (Rhabdina­pora flabelliformis parabola Zone) through to the middle Arenig (Isograptus victoriae Zone) in olistoliths contained within the Shellsville Member of the Dauphin Formation. The next biostratigraphic level identified, which is the equivalent of the "Diplograptus" decoratus Zone of Australia (Da 3; Vandenberg and Cooper, 1992) or the Pterograptus elegans Zone of Scandinavia (sensu Maletz, 1997b) and eastern Canada (Mitchell and Maletz, 1994), the late Arenig and earliest Llanvirn (Darrillian) has thus not been recognized. Following this, the youngest interval recognized, which is within the Martinsburg Formation, includes the Late Ordovician C. bicornis Zone (lower Diplograptus multidentis Zone of some authors) and D. clingani Zone. Although assemblages indicative of the preceding Nemagraptus gracilis Zone (as defined by Riva, 1972, 1974) have been recovered elsewhere in the east in the Hamburg klippe, only taxa indicative of the equivalent upper part of that zone, representing the C. bicornis Zone as defined by Williams (1995), have been recognized in our area.

The lowest biostratigraphic level within the Gravel Hill Road olistolith taxa at locality G-23 (Figs. 3 and 5) yielded conodonts (Fig. 12) from nodular limestones and dark gray, calcareous shale that demonstrate an earliest Ordovician (very early Ibxian) age. The presence of Iapetognathus sparkeri Landing, Cordyliodus lindstromi Druce and Jones, and Rossodus tenuis (Miller) indicates assignment to the Cordyliodus angulatus Zone of North American usage (Ross et al., 1997). This interval correlates with part of the broader Cordyliodus angulatus Zone of the North Atlantic conodont realm (Löfgren, 1997). Overlying these carbonates, a calcarenite sequence has yielded a few unidentified graptolite fragments, possibly belonging to benthic dendroids. This interval is analogous to that found in the earliest Ordovician at the proposed Cambrian-Ordovician boundary stratotype at Green Point, western Newfoundland. There, calcarenites of Bed 24 that are immediately above the defined systemic boundary in the middle of Bed 23 (based on conodonts) contain fragments of benthic dendroids that may have been transported from a shelf environment. The earliest planktic graptolites (Rhab­dinopora praeparabola (Bruton, Erdmann, and Koch) and Staurogaptus dichotomus (Emmons) first occur at Green Point several meters higher in an alternating limestone and shale sequence assigned to Bed 25 (Cooper et al., 1998).

The earliest identifiable graptolites in the area come from dark gray shale deposits in a small roadside outcrop at G-7 (north) along Gravel Hill Road immediately north of Route 22 (Fig. 5). Here, a number of small specimens have been recovered at the 44 m level; they closely match Cooper et al.'s (1998) redescription of Rhabdinopora flabelliformis parabola (Bulman) (Fig. 6). No graptolites have been found that indicate the underlying R. praeparabola Zone of Cooper et al. (1998). The dark gray shales of the R. f. parabola Zone are followed by a moderately thick sequence (~80 m) of unfossiliferous pale buff to gray-green shale that is traceable along strike to locality G-19 (Fig. 5). One level at this locality (G-19), however, has yielded both graptolites and conodonts from an interval of alternating dark gray siltstone and calcareous nodules. The graptolites include Rhabdinopora, which, based on Cooper et al. (1998), appear to be morphologically midway between R. flabelli­formis flabelliformis (Eichwald) and R. flabel­liformis anglica (Bulman) (see Figs. 6, 10, and 11), and Anisograptus matanensis Rue­demann (Fig. 6). This suggests a correlation with either the Anisograptus matanensis or R. f. anglica Zone of the lower early Tremadoc of Cooper et al. (1998). The sparse collection of conodonts (Fig. 12), including Rossodus tenuis (Miller) and Drepanoistodus pervetus Nowlan?, suggests the Cordyliodus angulatus Zone interval; this is consistent with the late early Tremadoc age.

The remainder of the Tremadoc and earliest Arenig sequence has been seen within the Gravel Hill Road olistoliths to the south of Route 22 at locality G-7 (south) (Fig. 5), where the lowest exposures apparently belong to the largely unfossiliferous pale shale discussed here. These are followed by 24 m of black shale that yield an abundant monospecific fauna of beautifully preserved Adelo­graptus tenellus (Linnarson) (Figs. 6 and 11). Although this species appears to range throughout much of the late Tremadoc (Cooper, 1999), the lack of any later forms here

---

Figure 8. (Continued) (E–I) Archiclimacosmatograptus riddellensis (Harris), [G-3], D–F, ×10, G–I, ×5; USNM 509884–888, respectively. (J–L) Archiclimacosmatograptus sp., [G-3], J, ×10, K, L, ×5; USNM 509899–891. (M–P) Hustedograptus sp. cf. H. teretiusculus (Hisinger) (sensu Maletz, 1997). M, N, P, [G-3], O, [G-1], ×5; USNM 509892–895, respectively. (Q–T) Haddingograptus oliveri (Boucek), [G-3], Q, ×10, R–T, ×5; USNM 509896–899, respectively. (U) Diplograptid sp. indet., [G-4], ×2.5; USNM 509900. (V–A') Cryptograptus schaeferi (Lapworth). V, Y, [G-16D], W, [G-16D], X, Z, [G-3], A–G, [G-6], V, W, ×10, X–A, ×5; USNM 509901–906, respectively. (B', D') Paraglossograptus tentaculatus (J. Hall). B', [G-17], D', [G-3], ×3; USNM 509907 and 509908, respectively. (C', E') Glossograptus holmi Bulman, [G-3] ×5; USNM 509009 and 509910, respectively. (F', G') Kalpinograptus sp., [G-20], ×10; USNM 509911 and 509912.
Figure 9. Caradoc graptolites from the Hamburg klippe. All figured specimens are reposited in type collections of the Department of Paleobiology, U.S. National Museum of Natural History (USNM), Washington, D.C. Locality is indicated by brackets. (A–C) *Dicellograptus intortus* Lapworth, [G-12], x5; USNM 509913–915, respectively. (D, E) *Dicellograptus salopiensis* Elles and Wood, [G-12], x5; USNM 509916 and 509917, respectively. (F) *Dicerograptus* sp. cf. *D. ramosus spinifer* Elles and Wood, [G-30], x5; USNM 509918. (G) *Pseudoclimacograptus scharenbergi* (Lapworth), [LP-24], x5; USNM 509919. (H) *Pseudoclimacograptus stenostoma* (Bulman), [LP-24], x5; USNM 509920. (I) *Diplograptus* sp. cf. *D. foliaceus* (Murchison), [G-10], x5; USNM 509921. (J, K) Orthograptus ex gr. *calcaratus* (Lapworth), [G-28], x5; USNM 509922 and 509923 respectively. (L) *Climacograptus bicornis* (J. Hall), [G-10], x5; USNM 509924. (M, N) *Corynoides calicularis* Nicholson, [G-28], x5; USNM 509925 and 509926, respectively. (O, P) *Orthograptus quadrimucronatus* (J. Hall), [G-28], x5; USNM 509927 and 509928, respectively. (Q, R) *Climacograptus antiquus* Lapworth, [G-12], x5; USNM 509929 and 509930, respectively. (S) *Reteograptus geinitzianus* J. Hall, [G-12], x5; USNM 509931.

suggests to us the presence of the earliest late Tremadoc *A. tenellus* Zone. This level is followed by mostly unfossiliferous pale siltstone and sandstone. A poorly preserved but diverse late Tremadoc graptolite assemblage was recovered at the 157 m level; the assemblage appears to include at least two *Kiaerograptus* species, including *K. bulbani* (Thomas) (Fig. 6), together with *Clonograptus*? sp. and possibly *Aorograptus victoriae* (T.S. Hall). These specimens, although fragmentary, are identical in terms of proximal development to those described by Williams and Stevens (1991) from the late Tremadoc interval of the Cow Head Group of western Newfoundland; they indi-
the presence of the Aerograptus victoriae Zone. Within the lower meter of the succeeding ribbon limestones (at 161.5 m), a sparse but similar assemblage was recovered.

From this level and within the succeeding meter of the limestone, conodonts recovered (Fig. 12) include Prioniodus oepiki (McF. Shash), Prioniodus? n. sp., Paltaudos subaequilis Pander, Paroistodus proteus (Lindström), Oelandodos aff. O. elongatus (Lindström), Drepandus arcuatus Pander, Paracordylodus gracilis Lindström, Tripudia albanii Stouge and Bagnoli, Periodon primus Stouge and Bagnoli?, and Oneotodus costatus Ethington and Brand. Stouge and Bagnoli (1988) recorded this association from the lower half of Bed 9 at the Ledge—Point of Head section in the Cow Head Group on the Cow Head Peninsula, western Newfoundland. They assigned this interval to their Prioniodus oepiki and P. adami zones. This interval of the Cow Head Group is within the lower three-quarters of the Cow Head Group is within the lower three-quarters of the Cow Head Group (Linnan, 1997). The youngest strata in the area belong to the lowest part of the Lower Cambrian (latest Da 3). Taylor (1997) recorded A. victoriae (Linnan) and also bear considerable similarity to assemblages of similar Da 3/4 age elsewhere in the world (see Maletz, 1997b). Considered as possibly to date from the earliest Middle Ordovician Age, the fauna in- cludes A. victoriae Zone and the following I. v. victoriae Zone, but the large size of the Isograptus specimens suggests a correlation with the I. v. victoriae Zone. In the Cow Head Group, the P. fruticosus and I. v. victoriae Zones are separated by the D. bifidus and I. v. lunatus Zones; however no specimens of D. (D.) bifidus (J. Hall) or of typical I. v. lunatus were recovered from this section. This may suggest the presence of significant but indistinguishable bedding-parallel faulting or a gap in deposition.

The D. bifidus Zone and possibly the I. v. lunatus Zone (or alternatively the I. v. victoriae Zone) are, however, represented at the western end of G-16 (G-16a) (Fig. 5), where D. (D.) bifidus (J. Hall) occurs in association with P. fruticosus (J. Hall), D. (E.) similis (J. Hall), X. squalaridens (Archer and Fortey), and G. thureaui (M'Coy) with abundant conodonts in a fine-grained sandstone. The conodonts, including Oepikodus evae (Lindström), are indicative of the Oepikodus evae Zone. In the Cow Head Group, D. (D.) bifidus and P. fruticosus overlap only in the lower half of the D. bifidus Zone (Williams and Stevens, 1988). Several meters to the east, G-16d and G-16e yield a diverse I. v. lunatus or I. v. victoriae Zone assemblage, including Isograptus dilemma Williams and Stevens?, Tetraplagaptus reclinatus reclinatus Elles and Wood, K. bidens (Keble), X. squalaridens (Archer and Fortey), Phyllograptus typus (J. Hall), Pseudotriograptus ensiformis (J. Hall), and G. thureauii (M'Coy), together with a few poor Isograptus specimens which appear to most closely match I. v. lunatus Harris. At G-18 in the Ridge Top olistolith, a poorly preserved fauna was recovered that included a single specimen of D. (E.) constrictus (J. Hall), X. squalaridens (Archer and Fortey), and a probable specimen of Acrograptus sp. cf. A. gracilis (Törnquist). This assemblage is consistent with an early to middle Arenig age (probably P. fruticosus Zone). Although A. gracilis was not collected below the I. v. lunatus Zone in Newfoundland by Williams and Stevens (1988), these authors mentioned that the species had been recorded from lower intervals elsewhere.

No later Arenig or early Llanvirn (Darriwilian 1 and 2) assemblages have yet been recovered from the study area. Middle Llanvirn (Da 3 or Da 4) graptolite localities (G-1, G-2, G-3, G-4, G-6, G-13, G-14, G-15, G-16b, G-16c, G-17, G-19 east, G-20, G-21, G-24, and G-27) in strata that constitute the matrix of the Shellsville Formation (Fig. 3) are, however, numerous and their faunas (Figs. 8 and 10) may be compared taxonomically with many of the taxa redescribed recently from the Oslo region by Maletz (1997b) and western Newfoundland by Taylor (1997). Diverse assemblages include Pterograptus elegans Holm, Archiclimacograptus riddellensis (Harris), Archiclimacograptus sp., Hustedograptus sp. cf. H. teretiusculus (Hisinger) (sensu Maletz, 1997b), Haddinograptus olivieri (Boucek), Cryptograptus schaeferi (Lapworth), Paraglossograptus tentacularus (J. Hall), Glossograptus holmi Bulman, Kalpinograptus sp., Pseudophyllograptus sp., Bergstroemograptus crawfordi (Harrisi)?, and Retograptus? sp., together with a number of benthic dendroids including Dendrograptus. Such taxa are identical to those described from the Table Cove and Black Cove Formations of western Newfoundland (Finney and Skevington, 1979; Mitchell and Maletz, 1994; Taylor, 1997) and also bear considerable similarity to assemblages of similar Da 3/4 age elsewhere in the world (see Maletz, 1997b). Considered as possibly to date from the earliest Middle Ordovician Age, the fauna in- cludes A. victoriae Zone and the following I. v. victoriae Zone, but the large size of the Isograptus specimens suggests a correlation with the I. v. victoriae Zone. In the Cow Head Group, the P. fruticosus and I. v. victoriae Zones are separated by the D. bifidus and I. v. lunatus Zones; however no specimens of D. (D.) bifidus (J. Hall) or of typical I. v. lunatus were recovered from this section. This may suggest the presence of significant but indistinguishable bedding-parallel faulting or a gap in deposition.

The D. bifidus Zone and possibly the I. v. lunatus Zone (or alternatively the I. v. victoriae Zone) are, however, represented at the western end of G-16 (G-16a) (Fig. 5), where D. (D.) bifidus (J. Hall) occurs in association with P. fruticosus (J. Hall), D. (E.) similis (J. Hall), X. squalaridens (Archer and Fortey), and G. thureauii (M'Coy) with abundant conodonts in a fine-grained sandstone. The conodonts, including Oepikodus evae (Lindström), are indicative of the Oepikodus evae Zone. In the Cow Head Group, D. (D.) bifidus and P. fruticosus overlap only in the lower half of the D. bifidus Zone (Williams and Stevens, 1988). Several meters to the east, G-16d and G-16e yield a diverse I. v. lunatus or I. v. victoriae Zone assemblage, including Isograptus dilemma Williams and Stevens?, Tetraplagaptus reclinatus reclinatus Elles and Wood, K. bidens (Keble), X. squalaridens (Archer and Fortey), Phyllograptus typus (J. Hall), Pseudotriograptus ensiformis (J. Hall), and G. thureauii (M'Coy), together with a few poor Isograptus specimens which appear to most closely match I. v. lunatus Harris. At G-18 in the Ridge Top olistolith, a poorly preserved fauna was recovered that included a single specimen of D. (E.) constrictus (J. Hall), X. squalaridens (Archer and Fortey), and a probable specimen of Acrograptus sp. cf. A. gracilis (Törnquist). This assemblage is consistent with an early to middle Arenig age (probably P. fruticosus Zone). Although A. gracilis was not collected below the I. v. lunatus Zone in Newfoundland by Williams and Stevens (1988), these authors mentioned that...
Figure 11. Photoplate of selective graptolite taxa, Hamburg klippe. All figured specimens are reposited in type collections of the Department of Paleobiology, U.S. National Museum of Natural History (USNM), Washington, D.C. Locality is indicated by brackets. (A, B) Adelograptus tenellus (Linnarsson), 135–140 m level, Gravel Hill Road [G-7], ×10; USNM 509836 and 509946. (C) Glossograptus sp., [G-26], ×20; USNM 509947. (D) Rhabdinopora flabelliformis subsp. cf. R. flanglica (Bulman), [G-19], ×5 (also in Fig. 6L); USNM 509831. (E, F) Reteograptus geinitzianus J. Hall, [G-26]. E, ×20, F, ×10; USNM 509949 and 509950, respectively. Excludes Dicellograptus intortus Lapworth, D. salopiensis Elles and Wood, Climacograptus bicornis (J. Hall), Climacograptus antiquus Lapworth, Diplograptus sp. cf. D. foliaceus (i.e., cf. D. multidentis; see Hughes, 1989), Orthograptus calciculus subsp., O. ampliclavus subsp., Pseudoclimacograptus scharenbergi (Lapworth), P. stensteniana (Bulman), and Reteograptus geinitzianus J. Hall (Figs. 9 and 11) in association with benthic dendroids. J. Riva (written commun. to T.O. Wright, 1976; R.D.K. Thomas, 1980; and R. Ganis, 1997) referred such assemblages present in this part of the sequence to the Nemagraptus gracilis Zone. Williams (1995), however, restricted the understanding of the N. gracilis Zone in Newfoundland, considering it to be characterized by the occurrence of N. gracilis (J. Hall) and/or Acrograptus superstes (Lapworth) and lacking C. bicornis. He considered the following Climacograptus bicornis Zone (lower D. multidentis Zone of many authors) to be dominated by more diverse diplograptid assemblages, together with species of Corynoides; both N. gracilis and A. superstes also occur in the earliest part of the C. bicornis Zone. We believe that the assemblages examined in this study indicate this higher level for the earliest part of the sequence rather than the earliest Caradoc N. gracilis Zone; this is apparently confirmed in G-26 (Fig. 3), where Corynoides sp. cf. C. calicularis Nicholson occurs in a poorly preserved assemblage together with Cryptograptus tricornis (Carruthers)?, Glossograptus sp., and Reteograptus geinitzianus J. Hall. However, J. Riva (1997, written commun. to Ganis) considered this level to belong to the N. gracilis Zone. The Martinsburg Formation in this study area in the previously mapped Hamburg klippe (sensu Stose, 1946) continues into the D. clingani Zone, demonstrated by assemblages from locality G-28 (Fig. 9) that include Orthograptus quadriramosus (J. Hall), O. ex. gr. calciculus (Lapworth), and Corynoides calicularis Nicholson, and from G-30, where Dicranograptus ramosus cf. D. spinifer was recovered. This level correlates with the Bushkill and/or Ramsey-
Figure 12. Lower Ordovician conodonts from the Hamburg klippe. All views lateral except as noted. All figured specimens are reposited in type collections of the Department of Paleobiology, U.S. National Museum of Natural History (USNM), Washington, D.C. Locality is indicated by brackets. (A, B, F, Q, R) Rossodus tenuis (Miller), A, \( x_{150} \) and F, \( x_{125} \), posteroventral views; R, \( x_{150} \), posterior view of conform elements, B, \( x_{200} \), Q, \( x_{125} \), olistodontiform elements; A, B, F, [G-23] (U.S. Geological Survey [USGS] locality 11559-CO); Q, R, [G-19] (USGS locality 11560-CO); USNM 509951-955, respectively. (C, D) Lepidognathus sprakersi Landing, Westrop, and Knox, upper and lateral views of two specimens, [G-23] (USGS loc. No. 11559-CO), \( x_{150} \) and \( x_{150} \), respectively; USNM 509956 and 509957. (E) Cordylodus lindstromi Druce and Jones, \( x_{150} \), [G-23] (USGS loc. No. 11559-CO; USNM 509958, (G) Periodon primus Stouge and Bagnoli, P(?) element \( x_{100} \), locality 2 of Ganis (1997) (USGS loc. No. 11561-CO) (carbonate nodules from Lenhartsville); USNM 509959. (H, I) cf. Acudos deltatus deltatus Lindström. H, M element \( x_{125} \), and I, P element \( x_{150} \), locality 2 of Ganis (1997) (USGS loc. No. 11561-CO) (carbonate nodules from Lenhartsville); USNM 509960 and 509961, respectively. (J-N, P, A', B') Priionodus oepiki (McTavish). J, Pa element \( x_{100} \); K, B', Sd element \( x_{125} \); L, posteroventral view of Sa element \( x_{100} \); M, Pb element \( x_{100} \); N, A', M elements \( x_{75} \) and \( x_{100} \); P, Sb element, \( x_{75} \); J-N, P are from locality 2 of Ganis (1997) (USGS 11561-CO) (carbonate nodules from Lenhartsville); A', [G-7 south] (USGS loc. 11560-CO); USNM 509962-969, respectively. (O) Tropodus comptus (Branson and Mehl), outer lateral view, \( x_{75} \), locality 2 of Ganis (1997) (USGS 11561-CO; USNM 509970) (carbonate nodules from Lenhartsville). (S) Paracordylodus gracilis Lindström, S element, \( x_{100} \), locality 2 of Ganis (1997) (USGS 11561-CO) (carbonate nodules from Lenhartsville); USNM 509971. (U) Tripodus albani Stouge and Bagnoli, anterolateral view of S element, \( x_{125} \), locality 2 of Ganis (1997) (USGS 11561-CO) (carbonate nodules from Lenhartsville); USNM 509972. (U) Drepanostodus perventus Nowlan. \( x_{150} \), [G-19] (USGS loc. 11560-CO); USNM 509973. (V) Drepanostodus arcuatus Pander, \( x_{75} \), [G-7 South] (USGS loc. 11562-CO); USNM 509975. (W) Priionodus? n. sp. P element, \( x_{75} \), [G-7 south] (USGS loc. 11562-CO); USNM 509976-979, respectively. (Y, E', H') Paraistodus proteus (Lindström). Fused pair (Y) \( x_{100} \), M element (E') \( x_{75} \), and S element (H') \( x_{75} \), [G-7 south] (USGS loc. 11562-CO); USNM 509980-982, respectively. (F') Oelandodus elongatus (Lindström). \( x_{75} \), [G-7 south] (USGS loc. 11562-CO); USNM 509983. (G') Onetothis costatus Ethington and Brand, \( x_{100} \), [G-7 south] (USGS loc. 11562-CO); USNM 509984.
ity slides, as olistoliths into a matrix of younger lower slope and rise sediments that underwent extensive soft-sediment deformation. This olistostrome is our Shellsville Member. These data suggest deformation during trench filling in a subduction complex. On the basis of their work in the eastern part of the Hamburg klippe, Lash et al. (1984) and Lash and Drake (1984) also suggested that much of the Hamburg sequence underwent these events. Probably at this time the subducting slab flexed, allowing localized outpouring of basaltic magma (the Jonestown Volcanics), as proposed by Lash 1984 in an olistostrome (?) containing Arenig-age limestone olistoliths.

What is surprising is the relatively short time interval during which this olistostrome formed, i.e., entirely within the Middle Ordovician Da 3/4 interval of ~6 m.y. duration (interpolated from Gradstein and Ogg, 1996). While the olistostrome was forming, turbiditic flysch was also being deposited into large submarine fans, forming the Nyes Road Member. Whether all parts of the Lower Ordovician sequence were fragmented and reincorporated into an olistostrome throughout the klippe is not known. Throughout the Arenig and Llanvirn, pelagic red beds and cherts and associated sediment also accumulated in areas distal to, and perhaps between, the submarine fans.

Third, a period of synorogenic turbiditic flysch sedimentation began in the Martinsburg foreland basin during the time of C. bicornis and early D. clingani zones. As with the other Taconic terranes of the Appalachians, the carbonate platform foredrowned and was drowned in response to the tectonic loading during this event. Boulder conglomerates (wildflysch deposits) developed in advance of the allochthon emplacement, although these deposits are scattered and not uniformly distributed. Fossil evidence suggests that the Hamburg klippe was emplaced in the time of the early D. clingani Zone, or slightly later, either as a coherent mass or in pieces.

The large size of the allochthon must have occupied a very significant part of the Martinsburg foreland basin, diverting sediment to and around its fringe (Faill, 1997). Eventually, the klippe was covered by late Martinsburg deposition during Edonian time (late Caradoc, as revealed by the shelly fauna and graphtolites (Climacograptus spiniferus Zone of Riva, 1969, 1974) found at Swatara Gap (Stephens et al., 1982). No graphtolite faunas between upper C. bicornis or possibly lower D. clingani Zone through the C. spiniferus Zone have been found. This represents the time interval when the presence of the allochthon diverged deposition until the foreland basin filled on either side and its sediments finally overlapped it.

Tectonic Setting

The Hamburg allochthon arrived in its current position relative to the lower Paleozoic strata in this part of the Appalachians (Figs. 1 and 2) during the Middle to Late Ordovician Taconic orogeny (Stose, 1946). It arrived completely detached from its original basement crust and continental fringe. The possible relationship between the Hamburg sequence and other lower slope and basinal deposits of the Westminster terrane, which was also obducted onto the Laurentian margin in the nearby Piedmont, was summarized by Faill (1997). This relationship is complicated and involves the configuration and sedimentation of the oceanic fringe with microcontinent and island-arc elements outboard of the Laurentian platform. Faill (1997) suggested that an Octoraro sea developed and received sediment from both Laurentia to the west and microcontinent(s) to the east. This scenario is similar in many respects to models proposed by Thomas (1977), Lash et al. (1984), and Lash and Drake (1984). The imbrication of westward-obducted multiple terranes is the classic Taconic pattern that involved outboard island arcs, drifted microcontinents, and intrabasinal sequences formed along the way (Rodgers, 1971; Drake et al., 1989; van der Pluijm et al., 1995; Faill, 1997).

Faill (1997) described an Octoraro sea as separating Laurentia from a microcontinent complex. Beyond this complex was the Theic ocean and depositional basin to the east, which included an island arc, the Wilmingon Complex. According to Faill (1997), the Hamburg klippe was a gravity detachment from the Octoraro sea sequence (some part of the Westminster terrane) lifted high on the Martic thrust (first suggested by Kay, 1941) after westward obduction. The depositional location of the Hamburg sequence within the Octoraro sea was not specified.

The contents of the Hamburg sequence differ significantly from the Octoraro sea sediments. The Hamburg klippe contains lithofacies and depositional characteristics not present in the other Octoraro sea successions, such as abundant deep-water limestone facies; thick, often red, chert and cherty shale (commonly forming long mappable ridges); large masses of amygdaloidal basalts, which were extruded over limestone; diabase dikes in the area near the basalts; thin volcanic ash beds; and large olistostromal complexes. The Octoraro sequences contain thin scattered ocean-floor basalts (Smith and Barnes, 1994), but no such corresponding intrusions occur in the Hamburg sequence. The dissimilarity of the Hamburg sequence from the other Octoraro sea sediments (the Westminster terrane) suggests that these two successions may have been deposited in different depositional environments or at different times. However, because none of the other Octoraro sea successions have been dated, no confident correlation between or among them can be made. Volcanic ash beds in the Hamburg sequence also demonstrate an original location in closer proximity to a volcanic source (Wilmingon Complex?) than the Westminster sequence, which does not have such ash beds reported.

Separated from, and south of, the Hamburg klippe is an area of shale and other clastic lithologies mapped as the Cocalico Shale (Jonas and Stose, 1930). Stose (1946) included the localities in the Hamburg klippe, and Jonas and Stose (1930) reported poorly preserved, possible Middle Ordovician graptothelites of Normanskill type. Stose and Jonas (1927) and Stose (1946) also classified a variety of purple shale found in the Cocalico as being of tuffaceous origin. Direct comparison of the Cocalico sequence with the Hamburg sequence remains problematic. Just as with the Westminster terrane, the Cocalico sequence differs significantly from the Hamburg sequence. How this terrane fits into the overall scheme of Octoraro sea, Theic ocean, or Martinsburg basin components awaits further study.

Because the Hamburg klippe is now detached from its immediate provenance, its origin remains in the realm of speculation. Lash and Drake (1984) and Lash et al. (1984) proposed that the Hamburg sequence was deposited between a microcontinent and Laurentia. We support this hypothesis and envision a process of westward (present orientation) obduction and overthrusting that brought the Hamburg sequence over westerly sourced Octoraro sea sediments.

Conclusions

1. The western portion of the Hamburg klippe is composed of an allochthonous body or bodies contained within the autochthonous Martinsburg Formation. The allochthon was emplaced by gravity sliding during early-middle Caradoc time (late C. bicornis to D. clingani zones).

2. Flysch deposited in the Martinsburg foreland in advance of the incoming allochthon may be slightly older than other parts of the
NEW BIOSTRATIGRAPHIC INFORMATION FROM THE WESTERN PART OF THE HAMBURG KLIPPE

4. The contents of the western part of the allochthon (Hamburg klippe) are herein named the Dauphin Formation; there are three interfingering members. The pelagic Manada Member (new) of early Arenig to middle Llanvirn (Da 3/4 age) contains strata of red and tan shale, chert, and minor carbonate and volcanic ash beds. The Shellsville Member (new) comprises fine-grained, variegated lower slope and rise sediments of Da 3/4 age that contain faunally distinctive Lower Ordovician olistoliths. One olistolith contains a nearly complete Tremadoc graptolite succession (and possibly some late Cambrian strata), whereas other olistoliths contain strata of early and middle Arenig age. The Nyes Road Member (new) is also Da 3/4 age and is a submarine canyon turbiditic flysch unit.

ACKNOWLEDGMENTS

We acknowledge the Natural Science and Engineering Research Council of Canada (NSERC) who provided funding to S.H. Williams for participation in this work. The Geological Survey of Canada at Calgary provided facilities and equipment during preparation of this paper. Lucian Platt generously lent us his collection of graptolites from previous work and John Riva provided his file of correspondence regarding earlier graptolite studies in the Hamburg klippe. Sharon Lucisano drafted the figures, and Benjamin Ganis typed the manuscript. We also acknowledge the useful comments of Avery A. Drake Jr. and Stig Bergstrøm.

REFERENCES CITED


Berry, W.B.N., 1960, Graptolite faunas of the Marathon region, west Texas: University of Texas Publication 6005, 179 p.


Berry, W.B.N., 1970, Review of Late Middle Ordovician faunas, and Benjamin Ganis typed the manuscript. We provided funding to S.H. Williams for participation in this work. The Geological Survey of Canada at Calgary provided facilities and equipment during preparation of this paper. Lucian Platt generously lent us his collection of graptolites from previous work and John Riva provided his file of correspondence regarding earlier graptolite studies in the Hamburg klippe. Sharon Lucisano drafted the figures, and Benjamin Ganis typed the manuscript. We also acknowledge the useful comments of Avery A. Drake Jr. and Stig Bergstrøm.

REFERENCES CITED


Berry, W.B.N., 1960, Graptolite faunas of the Marathon region, west Texas: University of Texas Publication 6005, 179 p.


Berry, W.B.N., 1970, Review of Late Middle Ordovician faunas, and Benjamin Ganis typed the manuscript. We provided funding to S.H. Williams for participation in this work. The Geological Survey of Canada at Calgary provided facilities and equipment during preparation of this paper. Lucian Platt generously lent us his collection of graptolites from previous work and John Riva provided his file of correspondence regarding earlier graptolite studies in the Hamburg klippe. Sharon Lucisano drafted the figures, and Benjamin Ganis typed the manuscript. We also acknowledge the useful comments of Avery A. Drake Jr. and Stig Bergstrøm.

REFERENCES CITED


Berry, W.B.N., 1960, Graptolite faunas of the Marathon region, west Texas: University of Texas Publication 6005, 179 p.


Berry, W.B.N., 1970, Review of Late Middle Ordovician faunas, and Benjamin Ganis typed the manuscript. We provided funding to S.H. Williams for participation in this work. The Geological Survey of Canada at Calgary provided facilities and equipment during preparation of this paper. Lucian Platt generously lent us his collection of graptolites from previous work and John Riva provided his file of correspondence regarding earlier graptolite studies in the Hamburg klippe. Sharon Lucisano drafted the figures, and Benjamin Ganis typed the manuscript. We also acknowledge the useful comments of Avery A. Drake Jr. and Stig Bergstrøm.

REFERENCES CITED


Berry, W.B.N., 1960, Graptolite faunas of the Marathon region, west Texas: University of Texas Publication 6005, 179 p.


Berry, W.B.N., 1970, Review of Late Middle Ordovician faunas, and Benjamin Ganis typed the manuscript. We provided funding to S.H. Williams for participation in this work. The Geological Survey of Canada at Calgary provided facilities and equipment during preparation of this paper. Lucian Platt generously lent us his collection of graptolites from previous work and John Riva provided his file of correspondence regarding earlier graptolite studies in the Hamburg klippe. Sharon Lucisano drafted the figures, and Benjamin Ganis typed the manuscript. We also acknowledge the useful comments of Avery A. Drake Jr. and Stig Bergstrøm.

REFERENCES CITED


Berry, W.B.N., 1960, Graptolite faunas of the Marathon region, west Texas: University of Texas Publication 6005, 179 p.


Berry, W.B.N., 1970, Review of Late Middle Ordovician faunas, and Benjamin Ganis typed the manuscript. We provided funding to S.H. Williams for participation in this work. The Geological Survey of Canada at Calgary provided facilities and equipment during preparation of this paper. Lucian Platt generously lent us his collection of graptolites from previous work and John Riva provided his file of correspondence regarding earlier graptolite studies in the Hamburg klippe. Sharon Lucisano drafted the figures, and Benjamin Ganis typed the manuscript. We also acknowledge the useful comments of Avery A. Drake Jr. and Stig Bergstrøm.


Taylor, R.S., 1997, Taxonomy and biostratigraphy of Middle Ordovician (Llanvirn) graptolites from the Table Cove and Black Cove formations, western Newfoundland (M.S. thesis): St. John’s, Memorial University of Newfoundland. 258 p.


Williams, H., 1978, Tectonic lithofacies map of the Appalachian orogen: St. John’s, Memorial University of Newfoundland, scale 1:1 000 000.


Williams, S.H., 1995, Middle Ordovician graptolites from the Lawrence Harbour Formation, central Newfoundland, Canada: Palaeontographica, v. 235, p. 21-77.


MANUSCRIPT RECEIVED BY THE SOCIETY APRIL 16, 1999
REVISED MANUSCRIPT RECEIVED FEBRUARY 1, 2000
MANUSCRIPT ACCEPTED FEBRUARY 14, 2000
Printed in the USA
CHAPTER 2, FIGURE 4. MODEL FOR DEVELOPMENT OF THE WESTERN HALF OF THE MARTINSBURG/HAMBURG FORELAND SEGMENT; DIAGRAMMATIC; VERTICAL SCALE HIGHLY EXaggerated AND NON-SPECIFIC.
CHAPTER 3, FIGURE 3. LATE CAMBRIAN SECTIONS

General description of the Onyx Cave and Sacony Members of Lash and Drake (1984) with interpreted correlative lithologies for sections described herein.

INDIANTOWN SECTION

UNIT H-2

FLY SCH

quartzofeldspathic sandstone
shale (sometimes grading to silt shale);
color indicated: bm = brown, blk = black,
gm = green, and gry = grey

FLY SCH

SILTY SCH

ribbon limestone with less interbedded black shale;
often slumped

black shale interbedded with lesser amounts of interbedded ribbon limestone

carbonate real conglomerate
phosphatic/glauconitic sandstone and coarse phosphorite

covered interval

VESLE RUN SECTION

est. 90 m thick; Late Cambrian to Early Ordovician age conodonts

Micaceous & feldspathic Sandstone
Siltstone
Shale & Mudstone
MANADA HILL TRUCK STOP CUT

Caradoc; Unit M-1; Turbidites
unconformity
132 m covered
Tan Shale; occ. maroon tint
Maroon siliceous, blocky shale
Maroon shale, crumbly weathering
Tan Shale
Maroon shale, crumbly weathering
Tan Shale, crumbly weathering
Maroon shale, crumbly weathering
Tan Shale, crumbly weathering
Maroon shale
Tan shale

Cordylodus homodus Barnes & Poplawski
Drepanodus? sp.; olstodontiform element
Paroistodus? sp.; drepanodontiform element
Periodon aculeatus Hadding
Protopanderodus sp. or spp.
+ linguloid brachiopod; sponge spicule

Couplets of massive chert & maroon shale
Tan blocky shale; minor maroon:
Red blocky chert & red shale

SCARPIGNATO QUARRY AT LENHARTSVILLE

Paroistodus cf. P. originalis (Sergeeva)

Thin Brown graywacke w/ ash. T H iD rn u m / i r a w u m / x l / a

LEGEND

\[ \text{shade, color indicated} \]
\[ \text{shade, color indicated} \]
\[ \text{chert with shale} \]
\[ \text{siliceous shale} \]
\[ \text{indented shale with chert or siliceous shale} \]

CHAPTER 3, FIGURE 11. PELAGITES; UNIT H-1