A Thesis Entitled

ASPECTS OF MACRO-REGIONAL
GEOCHEMICAL MAPPING IN AUSTRALIA

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This thesis discusses aspects and experimentation involved in a "macro-regional" geochemical mapping programme over 4.2 million km$^2$ of the continental land mass of Australia.

Section A defines, and then reviews, the objectives and current status of "macro-regional" geochemical mapping in the world as seen by the writer.

A broad outline of the Australian continental macro-regional geochemical programme, as conducted by Australian Anglo American under the direction of the writer, is given in Section B. The project's evolution, aims and objectives, sampling and analytical requirements, the simplistic operating and data validation systems developed are discussed in depth.

Section C outlines an experiment in a very detailed geochemical interpretation of the macro-regional stream sediment and concentrate coverage of a typical 17 000 km$^2$ 1:250 000 sheet area. Generally, because of the immense amount of data on file a quick perusal of these data is only possible, followed by brief notes which try to summarise the salient geochemical patterns and gross anomalies. The aim of the experiment is to maximise the information content of the data by univariate and multivariate techniques. Experimentation is also carried out within the section, with line printer cartography for rapid spatial representation of data for pattern recognition, and with the family of multivariate techniques classified under the term factor analysis. The former and latter are carried out through the now available user orientated, but non geological computer package SYMAP and SPSS(Statistical Package for the Social Sciences).

Aspects of investigations of local anomalies and regional patterns are discussed in Section D through a series of case studies. An attempt is made to show how some old methods of geochemical prospecting can still have a valid place in a modern integrated exploration programme.
Section E consists of two experiments in the search for the granitoid commodity elements, tin and tantalum, in a 100 000 km$^2$ area of the Pilbara block in northwest Western Australia. The search for exploration targets is conducted by an overview of the macro-regional Sn and Nb stream concentrate geochemical data integrated with satellite imagery. The applicability of the use of discriminant analysis on the semiquantitative stream concentrate data set is investigated through two contrasting algorithms. It is subsequently applied to the regional data set in an attempt to give better definition to targets noted in the univariate data analysis.

In the final section, Section F, the writer investigates in a very preliminary manner only, the concept of using "loam" (soil) heavy mineral concentrates as a medium for regional geochemical mapping in areas devoid of drainage.

The writer acknowledges the assistance of Australian Anglo American Limited. The Exploration Manager, Mr. R. J. Kernick, is thanked for his permission to pursue this thesis. The many staff are also thanked for their invaluable assistance. Dr. C. H. James who supervised the thesis is thanked for his constructive criticisms, discussions and advice when the writer visited the Geology Department, University of Leicester. Lastly, but never overlooked, my wife Beth, for her patience and understanding over the last five and a half years.
SECTION A

ASPECTS OF MACRO-REGIONAL GEOCHEMICAL SURVEYING

INTRODUCTION

Multi-element geochemical mapping of a continental land mass by a private organisation at the macro-regional level of coverage is a unique accomplishment in the western world. As a preliminary to discussions in subsequent sections of the methodology of the Australian continental programme and some concepts being developed, tested and applied by the writer in regional geochemical exploration, the first section of this thesis discusses aspects of macro-regional geochemical mapping.

After initial foundation work in the 1950's and early 1960's by many researchers in the western world, regional geochemical surveys have virtually become worldwide standard practice in mineral exploration under a variety of environmental conditions. Regional geochemical surveys, together with airborne geophysics, have generally proved to be the most reliable and cost effective method of areal selection of ground for more detailed evaluation and appraisal. Regional geochemical surveys, therefore, are best thought of as a "first pass" collection and analysis of material of diverse origin (soils, sediments, water, vegetation, gasses) taken at some specified density over a large area in order to detect smaller areas of enhanced or above average trace metal content in the earth's crust. This regional work is carried out over areas varying in size from $10 \text{ km}^2$ to greater than $25,000 \text{ km}^2$ and, depending on the sample material and the objective, at variable sample densities.

1. OBJECTIVES OF REGIONAL GEOCHEMICAL SURVEYING

Regional geochemical surveys are generally directed at some specific level of detection, varying from the macro-scale level of geochemical provinces (major and minor) to mineralised belts, to orefields within the belts, and finally to actual orebodies.

The objective of any geochemical survey is most important as this dictates ...2.
the area to be surveyed and methodology of surveying (sample type, density, elemental determinations). The two main users of regional geochemical surveys, the private and public sectors, have different objectives but overlap functionally. It is the difference in the objectives of these users that influences the level and extent of regional geochemical surveys.

In the private sector, the objective of geochemical surveys is the location of mineral deposits, be they of a specific element or a range of elements (based usually on an order of priority dictated by metal market economics) in concentrations which have a monetary value (grade, tonnage), that is commensurate with company financial policy. If appreciable "grass-roots" prospecting is called for, the scale of regional geochemical work generated is essentially on the MICRO-REGIONAL scale and the area covered may vary from 10 to 25 000 km². The sample density employed is governed by the type of target sought and material to be sampled, and is either directed to the detection of ore or the indication of an ore host environment.

The material to be sampled is a direct consequence of practicalities based on environment and exploration economics. For example in very arid regions where drainage is non-existent, soils and rocks are generally used, while in humid areas stream sediments may be employed. The cost per km² using soils and rocks is greater than sediments because of the greater density of sampling needed to detect dispersion from mineralisation. Thus, it would be economic folly to sample soils rather than sediments in a first pass in a humid area where drainage is well developed. Likewise, in arid regions of minimal drainage, residual soil sampling is to be preferred to bedrock sampling by overburden drilling. The sample densities for the media commonly employed at the micro-regional scale of activity are: stream sediments from 10 samples per km² to 1 sample per 20 km²; soils from 20 to 125 samples per km², and rocks 50 to 200 samples per km². Generally there is a tendency for the density of sampling to be too great and on the "overkill" side since little thought is usually given to a target probabilistic approach to sampling density, a "best guess" or intuitive feel being employed.

The sample media which have been discussed here are those which are most commonly used. Water, vegetation and gases may be used as sampling material at the micro-regional level, but generally, these are only used as "last resort" methods in general exploration.
In the public sector, the objective is to provide a service so that the general welfare of the country may benefit through research or direct action. Regional geochemical work here is carried out at both the MICRO-REGIONAL and MACRO-REGIONAL SCALE.

The MICRO-REGIONAL SCALE of work carried out by the public sector is similar and generally overlaps with that undertaken by industry. There is an increasing tendency for governments to be active in mineral exploration. This activity is carried out in two ways:

1. Giving encouragement to industry by making regional geochemical surveys in geologically little known terrain as part of a countrywide resource inventory policy. Any positive results may lead to companies taking up ground and undertaking detailed work which in turn may result in discoveries of economic interest. An excellent example is the work carried out by the Geological Survey of Canada as part of the Federal Uranium – Base Metal Reconnaissance Programme.

2. Direct competition with industry by carrying out programmes of exploration for energy and base metals to varying levels of completion. The Bureau of Mineral Resources in Australia could be cited as an example of the public sector carrying out programmes to partial completion. Their regional soil geochemical work and geological mapping led to the discovery of the Woodcutters L5. lead-zinc prospect in the Northern Territory. This information was subsequently passed to a private enterprise consortium, Peko-Wallsend Ltd – Electrolytic Zinc Company of Australia, and led to the delineation of a small rich ore body of 600 000 tonnes grading 8% Pb, 16% Zn and 224 grams Ag per tonne. (Peko-Wallsend Annual Report 1971, Joyce 1974).

Other examples of the latter type of activity are exploration by the French Government (through B.R.G.M.) for base metals and uranium in France and the ex-French colonies in Africa; and, in Canada, the programmes of the provincial government of Quebec's mining corporation, S.O.Q.E.M.

The public sector differs from the private sector at the micro-regional level of geochemical surveys in that other information is utilised or may be of...
importance. In addition to purely prospecting activities geochemical data may aid regional geological mapping in areas of poor exposure since geochemical data tends to reflect variations in the underlying bedrock. Stigzelius (1976) outlined the work of the Geological Survey of Finland in northern Finland. A systematic evaluation of the various 1:100 000 geological map sheets of northern Finland, integrated with airborne geophysics, has been in progress since 1971. The region of the Baltic Shield was glaciated during Pleistocene times and is still covered by tills and associated glacial deposits. Outcropping bedrock is sparse (3%) and outcrops are unevenly distributed among the different metamorphic and plutonic rocks. However, till has been found to be a most suitable sampling medium for geological and geochemical survey work. Lithologically the tills reflect the underlying bedrock, and consequently the chemical compositions of the bedrock and the till blanket are roughly compatible. Thus by geochemical surveys, geological mapping can be effected, as well as the recognition of mineralised areas.

The study of natural regional variations in geochemical data has also been applied to agricultural and public health problems such as, natural trace element deficiencies or excesses which may affect crops and animals. (Webb, 1970, 1974). Man-made additions of trace elements to the environment, (i.e. industrial pollution) have also been studied in this way.

The term MACRO-REGIONAL geochemical survey is introduced and used here to define regional work, conducted over areas greater than 25 000 km², in order to delineate geochemical (and/or metallogenic) provinces and specific mineralisation within provinces. The parameters of macro-regional work are themselves variable, in terms of sample material employed, sample density and the size of the area covered which can vary from provincial to continental coverage. This work involves massive sustained expenditure and effort over a long time period. If conducted on a countrywide or continental scale a minimum of ten years would only accomplish a portion of the desired results. Indeed, Boyle (1977) states that for most countries a programme of production of standardized regional geochemical maps on a national scale, based on the analysis of samples of the lithosphere (rocks), pedosphere (soils), hydrosphere (waters, stream and lake sediments), and biosphere (vegetation, etc.) for the principal elements of the periodic table, may require a concentrated effort for a century or so. Geochemical work here is therefore limited to the public sector although the private
sector may participate at the lower limits of the scale of areal coverage. The main reasons why the private sector does not participate in macro-regional geochemical surveys are financial and the fundamental difference in objectives. These financial reasons are essentially, (1), time scale of the short company budgetary periods, which are usually annual; and (2) the uncertainties and fluctuations of exploration budgets, coupled with varying priorities which are directly dependent upon and controlled by the metal market. Furthermore management is often willing to commit exploration expenditure for long time periods, especially on unsecured ground.

There are, however, some industrial exceptions to this rule, and the following example is such an exception. De Beers Consolidated Mines has completely covered countries such as Rhodesia, Zambia, Uganda, Tanzania, much of Botswana, Angola, Namibia, South Africa and Mozambique. In these areas, the technique of mineralogical prospecting using soil ("loam") and stream sediment concentrates has been applied. Indeed, De Beers could be called the pioneer in the private sector of the principles of the approach to macro-regional geochemical work. The collection by De Beers of material at low densities (stream concentrates 1 sample per 50-125 km$^2$ and soil "loam" concentrates 1 sample per 8-15 km$^2$), over vast regions with subsequent mineralogical analysis, has led to the delineation of kimberlitic mineral provinces within which more detailed follow-up sampling has revealed kimberlitic fields (analogous to mineral belts) and diamondiferous kimberlites (the ore bodies). A brief review of the historical development and current status of macro-regional geochemical prospecting is given below.

2. CURRENT STATUS OF MACRO-REGIONAL GEOCHEMICAL SURVEYING

A brief resume of some of the highlights in the history of macro-regional geochemical prospecting and its current status is given from a literature search:

The first macro-regional survey in the western world was carried out in 1954-55 in New Brunswick, Canada. (Hawkes, Bloom, Riddell and Webb (1956)). The survey was initiated to locate areas of Cu, Pb, Zn mineralisation. Orientation studies had indicated the existence of anomalous trace element levels in drainage sediments over known mineralised zones compared...
with those derived from barren areas. The survey involved the collection of active sediments, at a mean sample density of one sample per 4 km$^2$, over an area of 69,120 km$^2$ with subsequent sample analysis for cold-extractable heavy metals. A number of anomalies were revealed, some of which were related to new mineralisation. It was also noted that broadscale variation in heavy metal patterns correlated with major geological units. This observation, together with other data from central Africa (Webb 1958) indicated the possible use of regional geochemical maps based on multi-element analysis of stream sediments to indicate areas of increased mineral potential and to aid geological mapping.

On conceptual geological grounds in the early 1960's, Consolidated-Zinc-Riotinto Australia Exploration Ltd (C.R.A.E.) focussed their attention on the search for porphyry Cu (Mo) deposits in north eastern Australia and Oceania. Initially, the search was directed to the state of Queensland, where areal selection was based on geological considerations and screening accomplished by regional stream geochemistry. This work led to the discovery of minor low grade mineralisation at Eungella (Cu) and Moonmera (Cu, Mo). However, following the discovery of the "bonanza" Panguna porphyry Cu (Au) deposit on Bougainville in 1964 by the use of the same geological reasoning and follow-up methodology, a decision was taken by the C.R.A.E. management to extend the area of search to cover New Britain, New Ireland and part of the mainland of New Guinea. Some 38 000 km$^2$ of the above islands were covered with low density drainage sampling in a 6 months period under strict infrastructural conditions, (i.e. the location of porphyry Cu deposits/provinces within 40 km of the coast). This was achieved by a helicopter supported modified tuna-fishing vessel named the Craestar. The 27,5 m long vessel which cruised at 9,5 knots was used as a mobile helicopter base and laboratory. (Fisher 1971, Joyce 1974).

A study over some 39 000 km$^2$ of the Basement Complex of Sierra Leone by Garrett and Nichol (1967), employing widely spaced stream sediment samples (one sample per 130 to 260 km$^2$) and subsequent multielemental analyses showed that the method revealed the existence of marked regional variations in geochemical background, and demonstrated, that the significant increases in chromium levels on a regional scale were associated with an area of known chromium mineralisation and a minor chromium province. Additional areas of possible chromium mineralisation were suggested which may represent an extension of the known mineralised belt.
Armour Brown and Nichol (1970) carried out a regional reconnaissance drainage survey over 208,000 km$^2$ of Zambia at an average density of one sample per 190 km$^2$. The study was designed to investigate the applicability of low density drainage sampling and multielemental analysis to the identification of variation in regional background levels of minor element contents associated with different metallogenic zones. The study was successful in that some elements (noticeably Cu, Sn and Sr) disclosed highs which correlated with known copper, tin and carbonatite provinces.

The Applied Geochemistry Research Group at the Imperial College, London, has now nearly completed geochemical atlases of Northern Ireland (14,146 km$^2$), and England and Wales (151,119 km$^2$). This effort originated from stream sediment samples which were collected in the late 1960's at a density of one sample per 2 to 3 km$^2$ and analysed for 25 elements. The regional data is being studied in relation to the incidence of plant and animal diseases, pollution and mineral resources. (Webb 1970, 1973, 1975). The Institute of Geological Science is now embarking on a more detailed geochemical mapping programme, at present mainly in Scotland, as part of a nationwide resource inventory programme.

A reconnaissance geochemical survey of the entire United States (to be completed in the early 1980's) utilising stream sediments, stream waters and ground waters was commenced in 1975 by the Energy Research and Development Administration (ERDA) primarily as part of the assessment of the country's uranium resources. The systematic programme is also intended to assist the private sector's exploration effort by supplying information on the occurrence and distribution of uranium, and by identifying new areas favourable for uranium exploration (Carter 1975). In the eastern United States stream sediment and water samples are collected over crystalline and sedimentary rocks at densities of one per 13 km$^2$ and 20 km$^2$ respectively while ground waters are collected at an average density of one site per 20 km$^2$. Measurements made at each site include pH and conductivity. Dissolved ions are recovered quantitatively in the field from 1 litre of water with an ion exchange resin. Concentrations of U and 20 other elements are determined by neutron activation techniques. (Price 1976, 1978).

Gleeson and Brummer (1976) outlined the results of helicopter supported
reconnaissance stream sediment surveys carried out by Occidental Minerals Corporation of Canada in 1970 and 1971 over 63,500 km² of the south-west Yukon. Stream sediment samples were collected at approximately 1 sample per 5 km² and analysed for Cu, Zn and Mo. The object was to outline viable target areas in the search for porphyry Cu-Mo deposits. Many interesting anomalies were delineated and subsequent follow-up work on some showed them to be related to Cu-Mo mineralisation in Triassic-Tertiary intrusions. Regional geochemical maps employing the residuals from rolling mean smoothing outlined metallogenic zones and showed that the major metal trends for Cu, Zn and Mo corresponded to the regional northwesterly structural fabric of the area and to Mesozoic-Tertiary intrusive rocks.

Macro-regional stream geochemical surveys at the lower levels of areal coverage are now becoming common in third world countries. These are run by governments with help from international aid organisations, e.g. United Nations (UNEDP) or technical cooperation programmes financed and staffed by a developed country. The published results of ongoing regional geochemical-geological mapping programmes conducted under technical cooperation programmes between the United Kingdom and the governments of Peru and Indonesia are examples of such work in third world countries. (Baldock 1977, Page et al 1978).

The objectives of the exercise in Peru were the preliminary exploration of 25,000 km² of the northern sector of the Western Cordillera and the assessment of the overall mineral potential of this poorly known part of a polymetallic province. (Baldock 1977). The area was thought to be particularly favourable for porphyry copper mineralisation. A detailed, systematic geochemical survey of the whole region was impracticable within the time and resources available, therefore, after an initial orientation survey over the large virgin Michiquillay copper porphyry (500 x 10⁶ tonnes @ 0.7% Cu) a low density geochemical drainage survey was designed to locate and indicate other discrete mineral deposits rather than to delineate broad mineralised provinces or belts as had been successfully achieved by previously cited workers. (Armour Brown et al 1970, Garrett et al 1967). An initial spacing of one sample every 10 km along suitable drainage channels (mean sample density one per 25 km²), with analysis of the minus 175 micron fraction for Cu, Pb, Zn, Ag, Mo, cold extractable Cu and "Total" Heavy Metals, proved adequate for the successful detection of the known large individual deposits and the location of four important...
new centres of copper mineralisation. Various other anomalies; Cu-Mo, 
Ag-Cu-Pb-Zn, appear to be as yet unproved geochemical indicators of extensions of known mineralised districts.

In Indonesia the objective is to evaluate the mineral potential of an area of 175 000 km$^2$ of rugged rain forest in northern Sumatra; and to indicate geological environments and geographic zones worthy of more detailed examination for metallic and non metallic minerals (excluding oil and gas). (Page et al 1978). Mineralised areas and favourable geological environments have been recognised from the use of traditional geochemical and geological techniques. Where possible collection of stream sediments and concentrates is carried out at 4 km intervals along drainage (an approximate sample density of one per 10 to 12 km$^2$); with analysis of the milled - 150 + 100 micron fraction of the sediments and magnetic and non magnetic fraction of the concentrates for Cu, Pb, Zn, Co, Ni, Mn, Ag, Li, K, Cr, Fe, As, Sn, Mo, V, Hg (sediments only). The regional geochemistry is reported to reflect the underlying geology and has broadly delineated zones of different elemental associations which accord on a regional scale with the observed distribution of mineralisation. Pb, Zn anomalies and Pb mineralisation occur along the northeastern flank of the mountainous interior and two zones of Cu based anomalies and mineralisation (with associated Ni-Cr or Au-Ag-Mo) fall along the median Sumatra Fault Zone and the western seaboard over mafic-ultramafic rocks or granodiorite stocks.

To close this resume, some interesting aspects of the macro-regional geochemical techniques being developed by the Geological Survey of Canada, and the Geological Survey of Sweden should be mentioned. The Geological Survey of Canada (GSC), after considerable orientation studies, introduced centre-lake sediment and water sampling as a macroregional reconnaissance geochemical technique within the Canadian Shield in the early 1970's (Allan 1971; Allan et al 1973). Under the auspices of the Federal Uranium Reconnaissance Program, the G.S.C. is carrying out large scale reconnaissance surveys to outline areas deserving more detailed exploration for mineral deposits and to assist in resource inventory appraisal. Since 1975 some 414 000 km$^2$ of the Canadian Shield has been sampled by the collection of samples at a mean density of one sample per 13 km$^2$. (Maurice et al 1978).
A variety of features have contributed to the effectiveness of these methods within the shield areas. These are:

1. The great abundance of lakes ranging in frequency up to one per 2-3 km², whereas streams that might contain inorganic sediments suitable for geochemical surveys are rare because of the impeded and disorganised drainage in this predominantly flat and glaciated terrain.

2. The detrital portion of lake sediments appears to be a good composite sample of the surrounding bedrock.

3. The fine grained fraction (minus 60 micron) of centre-lake bottom sediment is found to provide a homogeneous sample medium, in which trace elements accumulate. Part of these trace elements may result from weathering of any nearby sulphide deposits and subsequent transportation by ground-water flow, and/or surface flow into the lake.

4. Most importantly the amenability of this procedure to rapid helicopter sampling allows large areas to be sampled rapidly and relatively cheaply.

Levison (1974) pointed out that lake sediments have been used by private companies for the initial reconnaissance stage of exploration programmes since the early 1960's both within and outside the Canadian Shield, but very few of the results have been published to judge the level of their success.

A recent example of this macro-regional activity is a lake sediment and water geochemical survey over 73 000 km² in eastern Labrador. The survey was carried out at an average density of one sample per 13 km². Lake sediments were analysed for U, Cu, Pb, Zn, Ni, Co, Ag, Mn, Fe, Mo, Hg, As, F and loss-on-ignition to estimate organic carbon content while lake waters were analysed for U, F and pH. (C.S.C. Open File Release NGR 20, 21, 22, 23, 24 - 1977, 1978). Note that where applicable, conventional stream sediment and water sampling are also used under the same federally funded programme. For example the recently published results of a 63 000 km² survey in the Central Yukon Territory. Sampling here was carried out at an average density of one sample per 13 km² with stream sediments...
being analysed for U, Cu, Pb, Zn, Ni, Co, Ag, Mn, Fe, Mo, Ba, W and Hg while stream waters were analysed for U, F and pH. (G.S.C. Open File Release NCR 29, 20, 21 - 1977, 1978). All of these studies suggest that ore fields can be detected by low density sampling.

A method of nationwide macro-regional geochemical prospecting was developed in the early 1970's by the Geological Survey of Sweden (S.G.U.) which is based in part on organic stream sediments and/or heavy minerals extracted from till (Brundin and Nairis, 1972; Brundin and Bergstrom, 1977). The collection of organic stream sediment samples is being based on road-stream intersections at a density of one sample per 3-6 km$^2$ while till is obtained from road cuttings at mean density of one sample per 10 km$^2$. The required sampling density is maintained by the use of boats, amphibious vehicles and helicopters where there is a less well developed road net. Brundin and Bergstrom reported that during the years 1971-1975 some 300 000 km$^2$ have been sampled by the latter technique, and that the results have delineated new areas of mineralisation.

SUMMARY CONCLUSIONS

Three important points emerge from the preceding resume, even though the majority of the chronological events cited are mainly information published by the public sector. These important points are:

1. This work is dominantly the domain of the public sector. It is only carried out by the private sector under strict company objectives and guidelines, e.g. the previously cited C.R.A.E. and Occidental Minerals examples.

2. The sampling media employed are principally associated with the hydrosphere and to a lesser extent the pedosphere and lithosphere, and are usually subjected to multi-elemental analytical work.

3. Sample density is variable in nature, but generally speaking the number of samples collected is greater than one per 25 km$^2$. This has come about because major geochemical or metallogenic provinces are, in the main, known and therefore low density sampling as in the cases cited from Zambia and Sierra Leone would appear to be unnece-
ssary. However, there are still minor provinces and mineralised belts to be identified. It appears that the aim of current macro-regional geochemical work is directed to the detection of minor geochemical provinces and belts, but with the density biased to the possible reflection of individual deposits or ore environments.

The following Section(s) discuss aspects and experiments carried out by the writer as part of a macro-regional geochemical programme being conducted by Australian Anglo American.
SECTION B
THE AUSTRALIAN MACRO-REGIONAL GEOCHEMICAL PROGRAMME

INTRODUCTION

Anglo American Corporation of South Africa, the world's largest mining and finance group, established interests in Australia in 1965 as Australian Anglo American Ltd. (A.A.A.). Active diamond exploration in Australia was begun in 1966 by a member of the group, De Beers Consolidated Mines. As previously mentioned, their main modus operandi for the location of primary diamond deposits was to undertake regional mineralogical drainage surveys at a sample density of between one sample per 65-175 km$^2$ for kimberlitic indicator minerals.

In late 1968, it was realised that this exclusive possession of low density regional drainage samples over a large, highly prospective continental area could be used by the company to obtain regional geochemical data. In view of the exceptionally large area covered in this way, this concept would be unique in the history of mineral exploration in western countries. A recommendation was therefore made to management that every effort be made to optimise the use of the samples being generated, since this work could be done at little extra cost above that of the kimberlite search. The Regional Geochemical Project was thus born. However, initially little was accomplished due to the untimely death, after a few months service, of the company's first appointed geochemist. The Project's dormancy lasted until 1972, when a new geochemist was appointed to oversee this unique endeavour.

Section B is essentially an outline of the basis of the programme under the following headings:

1. The Objective of the Project
2. Geochemical/Metallogenic Provinces
3. Sampling
4. Analytical Requirements

...2.
1. PROJECT OBJECTIVES

Before discussing the methodology of the continental macro-regional geochemical programme being carried out by Australian Anglo American, the objective of the project should be stated. The objective is the location of both major and minor geochemical provinces in Australia, from which hopefully will stem new metallogenic provinces. This objective is being carried out by multi-element analyses of low density drainage samples collected by a peripheral organisation of the Anglo American Corporation in Australia, with subsequent compilation, production and interpretation of geochemical maps. The data generated constitutes an aid to exploration activities within Australia by guiding conceptual thinking on geological environments, and at times is of assistance in indicating the potential of ground held by other parties.

2. GEOCHEMICAL AND METALLOGENIC PROVINCES

The objective, as stated, is to locate geochemical provinces from within hopefully, by further exploration, may stem previously unknown metallogenic provinces. What are geochemical and metallogenic provinces? Geologists and prospectors alike, through the "elephant country concept", have long recognised that specific parts of the world or country are characterised by groups of deposits of certain elements, which occur in zones or clusters frequently covering more than a few hundred square kilometres. The local accumulation of the elements in the crust is such that they may be extracted for economic gain. Such regions have been termed metallogenic, metallogenetetic or metallographic provinces. Additionally often such provinces show evidence of more than one metallogenic epoch, i.e. similar deposits of different ages grouped together spatially. This would imply that there are perhaps permanent heterogeneities in the earth's crust comprising such provinces.
Some of these metallogenic provinces lie within much larger well-defined areas of elemental enrichments (or depletions) called geochemical provinces. Geochemical provinces, thus may be considered as the largest example of primary geochemical haloes. The words metallogenic province, as used in the literature, are somewhat of a misnomer, as they infer that one element is present or of importance; whereas in many provinces several elements may accumulate, but are not of economic interest. For example, base metal provinces are also really sulphur provinces, tin provinces are often fluorine, and boron provinces. Also as demand increases and the supply of readily accessible areas of accumulation of metals diminishes, technological advances have allowed some geochemical provinces to become metallogenic provinces. Hence, some workers would prefer the term geochemical province to be used instead of metallogenic province (Boyle 1967). It should be stressed that generally the two are found together but this is not always the case. In this thesis the two terms will be kept separate, although one may grade into the other on the basis of economics.

3. SAMPLING

It will be recalled from the Introduction that the Regional Geochemical Project was a "spin off" from the search for diamond deposits by De Beers Consolidated Mines. Their main modus operandi for the location of primary diamond deposits was to undertake regional drainage surveys for kimberlitic indicator minerals at a variable sample density of between one sample per 65 to 175 km². At each drainage sample site 20 kg of material was taken from a likely heavy mineral trap and bagged. At the same time approximately 500 gm of active sediment was taken from the centre of the stream channel and placed in paper envelopes. The large trapsite samples were subjected to sizing and heavy mineral separation by field hand jigging, and later laboratory heavy liquid separation, to produce concentrates for mineralogical examination for kimberlitic indicator minerals. The stream sediment material retained was to be used for any trace element analysis work associated with the location of kimberlites. The dual collection of samples continued unmodified until 1972, when the Regional Geochemical Project got underway.
Certain aspects of sampling (sampling procedure, sample type, sample density, etc.) may present difficulties when an autonomous company of a mining-finance conglomerate is carrying out the physical collection of samples for a purpose that is not necessarily that of the collecting company itself.

3.1 Density of Sampling

The diamond programme as conceived is a three phase exercise and bears similarities to a modern day programme of resource inventory in an underdeveloped third world country. It is carried out by (1) regional mineralogical studies which seek kimberlitic provinces (analogous to geochemical provinces), (2) by the delineation of kimberlitic districts (analogous to delineation of mineralised belts), and (3) by the location of the kimberlites themselves (analogous to the discovery of an ore body). In exploration terminology the threefold division is simply (1) areal selection by reconnaissance, (2) prospecting of selected areas and (3) detailed evaluation. Bradshaw et al (1972) found it convenient to discuss geochemical surveys at these three levels on the basis of the number of stream sediment samples taken per square mile. In decreasing order, the sample densities (in metric units) considered were: (1) one sample per 100-200 km$^2$, (2) one sample per 10-50 km$^2$, (3) one sample per 2-5 km$^2$. Each category is specific for a particular objective, and reflects different geochemical features.

Prior to the commencement of the programme no primary kimberlites were known in Australia, though diamonds had been recovered and recorded with gold in ancient and modern alluvials in New South Wales (Wellington, Copeton), South Australia (Echunga) and Western Australia (Nullagine). The occurrences in the latter two states are suspect, however, and might only be related to late nineteenth century promotional mining activities. Thus De Beers primary objective was the rapid coverage of the $7.68 \times 10^6$ km$^2$ continental land mass of Australia, where possible, by drainage sampling to locate kimberlitic provinces, in which further detailed investigations would be made. The target area for drainage coverage not overlain by Recent cover amounted to some $4.23 \times 10^6$ km$^2$, which is 55% of the total area of the Commonwealth of Australia. Figure B1. The majority (95%) of this initial target area is now covered by sampling.
Looking at the Australian macro-regional geochemical programme, the coverage is variable due to factors such as frequency of drainage, and accessibility, i.e. whether the programme has been carried out by road or helicopter operations. In all, sample density is of the order of one sample per 50-70 km$^2$. At this level minor geochemical provinces and mineralised belts can be detected. It would be extremely fortuitous if individual deposits were found using this sample density. Coverage is planned in advance. The selection of sites to be visited, is made independently and without conscious reference to the order of drainage. Actual sample site positions are often modified during the field operation if a satisfactory trap site for heavy mineral deposition cannot be found. However, this does not alter the fundamental evenness of coverage. Figure C18 in Section C is an example of sample coverage for the Marble Bar 1:250 000 sheet in Western Australia.

Concentrate analytical data coverage is less comprehensive than that for stream sediments and is chiefly lacking in the Kimberley Region of Western Australia and South Australia. It is also somewhat sparse in Victoria and Eastern Queensland. This situation is due to the fact that the fine discard materials from the mineralogical analysis of stream concentrates had not been made available for geochemical analysis until the end of 1972. The total number of samples on the analytical files is 67 000 stream sediments and 30 000 concentrates.

3.2 Sampling Control

The important aspect for the reader to realise is that samples are generated by a peripheral company of the organisation. Samples are made available on the understanding that the resources, i.e. money and manpower, allocated to the kimberlite search and evaluation, suffer little distraction. However, the concept of correct sampling is important to both parties. Incorrect sampling would invalidate both exercises.

Since 1972, samples collected in this project have been subject to sampling control with the use of duplicate collection at 10% of the sites, i.e. generally sample numbers ending in zero are duplicated. The stream sediment sample itself is ideally a series of representative...
grab samples of active sediment from the central portion of the drainage channel with an emphasis on the collection of the finer size fraction of the sediment. For a significant interpretation of the results of regional geochemical work, the effects of sampling and analytical errors must be smaller than the overall data variability otherwise comparisons cannot be made between areas. To this end, the original and duplicate sample analytical results are subjected to a one way analysis of variance through a computer program GANOVA. In situations where sampling and analytical errors are high use of the moving average smoothing technique produces more reliable regional maps of broad scale features. (Howarth and Lowenstein, (1971)).

In the case of the concentrates analysed, little control can be exercised in the actual concentrate sampling. Here reliance is placed on the collection methodology developed by De Beers in both ephemeral and ephemeral streams. Research has been carried out on the recognition of the optimum trap site to sample for high yields of heavy mineral bearing sediments in youthful, mature and old age drainage systems. (Joyce, (1973, 1974)). In any sampling programme, the recognised best site for heavy mineral bearing sediments is always sampled first.

Where duplicate samples have been taken from the same type of trapsite there is some correspondence in the pattern of values. For example, Table B1 outlines emission spectrographic Cu, Pb, Zn data for duplicate concentrate samples from the Edmund 1:250 000 Sheet. It can be seen that considerable relative variation in data can be obtained. This is in part a reflection of the semiquantitative analytical method used.

All sources of error are fundamentally important and are avenues of research to learn how to minimise or control their effects. The relationship of sampling to total procedural error is becoming more important as analytical error is being minimised. Once, analytical error (e.g. for optical spectrographic techniques) was far greater than sampling error, but now the situation is reversed. The days of finding exposed virgin mineralisation in well explored, mineral districts by direct detailed geochemical means are largely over. The future of exploration success lies partly in well controlled...
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1118A</td>
<td>40</td>
<td>10</td>
<td>70</td>
<td>Analyses by optical emission spectroscopy on minus 150 micron size fraction.</td>
</tr>
<tr>
<td>B</td>
<td>30</td>
<td>30</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>F1119A</td>
<td>40</td>
<td>80</td>
<td>50</td>
<td>Detection limits for Cu, Pb, Zn are 5, 10, 10 ppm respectively.</td>
</tr>
<tr>
<td>B</td>
<td>30</td>
<td>20</td>
<td>120</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
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<td>10</td>
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<td></td>
</tr>
<tr>
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<td>0</td>
<td>60</td>
<td></td>
</tr>
<tr>
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<td>20</td>
<td>50</td>
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<tr>
<td>B</td>
<td>50</td>
<td>20</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Table B1 Duplicate trap site concentrate results
sampling schemes, coupled with multielement analytical techniques with enhanced precision and low detection limits (e.g. new generation XRF and ICP equipment) to detect the weak signal of mineralisation in the general geological noise.

4. ANALYTICAL

4.1 Analytical Media

Analytical work is carried out on the minus 175 micron fraction of the stream sediments and minus 150 micron stream concentrate residues from mineralogical examination. The selection of the stream sediment size fraction was made independently of any orientation work and was forced upon the project by previous analytical work. Large drainage basins of 50 to more than 100 km$^2$ in size have been sampled. On the theoretical basis that the sample represents the lithologies present in the basin (including mineralisation) modified by the effects of weathering and comminution, the minus 175 micron fraction, which contains both clastic and chemical components of dispersion, can be considered to be a satisfactory sampling medium for geochemical purposes. This early thinking was, in part, verified by world-wide literature which cites the usage of the minus 175 micron fraction in a variety of climatic and topographic regimes. Admittedly, as time progressed, it was found that values and geochemical contrasts in stream sediments with this size fraction were lower in arid areas of ephemeral drainage and low relief compared with humid areas of more positive relief having more regular drainage. This has not caused undue concern because of the familiarity and "feel" for the stream data developed by the project geochemist and the complimentary usage of the minus 150 micron concentrates. However, surveys that make use of minus 175 micron active sediments, the most common approach, are increasingly being questioned.

Duff (1975), in an ancillary role, attempted to determine the sampling technique that would be most effective in low density regional geochemical mapping. He studied the "total" Co, Cu, Ni, Pb, Zn, Fe and Mn results of various size fractions (-20#, -80# and -140#) of duplicate stream samples collected from six field areas that covered a wide
cross-section of climate, geology and physiography in Australia. His results highlighted the difficulty in selecting a single size fraction and sampling plan to minimise sampling error for all elements in multi-elemental surveys. However some broad trends were evident such as the preference of the coarse size fraction in arid areas.

As a generalisation, in areas having extreme climates or for which information from the fine sediments is not adequate, enhancement of anomalies may require the sampling of organic material; specific coarse size fractions of inorganic sediment; selected mineral groups within the sediment that may be isolated mechanically or chemically; or a combination of these techniques. In this project, a variety of sampling and analytical methods have been developed as a result of orientation surveys which were undertaken as a part of follow-up investigations. These methods were designed to accommodate regional geomorphological and climatic variations and to meet the objectives of the survey whether for project purposes or strictly for prospecting. For example both sets of regional data highlighted areas for Cu, Zn investigation underlain by the acid volcanoclastic phase of the Archaean cyclic volcanicity in the Eastern Goldfields of Western Australia. Orientation work showed that further geochemical work, coupled with regional mapping in these prospective areas, could be best served by collection of stream samples at 1 to 2 km² and analysing the -0.84 + 0.42 mm size fraction for Cu, Ni, Pb and Zn and to produce -2.83 + 0.84 mm concentrates by hand jigging for spectographic scanning. High contrast anomalies were obtained in the coarse size fraction of both media due to the limited dispersion from source. The spectrographic analyses of the easily produced concentrates, drew one's attention to other environments that would perhaps have been overlooked, e.g. syenetic/carbonititic intrusives.

4.2 Analytical Methods

The effectiveness of continental regional geochemical work is, to a large extent, dictated by the existence of multi-element analytical techniques which are reliable, inexpensive (as a result of their simplicity and rapidness of determination), sensitive, and sufficiently accurate and precise. At present a wide range of elements can be analysed by a variety of techniques. Figure B2 from Levison (1973)
Analytical methods in exploration geochemistry
(after Levinson 1974)
reviews these techniques. The analytical schemes and methods used for stream sediments and heavy mineral concentrates vary. Stream sediments are analysed by either colorimetric or atomic absorption methods after a suitable sample digestion to liberate the elements to be determined. Stream concentrates are analysed by emission spectrophotography. All work is carried out by contract laboratories.

Colorimetric methods cover those techniques where the element sought is made to react with specific organic reagents to form a coloured metal complex, the colour of which changes in intensity or shade according to the amount of trace element present. These coloured complexes are measured by direct visual comparison with a series of known standards. Atomic absorption spectrophotometry (AAS) has taken over from colorimetry for most routine geochemical analyses. A solution of the element sought is sprayed into a flame. The elements present are converted to an atomic state, in which they are capable of absorbing radiation at wavelengths which are specific to the element concerned. A source of incident radiation is required for each element to be determined, and this is usually produced by a hollow cathode lamp whose cathode is made from the relevant element. These lamps emit characteristic line spectra which, when passed through the flame, will only be absorbed by atoms of the same element as that of the cathode material. The absorption in the flame is proportional to the concentration of a particular element present.

4.2.1 Stream Sediment Analytical Scheme

Initially it was decided that all stream sediment samples were to be analysed for 15 elements, but two of the elements, Be and W, were deleted because of analytical problems leaving a thirteen element scheme. The current analytical scheme with detection limits in ppm in brackets is as follows:

(a) Hot perchloric acid digestion/atomic absorption spectrophotometry
   - Cu (2), Pb(2), Zn(2), Co(2), Ni(2), Mo*(0.25), As*(1)

(b) Hot aqua regia digestion/atomic absorption spectrophotometry
   - Ag(0,1), Bi(1), acid soluble Cr(10), Mn(10), V(10)
B10.

(c) Ammonium iodide sublimation/hydride generation, atomic absorption spectrophotometry – Sn*(l)

The elements asterisked were formerly analysed colorimetrically, but spiralling labour costs in Australia have led laboratories to develop or use new automated digestion/analytical techniques coupled to the atomic absorption spectrophotometer. Generally this has resulted in stability of analytical costs due to an increase in productivity. A reduction of elemental detection limits and an improvement in analytical precision has also been noticeable.

A more comprehensive outline of the above analytical schemes is as follows:-

(a) Hot perchloric acid digestion Cu, Pb, Zn, Ni, Co, As, Mo

One gram of sample is weighted by top pan balance into 18 x 150 mm tubes and 5 ml of 70% perchloric acid. The sample is digested at 180°C for three hours on a programmable dry heating block. The digestant is cooled and diluted to 20 ml with demetallised water and allowed to clear. The digestant is then aspirated directly into an air/acetylene flame of an atomic absorption spectrophotometer (AAS) and the concentration measured for Cu, Ni, Pb, Zn and Co. Non atomic absorption corrections are made for lead. The methods used for As and Mo determinations vary.

Currently As is determined by the metal-hydride vapour generation technique on 1 ml aliquot of digestion. To the aliquot, 14 ml of demetallised water and 5 ml of 35% hydrochloric acid are added followed by 5 ml of sodium borohydride solution. Arsine is generated in a vapour generation kit which is attached to the AAS. The generated arsine is flushed through with nitrogen into a hydrogen flame. The absorbance measured is recorded on a chart recorder. Detection limit is 0.20 ppm but the results are generally read to the nearest ppm.

Previously, As was determined colorimetrically on 5 ml aliquots of digestant. The digestant was allowed to stand for 3 minutes with 10 ml 1:1 HCl and 5 ml of reducing solution (stannous chloride-potassium...11.
iodide) in a 50 ml erlenmeyer flask. One gram of Zn pellets were added to the flask and arsine allowed to evolve for 20 minutes and be bubbled into 8 ml of absorbing solution (iodine – sodium bicarbonate – potassium iodide) in 18 x 150 mm test tubes standing in iced water. Five ml of developing solution (ammonium molybdate – sulphuric acid) was then added to the absorbing solution and the tubes immersed into 5 cm of boiling water for a further 20 minutes. After this time interval the tubes were allowed to cool and the As determined colorimetrically from the now developed molybdenum blue complex. The method was found to be suitable for 5 to 1000 ppm As in samples.

The analytical method for Mo is in part the method as outlined by Baker (1965). After the above digestion, 5 ml of 1:1 absorbic acid – potassium thiocyanate reagent is added to a ml of digestant and placed over a hot water bath for 5 minutes. The absorbic acid reduces the stable Mo$^{6+}$ to Mo$^{5+}$ which reacts with thiocyanate ions to form an orange complex. The complex is extracted by adding 1 ml of 20% (V/V) solution of amyl alcohol in chloroform and shaking for a minute. The concentration is measured against known standards in a photometer. The colorimetric finish has now been superseded by extracting the complex with 4 methyl pentan-2-one and aspirating directly into a nitrous oxide-acetylene flame of the atomic absorption spectrophotometer. The latter procedure is dangerous and explosions have recently caused fatalities to inexperienced operators. The procedure as outlined allows determination of acid soluble molybdenum in samples in the range 0 to 100 ppm. A detection limit of 0.2 ppm is possible with the latter technique.

(b) Hot aqua regia digestion Ag, Bi, Cr (acid sol), Mn, V

One gram of sample is weighted by top pan balance into 18 x 150 mm tubes. Four ml of a 30% hydrochloric acid – 70% nitric acid mixture, which is a 1 : 3 proportion by volume, is added to the tubes and the sample is taken to dryness. The residue is leached with 3 ml 35% hydrochloric acid and then topped to 10 ml with demetallised water. The solution when cleared is aspirated directly into the flame of the AAS. Mn determinations are made with an air/acetylene flame;
V, Cr with a nitrous oxide/acetylene flame and Ag, Bi with an air/hydrogen flame. Ag values are corrected for non-atomic absorption effects.

(c) Sn

Tin determinations are made on 500 milligrams of sample which has been ground to 75 microns. The sample is weighted by top pan balance into 18 x 150 mm tubes. One gram of ammonium iodide is added to the sample and mixed. The mixture is then sublimated in a rotary burner for 10 minutes. The sublimate is leached with 10 ml of 10% hydrochloric acid on a water bath for 30 minutes, then is broken up and allowed to settle. The clear solution is aspirated directly into an air/hydrogen flame. The method formerly used a colorimetric (gallein) finish.

Through follow up investigations this method has been found to be unreliable in that the efficiency of the digestion has been found to be extremely variable ranging from 40 to 80% extraction of tin. A sodium peroxide fusion was therefore introduced. The 500 mgm sample weight (ground to 75 microns) is sintered with 4 gm of sodium peroxide at 480°C for 30 minutes. The cooled sinter is leached with demetallised water for 30 minutes and then acidified with 1:1 HCl. The solution when cleared is aspirated into a nitrous oxide/acetylene flame. Recently XRF analyses for Sn on a pressed powder mount has been substituted for the fusion.

4.2.2 Stream Concentrate Analytical Scheme

After mineralogical examination the remaining minus 150 micron fraction of the heavy mineral concentrates were subjected to a 15 element scan on an optical emission spectrograph. The nature of the work, which is carried out by Anglo American Research Laboratories in Johannesburg, is at best semi-quantitative with precision for some element at low levels ranging up to 200% though an overall precision level of ± 60% is quoted by the laboratory. The emission spectrograph is a Hilgar Large instrument and consists of three main components, a direct current (dc) arc, a dispersing unit (prisms) and photographic detection equipment. The excitation of the sample takes place between
<table>
<thead>
<tr>
<th>Element</th>
<th>Analytical Line</th>
<th>Detection Limit (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Reading Interval</td>
</tr>
<tr>
<td>Ag</td>
<td>3382.9</td>
<td>0.1</td>
</tr>
<tr>
<td>Be</td>
<td>2348.6, 3131.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Bi</td>
<td>3067.7</td>
<td>1</td>
</tr>
<tr>
<td>Co</td>
<td>3395.4</td>
<td>10</td>
</tr>
<tr>
<td>Cu</td>
<td>3274.0, 2824.4</td>
<td>5</td>
</tr>
<tr>
<td>La</td>
<td>3245.1</td>
<td>100</td>
</tr>
<tr>
<td>Mo</td>
<td>3170.3, 2816.1</td>
<td>5</td>
</tr>
<tr>
<td>Nb</td>
<td>3163.4</td>
<td>100</td>
</tr>
<tr>
<td>Ni</td>
<td>3050.8</td>
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</tr>
<tr>
<td>Pb</td>
<td>2833.1</td>
<td>10</td>
</tr>
<tr>
<td>Sb</td>
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</tr>
<tr>
<td>Zn</td>
<td>3345.0</td>
<td>10</td>
</tr>
</tbody>
</table>

Table B2 Spectrographic Analytical Scheme - Stream Concentrates
graphite electrodes. This excitation at temperatures of up to 3 000°C changes an atom of an element from the ground to the excited state. After a time period in which appropriate electronic transition between orbital levels occurs within the atom, the atom returns to a lower energy state and emits electromagnetic radiations of characteristic wavelengths, which may be detected after dispersion through a prism (or grating) as emission lines. Usually the strongest and most characteristic line intensity with minimal interference is measured for the various elements. Visual comparisons of line intensities are made between the sample and standards of known composition.

Table B2 outlines the 15 elements analysed semi-quantitatively and gives detection limits encountered, and lines measured. Due to the differing volatilities of the elements, three burns are made for each sample at sample weights varying from 10 to 50 mg; each burn being for a different period of time. This improves precision and accuracy, but at low concentration levels precision for some elements, e.g. Mo, can be up to ± 200%.

4.2.3 Analytical Control

Safeguards must be taken by both the contract laboratory carrying out the work and project personnel to ensure that gross errors do not occur during the analysis and secondly to gain an idea of analytical error. Errors can occur at any stage of the procedure, i.e. from sample preparation, through sub-set sampling to the final quantitative estimations. Analytical control is discussed at two levels, that of the contract laboratory and the project itself.

A. Contract Laboratory

For purposes of analytical control, three general methods are used by all laboratories. These methods are:

(i) The institution of blanks, which obviate against the occurrence of gross errors such as contamination and is a measure of instrumental drift.
(ii) Replicate analyses of 5 to 10% of samples randomly selected from the job.

(iii) Replicate analyses of standards carried out at frequent intervals within a batch and between batches. These standards are laboratory solutions, and represent samples of differing matrices of international or local origin.

Readings for laboratory stock standard solutions are recorded to eliminate operator error in making standards. Old stock standards solutions are compared to the newly made stock solutions. Stock solutions for base metals (1 000 ug/ml) are generally replaced every 6-8 weeks while working solutions are replaced every week.

The majority of laboratories make use of control charts with action and warning limits of precision to control overall laboratory precision. At the end of the day jobs are plotted and batches that fall outside the defined limits are further checked. One of the greatest problems a laboratory faces is the problem of accuracy. This is overcome to a great extent by checks involving: (1) other analytical methods, e.g. for Sn analyses by fusion/AAS, samples are checked by X-ray fluorescence; (2) sending samples to another laboratory which uses the same preparation, digestion and analytical procedure, and (3) internal checks using international standards and internal standards which have been checked by other laboratories.

B. Project Monitor

Currently three methods are used to monitor laboratories. These are:

(i) Monitoring replicate analyses of samples from the laboratory.

(ii) Resubmission of (i) or samples selected at random over the concentration range from a number of batches.

(iii) Submitting a percentage to another laboratory that uses the same digestion method and analytical finish to check accuracy.
<table>
<thead>
<tr>
<th>Element</th>
<th>GANOVA</th>
<th></th>
<th></th>
<th></th>
<th>PRECAL</th>
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<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Pb</td>
<td>24</td>
<td>115</td>
<td>30*</td>
<td>49</td>
<td>6</td>
<td>24</td>
<td>32*</td>
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<td>Zn</td>
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<td>179</td>
<td>17</td>
<td>182</td>
<td>6</td>
<td>26</td>
<td>16</td>
<td>10</td>
</tr>
</tbody>
</table>

$P_{SA^\%}$ = Sampling - analytical precision

$P_{A^\%}$ = Analytical precision

$m$ = Mean elemental concentration (ppm)

Table B3  Comparison of the results of sampling-analytical and analytical precision calculations by GANOVA and PRECAL
Precision calculations (sampling – analytical, analytical) are carried out by computer using a Fortran programme, GANOVA a much modified method after Garrett (1969) or more lately by PRECAL, a programme following the simple graphical method of Thompson and Howarth (1973). GANOVA gives a precision value at the 95% confidence level (C.L.) for a specific mean of the concentration for the range of values encountered in the duplicated samples. Thompson and Howarth though, recognise that precision changes with concentration. Their precision value can be calculated graphically and the resulting precision value is the maximum limit of precision below, which 90% of the values will fall at the 95% C.L.. Sampling – analytical precision and analytical precision calculated by both methods for Cu, Pb, Zn, stream data from the Mount Bruce 1:250 000 Sheet area are shown in Table B3.

In this case, the Pb results were treated with suspicion and the laboratory was requested to re-analyse the batch. The cause of the imprecision was found to be a waning Pb lamp on the AAS unit.

5. PROJECT OPERATING SYSTEM

As some thousands of samples with multi-elemental analyses were already on file in 1972 and awaiting processing for study, and more analytical data would be generated from samples held in storage and from the ongoing programme of a now activated project, it was imperative to set up an effective data processing system.

A staged approach to setting up the data processing system was adopted. The initial requirement firstly was to have the raw data plotted so that a subjective interpretation of the data could be made, aided by simple statistics. In this way obvious anomalous patterns in the data could be detected and followed up. A very simplistic univariate approach would be a basis to lead into more advanced areal analysis and multivariate techniques to bring out the more subtle patterns and features in the data. The total system is best thought of in three distinct parts, i.e. data preparation, data processing and plotting and interpretation. Figure B3 summarises the current operating system.

...16.
5.1 Data Preparation

Ideally the information required by the project was sample number, sample location, geochemical data, sample characteristic, date, mineralogical data of concentrates collected and perhaps at a later date specific geological, pedological and topographical data. This data would be prepared by putting it in a coded format for processing and plotting.

The first three items (sample number, location and stream geochemical data) were taken and used initially in the coded 80 column card format designed for stream sediment data. (Refer Figure B4). The sample number is a 6 digit figure, columns 1 and 2 are reserved for alphabetic characters while columns 3 to 6 are for numeric information. A number series is generated commencing at A 0000-9999 to ZZ 0000-9999. This system allows for tens of millions of samples to be collected and stored.

The map numbering and co-ordinate system is based on the national system. The basic map unit in Australia is the 1:1 000 000 map series which is broken down into a 1:250 000 series, then into a 1:50 000 series. All the map series are on a transverse mercator projection. The basic map unit chosen to collect and record sample location on is the 1:250 000 scale which offers Australia wide coverage. Figure B5 illustrates the 540 map sheets covering the continent and Tasmania. This map scale is convenient because of the ancillary geological coverage being generated by a co-ordinated effort of the various State Geological Surveys and the Commonwealth Bureau of Mineral Resources. From Figure B5 each 1:1 000 000 sheet block is designated by a unique alpha-numeric co-ordinate system. In an easterly direction an alphabetic system applies, i.e. grids D to K while in a southerly direction a numeric system applies 49 to 54. The individual 1:1 000 000 sheets are further subdivided into 16 blocks numbered 1 to 16. Therefore if samples were collected over the Marble Bar 1:250 000 sheet in Western Australia, the sheet would be designated F5008. The sheet number is placed in columns 7 to 11, column 12 designates which half of the 1:1 000 000 block the sheet is found, i.e. W west or E east. Therefore, for the Marble Bar sheet the entire designation is F5008E (Refer Figure B5).
### Geochemistry Class 1

<table>
<thead>
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<th>Field</th>
<th>Identification</th>
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<th>Ag</th>
<th>As</th>
<th>Be</th>
<th>Bi</th>
<th>Co</th>
<th>Cr</th>
<th>Cu</th>
<th>Mn</th>
<th>Mo</th>
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<td>4</td>
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<td></td>
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<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Geochemistry Class 2

| Field | Identification | Coordinates | Bi | Pb | Zn | Sb | Sn | Y  | Be | Mo | Nb | Cu | Ni | La | Ag | Co | V  |
|-------|---------------|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1     |               | East        | 0  |    |    |    |    |    |    | 2  | 1  | 0  |    |    |    | 0 | 0 |    |
| 1     |               | North       | 0  |    |    |    |    |    |    | 0  | 0  | 0  |    |    |    | 0 | 0 |    |
The sample locations from these 1:250,000 sheets are listed on field sheets by the sampling teams at the time of collection, either with reference to cartesian grid co-ordinates or in degrees and minutes of latitude and longitude. Fortunately the latter was abandoned at an early date and the co-ordinate system based on the Australian National Yardage Grid is used. Using an 8 digit number, the position of any sample on the continent may be uniquely defined to the nearest 1000 yards. For example, a sample collected may have the co-ordinate 6 502 1324 (6 = zone designate, 502 eastings in 1000's of yards, 1325 northings in 1000's of yards). A disadvantage of using this scheme is that samples closer together than a 1000 yards cannot be distinguished, but for the continental wide regional study, this is not a severe restriction. This co-ordinate system was also acceptable because sample co-ordinates were being listed after being read confidently from 1:250,000 plans by field personnel. Acceptance of their co-ordination makes this facet of data preparation easier and cheaper. Should definition to the nearest 100 or 10 yards be required, as in field follow up, a new file would be created to optimise the new map scale.

Analytical data is entered in right hand notation in F4.0 format columns 21 to 80. Simple nomenclature was instituted for specific cases encountered with the analytical data. For example, "missing sample" or "not analysed" -1, "below detection" -0, "greater than range" 999 or 99.9. Data (sample number, sample co-ordinates and separate analytical data) were initially collated on coding sheets before being sent to a bureau for key punching and verification. At the time, the economies of "in-house" key punching versus a bureau were investigated and marginally favoured an in-house key punch. However, on the basis of the noise level that would be created in the office, it was decided to use a bureau. General labour economics, and the competitive nature of card punching now favour bureau facilities. As the bureau become familiar with the punching of the data, raw analytical data was key punched directly from analytical sheets, verified, listed and checked. This analytical card deck was then merged with a co-ordinate deck previously punched from a sample number geographic co-ordinate coding layout sheet that had been verified, listed and checked. This analytical card deck was then merged with ...
a co-ordinate deck previously punched from a sample number geographic co-ordinate coding layout sheet that had been verified, listed and checked. The merging was done by a simple computer programme of the merge/sort type on the basis of a common sample number between the decks. A new co-ordinated sample deck was thus produced for statistical and plotting purposes, and this new deck became part of the master file.

As the backlog of samples and current incoming samples were being analysed, a decision was taken to insist that the laboratory either present the analytical data directly on cards or on coding sheets in the designated format for key punching. This analytical deck was treated in the same manner as the above. Towards the end of 1972, concentrates were obtained for spectrographic analysis. The resulting analytical data were treated in a similar manner but a merge was carried out with the master stream sediment analytical file. The new deck generated in this case became the master concentrate analytical file. For filing purposes the elements on the cards are not arranged in alphabetical order and the buff cards have a distinctive red top.

As the project grew and field follow-up was initiated by sampling teams, field data on samples collected were added to the system. These data were recorded on field sheets for direct key punching. The field data deck generated was again used for merging purpose. Unfortunately, field data for the original regional samples taken are unavailable, but might have been valuable in sorting out geochemical drainage effects. However, the writer has mixed feelings on the quality of field data generated by non professional field staff if not properly supervised. Compatible stream sediment analytical data from both within the company and from external sources have been added to the data bank. While these data broaden the data base they cannot be strictly regarded as belonging to the macro-regional data base. Data preparation is now rapidly accomplished by digitizing co-ordinates, from which a co-ordinate card deck is produced and which is finally merged with a checked and verified analytical deck produced from key punching analytical result sheets.
As the data is representative of map sheets it is filed in card banks in sequential blocks corresponding to the 1:1,000,000 sheets, e.g. G50 Sheets 1 to 16, with a card index reference of the number of samples per sheet. The data types of the master file are filed separately and are distinguished by diagnostic colours, e.g. buff - master stream sediment analytical file, buff with red top - master concentrate analytical file, orange - field data file, green - detailed follow-up field data file, buff with green top - detailed follow-up stream sediment file. The cards are kept in metal card filing cabinets in the air conditioned office under fairly constant environmental conditions. All data have been entered onto two back-up magnetic tapes before entering the master card bank; one of these is stored in a bank while the other is held at the computer centre.

5.2 Data Processing and Plotting

Before even entering the data preparation stage a thorough review was made of time sharing and plotting facilities offered by various organisations in line with what the project wanted to accomplish. The time sharing facilities of Computer Sciences of Australia (CSA Ltd) was initially selected for usage because of the proximity of their terminal and comprehensive library of statistical package programmes. Later Control Data Corporation (CDC) was added to the list because of the facilities they offered. Besides statistical processing of data the procuring of computer services aided the streamlining of data preparation and the structuring of the data bank.

With data plotting and contouring there are three alternatives, namely manual plotting and contouring, automatic plotting and manual contouring, automatic plotting and contouring. Which of these to use is decided on the basis of job size, production costs and the time required for job completion. Each of these items are inter-related with the job in hand; however, the prime requisite is time. The more quickly geochemical maps can be produced and interpreted, the more swiftly the follow-up work is instituted, and hopefully if warranted licences taken out for detailed evaluation. It was decided to produce plans of results on transparent or translucent overlays to the 1:250,000 scale geological sheets and subjectively interpret the geochemistry by manual contouring guided by topography and geology after selection ...20.
of intervals from a study of the simple statistical data.

Automatic plotting and contouring would be limited to the final stages of areal analysis and to the extraction of the major regional trends and subtleties.

Once the problems associated with data processing and plotting were overcome, the system extended its services to general exploration projects. The problem with the accumulation of a vast amount of data in general is that much of it is only superficially examined before being discarded, or if lucky, archived. Even the minor amount of data which does reach print tends to be rapidly demoted in importance. The need to both conserve and make better use of such expensive and valuable information is obvious. Therefore, the project has gradually become a centre for the collation and computerisation of drill hole, surveying, geophysical and geochemical data for other exploration projects, with the end result of maximising the use of information and consequent saving of time and money.

5.3 Interpretation

All data were initially reviewed on a 1:250 000 sheet basis following a simple univariate statistical treatment. The present status of the Australia-wide 1:250 000 review can be seen in Table B4.

Of these sheet totals, emphasis has been directed to data in areas of significant sample density, and geological and infrastructural interest.

As previously stated a simplistic univariate approach is taken for the individual 1:250 000 sheet analytical results. The data is first run through an inhouse programme called VSTAT which lists the data, generates summary statistics (i.e. range, mean, standard deviation, variance, coefficient of variation, skewness and kurtosis), followed by a correlation and incidence matrix and finally elemental histograms with cumulative frequencies based on 100 class intervals, for both arithmetic and logged data. Production of elemental plans is accomplished after appropriate population intervals are selected from a study...
<table>
<thead>
<tr>
<th>State</th>
<th>Number of Sheets</th>
<th>Number of Sheets with geochemistry</th>
<th>Number of Sheets Individually reviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria</td>
<td>18</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>New South Wales</td>
<td>49</td>
<td>37</td>
<td>22</td>
</tr>
<tr>
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<td>87</td>
<td>60</td>
</tr>
<tr>
<td>Western Australia</td>
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<td>96</td>
<td>61</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>82</td>
<td>37</td>
<td>10</td>
</tr>
<tr>
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<td>68</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td><strong>524</strong></td>
<td><strong>310</strong></td>
<td><strong>198</strong></td>
</tr>
</tbody>
</table>

*Equivalent to $4.4 \times 10^6 \text{km}^2$ or 59% of the Australian continent.

Table B4 Status of 1:250 000 sheet reviews
of the above statistical data. The raw elemental data, including the ringing of significant populations selected from the prior study of cumulative frequency plots, is Calcomp plotted on transparent or translucent media to overlay the relevant 1:250 000 scale geological sheet. The geochemistry is then subjectively interpreted by further manual contouring of basins guided by topography and geology and "stacking" of elemental plaques.

A previous study of the correlation matrix draws one's attention to elemental associations which may be indicative of specific geological environments on the sheet. For example, the presence of a high correlation between Cr-Ni-Co-V and a lesser but still significant Ni-Co-Cu association alerts one to the respective presence of ultramafic-mafic rock types and possible sulphides. The "stacking" of the elemental plaques and summarising of the elemental patterns generally confirms the initial observations and inferences made from the correlation matrix as well as pinpointing areas for detailed investigation. Due to the immensity of the data bank, a brief perusal is only possible of the sheet geochemistry followed by short notes outlining the salient geochemical features with recommendations for exploration work. After the examination of a number of sheets in a region, specific geological environments highlighted in the geochemistry are occasionally "stripped" out. The geochemical data is reexamined in more depth after intermeshing, with detailed geology, compiled from published data and/or field and photo studies, and published magnetic and gravity data. At this level multivariate statistical techniques such as principal component analysis have been found useful.

The slowness of the individual 1:250 000 reviews has resulted in the total stream sediment and concentrate Cu, Ni, Pb, Zn and Sn data base, the basic five commodities of the corporate objective, to be further processed by computer printer plotting at 1:1 000 000 scale. These printer outputs are presented in the form of chloropleth "greyscale" plots, which have been subsequently re-drafted by a tracer to overlay 1:1 000 000 drainage base maps, mineral occurrence compilations and geological maps. The Fortran programme GREY in use was modified from a programme developed for plotting spatially distributed data (Howarth 1972). The programme is designed to enable rapid plotting of an unlimited...
number of data points using the computer line printer for output. Although this involves some sacrifice in overall plotting accuracy it is cost effective and enables one to rapidly visualise and absorb spatial patterns of variation in the geochemical data, i.e. highlighting regional and to a lesser extent local anomalies. The maps display the output in as many as 10 grey intensity levels. Each level is represented by a character of increasing visual density (the grey scale). Overprinting is used to supply the darker grey tones.

It is not necessary for the investigator to know, a priori, the best class intervals for displaying "patterns" in the data, because several maps with different combinations of class intervals may be obtained from the same data in a single computer run. In each situation the frequency distribution of the classes is obtained. Also, it is possible to use non-linear class intervals. However, in practice, the frequency distribution is first run by using another programme VSTAT to select the intervals. This is cost saving in computer time.

Plotting by this means is complete for the 5 basic commodity elements and the geochemistry of the individual states is currently being reviewed. An illustration of the ancillary 1:1 000 000 "greyscale" programme is given for Ni in stream sediments for the eastern half of the state of New South Wales. Figure B6. This data covering an area of 532 000 km² was outputted originally at 1:1 000 000 but has been further reduced to 1:4 000 000 to allow presentation as an overlay to a geological map of the same scale. (Figure B7). Even at this scale gross geological features, e.g. Tertiary Basalts and Palaeozoic "alpine" serpentinite belts in the eastern half of the state are obviously expressed in the data.

6. DATA VALIDATION

One of the most important questions to answer in such a survey is "what does the data mean?" This is best discussed briefly at three levels; the 1:1 000 000 overview, the 1:250 000 map sheet and the local basinal anomaly. The first and latter are discussed in some detail in Section D and conclusions drawn in that discussion are not considered here.
(1) At the gross 1:1,000,000 overview, anomalous geochemical patterns can be related to both known and unknown broadscale features, (as in the previously discussed 1:1,000,000 Ni plan reduction, the known Palaeozoic "alpine" serpentinite belts of N.S.W.), known mineralised areas, and anomalous patterns over prospective geological environments.

(2) At an early stage in the project, the available summary findings of detailed stream sediment work carried out in a joint venture on a 1:250,000 sheet was compared with the results of the project's regional sampling. Stream sediment samples were collected at a density of one sample per 2 km² by the joint venture operator over a 2750 km² licence underlain by the Middle Proterozoic Bangemall Basin. The minus 175 micron size fraction of the sediments were analysed for Cu and Zn by AAS after a hot perchloric digestion. Cu and Zn values of 80+ and 100+ ppm respectively were defined by the joint venture operator as being anomalous. The summarised anomalous geochemical results and mineralisations found in the licence and the macroregional Cu and Zn data over the 8500 km² eastern half of the 1:250,000 sheet are presented in Figures B8 to B11 as coloured transparencies to overlay a geological and sample location map.

The data illustrates:

(a) A general correlation between the joint venture anomalies and regional stream sediment enhancements in Cu and Zn in the sedimentary basin.

(b) The gross difference in macroregional terms of the Archaean granitic terrain of the craton and the Middle Proterozoic sedimentary basin, i.e. low Cu, Zn over the craton contrasting with high Cu, Zn, over the black shale environment of the sedimentary basin. Anomalous areas are evident within the enhancements over the sedimentary basin. The Cu, Zn concentrate data when compared with the stream sediment data for the area shows similar patterns.

...24.
QUATERNARY AND TERTIARY COVER: Alluvium and laterite

UPPER BANGEMALL GROUP: Formations at base of Bangemall Group

LOWER BANGEMALL GROUP: Discovery Chert

GEOLOGICAL THRESHOLDS

MICACIOUS SCHIST: Includes locally well-foliated units

SCHIST, CHARACTERISTICALLY BASIC

SEDIMENTS: Includes locally well-foliated units

SCALE 1:500,000

GEOLOGY
QUATERNARY & TERTIARY COVER: Alluvium and laterite

UPPER BANGEMALL GROUP: Formations above Discovery Chart

LOWER BANGEMALL GROUP: Discovery Chart and formations below

SANDSTONES & CONGLOMERATES AT BASE OF BANGEMALLS: Probable correlative of Brunswick Group

GRAINTE AND GNEISSIC GRANITE

MICACEOUS SCHIST: Includes locally well-foliated gneiss

SCHIST, CHARACTERISTICALLY BASIC: But includes micaeous variants

SILICEOUS SCHIST AND GNEISS

SCALE 1:500,000

EASTERN HALF MT. PHILLIPS SHEET

SCOLE 1:800,000

GEOLOGY

Fig. B11
Laboratory AA Cu ppm - 175 mm

Field ex Cu ppm - 175 mm

LOCAL BASIN - ANOMALY

KANJENJIE CREEK

Fig. B12
(3) At the local basinal level an example is given for follow-up of an anomaly in a geological environment deemed prospective for Cu. Figure B12 compares the results of the field mapping and field ex Cu geochemical work programme with the subsequent laboratory results. Pyritic mineralisation was located in the regionally anomalous basin, thereby explaining the original regional anomaly. A correspondence is found between the Cu results of the original sample site and those obtained by subsequent resampling. Aspects of field investigations are discussed more fully in Section D.

7. DISCUSSION

The programme is considered to derive great advantage from the extent of data coverage and methods of presentation. Data coverage is available on areas which would not necessarily be prospected in the course of specific base or precious metal exploration and the broad database permits regional and local responses to be placed in the appropriate geological perspective. Responses in widely differing environments can often be compared and related.

The results of the initial geochemical interpretation in the form of summary plans and appropriate review notes, with responses of interest assigned a geochemical rating of A to C are handed on to the relevant operating division. Divisional exploration personnel review the data further. Raw data covering specific areas of interest are plotted on transparent overlays to the original sample location plan generally at a scale of 1:250 000 or larger. This stage permits the response to be considered in its local context a more closely attributed to specific geological units.

The response is considered in both a local and limited regional (1:250 000 sheet) context by reference to absolute geochemical levels and 1:250 000 sheet statistics. After considering infrastructure in broad terms and ground availability, an action priority based on all three factors is assigned and an outline of necessary work is drawn up. Action required may comprise research of previous exploration, mineral occurrences or environmental possibilities and/or field...
geological and geochemical follow-up to validate the original results and subsequent research ideas. Following any necessary research and appraisal of all relevant data a field programme is drawn up and carried out.

The objective of the field programme is to identify or develop projects for the respective operating division. Project status would generally be defined as the identification from a field programme, of an area having clear evidence or obvious potential for mineralisation of a target size, further exploration of which, would require a sustained programme over ground normally secured by a tenement. Generally, projects are justified only after the acquisition and consideration of all relevant data i.e. geology, geochemistry, geophysics, infrastructure, target potential (as indicated by known mineralisation and environment possibilities) in relation to target requirements. At this stage, a logical work programme can be set out on targets that appear to be specific in nature.

It is becoming clear that consideration and research using the macro-regional geochemical data bank and published regional geological geophysical data and perhaps satellite imagery will suggest areas or regional geological units which may have potential for economic mineralisation and which hitherto have not been specifically indicated. Such situations if proposed are potential "grass roots" projects and would receive an appropriate action rating from the operating division.

The above approach is therefore two pronged and is intended to ensure that not only are anomalous geochemical responses which warrant follow-up in their own right are investigated, but that the inferences which may be drawn from the data with appropriate geological input are used as a regional tool for areal selection and for detailed exploration investigations.
SECTION C
GEOCHEMICAL INTERPRETATION
OF THE MARBLE BAR 1:250 000 SHEET

INTRODUCTION

This section follows on from the generalised outline of the interpretative methodology discussed in Section B. Generally because of the immense amount of data on file a brief perusal of these data followed by notes of interpretation in possibly less than five hundred words attempts to summarise the salient geochemical patterns and obvious gross anomalies. However, a wealth of information could be extracted from the data. The section is thus devoted to an experiment in a very detailed interpretation of macroregional stream sediment and concentrate geochemical data for a typical 1:250 000 sheet area, i.e. maximising the information content of the data to its limits. The sheet geochemistry discussed in that of Marble Bar in Western Australia. Simplistic univariate and multivariate techniques are applied in the interpretation. Comparisons are made of the geochemical responses of the two sample media and the techniques applied. The results of the detailed interpretation are used in a latter section devoted to pattern recognition and classification. Refer Section E.

1. LOCATION

The Marble Bar Sheet, SF50-08, on the International Grid, is found within the western portion of the Pilbara Goldfield in northwestern Western Australia (Figure C1). The sheet, an area of some 17420 km², is bounded by latitudes 21° and 22° south and longitudes 118°13' and 120° east. The only real centre of population is Marble Bar (394 persons) in the northwest corner of the sheet area. This is a centre for limited mining activity, formerly gold, but now tin, cattle ranching and some tourism. Marble Bar itself is situated on the graded earth road (the Great Northern Highway), 225 kms south of the iron ore export centre of Port Hedland on the coast, and from the iron ore town of Newman, a further 240 kms to the south. Access to most of
the sheet area is only possible by poor quality cattle and mining tracks. The western portion of the sheet is traversed by the Mt. Newman Iron Ore Co. railway line.

2. CLIMATE AND VEGETATION

The climate of the sheet area is typical of the arid grasslands of low latitude areas on the western side of southern continents with hot summers and mild winters prevailing. Historically, a daily mean maximum and minimum temperature of 40°C and 25°C respectively is common, for at least three months of the year. Before the advent of the iron ore towns this fact had given rise to Marble Bar's reputation as being Australia's summer "hot spot". Winters are milder with the lowest mean maximum and minimum daily temperatures of 26°C and 12°C occurring in the month of July. The region is influenced partly by summer northern rainfall systems of tropical origin which are responsible for heavy cyclonic thunderstorms during the summer months of November to March, and also by the southern systems from May to August which bring winter rains to the area and the southern portion of the state. The annual evaporation rate of some 2 500 mm far exceeds the average annual rainfall of 334 mm.

Spinifex grass (Triodia sp) and associated shrubs are common throughout the area. Eucalypts and acacias are mainly confined to watercourses. Generally shrubs and trees are comparatively scarce, a fact which influences the erosion of the country and the quantity of water available as surface supplies for ranching activities.

3. PHYSIOGRAPHY

The sheet area is part of what is described as "Pilbaraland", a dissected plateau of which remnants are still preserved (Jutson 1950). In broad terms, the physiography consists of sand plains and ranges of low razor back hills lying between 150 and 400 m above sea level. The main river systems, the Shaw, Yule, Coongan, Turner and Brockman form part of a northerly flowing, superimposed ephemeral and generally dendritic drainage system. (Figure C1).
The present land surface is the product of multiple erosion cycles. Remnants of at least three previous land surfaces, the Hamersley, Intermediate and Yule, exist within the area. The oldest, the Hamersley Surface, is a dissected, mature Tertiary peneplain (Macleod 1966) occurring at a variety of heights of greater than 200 m above sea level. The Intermediate Surface is sometimes preserved 30 m above the Yule Surface, and generally, the summits of the large expanse of granite hills in the area are at an elevation that approximates to the level of the Intermediate Surface. The Yule Surface was first recognised on the Yule Plain in the western adjoining 1:250 000 Pyramid Sheet area (Kriewaldt and Ryan 1967). It extends into the Marble Bar Sheet area and forms a large part of the sand and gravel plains. The present surface occurs as sand plain below the level of the Yule Surface. It is also represented by scree near and within hilly areas, by drift sand and sand dunes in the northwest part of the sheet area and by loose sandy pebble beds and boulder deposits in creeks and river beds.

Five general physiographic units (plateau, dissected plateau, range, low granite hills and plain), have been recognised by Hickman and Lipple (1975). Figure C2 taken from Hickman and Lipple (1975) outlines the physiography of the sheet area.

The plateau is equated to the Hamersley Surface of tertiary peneplanation. It only occupies 2% of the sheet area. Over Archaean terrain, it is usually capped by laterite and is separated from outliers by steep talus slopes or cliffs.

Between plateau and plain is a region of dissected plateau occupying 12% of the sheet area. This generally corresponds to the outcrop area of the Proterozoic Fortescue Group between 180 and 450 m above sea level. 'V' shaped valleys, waterfalls and gorges prevail and indicate the juvenile nature of the dendritic drainage system. At contacts with areas of plain, as in the southwestern and southeastern part of the sheet area, a prominent erosion scarp exists. This scarp often exceeds 100 m in height.
Rugged razor-back hills and strike ridges, separated by narrow steep-sided valleys, constitute the range physiographic sub-division. This sub-division coincides with the "greenstone belts" and occupies 26% of the sheet area. Differential erosion of the steeply dipping volcanic and sedimentary lithologies have given rise to the physiography. Drainage within the ranges is strike controlled and generally exhibits a trellised pattern.

The low granite hills sub-division occupies 16% of the area. Generally it consists of low rounded to rugged hills of bare granite between 200 - 400 m above sea level.

The majority of the area (44%) is occupied by topography of the plain sub-division. The plains are featureless, flat expanses of sand and gravel deposits overlying granite at 100 - 200 m above sea level. Their monotonous character is broken by low outcrops of granite, dyke ridges, quartz reefs, "blows" and scattered inselbergs. Larger rivers traversing the plains have braided channels and drainage patterns are usually dendritic.

4. GEOLOGY

The sheet area is situated in the centre of the structural unit termed the Pilbara Block (Daniels and Horwitz 1969) and occupies approximately half of this major tectonic unit. A simplified geological map of the sheet area can be seen in Figure C3. In summary, the geology can be described as being composed of granitic batholith domes separated by linear and arcuate broadly synclinal "greenstone belts" of Archaean age which are unconformably overlain by remnant gently folded Lower Proterozoic sediments and volcanics. Figure C4 summarises the major structural units of the sheet and the outline of the major batholiths.

The Archaean "greenstones" are assigned to the Warrawoona and Gorge Creek Groups. The Warrawoona Group is the oldest and consists of a complex, and partly cyclic, sequence of mafic and felsic volcanics, ultramafic rocks, clastic sedimentary rocks and cherts. This succession
### Table C1 Generalised Archaean succession, Marble Bar Sheet. (After Geological Survey of Western Australia)

<table>
<thead>
<tr>
<th>GROUP</th>
<th>SUBGROUP</th>
<th>FORMATION</th>
<th>MAXIMUM THICKNESS (M)</th>
<th>LITHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gorge Creek</td>
<td>Soanesville</td>
<td>Budjan Creek Formation /Lalla Rook Sandstone</td>
<td>2-3</td>
<td>Sandstone and conglomerate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Honeyeater Basalt</td>
<td>0.5</td>
<td>Pillow Basalt</td>
</tr>
<tr>
<td></td>
<td>Subgroup</td>
<td>Paddy Market Formation</td>
<td>1</td>
<td>Banded iron formation, ferruginous clastic sedimentary rocks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corboy Formation</td>
<td>1-2</td>
<td>Quartzite, sandstone and psammopelitic sedimentary rocks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wyman Formation</td>
<td>1</td>
<td>Porphyritic rhyolite</td>
</tr>
<tr>
<td></td>
<td>Salgash</td>
<td>Panorama Formation /Kelly Formation</td>
<td>1</td>
<td>Dacitic lava, tuff, agglomerate with local sedimentary rocks</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-5</td>
<td>Pillow basalt, chert</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marble Bar Chert</td>
<td>0.1</td>
<td>Banded chert</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duffer Formation</td>
<td>5-8</td>
<td>Dacitic agglomerate</td>
</tr>
<tr>
<td></td>
<td>Talga Talga</td>
<td></td>
<td>5-8</td>
<td>Pillow basalt with subordinate felsic, ultramafic and chert units.</td>
</tr>
</tbody>
</table>

### Table C2 Lower Proterozoic Fortescue Group succession, Marble Bar Sheet. (After Geological Survey of Western Australia)

<table>
<thead>
<tr>
<th>FORMATION</th>
<th>MAXIMUM THICKNESS (M)</th>
<th>LITHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maddina Basalt</td>
<td>10-20</td>
<td>Vesicular amygdaloidal basalt</td>
</tr>
<tr>
<td>Kuruna Siltstone</td>
<td>20</td>
<td>Siltstone, pisolitic tuff</td>
</tr>
<tr>
<td>Nymerina Basalt</td>
<td>50</td>
<td>Massive basaltal lava with intercalated vesicular amygdaloidal lava</td>
</tr>
<tr>
<td>Tumbiana Meentheena Carbonate Member</td>
<td>30-40</td>
<td>Siliceous limestone-dolomite intercalated tuff, shale</td>
</tr>
<tr>
<td>Tumbiana Mingah Tuff Member</td>
<td>20-30</td>
<td>Pisolitic tuff, local agglomerate, siltstone</td>
</tr>
<tr>
<td>Kylena Basalt</td>
<td>0-300</td>
<td>Basaltic lava intercalated with sandstone</td>
</tr>
<tr>
<td>Hardey Sandstone</td>
<td>0-1000</td>
<td>Conglomerate, sandstone, tuff and shale</td>
</tr>
<tr>
<td>Mt. Roe Basalt</td>
<td>50</td>
<td>Basaltic lava with minor basal sandstone</td>
</tr>
<tr>
<td>AGE</td>
<td>GRANITE</td>
<td>MAP DESIGNATION</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Late Tin Granites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2600-2700 my</td>
<td>Woolyella Adamellite</td>
<td>Agy</td>
</tr>
<tr>
<td></td>
<td>Coondina Granite</td>
<td>Agc</td>
</tr>
<tr>
<td></td>
<td>Numbana Granite</td>
<td>Agc</td>
</tr>
<tr>
<td></td>
<td>Cooglegong Adamellite</td>
<td>Agc</td>
</tr>
<tr>
<td></td>
<td>Spear Hill Adamellite</td>
<td>Agc</td>
</tr>
<tr>
<td></td>
<td>Mondana Adamellite</td>
<td>Agc</td>
</tr>
<tr>
<td>Middle Granites</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strelley Granite</td>
<td>Ags</td>
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<td></td>
<td>Nardoopiquithanna</td>
<td>Agb</td>
</tr>
<tr>
<td>Old Granites</td>
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</tr>
<tr>
<td>3100 my (-)</td>
<td>Bamboo Springs</td>
<td>Agp</td>
</tr>
<tr>
<td></td>
<td>Adamellite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eley Adamellite</td>
<td>Agp</td>
</tr>
<tr>
<td></td>
<td>Carbana Pool Adamellite</td>
<td>Apg</td>
</tr>
<tr>
<td></td>
<td>Pincunna Adamellite</td>
<td>Apg</td>
</tr>
<tr>
<td></td>
<td>Abydos Adamellite</td>
<td>Apg</td>
</tr>
<tr>
<td></td>
<td>Kangan Granite</td>
<td>Agp</td>
</tr>
<tr>
<td></td>
<td>Unnamed Granite</td>
<td>Aga</td>
</tr>
<tr>
<td></td>
<td>North Shaw Tonalite</td>
<td>Agd</td>
</tr>
<tr>
<td></td>
<td>Mount Gratwick</td>
<td>Agi</td>
</tr>
<tr>
<td></td>
<td>Granodiorite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unnamed Granite</td>
<td>Agt</td>
</tr>
<tr>
<td></td>
<td>Coorong Creek</td>
<td>Apl</td>
</tr>
<tr>
<td></td>
<td>Adamellite</td>
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</tr>
<tr>
<td></td>
<td>Woodstock Adamellite</td>
<td>Apl</td>
</tr>
<tr>
<td></td>
<td>Mulgandinnah Adamellite</td>
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</tr>
<tr>
<td></td>
<td>Tambourah Granodiorite</td>
<td>Apg</td>
</tr>
<tr>
<td></td>
<td>North Pole Adamellite</td>
<td>Agm</td>
</tr>
</tbody>
</table>

Batholiths: 1 = Mt Edgar  2 = Shaw  3 = Yule  4 = Corunna  5 = Mt Turner  6 = Strelley  7 = Carlindi  Downs

Table C3 Recognised granitic subdivisions in the various batholiths on the Marble Bar Sheet. (After the Geological Survey of Western Australia)
has been intensely folded, sheared, and metamorphosed from greenschist to lower amphibolite facies. The Gorge Creek Group unconformably overlies the Warrawoona Group and consists predominantly of chemico-clastic sediments (ferruginous shale, chert, sandstone, shale, conglomerate) with some volcanics.

This too was folded and metamorphosed during the Archaean. Table C1 and Figure C4 respectively summarises and outlines the generalised stratigraphy of the Archaean succession in the greenstone belt. Recent mapping by Hickman and Lipple (1975) has established that most of the volcanic assemblages can only be assigned to subgroups even though certain formations can be recognised.

The "greenstone belts" are intruded by several complex ovoid batholiths of granitic rocks in which several major phases of intrusion can often be recognised. The outlines of the major batholiths, the Shaw, Yule, Turner, Mt. Edgar, Corunna Downs, Carlini and Strelley may be seen in Figure C4. These (and particularly the Yule and Shaw Batholiths) are structural domes of considerable thickness as indicated by the recent preliminary Bouguer anomaly contour map prepared by the Bureau of Mineral Resources. Their tectonic history covers a prolonged period of plutonism commencing with the early formation of a migmatite suite, phases\( \ast \) Agm, Agd, Agt, Agi and subsequent emplacement of early tectonic and syntectonic plutons phases\( \ast \) Agp. The early plutons are generally granodiorite and tonalite and the latter are usually adamellite in composition. This tectonic period culminated in the intrusion of post tectonic plutons, phases\( \ast \) Agc, Agy, including the "tin-tantalite" bearing adamellites. Table C3 and Figure C3 respectively outlines the nomenclature and areal extent of the asterisked phases. De Laeter and Blockley (1972) have reported ages ranging from \( 3125 \pm 366 \) m.y. for the older migmatite suites to \( 2670 \pm 95 \) m.y. for the young "tin-granite" at Moolyella in the northeast corner of the sheet.

Lower Proterozoic rocks of the Fortescue Group occupy approximately 15% of the sheet area and rest unconformably on the Archaean. The succession consists of flood basalts and andesites with thickly inter-
calated sediments (tuffs, shales and sandstones) and probably once covered most of the sheet area. It has since been gently folded, weakly metamorphosed and extensively faulted. Erosion during the Phanerozoic removed much of the Proterozoic cover to expose the underlying "greenstones" and granitic rocks. Table C2 outlines the Lower Proterozoic succession.

Minor intrusions of variable age and type are present in the area. They form chiefly dykes and sills. Of prominence, especially on space photography, are the extensive thick, medium to coarse grained Lower Proterozoic dolerite dykes, which trend in a north-northeast direction, forming prominent dark ridges particularly on the Shaw and Corunna Downs Batholiths. Here they have been called the Black Range Suite. The Black Range dolerite itself has a total length of over 100 km and is up to 150 m wide.

Cainozoic deposits are present on the Sheet. Some of these (laterite, pisolite, opaline silica) are related to the widespread peneplanation and laterisation that occurred in tertiary times. In the main the superficial Quaternary deposits are more widespread and occur over most of the area, concealing the extensive granite terrain.

The structural geology of the Archaean granite and greenstone areas is extremely complicated. Both types of rocks exhibit evidence of several periods of deformation in contrast to the Proterozoic rocks which have undergone only one period of weak deformation.

5. MINERALISATION

Figure C5 illustrates the mineral occurrences of the Marble Bar Sheet. The Sheet area occupies the most productive part of the Marble Bar District of the Pilbara Goldfield. In the early part of this century, Marble Bar itself was a thriving gold mining centre and a hub for other small mining centres across the Sheet area. Today only desultory gold mining activity is carried out with ore and tailings being treated at the State Battery at Marble Bar. Gold production of some 11,146 kg has come from 200 mines of which 15 have produced more than 5,0 kg
of gold. Primary gold mineralisation of economic importance is confined to the Warrawoona Group. Small high grade auriferous quartz veins occur in sheared mafic, ultramafic and sedimentary rocks. The primary gold deposits may have originated from the "greenstones" by a hydrothermal action and metasomatic replacement associated with the regional deformation and intrusion of granitic magma at depth. Silver has always been an important by-product of gold mining activities. Erosion of the Archaean primary deposits during Proterozoic times has resulted in the formation of "deep leads" in Proterozoic conglomerates. Quaternary alluvial and eluvial deposits also contain gold in the vicinity of mineralised rock.

Of the other economic minerals only cassiterite and tantalite are currently worked on a large scale. Production of cassiterite concentrate from the Sheet area has amounted to 14,950 tonnes approximately half of Western Australia's production. Though production peaked at 1,238 tonnes in 1967, tin mining is still currently in progress at Moolyella, Coondina and Googlegong. Indeed due to the high tin prices production of some 430 and 30 tonnes of cassiterite and tantalite respectively will be produced by Pilbara Tin Pty. Ltd. at Moolyella in 1980. The more important deposits are related to the "younger granites" (Blockley, 1970). Alluvial and eluvial deposits of economic grade have resulted from the weathering and breakdown of localised cassiterite bearing pegmatites. These pegmatites also contain concentrations of tancolumbite minerals, beryl, gadolinite and lepidolite. The first accessory is usually a valuable by-product of the alluvial tin mining. The most extensive production of cassiterite has come from deposits of buried alluvium (deep leads) at Moolyella, Googlegong and Eley. Older, possibly Tertiary deposits are mined from a dissected lime and clay cemented gravel at Coondina and near Googlegong. The only important production of primary cassiterite and tantalite has come from Wodgina, where albrite pegmatites and associated tourmaline lodes have been mined for some 380 and 112 tonnes of concentrates respectively. The chief tantalite ore mineral is manganotantalite with some very minor fergusonite, (Blockley, (1971)).
Figure C6 Comet Gold Mine, Marble Bar.

Figure C7 Typical Scenery - Coongan Greenstone Belt.
Since the "exploration boom" in the late 1960's nickel and copper-zinc mineralisation has been actively sought in the ultramafics and in the acid volcanic phases respectively of the Archaean cyclic vulcanicity. Published mapping by the Geological Survey of Western Australia has greatly facilitated this as yet unrewarding search. Minor amounts of the ores of copper (7,285 tonnes) and lead-zinc (2.03 tonnes) have been produced. The Sheet's largest copper deposits occur in felsic rocks in the Archaean succession. At Copper Hills and Kelly, the major production centres, copper mineralisation is present in west-north-west striking subvertical shears and faults through felsic tuff and agglomerates. These fractures, often veined by quartz, cut sharply across the strike of the volcanic rocks and extend into the late Archaean granite. The deposits are thought to be either late Archaean or Proterozoic in age. Minor small copper, zinc and lead bearing volcanogenic massive sulphides have been found in Archaean felsic volcanic centres within the Warrawoona Formation. An example is the recently discovered Big Stubby deposit, 6.2 km south of Marble Bar. Minor nickel mineralisation has been found in ultramafics in the Soanesville belt.

Miscellaneous occurrences of beryl, asbestos, haematite, limonite, barite, pyrolusite, pyrophyllite, vanadinite, chromite, molybdenite, fluorite and uranium are recorded on the sheet. Of these economic minerals only beryl and asbestos have been produced while barite and iron ore production may be possible in the future. Beryl production (2,502 tonnes) has principally come from shallow open cuts in pegmatite bodies at Wodgina and Mt. Francisco. Chrysotile asbestos production has been small scale with the majority of the 283 tonne production coming from the Soanesville belt. Large vein and strata bound barite deposits in the North Pole area have been recently estimated at several million tonnes. Development is dependent on the activity of the oil industry in exploring the off shore northwest continental shelf flanking the Pilbara block. Similarly large deposits of low to medium grade iron ore are present and await development. These deposits occur in Archaean banded iron formation (B.I.F.), in the Pilgangoora Syncline, in Tertiary laterise over B.I.F. and in Tertiary pisolitic limonite deposits.
Well coordinated vehicle and helicopter borne sampling teams collected 420 active stream sediment samples over the 17240 km² area. This collection was ancillary to the taking of 20 kg bulk sediment samples at selected trap sites of heavy mineral deposition, for heavy mineral extraction with subsequent laboratory mineralogical examination for kimberlitic indicator minerals and later spectrographic examination of the minus 150 micron concentrate residues. At 5% of sites duplicate sediment samples were collected for procedural control purposes. The sampling programme was planned in advance by first plotting the actual sites to be visited on the 1:250 000 topographic sheet. The planning aimed for an evenness of coverage at a density of better than one sample per 60 km². The selection of the sites to be visited was made independently of the order of stream drainage. Actual sample site position was modified in the field collection operation if a satisfactory trap site could not be found. Generally the drainage sites sampled were of fourth and fifth order streams with basinal areas ranging in size from approximately 5 km² to 130 km². However these basinal areas are extremes and an overall evenness of coverage was attained at a mean sample density of one sample per 41.5 km², well within the planned sample density.

The thirteen element stream sediment analytical scheme discussed in detail in Section B was carried out on the minus 175 micron fraction of the sediment samples, the oversize being retained in storage for any other work deemed necessary. The elements determined were Ag, As, Bi, Co, Cr, Cu, Mn, Mo, Ni, Pb, Sn, V and Zn. Likewise the minus 150 micron heavy mineral residues from mineralogical examination that were made available for geochemical purposes, were subjected to a 15 element semi-quantitative scan, the elements determined here being Ag, Bi, Be, Co, Cr, Cu, La, Mo, Ni, Pb, Sb, Sn, V, Y and Zn. The Australian commercial laboratory itself randomly analysed in duplicate 5% of the sediment samples as well as running internal standards as a check on analytical precision.
All results from the laboratory were key punched in a designated format onto 80 column cards; interpreted, verified and merged with another deck containing locational information, i.e. map sheet number and coordinates, to produce a master deck for statistical and plotting work.

6.1 Data Validation

Prior to the detailed analysis of the stream geochemical data a measure of the overall reliability of the elemental data was first obtained from duplicate samples collected at approximately 5% of the regional sites and processed with the main regional data. These duplicates samples had also been subjected to replicate analysis. The resulting analytical data, for the original duplicate site pairs and the replicate analyses of the duplicate samples were subjected to a computer programme GANOVA which tests by Fisher's statistic:

(1) If the original and duplicate sample sites are from the same population as the regional sites i.e. how representative is the subset data.

(2) If the original and duplicate sample sites are from the same population.

(3) If the total data variability is greater than procedural variability, i.e. the variability between the duplicate sites previously shown to be representative of the regional sites is greater than sampling - analytical variability. This means that the observed geochemical relief between sample sites is real and that a statement to this effect can be confidently made.

(4) If the duplicate and replicated analyses of the duplicates are from the same population.

The application and calculation of F and precision (P) to geochemical data of sample pairs has been reported by Garrett (1969). A modified...
version of the methodology is the basis of GANOVA. Means and overall data variances are calculated for the regional survey sites (RS), original sites (O), duplicate sites (D) and replicate analyses of the duplicate (RD) by:

\[ V_i^2 = \frac{\sum_{i=1}^{N} (X_i - \bar{X})^2}{N-1} \]

where \[ \bar{X} = \frac{\sum_{i=1}^{N} X_i}{N} \]

\[ i = \text{separate individual data for RS, O, D and RD.} \]

Sampling - analytical (total procedural) variance within sites is calculated by:

\[ V_{SA}^2 = \frac{\sum_{i=1}^{N} (X_{Oi} - X_{Di})^2}{2N} \]

Analytical variance is calculated by:

\[ V_A^2 = \frac{\sum_{i=1}^{N} (X_{Di} - X_{RDi})^2}{2N} \]

Both raw and log base 10 transformed data can be used in the calculations.

As mentioned above the F test is involved when greater and lesser variance are compared. By consulting Fisher's F tables for \( N-1 \) and \( N \) degrees of freedom the critical value at the 95% confidence level can be determined. Thus, if the samples are drawn from the same population, the ratio should lie between the critical value and 1 for the defined confidence level. This is the expected outcome of the testing of the representivity of the duplicate subset to the regional sites. However, the ratio should equal or preferably exceed the critical value when the ratio of total data variance/procedural variance (\( V^2_D/V_{SA}^2 \)) is tested. If this is not the case, then at the usual confidence level taken, there is a greater 1 in 20 (95%) chance that the data variability observed could be due to a combination of sampling and analytical errors. In this case any interpretation of the data would be suspect.
Precision estimates ($P$) of procedure, sampling-analytical ($P_{SA}$) and analytical ($P_A$), can also be made at the 95% confidence level by:

$$P_{SA} = \left( \frac{V_{SA}}{\overline{X}_D} \right) 1.98 \times 100\%$$

$$P_A = \left( \frac{V_A}{\sqrt{\overline{X}}_{RD}} \right) 1.98 \times 100\%$$

These $P$ estimates are for a specific mean of the concentration over the range of values encountered in the respective duplicated samples and replicate analyses of the duplicated samples. However, $P$ estimates are preferred via the program PRECAL. This program is based on the method of Thompson and Howarth (1973) who recognise that precision changes with concentration. The $P$ estimates are calculated graphically by computer plotting the difference in values of site or analytical pairs against the mean of the value of site or analytical pair on a log-log scale i.e. $[X_O - X_D] \sim \overline{X}_D$ or $[X_D - X_{RD}] \sim \overline{X}_{RD}$. The resulting $P$ value can be read off with the aid of a template and is the maximum limit of precision below, which 90% of the values fall at the 95% confidence level.

Table C4 summarises the GANOVA output of log base 10 transformed raw data for the Marble Bar sheet. The log base 10 transformation was carried out since the majority of the data can be shown (Table C5) to follow in gross terms the conformity of the log normal distribution. The results of the F tests involving the duplicate samples are only considered though the tabulated results of the tests involving the original samples are a useful comparison. With the exception of Mo and Bi all the elemental subset data is representative of the regional elemental data. Inexplicably, however, the Mo and Bi data for the original and duplicate samples appear to be drawn from the same population. Mo and Bi also have procedural variabilities which are well in excess of the between site variabilities. The cause of the suspect Mo and Bi data is probably that the majority of recorded values are at the limit of detection or within the first reading interval. It is therefore not surprising that Mo and Bi in contrast to the remainder of the data do not conform in gross terms to the log normal distribution of the majority of the elements. Good procedural...
<table>
<thead>
<tr>
<th>Regional Sites (RS)</th>
<th>Original (O)</th>
<th>Duplicate (D)</th>
<th>Replicate (R)</th>
<th>Procedural (P)</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Precision (%)</th>
</tr>
</thead>
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<tr>
<td>RSM</td>
<td>RSV&lt;sup&gt;2&lt;/sup&gt;</td>
<td>OM</td>
<td>OV&lt;sup&gt;2&lt;/sup&gt;</td>
<td>EM</td>
<td>DV&lt;sup&gt;2&lt;/sup&gt;</td>
<td>RDM</td>
<td>RDV&lt;sup&gt;2&lt;/sup&gt;</td>
<td>SAV&lt;sup&gt;2&lt;/sup&gt;</td>
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<td>2.589</td>
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<td>1.683</td>
<td>0.033</td>
<td>0.0014</td>
<td>0.0003</td>
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</tbody>
</table>

Regional Sites (RS) = mean of regional survey samples
Original Sites (O) = mean of original site samples
Duplicate Sites (D) = mean of duplicate site samples
Replicate Duplicate analysis (RD) = mean of replicate duplicate samples
Procedural Variability = sampling-analytical variance
Analytical Precision = effects of 1st reading interval/detection limit removed

F Tests
F1. Test if original and duplicate sites are from the same population as the total regional population i.e. $RSV^2 \div OV^2$; $RSV^2 \div DV^2$ i.e. $F_0.05 = 2.12$

F2. Test if original and duplicate sites are from the same population

F3. Test if original and duplicate site variance, greater than analytical-sample variance

F4. Test if duplicate and replicate duplicate analyses are from the same population

Table C4 Procedural data variability—Stream Sediments
precision is indicated in the remainder of the elemental data though Ag is a little odd with roughly equivalent combined sample-analytical and analytical precision estimates. The procedural variances have been ratioed (R). With the exception of Mo, Bi, Ag and Co these are greater than 2.5. The precision estimates for total procedure (sample-analytical) are greater than analytical procedure in all but Ag and Mo. The bracketed procedural precision figures for the elements As, Bi and Sn are probably more realistic figures because the majority of the results for the control samples are at or near the detection limit and within the first reading interval. Analytical precision is generally good though it should be pointed out that the duplicate and replicated duplicate analytical results are statistically different.

Unfortunately no true estimates can be made on total data and procedural variability for the concentrates. However a statement on analytical precision of ± 60% overall is quoted by the laboratory.

6.2 Univariate Stream Sediment Geochemical Interpretation

The stream sediment statistics from the output of the VSTAT computer program are summarised in Table C5. With the exception of Co the gross data is strongly positively skewed and kurtotic suggesting that the data does not follow a normal distribution. This is not surprising since the individual elemental data is multimodal in nature. The majority of the data with the exception of Bi, Mo, Ni when subjected to a base 10 log transformation appears in gross terms to follow the log normal distribution. The Bi, Mo and Ni data however are still strongly positively skewed, but negatively kurtotic. The elements, Sn and Pb, have the opposite trend, being strongly positively kurtotic and the skewness follows the conformity of the log normal distribution.

A matrix of correlation coefficients for the elemental data is presented in Table C6. Due to the uncertainty of the elemental distributions the correlation coefficients were obtained by the non-parametric Spearman Ranking Method through the facility of the computer program NONPAR CORR in the SPSS (Statistical Packages for the Social Sciences)
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<tr>
<th>L</th>
<th>R</th>
<th>N</th>
<th>E</th>
<th>CVM</th>
<th>E *</th>
<th>A *</th>
<th>Liq</th>
<th>Hig</th>
<th>Liq</th>
<th>Big</th>
<th>CVM</th>
<th>Big</th>
<th>Aig *</th>
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<td>0.74</td>
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<td>5.1</td>
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<td>108.3</td>
<td>13.5</td>
<td>137.8</td>
<td>2.0</td>
<td>11.6</td>
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<td>1.689</td>
<td>0.517</td>
<td>0.458</td>
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<td>0</td>
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<td>6.6</td>
<td>6.8</td>
<td>79.1</td>
<td>10.7</td>
<td>90.2</td>
<td>2.3</td>
<td>9.8</td>
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<td>1.796</td>
<td>0.971</td>
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<tr>
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<td>21.7</td>
<td>13.2</td>
<td>56.1</td>
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<td>-3.1</td>
<td>0.7</td>
<td>2.9</td>
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<td>1.785</td>
<td>1.291</td>
<td>0.144</td>
<td>18.9</td>
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<tr>
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<td>120.6</td>
<td>114.1</td>
<td>94.6</td>
<td>9.6</td>
<td>80.7</td>
<td>2.6</td>
<td>11.1</td>
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<td>88.9</td>
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<td>1.7</td>
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<td>139.0</td>
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<td>1.271</td>
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<td>Sn</td>
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<td>10.1</td>
<td>10.7</td>
<td>106.4</td>
<td>37.1</td>
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<td>V</td>
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<td>2.346</td>
<td>1.715</td>
<td>0.191</td>
<td>11.1</td>
</tr>
</tbody>
</table>

Population Break Points **

| Ag  | 0.5(30) | 0.7(53) | 0.9(73) | 1.1(85) | 1.4(94.5) | 1.6(98.6) |
| As  | 5(59)   | 9(89)   | 13(94.5) | 18(97.5) |
| Bi  | 13(87)  | 25(98.2) |
| Co  | 11(126) | 19(150) | 28(166) | 35(83)  | 42(94.5) | 52(98.6) |
| Cr  | 50(19)  | 140(174) | 270(92) | 380(95.9) | 550(98.9) |
| Cu  | 13(24)  | 26(49.5) | 37(66)  | 52(80.5) | 72(95.4) | 92(98.9) |
| Mn  | 170(4)  | 210(39) | 500(83) | 720(82) | 900(92) | 1120(95.5) | 1230(99.4) |
| Mo  | 0.75(62) | 1.2(84) | 2.5(99.3) |
| Ni  | 20(22)  | 37(40)  | 55(55)  | 80(74.5) | 105(86.5) | 140(94) | 215(98.0) |
| Pb  | 13(10)  | 22(58.5) | 29(81.5) | 37(93.5) | 45(95.0) | 65(98.5) |
| Sn  | 5(33)   | 9(66)   | 12(82)  | 17(89)  | 24(95)  | 55(99.3) |
| V   | 32(12)  | 32(26)  | 50(48)  | 65(58)  | 85(82)  | 125(92) | 155(94.5) | 200(99.7) |
| Zn  | 25(14)  | 46(43)  | 62(68)  | 88(80)  | 114(97) | 150(99.4) |

Number of Cases = 426 1=low 2=high 3=median 4=standard deviation 5=coefficient of variation 6=kurtosis 7=skewness 8=log 10 data
9 = Test for normality $Z = 6(N)^{1/2} \leq 3$ 10 = log 10 data

** Break points taken from log cumulative frequency plots, bracketed figure percentile of range.

Table C5 Summary Statistics - Stream Sediment Data.
Table C6 Rank Correlation Matrix - Stream Sediment Data.
library. Correlation analysis aids the identification of geological environments by way of a mathematical evaluation of the strength of association or correlation between the more important "indicator" trace elements and their accessories. Strong inter-correlation between elements leads to possible groupings of elements into associations which may identify or be suggestive of geological environments in the lithological or ore sense. The latter point being most important to the explorationist.

The significant correlation coefficients are annotated in the matrix on the basis of the 95%, 99% and 99.9% confidence levels from the program output. A histogram of the coefficients in the correlation matrix in ± 0.05 intervals has been constructed. Meaningful groupings of correlations appear to have resulted and these groupings have been assigned ratings of very strong (0.72+), strong (0.55-0.72), moderate (0.42-0.54) and weak (0.27-0.42). Before interpreting the individual elemental data an examination of the elemental associations within these groupings draws ones attention to geological environments having possible economic interest. These elemental associations of interest are:

<table>
<thead>
<tr>
<th>Rating</th>
<th>Association</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Strong</td>
<td>Co-Ni-Cu</td>
<td>possible Cu-Ni ores in ultramafic-mafic rock types.</td>
</tr>
<tr>
<td></td>
<td>Cu-Zn</td>
<td>possible volcanogenic, sedimentary ore types.</td>
</tr>
<tr>
<td>Strong</td>
<td>Ag-Cu-Zn-Mn</td>
<td>possible volcanogenic, sedimentary ore type.</td>
</tr>
<tr>
<td></td>
<td>As-Cr-Co</td>
<td>possible Cr-Pt in ultramafic rock types.</td>
</tr>
<tr>
<td>Moderate</td>
<td>As-Ni-Cu-Co</td>
<td>possible Cu-Ni ore in ultramafic mafic rock types.</td>
</tr>
<tr>
<td>Weak</td>
<td>Bi-Cu-Zn-Mn</td>
<td>volcanogenic-sedimentary ore types.</td>
</tr>
</tbody>
</table>

An interesting point, is the fact that even though the granite batholiths dominate the sheet geology, elemental associations appear to be predominantly indicative of lithological suites within the greenstones.

...15.
All the elemental data has been plotted on log cumulative frequency paper following the method of Lepeltier (1969), Sinclair (1974). Elemental populations were determined from obvious points of inflexion or break points on the individual graphical elemental distributions. The gross populations for the individual elements have been subsequently annotated on the elemental drainage base plans (Figures C8 to C20) which are complimentary to the summary geological and mineral occurrences plans Figures C3 and C5. Elemental patterns and spot responses falling over the simplistic structural subdivisions from the summary geological map are discussed below.

6.2.1 Silver

Silver patterns are prominent over the Proterozoic volcanic cover and to a lesser extent the greenstone belts and granite batholiths. Breakpoints are recognised at 0.5, 0.7, 0.9, 1.1, 1.4 and 1.8 ppm on the cumulative frequency plot in Figure C8. These breakpoints correspond to the 30, 52, 73, 85, 94.5 and 98.6 percentiles for the range of silver values encountered.

A general silver high is found over the Lower Proterozoic Fortescue Group volcanics especially in the southwestern corner of the sheet. The most prominent highs are, an area of 2.0 to 2.4 ppm Ag (1.1) underlain by Tumbiana Formation and Nymerina Basalt and four spotty 1.8 to 2.0 ppm Ag responses (1.2) underlain by Kylena Basalt. Elsewhere on the sheet Ag patterns over the Proterozoic volcanic cover are not as prominent, but however, highs are still present. For example, the 1.6 ppm (1.3) and 1.4 ppm (1.4) highs underlain respectively by Mt. Roe Basalt and Kylena Basalt in the northeastern quadrant of the sheet. The remaining 1.2 ppm basinal highs here are underlain by mainly the former formation with some Salgash Subgroup.

The North Shaw Belt is highlighted by Ag values in the northeastern and northwestern portions of the belt respectively. Two areas of 1.2 ppm and 1.1 to 1.8 ppm Ag (2.1), are present in the northern portion of the belt, which is underlain by felsic volcanics of the Panorama Formation, North Shaw Tonalite and some Mt. Roe Basalt.
MARBLE BAR SPD-OBK STREAM SEDIMENTS
SILVER PPM

POPULATION BASE

0 100 10 100 10 100 10
0 100 10 100 10 100 10
0 100 10 100 10 100 10
0 100 10 100 10 100 10

Km
The peak value of 1.8 ppm is underlain by the North Shaw Tonalite. Ag-Au-Cu and Au-Cu-Pb mineralisation is present on the southwestern periphery of the high. The eastern 1.2 ppm value is part of a pattern extending over the adjacent North Pole Dome. In the western central portion of the belt, a 1.1 to 1.2 ppm Ag high (2.2), is present over Salgash Subgroup, Paddy Market Formation and intrusive ultramafic. The high is part of a much larger regional pattern over the adjacent Soanesville Belt and Fortescue Group cover. Au-Cu mineralisation is present within the pattern. It is of interest to note the general low Ag values over the eastern portion of the belt.

As previously mentioned, an extensive Ag enhancement of 1.1 to 1.2 ppm (3.1) is present over the southern portion of the Soanesville Belt underlain by Soanesville Subgroup. Some minor Au, Cu and Cu-Ni mineralisation is recorded within the pattern.

Within the Pilgangoora Syncline, three areas of interest are present. These are; a 1.0 to 1.1 ppm Ag pattern overlapping the Syncline and the adjacent Turner Batholith (4.1), a 1.0 to 1.2 ppm Ag pattern overlapping the Syncline and the adjacent Carlindi Batholith (4.2), and a southern 1.2 ppm Ag pattern (4.3) in part overlapping the Yule Batholith. All patterns contain Au, Sn-Ta and/or Au-Cu-Pb mineralisation.

A 1.0 ppm Ag pattern (5.1) is present in the Lalla Rook Syncline underlain by sheared Gorge Creek Group and Talga Talga Subgroup. Ag-Pb-Zn mineralisation is present on the flanks of the northern basin.

The basinal sediments of the central eastern portion of the North Pole Dome are enriched in Ag with respect to the western portion of the Dome. Two areas of interest are present, a northern 1.0 ppm basinal high (6.1) and a southern area of 1.0 to 1.1 ppm Ag (6.2). Extensive Cu-Bi, Ba and Ag-Au mineralisation are present within the former area which is underlain by radially faulted North Pole Adamellite and Talga Talga Subgroup. The southern area is underlain by faulted Salgash Subgroup containing felsic volcanics of the Panorama Formation. The previously discussed southern adjacent 1.2 ppm high in the North Shaw Belt (2.1) is an extension of (6.2).
The Coongan Belt is accentuated by a general Ag enhancement of 0.9+ ppm in the southern portion of the belt. In the southeastern margins of the belt, a 2.4 ppm Ag high (7.1), is underlain by Salgash Subgroup, while to the south, a 1.2 ppm Ag high (7.2) is underlain by Salgash Subgroup, Wyman and Carboy Formations and Mt. Roe Basalt. The latter formation may be influencing the (7.2) basinal high. In the western central portion of the belt a 1.0 ppm basinal high (7.3) is underlain by Duffer Formation and Talga Talga Subgroup. The spot 1.1 ppm high (7.4) to the north is underlain by both Warrawoona and Gorge Creek Groups and Googlegong Adamellite (Agc) of the adjacent Shaw Batholith.

Little comment can be made on the Kelly Belt with the exception of the general 0.8 ppm high (8.1) over the felsic volcanics of the Kelly Formation in the northern and southern portions of the belt respectively. Ag-Cu mineralisation is present here.

A 1.0 ppm enhancement (9.1) is present over the southern and adjacent western portions of the Marble Bar and Warrawoona Belts respectively. The area is underlain by Warrawoona Group and some Mt. Roe Basalt. The latter may be influencing the pattern. However, extensive Ag-Au and Au-Bi mineralisation is present in the area.

The Wodgina Belt has two Ag areas of interest over the prominent northeast sheared greenstones of the Wodgina Subgroup and Kangan Granite. Basinal areas of 0.8 ppm (10.1) and 1.0 ppm (10.2) contain extensive Sn-Ta-Be-Ag mineralisation.

The Western Shaw Belt is unlike the majority of the greenstone belts, in that, with the exception of the southern portion of the belt and the sheared western contact of the belt with the adjacent Tambourah Granodiorite of the Yule Batholith, Ag values are low. The Ag values in the southern central portion of the belt form a 0.9 to 1.1 ppm high (11.1) which is underlain by Salgash Subgroup, Corboy Formation and a prominent northeasterly trending shear zone in a drag fold. Some Au mineralisation is associated with the western sheared contact of the belt and Yule Batholith.
Mixed Ag responses are evident over the batholiths. Higher Ag values are generally present where relict greenstones or regional mafic dykes are present. The most prominent Ag patterns over the granite batholiths which are not readily explicable are those which are associated with the Yule, Turner, Shaw and Corunna Downs Batholiths.

The pattern in the southeastern portion of the Yule Batholith is generally associated with dispersion from relict Fortescue Group cover. However there is a prominent inexplicable 1.4 to 1.6 ppm Ag high (12.1) on the western sheared portion of the Woodstock Adamellite (Ag1) stock and Salgash Subgroup of the Western Shaw Belt. Northwards, the northern portion of the stock is again accentuated by a consistent pattern of 0.8 to 1.0 ppm Ag values (12.2). Some Cu-Ta and Ta mineralisation is present in the southern high. A prominent Ag pattern is also present over the western portion of the stanniferous Numbana Granite (Agc) and the adjoining Kangan Granite (Agp) and sheared Wodgina Subgroup. Portion of this pattern underlain by the latter two units has been previously commented upon (10.2). However, the peak 1.6 ppm Ag value of the pattern (12.3), underlain by Numbana Granite contains Sn-Be-Ta-Nb mineralisation. The eastern portion of the Numbana Granite and adjoining Pincunah Adamellite have distinctive low order Ag enhancements of 0.7 (12.4) and 0.8 ppm (12.5) which also contain Sn mineralisation. The 1.0 ppm pattern (12.6) underlain by granitic phase Agm in the central portion of the batholith is inexplicable.

Within the Shaw Batholith inexplicable highs are associated with large areal Ag enhancements. These are; the 1.0 ppm basin (13.1) in the western portion of the batholith underlain mainly be stanniferous Cooglegong Adamellite (Agc) with minor Eley Adamellite (Agp) and Shaw phase Agm, and the 0.9 to 1.0 ppm enhancement (13.2) in the southern portion of the batholith underlain by faulted stanniferous Cooninda Granite (Agc), Bamboo Springs Adamellite (Agp) and Shaw phase (Agm).

The Corunna Downs Batholith Ag values are noticeably low especially in the central portion of the batholith. However highs are present.
These are; the 1.2 ppm high (14.1) underlain by the sheared northern portion of the batholith and Warrawoona Belt, and a 0.8 to 1.0 ppm high (15.2) in the southern portion of the batholith underlain by Mondana Adamellite. This is the extension of the pattern (7.1) noted over the adjoining Coongan Belt.

The Ag values over the Mt. Edgar Batholith are low with the exception of the 0.5 to 0.6 ppm enhancement (15.1) in the southeastern portion of the batholith underlain by domes of batholith phase Agm.

Little can be said about the Carlindi Batholith, as previously discussed patterns are associated with the Pilgangoora Syncline. However the central 1.2 ppm Ag value (16.1) has not been commented upon and is associated with some Talga Talga Subgroup and intrusive ultramafic.

The 1.6 ppm Ag (17.1) high in the Turner Batholith is underlain by the prominent northeasterly trending shear and granite phase Agm. Of interest is the previously discussed 1.0 to 1.1 ppm Ag pattern to the south (4.1) which overlaps both Turner batholith and Pilgangoora Syncline. Both patterns may be inter-related. No mineralisation is reported within the regional shear.

6.2.2 Arsenic

Patterns of high As values are prevalent over the Archaean greenstone belts and in part the early migmatitic phases of the Archaean granite and the Lower Proterozoic volcanic cover. Breakpoints at 5, 9, 13 and 18 ppm are recognised on the cumulative frequency plot in Figure C9. These breakpoints correspond to the 69, 89, 94.5 and 97.5 percentiles of the range of As values encountered. Some 17.6% of the analytical results fall below the 2 ppm detection limit for the analytical method.

The Pilgangoora Syncline is accentuated by a large pervasive As pattern (1.1) in which values range from 14 to 48 ppm. The pattern in part falls over the adjacent Turner and Carlindi Batholiths. A central area of 24 to 48 ppm As, is underlain by Lalla Rook Sandstone, Budjan Creek, Paddy Market and Corboy Formations, and some Salgash Subgroup.

...20.
Some Sn-Ta, Au-Cu-Pb, and Au and Fe (BIF) mineralisation is recorded in the northern and southern portions of the high respectively.

A northeast-southwest trending regional shear structure which cuts the Turner Batholith, northern Yule Batholith (Kangan Granite) and Wodgina Belt is highlighted by two As patterns (2.1, 2.2). As values in the northern pattern (2.1) range from 6 to 24 ppm. The peak value of 24 ppm falls over the Wodgina area, where Sn, Nb, Ta and Cu pegmatitic mineralisation occur in metamorphosed Wodgina Subgroup lithologies. The southern pattern (2.2) is a lower order As enhancement, with As values ranging from 6 to 12 ppm. The area is endowed with similar pegmatitic mineralisation.

In the central portion of the Sheet, the southwestern portion of the structurally complex Soanesville Belt (3.1) is highlighted by As values of 15 to 24 ppm. The pattern is underlain by the Soanesville Subgroup. Cu and Au mineralisation are recorded in the pattern.

The Western Shaw Belt is accentuated by an As pattern and spot high in the southern (4.1) and central (4.2) portions respectively of the belt. The southern pattern of 10 to 28 ppm As (4.1) is underlain by sheared Corboy Formation and Salgash Subgroup. The spot 8 ppm high (4.2) is underlain by sheared Tambourah Granodiorite of the Yule Batholith and Salgash Formation. Au mineralisation is present here.

The North Pole Dome is highlighted by a central As high of 16 to 20 ppm (5.1) over faulted Taiga Subgroup and North Pole Adamellite (Agm). Cu-Bi, Au-Ag and Ba mineralisation are known in the area.

An As pattern of 8 to 16 ppm (6.1) is found in the Lalla Rook Syncline. The pattern is underlain by both Gorge Creek and Warrawoona Group and a prominent regional shear. Minor Au-Ag-Pb and Cu mineralisation are associated with the shear and are found respectively in the central and southern 16 and 12 ppm basins.
The North Shaw Belt has a large low order north trending As enhancement of 6 to 12 ppm over the southern and western portion of the belt. The peak value of 12 ppm (7.1), is underlain by Salgash Subgroup, Paddy Market and Shaw Batholith phase Agm. Be-Sn-Ta mineralisation is known in the basin while a line of Au mineralisation is present in the central 8 ppm portion of the pattern.

The Coongan Syncline has areal As enrichments of 6 to 20 ppm which are underlain principally by the Corboy Formation and Warrawoona Group. General inexplicable As highs of 12 and 20 ppm (8.1) are found within the pattern in the northern portion of the belt.

The remaining greenstone belts, (Kelly, Marble Bar and Warrawoona Syncline) have moderate As values. The southern portion of the Marble Bar Belt and the central portion of the Warrawoona Syncline (9.1) have a general 10 to 12 ppm As enhancement underlain by Salgash Subgroup, Wyman Formation and Mt. Roe Basalt. The majority of the extensive minor Au mineralisation here is present within the pattern. A spot high of 12 ppm is found over the southwestern portion of the Kelly Belt (10.1), within a general As pattern of 6 to 8 ppm. This spot high is present over faulted Gorge Creek group and minor Proterozoic Fortescue Group cover and Warrawoona Group.

The Proterozoic Fortescue Group cover has As highs of 10 and 16 ppm amid areas of As enrichment of 6 to 8 ppm. These highs occur in the southeast corner of the sheet over Kylena Basalt and Hardey Sandstone (11.1) and in the southwest corner over Tumbiana Formation, Kuruna Siltstone and Nymerina Basalt (11.2). Southwest of Marble bar the Proterozoic cover has two areas of As enhancements; a 6 to 12 ppm high over sandstone of the Kylena Basalt and Mt. Roe Basalt (11.3), and a spot 12 ppm high over Mt. Roe Basalt (11.4).

Arsenic patterns over the granite batholiths are generally restricted to distinct areas underlain by various intrusive phases. In gross terms, areas within the Corunna Downs, Yule, Mt Turner, Carlini, Mt Edgar and Strelly Batholiths are defined. The Corunna Downs Batholith...
has a prominent As high of 24 ppm within a pattern of 6 to 8 ppm As over the southern portion of the Mondana Adamellite (Agc) stock (12.1); patterns of 6 to 8 ppm As over the eastern portion of the Carbana Pool Adamellite (Agp) (12.3), and 6 to 12 ppm As (12.3) over the northern sheared migmatitic phase Agm.

The Yule Batholith has marked As enrichments; the previously mentioned pattern 2.2 in the northeastern portion of the batholith contains extensive pegmatitic mineralisation in sheared Kangan (Agp) and Numbana (Agc) Granites and Wodgina Subgroup; the inexplicable 10 ppm areal high within a 6 to 8 ppm As enhancement in the southern portion of the batholith underlain by migmatitic phase Agm (13.1); again the inexplicable 6 to 8 ppm pattern containing two distinctive 16 ppm highs; and the 10 to 12 ppm enhancement over the northern and southeastern portions of the stock of Woodstock Adamellite (13.2). Some Au mineralisation is recorded in the latter enhancement. Spot highs of 6 (13.3) and 8 ppm (13.4) are found respectively over stocks of Abydos (Agp) and Pincunnah Adamellite (Agp).

The As patterns over the Turner and Carlinidi Batholiths have been previously mentioned in the discussion of the pattern (1.1) over the greenstone belt of the Pilgangoora Syncline. A general 6 ppm As pattern (14.1) is found over the extensive Moolyella alluvial tin field and the domed migmatitic phase Agm in the Mt Edgar Batholith. A spot 14 ppm As high (15.1) is also present in the Strelley Batholith over faulted granite phase (Agp). Some remnant greenstones (Salgash Subgroup lithologies) are present here.

6.2.3 Bismuth

Even though the Bi data is suspect distinctive Bi patterns are found over the Archaean greenstone belts, granite and Lower Proterozoic cover. Breakpoints at 13 and 25 ppm are recognised from the cumulative frequency plot in Figure C10. These breakpoints correspond to the 87 and 98.2 percentiles for the range of Bi values encountered. Some 11.6% of the Bi values fall below the 5 ppm detection limit for the analytical method.
The Lower Proterozoic Fortescue Group cover shows marked Bi enrichment in the southwestern corner of the Sheet (1.1), and northwest and southwest of Marble Bar (1.2, 1.3). The 20 to 40 ppm Bi pattern in the southwestern corner of the Sheet (1.1) is principally underlain by Nymerina Basalt, Tumbiana Formation and minor Kuruna Siltstone; the 15 to 30 ppm Bi pattern northwest of Marble Bar (1.2) by Mt Roe Basalt, some Kylena Basalt and minor Archaean Warrawoona Group; and the 20 to 40 ppm Bi pattern southwest of Marble Bar (1.3) by Kylena Basalt.

The eastern portion of the North Shaw Belt (2.1) has a prominent 20 to 40 ppm Bi pattern underlain by North Shaw Tonalite (Agd) Salgash Subgroup (in particular Panorama Formation felsic volcanics) and Mt Roe Basalt. The peak values of 30 and 40 ppm are mainly underlain by North Shaw Tonalite. Ag-Au-Cu and Au-Gu-Pb-Zn mineralisation are reported on the southwestern periphery of the 40 ppm high.

The northwestern and western central portions of the Coongan Syncline are enhanced by Bi values of 20 ppm (3.1, 3.2). The two areas are underlain by Talga Talga Subgroup and Duffer Formation. However, a more prominent Bi pattern is present over the south eastern portion of the Coongan Syncline (3.3). The pattern here is underlain by Salgash Subgroup and Corboy Formation. A 60 ppm high is present within values of 15 to 20 ppm Bi.

The 15 to 20 ppm Bi pattern over the Kelly Belt (4.1) is underlain by Salgash Formation, in particular acid volcanics of the Kelly Formation containing Ag-Cu mineralisation. A spot 20 ppm high (4.2) is present over a similar geological environment at Copper Hills in the eastern portion of the belt.

Miscellaneous Bi patterns of 15 to 20 ppm are present in the Soanesville Belt (5.1), Lalla Rook Syncline (6.1) and Pilgangoora Syncline (7.1). Minor Au, Cu, Ag-Cu-Pb mineralisation are associated with the patterns. The spot 15 ppm basin in the central portion of the North Pole Dome (8.1) contains Bi-Cu mineralisation on its northern periphery, while the two 15 to 20 ppm Bi patterns in the Marble Bar (9.1) and Warrawoona Belts (10.1) contain in part extensive occurrences of minor Au-Bi mineralisation.
As a generalisation the early migmatitic phases of the granite batholiths, especially Agm, are enhanced in Bi. The Corunna Downs Batholith in particular shows marked Bi enrichment. Two patterns are prominent, a northern 15 to 20 ppm Bi enrichment (11.1) and a central 40 ppm Bi high within a 15 to 20 ppm enrichment (11.2). The majority of the patterns are underlain by granite phase Agm. However, the peak 40 ppm Bi value in the central pattern is partly underlain by Carbana Pool Adamellite (Agp). The Shaw Batholith has two spot As highs of 25 and 20 ppm (12.1, 12.2 respectively). The 25 ppm high is underlain by Shaw Batholith phase Agm, while the 20 ppm high by faulted stanniferous Cooglegong Adamellite (Age). The Mt Edgar Batholith has a spot 20 ppm Bi high (13.1) over faulted granite phase Agm. The Yule Batholith has marked Bi enrichments of 15 to 20 ppm over migmatitic granite phase Agm (14.1, 14.2). However, the larger pattern 14.1, may reflect dispersion from remnant Kylena Basalt of the Fortescue Group. A spot 20 ppm high (14.3) is also present over the northern portion of the Woodstock Adamellite (Ag1), east of Abydos Homestead.

Three spot Bi highs of 15 to 20 ppm, (15.1, 15.2, 15.3), are found in the north western corner of the Sheet and in part are underlain by the sheared Yule Batholith Kangan Granite phase (Agp), greenstones of the Wodgina Subgroup and the adjacent northern migmatitic granite phase (Agm) of the Turner Batholith. The two southern Bi values are associated with extensive pegmatitic Sn-Ta-Nb-Be mineralisation.

6.2.4 Cobalt

In gross terms the greenstone belts and granite batholiths are easily differentiated by greenstone basinal Co values of greater than 20 ppm. The more prominent Co patterns occur over the Lower Proterozoic Fortescue Group cover, and the southern portion of the Soanesville, Western Shaw and Coongan Belts. Higher Co values in the batholiths are present only where rafts of greenstones are present as in the southern portions of the Corunna and Shaw Batholiths. Breakpoints of 11, 19, 26, 35, 42 and 52 ppm are recognised in the cumulative frequency plot in Figure C11. These breakpoints correspond to the 26, 50, 66, 83, 94.5 and 98.6 percentiles of the range of values encountered.
Various units within the Lower Proterozoic Fortescue Group cover are highlighted. In the south western corner of the sheet the Tumbiana Formation is accentuated by a 55 ppm Co high (1.1) and the Nymerina Basalt by a 52 ppm Co (1.2) though some influence is present from the former formation. Cobalt values over the Kylena Basalt range from 42 to 48 ppm Co with highs of 58 ppm (1.3) in the south western corner and 52 ppm (1.4) in the north eastern quadrant of the sheet. The latter high is part of a pattern of two basins, in which the southern most one is underlain by Mt Roe Basalt and Warrawoona Group. A high of 60 ppm (1.5) is present over Mt Roe Basalt in the south eastern corner of the sheet. Spot enhancements of 44 and 42 ppm are also present over the unit in the north eastern quadrant (1.6) and central portion (1.7) of the Sheet.

A prominent pattern of 48 to 55 ppm Co (2.1) is present in the southern portion of the Soanesville Belt and is underlain by lithologies of the Soanesville Subgroup. The basinal high of 55 ppm contains recorded Cu, Ni-Cu and asbestos mineralisation.

The Western Shaw Belt is unusual when compared with the other belts. In the north Co values are generally low ranging from 4 to 11 ppm. In contrast, the basins underlain by the reginally sheared western margins of the belt and Tambourah Granodiorite of the Yule Batholith, range from 16 to 18 ppm Co while the southern central portion of the Western Shaw Belt is highlighted by 37 to 55 ppm Co values (3.1). The latter area is underlain by sheared drag folded Salgash Subgroup and Corboy Formation.

The Coongan Belt is marked by a general enhancement of 36 to 52 ppm Co in the southern portion of the belt. In contrast the northern portion of the belt can be divided into an eastern area of moderate Co values of 30 to 34 ppm, and a western area of low Co values of 20 to 24 ppm. The 48 ppm high (4.1) is an inexplicable exception in the north western Co low. This high is underlain by the majority of units belonging to the upper and lower sections of the Warrawoona and Gorge Creek Groups. In the southern portion of the belt a 46 to 52 ppm Co high (4.2) is underlain by mainly Corboy Formation and
Salgash Subgroup with some influence from the Mt Roe Basalt of the Fortescue Group. Northeast of 4.2, 46 and 42 ppm values (4.3) are again underlain by the first two mentioned lithologies. The eastern most basin (46 ppm) is part of a more extensive pattern over the Mondana Adamellite of the Corunna Downs Batholith. This pattern may be related in part to the extensive regional dolerite dyke activity in the area. In the west central portion of the belt, straddling the north westerly trending Co enhancement, a basinal high of 44 ppm (4.4) is underlain by Talga Talga Subgroup.

The North Pole Dome underlain by radially faulted Salgash Subgroup is accentuated by an eastern enhancement of 32 to 42 ppm Co. The 42 ppm basinal high (5.1) also contains some Kylena Basalt and felsic volcanics of the Panorama Formation.

A Co high of 40 ppm (6.1) underlain by Gorge Creek Group is present in the Lalla Rook Syncline.

Within the Pilgangoora Syncline four Co areal enhancements are present; a north western area of 35 to 38 ppm Co (7.1) straddling both the greenstone belt and Mt Turner Batholith; a north eastern high of 36 ppm (7.2); a moderate central 40 ppm high (7.3) and a southern 36 ppm high (7.4). All are underlain by Salgash Subgroup and Gorge Group lithologies. Some intrusive ultramafic is present within 7.4. Extensive minor Cu mineralisation is also present in this latter high.

Little can be said about the remaining Kelly, Marble Bar, Warrawoona and Wodgina Belts with the exception of the local 36 ppm Co high in the Kelly Belt (8.1) which contains the Copper Hills Cu mineralisation.

Comments on the Co patterns over the batholiths have been made earlier in the resume and little more can be added with the exception of the high Co content of the Mondana Adamellite stock. The previously noted Co high of 44 to 56 ppm (4.3) is found in a general 20 to 32 ppm enhancement. Of interest too, is the 23 to 38 ppm Co enhancement (9.1) over the northern and western portions of the Woodstock Adamellite...
(Ag1) in the Yule Batholith, and the 35 ppm high (10.1) in the 31 to 32 ppm Co enhancement over faulted Bamboo Springs Adamellite (Agp) in the southern portion of the Shaw Batholith.

6.2.5 Copper

The gross copper results highlight the greenstone belts rather than the granite batholiths. From the cumulative frequency plot on Figure C12 breakpoints are recognised at 13, 26, 37, 52, 72 and 95 ppm which correspond to the 24, 49.5, 66, 80.5, 95.4 and 98.9 percentiles for the range of values encountered.

The most prominent copper patterns over the greenstones are found over the Lower Proterozoic Fortescue Group cover in the south western (1.1, 1.2), south eastern (1.3, 1.4), and north eastern (1.5) quadrants and in the central portion of the sheet. A prominent Cu high of 100 to 140 ppm (1.1) is underlain by Tumbiana Formation and Nymerina Basalt in a general area of high background 60 to 80 ppm Cu in the south western corner of the sheet. Northwards Cu also peaks at 96 ppm over Kylena Basalt (1.2). Similarly, spot Cu highs of 95 and 132 ppm are respectively present over Kylena Basalt (1.3) and mixed basaltic lithologies comprising Mt Roe Basalt, Hardey Sandstone, Kylena Basalt (1.4) in the south eastern corner of the sheet. High background situations of 74 and 75 ppm respectively are present over Kylena Basalt, locally sandstone (1.5) and Mt Roe Basalt (1.6) in the north eastern and central portions of the Sheet area.

A prominent Cu pattern with a definitive high is present in the southern portion of the Soanseville Belt. Here Cu values range from 60 to 80 ppm (2.1) over mafics of the Soanesville Subgroup. Cu and Cu-Ni occurrences are known within the pattern.

The Western Shaw Belt differs from the other greenstone belts in that it is abnormally low in Cu especially the northern and central portion of the belt where Cu values range from 4 to 11 ppm. In contrast, a pronounced Cu high is present in the southern portion of the belt (3.1). Here Cu values of 80 to 90 ppm are present over drag folded...
Talga Talga Subgroup and Corboy Formation which is cut by a northeast trending shear. The sheared western margin of the belt and adjacent Tambourah Granodiorite are also enhanced in Cu as evidenced by the 30 ppm basinal Cu value (3.2).

The western and northwestern portions of the North Shaw Belt, underlain by a variety of units, including remnant Fortescue Group, Salgash Group, Panorama and Paddy Market Formations are highlighted by higher Cu results of 40 to 75 ppm Cu in contrast to the 26 to 28 ppm Cu elsewhere. Enhancements are noted within the higher results and have been annotated accordingly, e.g. 60 ppm (4.1, 4.2), 68 ppm (4.3).

In the Pilgangoora Syncline three areas stand proud; 5.1 (56 ppm), 5.2 (54 ppm) and 5.3 (65 ppm), though slight enhancements of 39 to 40 ppm Cu (5.4) are present in the western portion of the belt. The first mentioned (5.1) is underlain by faulted Salgash and Soanesville Subgroups (Paddy Market and Corboy Formations). Sn, Ta mineralisation is recorded within the basin. The second (5.2) is underlain by Salgash Subgroup and Duffer Formation while the third (5.3), straddling in part the Soanesville Belt, by Talga talga Subgroup and intrusive ultramafic. Cu mineralisation is present within the latter high.

The slight Cu enhancement 5.4, is underlain by chemical sediments of the Paddy Market Formation and Corboy Formation.

A spot 56 ppm Cu (6.1) in the Lalla Rook Syncline is underlain by faulted Gorge Creek Group sediments and volcanics. Copper mineralisation is reported within the basin in sheared andesites.

The eastern portion of the large mafic pile which comprises the North Pole Dome is notably enhanced in Cu which ranges from 50 to 75 ppm. The area is underlain by highly fractured Salgash and Talga Talga Subgroup. Two 75 ppm highs (7.1, 7.2) are present within the enhancement. The northern one (7.1) contains a considerable number of mineral occurrences (Cu-Bi, Au-Ag, Au-Ag-Cu, Ba).
The Coongan Belt is marked by northern and southern Cu enhancements (8.1 to 8.4) over Warrawoona Group lithologies, principally Talga Taiga and Salgash Subgroups, Duffer Formation and Corboy Formation of the Soanesville Subgroup. Little comment can be made on the extreme northern enhancement of 55 ppm Cu (8.1). Some gold mineralisation is reported within the basin. Southwards from the central portion of the belt, Cu values generally increase. A subtle inexplicable local 70 ppm high (8.2) is found in the central portion of the belt. The extreme south eastern portion of the belt and the adjacent Corunna Downs Batholith and western portion of the Kelly Belt are noticeably high in Cu. A northern high of 85 ppm (8.3) is present over Mondana Granite and Salgash Subgroup containing acid volcanics of the Kelly Formation. The southern 80 to 85 ppm high (8.4) is underlain by the majority of the Warrawoona Group lithologies, Corboy Formation and Mt Roe Basalt of the Fortescue Group. Dispersion from this latter unit may however, be influencing the enhancement.

The Kelly Belt is marked by two areas of interest, both of which have copper occurrences. The northern 64 ppm basinal high (9.1), is found in the Copper Hills area, and is underlain by faulted Duffer Formation and Salgash Subgroup containing acid volcanics of the Kelly Formation. The southern basinal high of 55 ppm (9.2) is again underlain by Kelly Formation and Boobina Porphyry.

Little can be said about the Marble Bar and Warrawoona Belts and their general central 55 to 60 ppm Cu enhancements.

Generally the batholiths are marked by low Cu values of less than 12 ppm except where rafts of relict greenstones are present in early migmatitic batholith phases and where regional shearing has taken place along the margins of the batholiths and greenstone belts.

Within the Yule Batholith is a prominent copper pattern. In the southern portion of the batholith (10.1) it is a reflection of dispersion from remnant Fortescue Group Volcanics which overlie the granite with marked angular unconformity. Northwards the Cu values fall off, but here they reflect rafts of mafics in the early migmatitic granite...
phase Agm. On the eastern periphery of the batholith (10.2), the northern portion of the Woodstock Adamellite (AgI) is inexplicably enriched in Cu. Values range from 26 to 50 ppm. Within the northern portion of the batholith a prominent sheared wedge of metamorphosed greenstones (Wodgina Subgroup) has definitive highs of 26 to 36 ppm Cu (10.3) which may be related to extensive Ta, Sn, Be, Cu mineralisation. The mineralisation appears to be related to the prominent regional shear.

The Shaw Batholith has areas of Cu enrichment. The eastern portion is particularly enriched when compared with the western portion of the batholith. This is related in part to extensive regional mafic dyke activity (e.g. Black Range Niorite) and the sheared margins of the batholith and greenstone belts. However two local highs are present which are inexplicable. These are; a spot 40 ppm high (11.1) surrounded by 21 to 30 ppm Cu values which are underlain by migmatitic batholith phase (Agm), stanniferous Cooglegong Adamellite (Age) and Eley Adamellite (Agp); and an areal enhancement of 55 to 70 ppm with a distinctive 85 ppm high (11.2) underlain by mainly faulted Bamboo Springs Adamellite (Agp).

The periphery of the Corunna Downs Batholith is enhanced in copper because of the presence of rafts of mafic material in the migmatitic Agm phase. However, a pronounced high is present over the Mondana Granite (Age) stock in the southern portion of the batholith (12.1). Cu values here range from 60 to 85 ppm. The 85 ppm high is underlain in part by the Coongan Belt and has been previously discussed. A local high of 38 ppm (12.2) is also present over the Carbana Pool Adamellite in the eastern portion of the batholith and overlaps into the adjoining Kelly Belt.

Little can be said about the other batholiths, i.e. Turner, Carlindi, Strelley and Mt Edgar with the exception of the general Cu enhancements over the first three which again reflects mafic rafts in the migmatitic Agm phase.

...31.
6.2.6 Chromium

The greenstones especially the Archaean belts are easily differentiated from the Lower Proterozoic cover and Archaean granite batholiths by their prominent high Cr patterns. Breakpoints have been recognised from the cumulative frequency plot in Figure C13 at 50, 140, 270, 380 and 550 ppm which correspond to the 19, 74, 92, 95.8 and 98.9 percentiles for the range of values encountered.

The most extensive Cr pattern on the sheet is found over the Gorge Creek and Warrawoona Groups and minor intrusive ultramafic in the Pilgangoora Syncline (1.1). Cr values here range from 400 to 520 ppm with an eastern central 620 ppm high.

A smaller, but extensive Cr pattern is present in the central portion of the sheet over the southern portion of the Soanesville Belt, Tambina Complex and adjoining Shaw Batholith and North Shaw Belt. Cr values range from 320 to 480 ppm over the greenstone belts (2.1). A 600 ppm high is present over the Shaw Batholith and portion of the North Shaw Belt. The 400 to 480 ppm Cr high is underlain by Soanesville Subgroup, Paddy Market Formation and large areas of intrusive ultramafic. Asbestos occurrences are present within the pattern.

Chromium values over the majority of the Western Shaw Belt are notably low with the exception of the extreme northern and southern portions of the belt. In the north, Cr values of 190 to 240 ppm (3.1) are underlain by Salgash Subgroup. Asbestos and chromite occurrences are present within the pattern. In the south a prominent Cr high of 290 to 450 ppm (3.2) is present over north easterly sheared drag folded Salgash Subgroup and Corboy Formation. An eastern adjacent 700 ppm Cr high is present over minor greenstones and Shaw Batholith.

The western half of the North Shaw Belt is considerably enhanced in Cr when compared with the eastern half of the belt, i.e. 240 to 350 ppm Cr compared with 70 to 100 ppm Cr. The peak Cr value of 350 ppm (4.1) is part of the previously discussed pattern over the Soanesville Belt and Tambina Complex. The high is underlain by Talga Talga Subgroup, Paddy Market Formation and intrusive ultramafic.
In the Lalla Rook Syncline a 300 ppm central Cr high (5.1) within high background Cr values of 140 to 260 ppm is underlain by Gorge Creek Group.

The majority of the North Pole Dome, in particular the central and eastern areas, have low order Cr values of 90 to 130 ppm. Two areas of enhanced Cr values of 140 to 180 ppm (6.1) are present to the north and south of the actual dome and are underlain by radially faulted Salgash Subgroup.

In gross terms the southern portion of the Coongan Belt is enhanced in Cr, with values ranging from 140 to 240 ppm within which is a 280 to 320 ppm high (7.1) underlain by Salgash Subgroup, Wyman and Corboy Formations. However, in the northern half of the belt a distinctive north easterly trending high transects the low order Cr values. Cr peaks at 650 ppm within a pattern of 320 to 330 ppm Cr values (7.2). The high is underlain by Warrawoona and lower stratigraphic members of the Gorge Creek Groups. Asbestos occurrences are present in the southern portion of the high.

A high of 500 ppm Cr (8.1) straddles both the Marble Bar and Warrawoona Belts and lies within a general background of 160 to 230 ppm Cr. The high is underlain by sheared Salgash Subgroup, Duffer Formation and granite.

The northern portion of the Kelly Belt underlain by Duffer Formation, Salgash Subgroup and Boobina Porphyry has a 160 to 240 ppm Cr enhancement (9.1).

A prominent pattern of 140 to 210 ppm Cr with a central flanking high of 420 ppm (10.1) is present in the north eastern corner of the Sheet and is underlain by sheared greenstones of the Wodgina Belt lying within the Turner and Yule Batholiths.

In contrast with the majority of the Archaean greenstone belts the Lower Proterozoic Fortescue Group cover has low order Cr values which range from 20 to 80 ppm over the Hardey Sandstone in the south eastern
Corner of the sheet to 80 to 130 ppm over the basaltic members of the group. Small enhancements are present within these background values such as the 160 ppm basinal high underlain by Nymerina Basalt, Kuruna Siltstone and Maddina Basalt in the southwestern corner of the Sheet (11.1) and a small area of 160 to 200 ppm Cr (11.2) underlain by Mt Roe and Kylena Basalts in the southeastern corner of the Sheet. However, an exception is the northeastern corner of the sheet, where the previously discussed north easterly trending high over the northern portion of the Coongan Belt, continues and is underlain by Mt Roe Basalt and minor windows of Salgash Subgroup. Cr values here range from 160 to 290 ppm (11.3). A similar comment applies to the central area of Fortescue Group cover.

Cr values over the batholiths are generally higher over the more migmatitic suites, where relict rafts of greenstones or prominent regional mafic dykes are present. Odd in part inexplicable highs occur in the Yule, Shaw and Corunna Batholiths.

The Numbana Granite, Nardoopiquithanna Adamellite, Abydos Adamellite and Tambourah Granodiorite stocks within the Yule Batholith have low Cr values of 20 to 40 ppm and contrast with both the Woodstock Adamellite stock (Ag1) and the early migmatitic Agm phase. The northern portion of the Woodstock Adamellite has a 900 ppm high within an enhancement of 150 to 250 ppm Cr (12.1). A high of 100 to 120 ppm Cr is also found in the northern portion of early migmatitic phase Agm (12.2) in the central portion of the Yule batholith.

The western portion of the Shaw Batholith is enhanced in Cr. Previously discussed highs of 600 ppm (13.1) and 700 ppm (13.2) are present here in areas having relict greenstones. The southern portion of the Mondana Adamellite stock within the Corunna Batholith has a distinctive Cr high of 460 ppm within a 160 to 170 ppm Cr enhancement, (14.1).

Little can be said about the remaining batholiths with the exception of the spot 150 ppm Cr high (15.1) in the Mt Edgar Batholith.
6.2.7 Lead

High lead patterns of prominence are equally distributed over both the Archaean batholiths (Yule and Shaw in particular) and greenstones (Proterozoic cover and North Pole Dome). Breakpoints at 13, 22, 29, 37, 45 and 63 ppm are recognised on the cumulative frequency plot in Figure C14. These breakpoints correspond to the 10.5, 59, 81.5, 93.5, 96.7 and 98.5 percentiles of the range of Pb values encountered. Less than 1% of the samples fall below the 2 ppm detection limit for the analytical method.

Areal lead highs of prominence are present over the northern and southern portions of the Yule Batholith. In the northern portion of the batholith a prominent 34 to 85 ppm Pb pattern is present over faulted Numbana Granite (Agc) and the Pincunnah and Abydos Adamellite (Agp). Distinctive highs are present within the pattern especially over the Agp phases; e.g. pattern 1.1, a 50 to 80 ppm Pb high over the northern portion of the Abydos Adamellite stock, and pattern 1.2, an 85 ppm high over the southern portion of the nearby Pincunnah Adamellite stock. The pattern over the faulted south eastern portion of the Numbana Granite stock peaks at 48 ppm (1.3). Minor Sn mineralisation is present within the pattern. The central portion of the less prominent 30 ppm Pb pattern is principally associated with the Numbana Granite (Agc), Kangan Granite (Agp) and Nardopiquithanna Adamellite (Agb), and contains extensive Sn-Be-Ta-Nb mineralisation. On the north eastern portion of the batholith spotty enhancements of 30 to 36 ppm Pb are found over the northern portion of stocks containing adamellite phase Ag1, i.e. patterns 1.4 and 1.5 respectively over Woodstock Adamellite and Coorong Adamellite. The extensive 40 to 60 ppm Pb pattern (1.6) over the south eastern portion of the batholith and the minor 29 ppm Pb pattern in the central portion of the batholith (1.7) are underlain by the early migmatitic suite Agm. The southern pattern (1.6), may be influenced by remnant Proterozoic Kylena Basalt cover. A minor Sn occurrence is however present within the basin containing the 50 ppm Pb value. To the east of the above, a spot 34 ppm Pb (1.8) is present over the central portion of the Tambourah Granodiorite (Agm).
The Shaw Batholith has a prominent enhancement of 30 to 38 ppm Pb (2.1) over a stock containing the stanniferous Cooglegong Adamellite (Agc). A central high of 48 ppm is present within the pattern. Extensive alluvial Sn-Ta mineralisation is being worked at Cooglegong and Pilga within the high. In the southern portion of the batholith, a minor enhancement of 22 to 24 ppm (2.2) is underlain by stocks of Bamboo Springs Adamellite (Agp), stanniferous Coondina Granite (Agc) and unnamed granite phase Agl.

Within the Corunna Downs Batholith, the Mondana Adamellite (Agc) is highlighted by a Pb enhancement of 22 to 36 ppm (3.1). The peak value of 36 ppm Pb within the pattern is also in part underlain by the adjoining Kelly Belt. In the northern portion of the batholith, a spot 28 ppm Pb (3.2) highlights the sheared contact of the batholith and the Warrawoona Belt.

Little comment can be made about the Pb patterns over the Mt Edgar, Strelley, Carlindi and Mt Turner Batholiths, though the latter has a consistent 22 to 28 ppm Pb enhancement.

Lead enhancements are prominent over the Fortescue Group volcanic cover especially over outcrop in the south western and to a minor extent the south eastern, central and north eastern portions of the Sheet. In the south western corner of the Sheet, the Tumbiana Formation and Nymerina Basalt are accentuated by an 88 ppm Pb high (4.1), as is the Kylena Basalt by spot 62 and 50 ppm Pb highs (4.2). The 32 ppm Pb high (4.3) in the north eastern quadrant of the Sheet is mainly underlain by Mt Roe Basalt and minor Warrawoona Group.

The central portion of the North Pole Dome underlain by fractured North Pole Adamellite (Agm) and Talga Talga Subgroup is highlighted by a pattern of 24 to 130 ppm Pb values (5.1). The 130 ppm Pb value is the highest for the sheet. The basinal high contains extensive Ba and minor Ag-Au, Cu-Bi mineralisation.
A 24 ppm Pb pattern (6.1) in the Lalla Rook Syncline is underlain by Salgash Formation in sheared juxtaposition with Lalla Rook Sandstone and Budjan Formation. Minor Au-Ag-Pb and Cu mineralisation is recorded within the pattern.

Two Pb patterns of interest are present in the Pilgangoora Syncline. The most important is a 28 to 34 ppm Pb pattern (7.1) in the south western portion of the Syncline. This is underlain by Salgash Subgroup, Paddy Market, Corboy, Budjan Formations and Lalla Rook Sandstone. Minor Au and Fe (BIF) mineralisation is present in the southern most portion of the pattern. An area of 22 to 24 ppm Pb (7.2) is present over the north eastern portion of the Syncline and the adjoining Carlindi Batholith. Minor Au-Cu-Pb mineralisation is present within the Syncline.

The Soanesville Belt has northern and southern areas of Pb enhancement underlain by Salgash Subgroup and Gorge Creek Group. The less prominent northern Pb pattern of 22 to 27 ppm (8.1) contains minor Cu-Pb-Zn mineralisation, while the more prominent southern pattern of 32 to 36 ppm Pb (8.2) contains minor Au and Cu mineralisation.

The north western portion of the North Shaw Belt has a general enhancement of 24 to 28 ppm Pb. The pattern is underlain by sheared North Shaw Tonalite (Agd), Salgash Subgroup containing felsic volcanics of the Panorama Formation, and some Fortescue Group volcanics. Extensive Au-Ag-Pb-Cu vein mineralisation flanks the western periphery of the pattern.

The Western Shaw Belt has a distinctive enrichment of 24 to 26 ppm Pb (10.1) in the southern central portion of the belt. The pattern is underlain by an area of sheared Salgash Subgroup and Corboy Formation. This enrichment contrasts with the general 10 to 12 ppm low in the northern portion of the belt.

Within the Marble Bar Belt, a northern spot 28 ppm basinal high (11.1) is present and is underlain by Duffer Formation. Southwards, a general
24 to 26 ppm Pb pattern (11.2), overlaps respectively the southern and western portions of the Marble Bar and adjoining Warrawoona Belt. The pattern is underlain by Duffer Formation and Salgash Subgroup lithologies. Volcanics of the Fortescue Group may in part be influencing the southern portion of the pattern. Extensive minor Au-Pb, Au-Cu and Ag-Au mineralisation is however present in the area.

Southwards two broad Pb patterns are present in the Coongan Belt. A north-south trending, 22 to 25 ppm Pb pattern (12.1), in the north western portion of the belt is underlain by Talga Talga Subgroup and Duffer Formation. The southeastern portion of the belt is considerably enhanced by a pattern of 26 to 28 ppm Pb, within which are two basinal areas of 32 ppm Pb (12.2). The pattern is underlain by Salgash Subgroup, Wyman and Corboy Formations, with some influence from the volcanics of the Fortescue Group.

The eastern adjacent Kelly Belt has a marked 32 to 36 ppm Pb enhancement (13.1) over felsic volcanics of the Kelly Formation. Cu and Ag-Cu mineralisation is present within the northern portion of the pattern.

The Wodgina Belt is marked by two Pb enhancements of interest. These are a 30 to 40 ppm Pb pattern (14.1), and a spot basinal value of 32 ppm Pb (14.2). Both areas are underlain by sheared Wodgina Subgroup and Kangan Granite. Extensive Sn-Ta-Nb-Ag mineralisation is present within both patterns.

6.2.8 Manganese

From Figure G15 breakpoints at 170, 310, 500, 720, 900, 1120 and 1250 ppm are recognised in the cumulative frequency plot for manganese. These breakpoints correspond to the 4, 39, 63, 82, 92, 95.5 and 99.4 percentiles of the range of values encountered. Generally the greenstone belts, relict greenstones in the batholiths, and greenstone cover are easily differentiated from granite in the Mn results by basins containing values greater than 310 ppm Mn.
The most extensive Mn high is present in the central portion of the sheet over much of the southern half of the Soanesville Belt and adjoining Proterozoic Fortescue Group cover. This pattern can be subdivided into two parts; a western area of 980 to 1280 ppm (1.1) underlain by Soanesville Subgroup, and a larger eastern area of 1150 to 1200 ppm (1.2) underlain by Soanesville Subgroup, Honeyeater and Mt Roe Basalt.

Northwards, the prominent 1300 to 2100 ppm high (2.1) in the Lalla Rook Syncline is flanked to the east by a north-south Mn enhancement of 900 to 1000 ppm. The high is underlain by faulted Gorge Creek Group. Cu mineralisation is present within the 1300 ppm high.

The eastern portion of the Pilgangoora Syncline has an areal high of 900 to 1040 ppm (3.1) in a general 750 to 800 ppm Mn enhancement. The high is underlain by Gorge Creek Group and Salgash Subgroup.

The southern portion of the North Pole Dome (4.1) has a 1100 to 1200 ppm Mn pattern underlain by faulted Salgash Subgroup containing felsic volcanics of the Panorama Formation.

Southwards, a 900 to 1000 ppm Mn pattern (5.1), straddles the north-western portion of the North Shaw Belt and adjoining North Pole Dome. The pattern is underlain by Salgash Subgroup and minor Gorge Creek Group (Paddy Market Formation, Lalla Rook Sandstone, Budjan Creek Formation). Generally the western portion relative to the eastern portion of the belt has a two to three fold enhancement in Mn. The eastern low is underlain by Talga Talga Subgroup and intrusive ultramafic.

The Western Shaw Belt is markedly differentiated in the Mn results, with the northern and southern portions respectively of the belt, being part of a general low and of a regional Mn enhancement. A distinctive 990 to 1050 ppm high (6.1) is present in the central southern portion of the belt. The high is underlain by Salgash Subgroup and Corboy Formation which have been regional sheared.

...39.
The Kelly Belt has three areas of interest; a pronounced 6500 ppm Mn high underlain mainly by Lalla Rock Sandstone, Budjan Creek Formation (7.1); a 960 to 1080 ppm Mn high (7.2) which straddles both the Kelly Formation within Salgash Subgroup and the Mondana Adamellite of the adjoining Corunna Downs Batholith; and portion of a 600 ppm high (7.3) underlain by faulted Duffer Formation and Salgash Subgroup. Ag-Cu and Cu mineralisation are present within 7.2.

Two areas of interest are present in the southern portion of the Coongan Syncline which has a marked enrichment of manganese. The first is the western 1000 ppm high straddling sheared Shaw Batholith, Talga Talga Subgroup and Duffer Formation (8.1). The second is the eastern and northern adjoining 960 ppm basins (8.2). Both of these basins are underlain by mainly Corboy Formation with some Wyman Formation and Salgash Subgroup. In the northern portion of the belt, a 720 to 760 ppm enhancement (8.3), is underlain by the same units with some influence from the Paddy Market Formation.

A 850 ppm high (9.1) straddles the northern and southern portions of the Warrawoona and Marble Bar Belts. This area is underlain by faulted Duffer Formation and Salgash Subgroup.

The Wodgina Belt is accentuated by a spot 560 ppm high (10.1) underlain by sheared Wodgina Subgroup.

Various Proterozoic Fortescue Group lithologies are highlighted in the data. These being; the Tumbiana Formation, in particular the Meentheena Carbonate Member by 1100 to 1200 ppm Mn in the southwestern corner of the sheet (11.1); the Kylena Basalt and Hardey Sandstone by 1200 ppm values in the southeastern corner of the sheet (11.2); and in the northeastern quadrant the 900 and 1000 ppm Mn results (11.3) underlain by Mt Roe Basalt with some contributing influence from the Salgash Subgroup.

As remarked previously the granite batholiths are easily differentiated from the greenstone belts. Generally values of less than 310 ppm...
The Pilgangoora Syncline has a prominent areal Mo enhancement of 1.2 to 3.0 ppm (3.1) underlain mainly by faulted Gorge Creek Group lithologies. Minor Sn-Ta mineralisation is present within the northern portion of the pattern. Southwards, a spot 1.2 ppm Mo (3.2) is present over both the greenstone belt and adjacent Yule Batholith. Much of the underlying lithologies here consist of unnamed granite stocks, Agt and Agm, Talga Talga Subgroup and intrusive ultramafic. Au, Be and Cu mineralisation is present in the basin.

A 1.2 to 2.0 ppm Mo pattern (4.1) is present over faulted Salgash Subgroup in the northern portion of the Lalla Rook Syncline and over adjacent granite (Agm) of the Carlindi Batholith. Minor Au-Ag-Pb mineralisation is present on the southeastern margin of the pattern.

On the southern and northern margins of the North Pole Dome and North Shaw Belt respectively, a 1.2 to 2.0 ppm Mo enhancement (5.1) is present. This area is underlain by faulted Salgash Subgroup, Wyman and Paddy Market Formation with some Mt Roe Basalt. This latter unit may be the cause of the enhancement.

A prominent Mo high of 1.2 to 2.0 ppm (6.1) is present over the northern portion of the Western Shaw Belt and portion of the adjoining Yule Batholith. The pattern is underlain by Salgash Subgroup, Woodstock Adamellite (Agi) and granite phase Agm. The area contains a diversity of mineralisation, e.g. Ta, Ta-Cu, Zn, Cr and asbestos.

The north western portion of the Shaw Batholith has a large Mo high of 1.2 to 2.0 ppm (7.1) underlain by Shaw batholith phases Agm with the minor Mulgandinnah Granite (Agl) and stanniferous Spear Hill and Cooglegong Adamellites (Age). Extensive alluvial Sn-Ta mineralisation is being worked within the pattern at Cooglegong and Pilga. A spot 2.0 ppm value is present straddling the eastern margins of the batholith phase Agm and the Salgash Subgroup of the Coongan Belt.

Three areas of interest are found in the Corunna Downs Batholith. These are, a 1.2 to 3.0 ppm Mo high (8.1) over the southern portion of the Mondana Adamellite (Agc), Boobina Porphyry and felsic volcanics...
of the Panorama Formation in the Kelly Belt; a 1.2 to 2.0 ppm high (8.2) over northern granite phase Agm and Carbana Pool Adamellite (Agp) and a spot 1.2 ppm (8.3) high over the latter mentioned granite phase. Ag-Cu and Cu mineralisation is present within pattern 8.1.

Northwards, a 1.4 to 2.0 ppm Mo high (9.1) is present over granite phase Agm of the Mt Edgar Batholith.

The Turner batholith is highlighted by a 1.2 to 2.0 ppm Mo pattern (10.1) which is underlain by granite phase Agm, minor phase Agp and some faulted Wodgina Subgroup.

In the northern portion of the Yule batholith a spot 1.2 ppm enhancement (11.1) is present over the regional northeasterly trending mineralised shear, Kangan Granite (Agp) and Wodgina Subgroup. Pegmatitic mineralisation (Be-Sn-Ta-Nb) is present within the basin.

6.2.10 Nickel

The greenstone belts and granite batholiths are easily differentiated in the nickel results. Generally Ni values of less than 54 ppm outline the granite batholiths except where rafts of relict greenstones are present. Breakpoints at 20, 37, 55, 80, 105, 140 and 215 ppm are recognised in the cumulative frequency plot in Figure C17. These breakpoints correspond to the 22, 40, 55, 74.5, 86.5, 94 and 98.8 percentiles of the range of values encountered.

The most prominent Ni pattern (1.1), is present in the central portion of the sheet over the southern portion of the Soanesville Belt, adjacent Tambina Complex and North Shaw Belt. A 245 to 260 ppm Ni high is surrounded by a 125 to 180 ppm Ni enhancement. The high is underlain by Soanesville Subgroup and intrusive ultramafic. Au, Cu-Ni and Cu mineralisation is recorded within the high, while crysotile asbestos is recorded both within the high and enhancement over the southern adjacent Tambina Complex.
Three enhancements are present in the Pilgangoora Syncline (2.1 to 2.3). Two of these (2.1, 2.2) have distinctive highs. The prominent 160 to 180 ppm Ni enhancement with an associated 250 ppm Ni high (2.1) in the central portion of the Syncline is underlain by faulted Salgash and Talga Talga Subgroup with some Paddy Market Formation. Southwards, the abutting 220 ppm Ni high (2.2) is underlain by faulted Talga Talga Subgroup and intrusive ultramafic. The northern Ni pattern of 150 to 160 ppm (2.3) is underlain by Salgash Subgroup, Paddy Market Formation and Lalla Rook Sandstone and Budjan Creek Formation.

Within the Lalla Rook Syncline an odd spot 160 ppm Ni basinal high (3.1) is present in an area underlain by Gorge Creek Group. The Honeyeater Basalt unit within the basin may be causing the Ni high. On the northwestern extremities of the Syncline, the 115 ppm Ni enhancement (3.2) is underlain by a variety of faulted Gorge Creek and Warrawoona Group lithologies.

A 120 to 140 ppm Ni enhancement (4.1), over the northwestern portion of the North Shaw Belt and adjoining North Pole Dome is underlain by Salgash Subgroup and minor Paddy Market Formation. The eastern portion of the belt is generally low in Ni.

The Western Shaw Belt differs from the other greenstone belts, in that with the exception of the southern and extreme northern portion of the belt, Ni values are unusually low. The sheared western contact of the belt with the adjacent Tambourah Granodiorite stock of the Yule Batholith is also highlighted. The southern central, 95 to 175 ppm Ni high (5.1), is underlain by faulted Salgash Subgroup and Corboy Formation.

In the Coongan Syncline, northern and southern regional Ni enhancements are present, within which are distinctive highs. The 160 to 240 ppm (6.1) northern high is underlain by the upper and lower member respectively of the Warrawoona and Gorge Creek Groups. Likewise, the 150 ppm (6.2) and 152 ppm Ni (6.3) highs in the southern portion of the Syncline. The 152 ppm Ni high may in part be influenced by Mt Roe Basalt.
Little comment can be made on the remaining greenstone belts with the exception of; the spot 120 ppm Ni (7.1) over the Salgash Subgroup on the eastern extremity of the Kelly Belt; the spot 110 ppm Ni (8.1) over Wyman Formation and Salgash Subgroup in the Warrawoona Belt; the low order 70 ppm Ni high (9.1) in the Wodgina Belt, and the regional differentiation of the North Pole Dome into a more Ni enriched (60–75 ppm) eastern half.

The Lower Proterozoic cover is marked by enhanced Ni over the Kylena Basalt, especially the 170 ppm Ni in the northeastern quadrant (10.1); 80 to 120 ppm Ni (10.2) and 90 ppm Ni (10.3) in the southwestern outcrop area; and 95 ppm Ni (10.3) in the southeastern outcrop area. The Mt Roe Basalt has been previously commented upon, as influencing Ni enhancements in the southern portion of the Coongan Belt. However, gross Ni enhancements over Mt Roe Basalt are particularly prevalent in the northeastern quadrant where a prominent 110 to 135 ppm (11.1) Ni pattern is present. Spot highs of 88 (12.1) and 100 ppm (13.1) respectively are present over Nymerina Basalt and Mingah Tuff in the southwestern outcrop area.

As previously mentioned at the beginning of this resume on the Ni geochemistry, Ni values are generally low over the batholiths except where relict rafts of greenstones and regional mafic dykes are present. The western portion of the Shaw Batholith is perhaps a good example. Some of the Ni patterns though are inexplicable. For example, the pronounced 290 ppm high in the Mondana Adamellite stock of the Corunna Downs Batholith (14.1); the spotty consistent 150 to 170 ppm high (15.1) in the northern portion of the Woodstock Adamellite of the Yule Batholith; lower order Ni values of 65 to 75 ppm over the Bamboo Springs Adamellite (16.1) in the Shaw Batholith; and the 60 to 76 ppm Ni over the Carbana Pool Adamellite in the Corunna Downs Batholith (14.2).

6.2.11 Tin

Tin patterns are generally more prominent over the granite batholiths than the greenstone belts. Breakpoints at 5, 9, 13, 17, 24 and 55 ppm...
are recognised from the cumulative frequency plot in Figure C18. These breakpoints correspond to the 33, 66, 82, 89, 95 and 99.3 percentiles for the range of tin values encountered. Some 6.1% of the values fall below the 2 ppm detection limit for the analytical method.

The Shaw Batholith has the most prominent Sn patterns in the regional data. These patterns are found in the northern (1.1), east central (1.2), and southwestern (1.3) portions of the batholith. The northern pattern of 18 to 40 ppm is the most prominent in areal extent and contains the Cooglegong, Pilga and Eley tin fields. The northern portions of the stanniferous Cooglegong Adamellite (Agc) and Spear Hill Adamellite (Agc) stocks underlie the majority of the pattern with earlier migmatitic Mulgandinnah Adamellite (AgI) and phase Agm. The east central pattern of 16 to 75 ppm Sn (1.2) has its peak value of 75 ppm and supporting 24 ppm values underlain by stanniferous Cooglegong Adamellite (Agc) and Eley Adamellite (Agp). Tin is not recorded in this pattern. The southwestern pattern (1.3) of 16 to 70 ppm Sn, is underlain by stanniferous Coondina Granite (Agc) and early migmatitic phases Agm and Bamboo Springs Adamellite (Agp). Tin mineralisation is recorded at Coondina in the basin containing the 20 ppm enhancement adjacent to the 70 ppm high.

The central portion of the Mount Edgar Batholith has a 16 to 35 ppm Sn enhancement which is underlain by migmatitic phase Agm and the faulted stock of stanniferous Moolyella Adamellite (AgY). The peak 35 ppm value contains the extensive alluvial-eluvial Sn workings at Moolyella.

Southwards, the southeastern, central and northern portions of the Corunna Downs Batholith are highlighted by a general Sn enhancement accompanied by spot highs (3.1 to 3.4) over a number of granitic phases. The Carbana Pool Adamellite stock (Agp) in particular is highlighted by spot 10, 12 and 24 ppm basinal values (3.1), the Mondana Adamellite (Agc) by 30 (3.2) and 20 ppm (3.3) values. These latter basins also contain Boobina Porphyry (3.2) or overlap the felsic volcanics of the Kelly Belt (3.3). Ag-Cu and Cu mineralisation is present in the latter basin. The sheared northern extremities of the batholith and adjacent Warrawoona Belt (3.4) is highlighted by 12 to 16 ppm Sn values.
Distinctive patterns are present in the Yule Batholith. Of prominence, is the large inexplicable 24 to 35 ppm Sn high (4.1) underlain by migmatitic phase Agm in the western portion of the batholith. Eastwards, the 10 to 14 ppm Sn pattern (4.2) is similarly underlain by Agm, but northwest faulting contains Sn-Ta mineralisation. Northwards from (4.1), a pronounced pattern of 12 to 24 ppm Sn is present over fractured stanniferous Numbana Granite and adjoining Kangan Granite and the sheared southern remnants of the Wodgina Belt (4.3). Even though the Numbana Granite is stanniferous it is only the western portion of the stock that is highlighted, especially the peak 16 ppm value (4.3a) and the spot 6 ppm basin (4.3b), which contains minor tin mineralisation. The other distinctive 18 to 24 ppm Sn high (4.3c) contains extensive pegmatitic Sn-Ta-Be mineralisation associated with a northeasterly trending regional shear. Northwards, into the Wodgina Belt proper, a 20 ppm Sn high (4.3d) outlines similar extensive mineralisation. The northeastern portion of the batholith is also enriched in tin. Especially, the 12 to 16 ppm Sn pattern (4.4) over the western portion of the Pincunnah Adamellite (Agp) and eastern portion of the Nardoopiquithanna Adamellite where Sn occurrences are known; the inexplicable consistent 20 to 40 ppm highs (4.5) in the northern portion of the stock of Woodstock Adamellite; and the two spot enrichments of 14 and 45 ppm (4.6) in the Abydos Adamellite (Agp).

Little comment can be made on the patterns over the Carlindi and Strelley Batholiths, with the exception of the general 10 to 16 ppm Sn enhancement over the former. The western 14 ppm basin in the Carlindi Batholith (5.1) overlaps the Pilgangoora Syncline.

A spot 120 ppm Sn high (6.1) is present in a large basin over the southwestern and northeastern portion of the North Pole Dome and Soanesville Belt. Unfortunately insufficient sample material remained to check the validity of the value.

The northern portion of the Lalla Rook Syncline is highlighted by a 16 to 32 ppm Sn enhancement, which is underlain by Talga Talga
Subgroup faulted against Lalla Rook Sandstone and Budjan Creek Formation. Cu and Au-Ag-Pb mineralisation is found respectively within the 28 and 20 ppm basins (7.1). The 32 ppm high (7.2) is inexplicable, though portion of the basin overlaps the North Pole Dome and its headwaters have reported Au-Ag-Cu mineralisation.

A northeasterly trending 16 ppm Sn enhancement encompassing an 18 ppm high (8.1) is present in the Pilgangoora Syncline, over mixed lithologies of the Gorge Creek Group. Au mineralisation is reported within the 18 ppm basinal high.

The North Pole Dome is marked by a north-south trending Sn enrichment over the central portion of the dome within which Ag-Au, Au-Cu-Bi and Ba mineralisation are reported. The southern portion of the pattern has an 18 ppm Sn high which is associated with 16 and 28 ppm Sn values over the adjacent North Shaw Belt.

Sn highs over the northern adjacent North Shaw Belt and Lower Proterozoic cover constitutes a distinctive regional high (9.1). Ag-Au-Cu mineralisation is reported on the southern flanks of the high. The high is mainly underlain by felsic volcanics of the Panorama Formation, the Northern Shaw Tonalite (Agd) and Mt Roe Basalt. A general 10 ppm Sn pattern is present over mainly sediments of the Salgash Subgroup in the western central portion of the belt. Minor Au mineralisation is associated with the pattern. The 32 ppm basinal Sn high (9.3) in the southern portion of the belt and adjoining Shaw Batholith contains extensive Sn-Ta-Be mineralisation.

Straddling the Marble Bar and Warrawoona Belt is a 40 ppm Sn high (10.1) in a general 8 to 12 ppm Sn enhancement. The general area is underlain by Salgash Subgroup and Mt Roe Basalt. The basinal high itself contains extensive As-Ag-Au and Cu-Pb-Zn mineralisation.

The Coongan Belt, though marked by low Sn values of 0 to 4 ppm has three distinctive areal highs. These areal highs from north to south are; a spot 16 ppm Sn (11.1); an area of 12 to 15 ppm Sn (11.2); and a large 10 to 40 ppm tin pattern (11.3). The main lithologies underlying all
three highs are Duffer Formation and Salgash Subgroup. Regional shearing is prevalent in the individual peak basinal values in all three areas. No mineralisation is recorded, but from analogous situations elsewhere (e.g., Lalla Rook Syncline) hydrothermal mineralisation of undetermined type is suspected.

The Soanesville Belt is marked by northern and southern highs. However, the northern area (12.1) is portion of the previously discussed high over the Woodstock Adamellite in the Yule Batholith. The southern 12 to 16 ppm Sn high (12.2) is underlain by Soanesville Subgroup. Cu and Au mineralisation is recorded within the latter pattern.

A north-south trending, 10 to 14 ppm Sn pattern, is present over the regionally sheared western contact of the Western Shaw Belt and the Tambourah Granodiorite of the Yule Batholith. The 14 ppm basinal high (13.1) in the general 10 ppm Sn pattern straddles the Tambourah Gold Mining Centre. Au mineralisation is present here in the shear.

Southeast of this high, a 12 ppm basinal Sn value (13.2) stands out in a general 10 ppm Sn enhancement. This area has been prominent in the other elemental results. Sheared dragfolded Salgash Subgroup and Corboy Formation underlies the area.

Interesting Sn patterns are found over the Proterozoic Fortescue Group volcanic cover in the southwestern and northwestern corners of the Sheet. The high Sn values in the southwestern corner are in sharp contrast to those in the southeastern corner. The Tumbiana Formation and Nymerina Basalt here have 16 to 28 ppm Sn enhancements (14.1) while the Kylena Basalt have 20 to 25 ppm enhancements (14.2). The 28 ppm high in pattern 14.1 may in part be influenced by remnant Kylena Basalt. A Sn occurrence is present in the eastern most 20 ppm basin (14.2). In the northwestern portion of the Sheet, basins underlain in part by Mt Roe Basalt have been commented upon as being enhanced in Sn, especially the western portion of the Proterozoic cover abutting the Marble Bar and Warrawoona Belts and the eastern portion abutting the North Shaw Belt and North Pole Dome. The 16 ppm basinal high (14.3) here, is however, underlain by sandstone of the Kylena Basalt.

...49.
6.2.12 Vanadium

The granite batholith and greenstone belts can be easily differentiated in the vanadium results. As a generalisation vanadium responses are lower over granite batholiths (less than 65 ppm) except where basinal values are influenced by remnant rafts of greenstones or major mafic dyke activity.

From the cumulative frequency curve in Figure C19 breakpoints are recognised at 32, 50, 65, 85, 125, 155 and 200 ppm which corresponds respectively to the 28, 48, 66, 72, 92, 96.5 and 99.6 percentiles of the range of vanadium values encountered. No values fall below the 5 ppm detection limit for the analytical method.

The Coongan Belt is characterised by a north-south trending enrichment of 150 to 230 ppm V on the western margin of the belt, and 155 to 240 ppm enrichment over the southern portion of the belt. The peak 230 ppm V (1.1) in the western portion of the belt is underlain by Talga Subgroup and some Duffer Formation. The 240 ppm basinal high in the southern portion of the belt (1.2) is underlain by Duffer Formation, Wyman Formation, Salgash Subgroup and minor Mt Roe Basalt. The 175 ppm high (1.3) is portion of a general enhancement extending over the southeastern portion of the greenstone belt and the Mondana Adamellite in the southern portion of the Corunna Downs Batholith.

The Lower Proterozoic Fortescue Group volcanic cover is highlighted in the southwestern and southeastern corner, central and northeastern quadrant of the sheet. The Kylena Basalt is accentuated by spot 160 ppm highs (2.1, 2.2, 2.3) as is the Nymerina Basalt (2.4). In the central portion of the sheet, a 135 to 150 ppm V pattern (2.5) is underlain by the Mt Roe and Kylena Basalt and Salgash Subgroup and extends eastwards over the North Shaw Belt. In the southeastern corner a V high of 170 to 180 ppm (2.6) is present over Mt Roe Basalt.

The majority of the eastern portion of the North Pole Dome underlain by Salgash Subgroup is highlighted by a general 125 to 150 ppm V enhancement (3.1).
The Pilgangoora Syncline is highlighted by a central 160 ppm high (4.1) abutting a central 90 to 120 ppm enhancement. The high is underlain by faulted Salgash Subgroup, Paddy Market and Corboy Formation. Southwards, straddling the Pilgangoora Syncline and the northern portion of the Soanesville Belt, a 140 ppm high (4.2) is underlain by Talga Talga Subgroup and intrusive ultramafic. This high is part of a V enhancement extending over the northern portion of the stock of Woodstock Adamellite (Agl) in the adjoining Yule Batholith.

The southeastern portion of the Soanesville Belt is highlighted by a 135 ppm high (5.1) underlain by Soanesville Subgroup. Cu-Ni, Cu Au and asbestos mineralisation is present in the basin.

Little can be said about the Marble Bar, Warrawoona, Kelly, Wodgina and Western Shaw Belts. The latter however is an exception in that high elemental results (150 to 115 ppm) have again highlighted the southern central portion of the belt (6.1) and the regionally sheared western margin of the belt in contact with the Yule Batholith.

As stated previously, the general V responses over the batholith are low, except where basinal values are influenced by remnant rafts of greenstones (e.g. Fortescue Group volcanics in the southern portion of the Yule Batholith) or mafic dyke activity. The 100 to 175 ppm V pattern in the Mondana Adamellite stock of the Corunna Downs Batholith (pattern 1.3), the 75 to 160 ppm V highs (7.1) in the northern portion of the stock of Woodstock Adamellite (Agl) in the Yule batholith, and the miscellaneous 95 to 130 ppm V highs (8.1 to 8.3) in the Shaw Batholith, have no obvious explanation though prolific mafic dyke activity in the latter batholith may in part be the cause of some of the patterns.

6.2.13 Zinc

The greenstone belts and granite batholiths are again easily differentiated in the zinc values. Generally Zn of less than 46 ppm outlines granites except where relict greenstones are present.
Breakpoints at 25, 46, 62, 80, 114 and 150 ppm are recognised in the cumulative frequency plot in Figure C20. These breakpoints correspond to 16, 43, 68, 88, 97 and 99.4 percentiles of the range of values encountered.

The most prominent Zn patterns are present in the central portion of the sheet over the southern and northern portions of the Soanesville Belt. The southern pattern (1.1) is a 220 ppm Zn high surrounded by a 135 to 140 ppm Zn enhancement. The high is underlain by Soanesville Subgroup and intrusive ultramafic. Minor Au mineralisation is present within the basinal high and Cu, Cu-Ni mineralisation in the enhancement. The northern pattern (1.2) straddles the southern and northern portions of the Pilgangoora Syncline and the Soanesville Belt respectively. The 115 to 120 ppm Zn pattern is underlain mainly by Talga Subgroup, some intrusive ultramafic and Salgash Subgroup. Minor Cu and Cu-Pb-Zn mineralisations are present within the pattern.

Within the Lalla Rook Syncline, a Zn pattern of 130 ppm (2.1) is underlain by sheared Gorge creek Group and some Salgash Subgroup. Minor Cu mineralisation is present in the western basin. The adjoining Pilgangoora Syncline and North Pole Dome show zoning in the Zn results. There is a general trend of increasing Zn content from west to east in each of the entities. The 100 ppm Zn basin in the southern portion of the North Pole Dome (3.1) may be of interest because it contains felsic volcanics of the Panorama Formation.

Within the northwestern portion of the North Shaw Belt, an 80 to 95 ppm Zn enhancement (4.1) is present over Salgash Subgroup sediments and extends north eastwards over acid volcanics of the Panorama Formation. Zn values of 60 to 76 ppm are underlain by the volcanics. Ag-Au-Cu and Au-Pb-Cu mineralisations are present here. The zinc content of the western portion of the belt is notably higher than the eastern portion of the belt.

With the exception of the marked 80 to 90 ppm Zn high (5.1) in the southern portion of the Western Shaw Belt, the Zn content is remarkably low. The areal high is underlain by northeasterly sheared dragfolded Salgash Subgroup and Corboy Formation.
The Coongan Belt has interesting Zn patterns. The basins in the northern portion of the belt, with the exception of the 80 to 96 ppm high (6.1), have a lower Zn content than the southern portion of the belt. The high is mainly underlain by Soanesville Subgroup, Wyman Formation and Salgash Subgroup. A central 80 to 110 ppm (6.2), and southern 85 to 92 ppm (6.3) highs are dominated by the Corboy Formation of the Soanesville Subgroup. The 90 ppm basinal value (6.4) overlaps in part the Corunna Batholith and is part of the 90 to 160 ppm high over the Mondana Adamellite.

Little can be said about the Kelly Belt with the exception of; the increased Zn content, 64 to 70 ppm (7.1), over felsic volcanics of the Kelly Formation, and the Zn high of 85 ppm (7.2) in the northern portion of the belt underlain by mainly Duffer Formation, Talga Talga Subgroup and Boobina Porphyry.

In the Wodgina Belt, low order Zn enhancements of 48 to 50 ppm (8.1) are present over sheared greenstones of the Wodgina Subgroup and Kangan Granite which contain Sn-Ta-Nb-Cu-Ag mineralisation.

The Kylena Basalt of the Lower Proterozoic Fortescue Group cover is highlighted by a 124 ppm high (9.1) in a 90 to 100 ppm enhancement in the southeastern corner of the sheet. Spot enhancements of 80 to 96 ppm (9.2) are also present in the northeastern quadrant of the sheet though there is some influence from the Mt Roe Basalt. This latter unit is again highlighted in the southeastern corner of the sheet where high Zn values of 105 to 108 ppm (9.3) are present. The Nymerina Basalt, Meentheena Carbonate Member of the Tumbiana Formation and Kuruna Siltstone, in the southwestern corner of the sheet, are also highlighted by 80 ppm Zn values (9.4).

The batholiths are generally outlined by Zn values of less than 46 ppm except where relict greenstones and regional mafic dyke activity are present. There are some inexplicable regional highs in the Shaw, Corunna and Yule Batholiths. In the Shaw Batholith, a 65 to 75 ppm Zn pattern, is present over the Bamboo Springs Adamellite. The 80 ppm...
basinal high (10.1) within the pattern contains a major north-south fault. Much of the Zn enhancement in the northern portion of the batholith is due to relict greenstones. However, the 72 to 78 ppm high (10.2) within the enhancement is underlain by the stanniferous Spear Hill and Cooglegong Adamellites. Extensive alluvial Sn mining is carried out in the area.

Within the Corunna Batholith, a previously discussed Zn enrichment of 90 to 160 ppm (6.4), is mainly present over the Mondana Adamellite. The area is prominent in the majority of the elemental data. Elsewhere, an extensive areal Zn enhancement, containing a 64 to 70 ppm high (11.1), is present over the eastern portion of the Carbana Pool Adamellite and a spot 85 ppm Zn high (11.2) is present over the sheared northern contact of the batholith and the Warrawoona Belt.

The stocks within the Yule Batholith have unusual highs. The most prominent is the northern and central portions of the Woodstock Adamellite (AgI). Spotty though consistent highs of 80 to 190 ppm Zn (12.1), are present within a regional Zn enhancement. Minor enhancements of 46 and 60 ppm (12.2) are present over an allied granitic phase, the Coorong Adamellite (AgI), in the same area of the batholith. Northwards a spot 95 ppm Zn high (12.3) is present over regionally faulted Nardoopiquithanna Adamellite (AgB). Two enhancements of 48 ppm (12.4) and 46 to 55 ppm Zn (12.5), are underlain by highly faulted stanniferous Numbana Granite and the adjoining Pincunah Adamellite. Be-Ta-Nb-Sn occurrences are present with the patterns.

6.2.14 Stream Sediment Exploration Target Summary

Many of the observed elemental patterns can be related to areas of known mineralisation in Figure C5. However other patterns of interest emerge which are clearly unrelated to known mineralisation. To highlight these areas the data has been summarised in a qualitative manner from the detailed interpretation.

The primary aim of the summary is twofold; (1) to generate new areas for exploration activity where favourable geology and no mineral
C54.

occurrences are coincident, and (2) a rethink in areas of known mineralisation on the possibilities of other styles or models of mineralisation. This is accomplished by relating the observed multielemental associations to the underlying geological environment.

Three maps involving the following elemental suites, Ag-As-Bi-Mo-Sn; Ag-Bi-As-Cu-Co-Pb-Zn-Mn; and As-Cu-Co-Cr-Ni-V-Zn attempt the summary, and cover the basic spectrum of economic mineralisations in the various greenstone and batholithic entities comprising the sheet geology. For example, the first elemental grouping (Figure C21) attempts to cover hydrothermal mineralisations (Sn-Mo; Ag-Au) in the granitoids and greenstone belts respectively; the second (Figure C22), sulphides of sedimentary and/or volcanogenic affinities (Cu-Pb-Zn-Co) in the greenstone belts; and the latter (Figure C23), sulphides and oxides of interest (Cu-Ni-Co, Pt-Cr-V) in mafic and ultramafic lithologies in the greenstone belts. These three maps are in fact a compromise as there is overlapping of elements between associations. The maps are best examined with the aid of the geology (Figures C3, C4) and mineral occurrence maps (Figure C5).

6.2.14.1 Shaw Batholith

Extensive Sn patterns are present which reflect the known "tin" granites and areas of extensive eluvial-alluvial Sn mineralisation. However, an area of interest that bears investigation is the northern overlapping Mo pattern, especially the area with coincident Zn-Pb-(Bi), which is underlain by the northern portion of the Cooglegong Adamellite and the Spear Hill Adamellite, both late phase "tin" granites.

Ag is semicoincident with the eastern portion of the southern Sn pattern. This pattern is underlain by faulted Bamboo Springs Adamellite. The significance of the pattern is not known. The Co-Zn-Mn-V pattern in the area is associated with remnant mafics of the Talga Talga Subgroup.

6.2.14.2 Yule Batholith

The dominant pattern here is mono-elemental Sn. Surprisingly the ...55.
Sn response over the known "tin" granite (Numbana Granite) is poor. Areas of known pegmatitic Sn mineralisation are only characterised by (Ag)-Zn patterns. The prevalent Sn pattern is found over the older, migmatitic batholith suite, south flanking the younger granites, and may reflect mineralised dyke swarms. Indeed, a central area of coincident Ag-Pb may be related to extensions of known pegmatitic Sn-Ta mineralisation. The significance of the Pb-As-Sn pattern over the northern portion of the Abydos Adamellite and the strong Ag-Bi-As-Cu-Ni-Cr-Zn-Sn over the northern portion of the Woodstock Adamellite in the eastern portion of the batholith would also bear investigation.

In the southern portion of the batholith semicoincident Ag-Bi-(Pb-As-Zn) is present over the migmatitic phase of the batholith and possible remnant Fortescue Group Volcanics. The latter however is suspected as the source of the anomalism.

6.2.14.3 Corunna Downs Batholith

The Corunna Downs Batholith is marked by a prevalent north central Bi pattern which in places has accompanying Mo and/or Sn-Mo-Zn. The northern Bi-Mo is underlain by migmatitic granite while the eastern Bi-Mo-Sn-Zn-(Cu-Ni) is underlain by Mondana Adamellite, Carbana Pool Adamellite and Boobina Porphyry.

The southern portion of the Mondana Adamellite is also marked by a Cu pattern with an accompanying central eastern multi-elemental association of As-Ag-Zn-Co-Ni-Cr-Mn and Ag-Bi-Mo-Pb-Zn-Sn which may be related respectively to basic dyke activity or to the influence of the adjacent Kelly greenstone belt.

6.2.14.4 Carlini, Turner, Mt Edgar, Strelley Batholiths

Little comment is made about the Carlini, Turner, Mt Edgar and Strelley Batholiths. Ag-Pb-(Bi-Sn) on the margins of the Carlini Batholith reflect an area of Au, Au-Cu-Pb mineralisation in the adjacent Pilgangoora Belt. Likewise Ag-As-Cu-(Ni-Co) patterns on the margins of the Turner Batholith appear to be also related to the adjoining Pilgangoora...
Belt. However, the southern adjacent Mo-Bi pattern over the Pincunnah Adamellite may be of some interest, as with the Ag-Bi pattern over the known NE-SW trending regional shear which is associated with mineralisation in the Wodgina Belt to the southwest. As-Sn reflects known mineralisation in the Mt Edgar Batholith, but the significance of the southern adjacent Mo-(Sn) pattern is unknown.

6.2.14.5 Soanesville Belt – Tambina Complex

Prominent semicoincidental elemental patterns of As-Cr-Ni-Cu-Co in the southern portion of the Soanesville Belt, Tambina Complex and northern portion of the Western Shaw Belt in sheared juxta-position with the Yule Batholith, focus attention on the area for Cu-Ni-Co and Cr-Pt(?) possibilities. Cu and Ni-Cu occurrences are known in the southern, eastern and southwestern portion of the Soanesville Belt. The discrete Bi-Co-Cu-Zn pattern within the larger Ni-Cr-As pattern also directs attention to the southern area as a whole. Intrusive ultramafics in the Tambina Complex and northern portion of the Western Shaw Belt are found largely within the southern As-Cr-(Ni) patterns. These intrusive ultramafics may bear investigation for their Cr and possibly Ni-Pt content. An odd Mo-Ag pattern in part accompanies the As-Cr. A revaluation of the area as a whole would be in order, on the basis of the prominence of the various coincidental elemental patterns.

6.2.14.6 Western Shaw Belt

The distinctive coincidental Ag-As-Cu-Co-Ni-Cr-Pb-Sn-Zn-Mn patterns in the southern portion of the Western Shaw Belt stand proud and are underlain by sheared Corboy Formation (chemical sediments) and Salgash Subgroup (ultramafic to felsic volcanics). Both Ag-Cu-Pb and Cu-Co-Ni targets are possibilities.

The As-Sn in the western central portion of the belt highlights extensive Au mineralisation in sheared greenstones abutting the adjoining Yule Batholith. This area may bear re-examination.
6.2.14.7 Pilgangoora Syncline

The Pilgangoora Syncline has interesting coincidental elemental patterns of unknown significance. A large north trending Cr pattern is accompanied in part by a northern coincidental As-Cu-Ni-(Co), a southern Zn-(Ni-Co) and central As-Bi-Mo-(Sn). A general Sn high crosscuts the southern portion of the belt. The first pattern may be related to a dominance of ferruginous and ultramafic sediments in the Salgash Subgroup within the Paddy Market Formation.

A basin in the extreme southern portion of the belt contains a Cu-Co-Ni-Zn response which may reflect extensive minor Cu mineralisation in mafic volcanics of the Salgash Subgroup.

6.2.14.8 Lalla Rook Syncline

The northern part of the Lalla Rook Syncline is dominated by coincidental As-Cu-Pb-Sn-(Bi-Mo-Zn) which appears to reflect minor Cu, Ag-Au-Pb mineralisation associated with a prominent regional shear. The style of mineralisation associated with the shear bears further investigation.

Mn with or without associated Zn, Co, Ni is also prominent over the Lalla Rook – Budjan Formations and may be related to manganiferous units within the formation.

6.2.14.9 North Pole Dome

The environs of the Ag-Bi-Cu-Ba mineralisation of the North Pole Dome is accentuated by the prominent coincidental As-Pb-(Ag-Bi-Cu) patterns. The mafic volcanics of the dome are also noticeably enriched in V and Mn. In the southern portion of the dome a basin containing coincident Ag-Cu-Zn-Mn is present over a large shear in the volcanic pile radiating from the central dome. Mineralisation is absent here. Taking the dome as a whole stratiform sulphide mineralisation within the pile is a distinct possibility. Recorded vein mineralisation associated with radial faulting in the pile may reflect leakage from such buried mineralisations.
6.2.14.10 North Shaw Belt

A very prominent Sn-Ag-Bi-Pb-(Zn-Cu) pattern is present in the north­eastern portion of the belt. On the southern periphery of the pattern Ag-Au-Cu-Pb vein mineralisation is recorded. The pattern is underlain by North Shaw Tonalite, Salgash Subgroup (mainly felsic volcanics) and Talga Talga Subgroup. In the west there is an overlapping Mo pattern, the eastern portion of which has coincident Cu-Zn-Mn-Ni and is underlain by North Shaw Tonalite and felsic volcanics. Attention should be directed to the felsic volcanics for possible Cu-Zn massive sulphide mineralisation and the tonalité for Cu-Mo.

The central portion of the belt, an area containing minor Au mineralisation in mafic volcanics has a Ag-Sn-Cu-(V-Ni-Mn) pattern. The Au and base metal (Cu) potential of these mafics should be reassessed.

As-Sn patterns in the southern portion of the belt appears to highlight an area of known Sn-Ta-Be pegmatitic mineralisation.

6.2.14.11 Marble Bar Belt

As, Bi-Pb, Pb-Mn patterns reflect mixed Au, Au-Ag, Au-Pb mineralisation in the belt. No obvious targets emerge. However, a rethink on the Au-Ag potential may be of value.

6.2.14.12 Warrawoona Belt

An extensive As pattern with spotty accompanying Ag-Bi-Pb-Zn appears to reflect the environs of a prolific number of Ag-Au-Bi occurrences. Of particular interest is the sheared margins of the belt in juxtaposition with the Corunna Downs Batholith. Here a Bi-Sn pattern with a part coincident Ag-Pb-Zn overlaps the extensive As pattern. No mineralisation is recorded in the pattern.

6.2.14.13 Coongan Belt

The northern portion of the Coongan Belt has an extensive Mo pattern. There is also some coincidence with other elements, notably
As-Sn-Mn-Ni-Pb-Zn-Cr (though the As-Cr is cross-cutting reflecting intrusive serpentinites), Cu on the extreme northwest and Bi-Cu-V-Zn which overlaps in part the adjacent Shaw Batholith. The significance of the regional patterns are unknown.

In the southern portion of the belt there are basinal Ag-Bi-Pb-Mn and Cu-Zn patterns mainly underlain by Corboy Formation (chemical sediments) and Wyman Formation, (felsic volcanics). They contrast with other basins underlain by the Talga Talga Subgroup (mafic-ultramafics) which contain the same assemblage but with in whole or part addition of Ni-Co-Cr-V.

6.2.14.14 Kelly Belt

In the southern portion of the belt there is a distinctive Pb pattern with northern coincident Ag-Bi-Mo-(Sn-Mn-Zn) underlain by felsic volcanics of the Kelly Formation. Cu-Zn is generally peripheral and is underlain by the adjoining Boobinda Porphyry. Ag-Cu mineralisation is known in the area and is associated with shears in the volcanic pile. The area of the felsic pile may have potential for both vein Ag-Au-Bi and stratiform Cu-Zn mineralisation.

Bi-Zn-Ag-Cu patterns with or without Ni-Co-Cr prevail in the northern portion of the belt, an area underlain by Duffer Formation (felsic volcanics - chemical sediments) and Boobinda Porphyry.

6.2.14.15 Wodgina Belt

This small greenstone belt is transected by a prominent northeast-south westerly trending regional shear which appears to have been a locus for widespread pegmatitic Sn-Ta-Be mineralisation. Ag-As-Cu-Bi-Sn-Pb-Zn patterns in particular reflect the mineralisation. A review of the style of pegmatite mineralisation would be warranted in view of the price for Ta and Sn.
6.2.14.16 Proterozoic volcanic cover

The Proterozoic cover is characterised by extensive Ag and to an extent Mn patterns especially in the southwestern corner of the sheet. Here an area of Ag-Cu-Pb-Co-Ni is present over Kylena Basalt, and Ag-Bi-Mo with in part coincident As-Cu-Ni-Cr-Zn and Cu-Sn-Co-V-Zn over Nymerina Basalt and the Meenthenna Carbonate Member of the Tumbiana Formation. In the northwestern quadrant of the sheet a Bi pattern with in part coincident Ag-Mo-Sn-Pb-Mn is also present over Kylena Basalt and Sandstone. In the southeastern corner of the sheet As-Mn are present over Hardy Sandstone and intrusive Spinway Porphyry.

The significance of these patterns with respect to the geological environment (dominantly terrestrial volcanism with marine incursions) is both odd and unknown.

6.3 Univariate Stream Concentrate Interpretation

The stream concentrate statistics are summarised in Table C7. The raw data is strongly positively skewed and kurtosic suggesting the data does not follow a gross normal distribution. This is not surprising since the majority of the elemental data can be shown to be polymodal. However the elemental data in gross terms when subjected to a log base 10 transformation are found to be generally log normal in nature. Bi, Ag, Mo and Nb are still strongly positively skewed because of the relatively few values above the respective elemental detection limits. The lesser positively skewed elements, La and Y, have a great dynamic range of values and do not conform to the log normal distribution.

A matrix of correlation coefficients for the elemental data is presented in Table C8. Due again to the uncertainty of the elemental distributions the correlation coefficients were obtained by the non-parametric Spearman Method through the facility of the computer program NONPAR CORR in the SPSS library. As for stream sediments a histogram of the coefficients was again constructed and more meaningful groupings of correlations appear to have resulted. These grouping have been assigned ratings of strong (0.65+), moderate (0.50-0.64), and weak (0.25-0.49). A weak antipathetic grouping of elements is also present i.e. -0.25. From an examination of the elemental associations within...
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**Population Break Points**

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**Number of cases = 426**

- L = low  R = high  N = mean  S = standard deviation  CVA = coefficient of variation  E = Kurtosis  A = skewness
- Test for normality: $E/S, (E/S)^2, (E/S)^3, (E/S)^4$
- Break points taken from log cumulative frequency plots, bracketed figure percentils of range
- Aig = log 10 data

Table C7 Summary Statistics - Stream Concentrate Data.
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Table C8 Rank Correlation Matrix - Stream Concentrate Data.
these groupings, geological environments of possible economic interest may be present. These elemental associations of interest are:

**Strong**  
Co-Ni-Cu  
- possible Ni-Co ores in ultramafic-mafic rock types

**Moderate**  
Zn-Ni-Co-V-(Cu)  
- possible volcanogenic/sedimentary ore types (black shale?)

Pb-Y-La  
- possible vein mineralisation in granites

**Weak**  
Sn-Pb-Y-La  
- possible Sn mineralisation in granite

Be-La-Y-Pb  
- possible Be mineralisation in granite

In contrast with the stream sediments a balance is seen between granitic and greenstone elemental associations. The weak antipathetic grouping of elemental correlations, e.g. Ni/Pb, Ni/Be, Ni/Y, Cu/Y, Cu/Be, V/Be, V/Pb, mirrors this balance.

As with the stream sediments all the concentrate elemental data has been plotted on log cumulative frequency paper and component populations determined from obvious points of inflexion or breakpoints on the individual graphical elemental distributions. The populations for the individual elements have been subsequently annotated on the elemental drainage plans, Figures C24 to C37, which are complimentary to the summary geological and mineral occurrence plans, Figures C3 and C5. Elemental patterns and spot responses falling over the simplistic structural subdivisions from the summary geological map are discussed below.

6.3.1 Antimony

All samples fall below the detection limit of 50 ppm for the method. No comment can therefore be made on the geochemistry.

6.3.2 Beryllium

Four break points are recognised on the cumulative frequency plot for Be in Figure C25. The break points at 0.40, 0.65, 1.30 and 2.50...62.
ppm correspond to the 72.0, 94.4, 98.6 and 99.7 percentiles respectively over the range of Be values encountered. Some 31.1% of the values fall below the 0.1 ppm detection limit for the method.

The majority of Be patterns fall over Archaean granite terrain, in particular stocks in the Yule, Shaw, Mt. Edgar and Turner batholiths containing the late stanniferous bearing phases Agy (Moolyella Adamellite), and Agc (Numbana and Coondina Granites; Cooglegong and Spear Hill Adamellites), and in part the greenstones of the Wodgina and Kelly Belts and the Proterozoic Fortescue Group cover in the southwestern corner of the Sheet.

The northwestern portion of the Yule Batholith and the Wodgina Belt are highlighted by highs within a general Be enhancement of 0.4 to 0.6 ppm. In particular, 1.5 and 5.0 ppm Be highs (1.1), underlain by Kangar Granite (Agp) and sheared Wodgina Subgroup contain extensive pegmatites which carry beryl, cassiterite, tantalite and columbite. A similar pegmatitic mineralised area is found to the north in a general 0.4 to 0.6 ppm Be (1.2) enhancement.

Be enrichment is also pronounced over the late stanniferous Archaean Numbana Granite pluton (Agc) in the Yule batholith. On the southern and northern margins of the granite distinctive patterns of 0.8 (1.3) and 0.8 to 1.0 ppm Be (1.4) are present. Some Nardoopiquithannana Adamellite (Agb) is present in the northern pattern. Further northwards, the Turner Batholith, remnant Wodgina Subgroup and the same pluton of Nardoopiquithana Adamellite are enhanced by a 0.9 ppm Be value (1.5). All of these enhancements occur in areas which have been highly fractured and have in part been intruded by later Proterozoic dolerite dykes. In the southern portion of the general Be enhancement, basins containing 1.0 ppm values (1.6, 1.7) are cut by northwest trending fault structures, which, in the case of the first mentioned basinal high (1.6), is known to carry tin mineralisation. The host granite here is Yule Agm phase and some Abydos Adamellite (Agp).

In the southern portion of the Yule Batholith, Be patterns of 0.4 to 0.6 ppm (1.8, 1.9, 1.10) are present over Yule granite phase Agm.
Some remnant Proterozoic Kylena Basalt may underlie the western pattern (1.9). The easternmost pattern (1.10) appears to outline the north­easterly trending sheared western margin of the Tambourah Granodiorite (Agm).

Within the Turner Batholith, a spot high of 1.5 ppm Be (2.1), is underlain by fractured granite phase Agm and Salgash Subgroup of the Warrawoona Group. The southern adjacent basin contains the Pil­gangoora pegmatite mining area.

Within the central portion of the sheet area, prominent Be enrichments are evident over the stanniferous granite phases of the Shaw Batholith. In particular, 2.0 to 3.0 ppm Be form a north-south trending high (3.1) over the eastern faulted portion of the stanniferous Cooglegong Adamellite stock (Agc). Tin, tungsten, beryl, tantalum and niobium mineralisation are recorded in the granite within the pattern. Be enrichment of 0.8 to 0.9 ppm (3.2) is evident in the Pilga area, a major area of eluvial/alluvial tin mineralisation. The pattern is in part underlain by Spear Hill Adamellite (Agc) another Sn rich intrusive granite. In the southern portion of the batholith a general east-west enhancement of 0.4 to 0.6 ppm Be (3.3), is present over a variety of granite phases. However, basins containing the peak 0.6 ppm Be values are underlain by Coondina Granite (Agc) another related stanniferous granite phase in the batholith.

The northeastern corner of the sheet is highlighted by a 0.4 to 0.7 ppm Be enhancement (4.1) over the stanniferous Moolyella Adamellite phase (Agy) of the Mount Edgar Batholith. The peak value of 0.7 ppm Be occurs over the southern fractured margins of the adamellite and the older batholith granite phase Agm. Tin-tantalite is currently being mined from eluvial-alluvial concentrations to the west of the Agy phase at Moolyella.

Be patterns are present over the Corunna Downs Batholith, especially in the northwest and central southeastern portions of the batholith. In the northwest, a Be enhancement of 0.4 to 0.5 ppm Be (5.1), is underlain by both Warrawoona Group in the Warrawoona Syncline and Corunna...
Downs Batholith phase Agm. The Be pattern in the central-southeastern portion of the batholith is extensive, occurring over granitic phases Agm, Agc, Agp, Agf, and extending over the adjacent Kelly Belt and Proterozoic Fortescue Group cover. The peak values within this pattern generally fall over the greenstones with the exception of the 0.6 ppm Be (5.2) in the central portion of the batholith.

Minor Be enhancements are present over the remaining batholiths; e.g., the 0.4 ppm enhancement over the Carlindi Batholith (6.1), and the 0.4 to 0.6 ppm enhancement over the Strelley Batholith (7.1) which overlaps in part over the greenstones of the adjoining Soansville Belt, Pilgangoora and Lalla Rook Synclines.

The most prominent Be enhancement over the greenstone belts is that of the previously mentioned pattern over the Kelly Belt in the southeastern corner of the sheet. Be values here range from 0.5 to 0.8 ppm. Three basins of interest are present. Two of these (8.1, 8.2) have prominent outcrop areas of acid volcanics and associated sediments of the Kelly Formation within Salgash Subgroup. Be peaks at 0.8 ppm (8.1) and 0.6 ppm (8.2) respectively. Ag–Cu mineralisation is reported in the area. The third basin (8.3) contains a 0.7 ppm value which is underlain by mainly Fortescue Group Mt Roe Basalt and Hardey Sandstone with some minor Gorge Creek Group.

The remaining patterns of interest in the greenstone belts are found over the central portion of the Coongan Syncline (9.1) and northern portion of the Western Shaw Belt (10.1). The Coongan Syncline Be enhancement of 0.5 to 0.6 ppm (9.1), is underlain by Warrawoona Group and Soansville Subgroup lithologies, while the Be enhancement of 0.4 to 0.6 ppm in the Western Shaw Belt (10.1), is underlain by Salgash Subgroup and Corboy Formation with some granitic Agm phase.

The Lower Proterozoic Fortescue Group has a number of Be enhancements. Of prominence is the 0.5 to 0.8 ppm enhancement (11.1) underlain by Kylena Basalt, Hardey Sandstone and Spinaway Porphyry in the southeastern portion of the sheet. North of this pattern is the previously mentioned enhancement (8.3) which is thought to be influenced by the Mt Roe Basalt and Hardey Sandstone. Miscellaneous Be enhancements
are present in the northeastern and southwestern quadrants (11.2, 11.3). A spot Be of 0.5 ppm is present over sandstones of the Kylena Basalt (11.2); while spot 0.4 to 0.5 ppm values fall over the Tumbiana Formation (11.3).

6.3.3 Bismuth

The majority of the samples (97.5%) fall below the 5 ppm limit of detection for the analytical method. However, from the cumulative frequency plot in Figure C26 values greater than the detection limit can be placed into two groups by the 12 ppm breakpoint.

Basins containing Bi values greater than 12 ppm are spottily distributed over the sheet area. Areas containing mineralisation have two cases, peak values of 20 ppm. In the North Pole Dome, at the North Pole Mining Centre, a 20 ppm Bi value (1.1) is present in a basin underlain by North Pole Adamellite (Agm) and Salgash Subgroup. Cu-Bi mineralisation is present within the basin at Breen's Prospect. A spot Bi of 20 ppm (2.1) is found in a basin containing recorded tin mineralisation in Cooglegong Adamellite (Aeg) of the Shaw Batholith. Some dolerite dyke activity is also present within the basin. The remaining 20 ppm Bi value (3.1) is present in a basin in the southeastern corner of the sheet containing Salgash Subgroup of the Goongan Syncline and some Mondana Adamellite (Aeg). Support is found in the eastern adjacent 5 ppm Bi basinal value over the Kelly Belt.

A spot Bi value of 15 ppm is present in the extreme northwest corner of the sheet (4.1) over the prominent northeasterly trending shear in the Mt Turner Batholith granite phase Agm.

A number of spot values and patterns of 5 to 8 ppm Bi are present in the Yule, Shaw and Corunna Downs Batholiths, Kelly and Marble Bar Belt, and Fortescue Group in the southeastern corner of the sheet.

In the Yule Batholith, patterns of 5 ppm Bi are present in two areas over the Nardoopiquithenna Adamellite (Agb) (5.1) and Yule Granite phase Agm (5.2), while a spot 5 ppm Bi (5.3) is present over the northern pluton of Woodstock Adamellite.
The Shaw Batholith has a spot 8 ppm Bi value (2.2) in a large basin underlain by granite phase Agm and the Western Shaw Belt. A spot 5 ppm Bi (6.1) is present in the Corunna Downs Batholith and is underlain by Carbanna Pool Adamellite (Agp) and Mondana Adamellite (Agc).

The previously mentioned pattern (3.1) over the Coongan and adjacent Kelly Belts is underlain by Salgash Subgroup and in particular the acid volcanics of the Kelly Formation. The spot 8 ppm Bi (3.2) in the eastern portion of the Kelly Belt, is underlain by the latter geological unit. Ag-Cu mineralisation is recorded within the Kelly Belt.

Two spot Bi highs of 5 ppm (7.1) and 8 ppm (7.2) are found over the Fortescue Group cover in the southeastern corner of the sheet. The 5 ppm high (7.1) is underlain by Mt Roe Basalt and Hardey Sandstone, while the 8 ppm high (7.2) is underlain by Kylena Basalt and Hardey Sandstone.

The 8 ppm Bi high in the Marble Bar Belt (8.1) occurs in a basin underlain by Salgash Subgroup and Fortescue Group Mt Roe Basalt. Extensive Au-Ag, Au-Bi occurrences are present in the area.

6.3.4 Cobalt

Some 40% of the samples are below the 10 ppm detection limit for the analytical method. Two break points 40 and 90 ppm are recognised from the cumulative frequency plot (Figure C27). The break points correspond to the 74 and 99.1 percentiles of the range of values encountered.

As expected Co is noticeably enhanced over the greenstone belts especially the Soanesville Belt (1.1). A cobalt enhancement of 90 to 150 ppm is present here, over Soanesville Subgroup and some minor Talga Talga Subgroup and Fortescue Group. Cu, Cu-Ni and asbestos mineralisation is recorded in the basin with the peak Co value of 150 ppm.
Eastwards from the Soanesville Belt, the adjacent North Shaw Belt has two prominent areas of 80 ppm Co. The larger northern area (2.1), is underlain by Soanesville Subgroup (Paddy Market Formation), Salgash Formation (in particular the Panorama Formation), Wyman Formation and some North Shaw Tonalite (Agd) and Proterozoic Fortescue Group. The smaller southern area of 80 ppm Co is underlain principally by Talga Talga Subgroup. In the northeastern portion of the North Shaw Belt, a 40 ppm Co pattern (2.3) is underlain by North Shaw Tonalite Agd) and Kylena and Mount Roe Basalts of the Fortescue Group.

The greenstone belt in the Coongan Syncline is likewise generally enhanced in cobalt. Four areas of interest (3.1) to 3.4) are underlain principally by the Salgash Subgroup, Corboy Formation of the Soanesville Subgroup and Wyman Formation. These areas are; a northern 40 to 100 ppm Co pattern (3.1) which contains some asbestos mineralisation; an area of 50 to 80 ppm Co (3.2) over the southeastern portion of the belt; a local 60 ppm Co high (3.3) over the Coongan Gold Mining Centre, and an area of 50 to 60 ppm Co (3.4) which is in part underlain by the western margins of the adjacent Corunna Downs Batholith.

The general cobalt pattern (3.2) over the southeastern portion of the Coongan Syncline overlaps the western portion of the Shaw Batholith and the eastern portion of the adjacent Kelly Belt. Two local highs of 60 ppm Co (4.1) are present in the western portion of the belt over similar lithologies to (3.2). The southern most basin however contains Lallah Rook Sandstone – Budjan Creek Formation and Mt Roe Basalt.

A pattern of 50 ppm Co is present in the Warrawoona Syncline (5.1) over Warrawoona Group lithologies. Likewise, a pattern of 50 ppm Co is present in the central portion of the Marble Bar Belt (6.1) over Duffer Formation and Salgash Subgroup. Extensive Au mineralisation is present in the northeastern portion of the patterns.

A large regional, 40 to 50 ppm Co pattern, with a central 80 ppm high (7.1) over the central portion of the North Pole Dome, is underlain by faulted Salgash Subgroup and minor Wyman Formation and Talga Talga Subgroup. In the adjacent Lalla Rook Syncline a spot 40 ppm basinal
Co value (7.2) underlain by Gorge Creek and Warrawoona Group lithologies contains Cu mineralisation.

A general 40 to 60 ppm Co pattern is present over Gorge Creek and Warrawoona Group lithologies in the Pilgangoora Syncline (8.1). The highest Co values (60 ppm) are found in the northern portion of the Syncline which contains Ta-Sn-Be and some Au mineralisation.

The central western highly sheared margin of the Western Shaw Belt and Yule Batholith is enhanced by 40 to 50 ppm Co (9.1). Extensive Au mineralisation is present here. Southwards, a 40 to 50 ppm Co pattern (9.2), is prominent over northeasterly sheared Salgash Subgroup and Corboy Formation.

High Co values over granite are rare, and when present, reflect ingested mafic material or mafic dyke activity. However, the Woodstock Adamellite (Ag1) of the Yule Batholith is an exception. A pronounced Co pattern (10.1) and a spot high (10.2) is present over the northern portion of the stock, east of Abydos Homestead. The peak value of 100 ppm is found in the northern most high (10.1). A 40 ppm spot high (10.3) is underlain by faulted Yule Batholith granite phase Agm and Abydos Adamellite (Agp). Rafts of mafic and ultramafic rocks are found within the basin.

The southwestern portion of the Shaw Batholith is highlighted by a Co high of 50 to 60 ppm (11.1). The area is underlain by Coondina Adamellite (Agc) and rafts of mafics of the Salgash Subgroup in the main Shaw Batholith granite phase Agm.

Patterns over the Lower Proterozoic Fortescue Group cover have in part been commented upon in the description of cobalt patterns over the Kelly, North Shaw and Marble Bar Belts. However, Co patterns are also prominent over the extensive area of Kylena Basalt and Mingah Tuff in the southwestern corner of the sheet (12.1 to 12.3). The peak Co values of 60 ppm are found over Kylena Basalt in pattern (12.2).

6.3.5 Copper
The majority of samples (99%) are above the 10 ppm detection limit for the analytical method. Four break points at 25, 70, 130 and 220 ppm are recognised from the cumulative frequency plot in Figure C28 and correspond to the 7.8, 70, 92.5 and 97.8 percentiles of the range of values encountered. As expected, gross lithological differences between the greenstones and granites are evident in the geochemistry. Basinal areas occupied by greenstones show Cu enrichment relative to granite. Cu values over greenstones are generally greater than 70 ppm.

The most prominent Cu enhancement is found in the southeastern quadrant of the sheet over greenstones. Three prominent 300 ppm highs (1.1, 1.2, 1.3) form portion of north-south trending enhancements over the eastern and western southern portions of the Goongan Syncline. The two eastern highs are underlain by a mixture of lithologies. Basin 1.1, Lallah Rook Sandstone and Mt Roe Basalt, in mainly the adjacent Kelly Belt, while basin 1.2 is underlain by Salgash Subgroup and Mt Roe Basalt. The western high of 300ppm (1.3) is underlain by Talga Talga Subgroup and Duffer Formation of the Warrawoona Group. Within the general Cu low in the northern portion of the Syncline a lone spot high of 250 ppm Cu (1.4) is present over highly sheared Duffer Formation, Salgash Subgroup, Wyman Formation (Warrawoona Group), Paddy Market Formation and Corboy Formation (in part Gorge Creek Group).

The northwestern portion of the adjacent Kelly Belt has a pronounced Cu enhancement of 80 to 90 ppm (2.1) underlain by acid volcanics of the Salgash Subgroup (Kelly Formation). Small Cu occurrences are present in the northern most basin.

A spotty but general Cu enhancement is evident over the Lower Proterozoic Fortescue Group cover. Distinct Cu highs are most prominent in basins underlain by Kylena Basalt and Mingah Tuff, especially the two adjacent 300 ppm highs (3.1), and the area of 150 to 200 ppm Cu on the western boundary of the sheet (3.2). In the extreme south eastern corner of the sheet, Cu peaks at 800 ppm over Kylena Basalt (3.3). ...70.
Copper is noticeably enhanced in the Pilgangoora Syncline in three distinctive areas (4.1, 4.2, 4.3). The northern most high (4.1) is a belt of 150 to 200 ppm Cu values stretching southwards from the Pilgangoora Mining Centre. The belt is underlain by lithologies belonging to both the Gorge Creek and Warrawoona Groups. Tin, tantalite, beryl and gold mineralisation are recorded within the basins. The western central high (4.2) is an elongate east-west area of 150 ppm Cu underlain by the Paddy Market and Corboy Formations of the Soansville Subgroup. Banded iron formation is prominent in the pattern. The southern 80 ppm Cu high (4.3) is portion of a more extensive pattern extending westwards over the Yule Batholith. The 80 ppm basin is underlain by Talga Talga Subgroup and intrusive ultramafic. Extensive Cu mineralisation is present within the basin.

In the Lalla Rook Syncline a spot Cu high of 80 ppm (5.1) is present over sheared Gorge Creek and Warrawoona Groups and North Shaw Tonalite (Agd). Cu mineralisation is known in the sheared mafics of the Warrawoona Group. A pronounced Cu enhancement of 80 ppm with a central 150 ppm high is present over the western (6.1) portion of the greenstone of the Soansville Belt. The area is structurally complex and is underlain by mafics and ultramafics of the Salgash Subgroup. Cu and Au mineralisation is recorded in the southern portion of the enhancement.

The northern and in part western portion of the North Shaw Belt is generally enhanced by 80 to 100 ppm Cu values. The northern pattern (7.1), is underlain by North Shaw Tonalite (Agd) and Salgash Subgroup, in particular felsic volcanics of the Panorama Formation. Au-Ag-Cu mineralisation is known on the southern periphery of the pattern. The western portion of the belt (7.2), has a spot Cu high of 80 ppm underlain by highly sheared Salgash Subgroup, intrusive ultramafic and some Fortescue Group. Ni mineralisation is present within the basin.

The central portion of the highly sheared contact between the Tambourah Granite (Agm) of the Yule Batholith and greenstones of the Western Shaw Belt is enhanced in copper. An 80 ppm Cu enhancement with a central high of 100 ppm (8.1) is present over sheared Salgash Subgroup.
The spot 100 ppm high (8.2) within the southern portion of the belt is underlain by northeasterly sheared Salgash Subgroup lithologies.

The large 80 to 200 ppm Cu enhancement, in the northeastern quadrant of the sheet is underlain principally by radially faulted Talga Talga and Salgash Subgroups of the North Pole Dome. Of prominence is the peak 200 ppm basinal Cu value (9.1) which lies to the south of the North Pole Mining Centre. Cu-Bi mineralisation occurs within the 100 ppm basin (9.2) at the North Pole Mining Centre.

The 80 to 100 ppm Cu enhancement in the northeast quadrant is in part present over the previously discussed Proterozoic cover, i.e. the Mt Roe and Kylena Basalts and portion of the Marble Bar Belt. Au, Ag-As-Au and minor Cu-Pb-Zn mineralisations are recorded within the general Cu enhancement (10.1) over the Marble Bar Belt.

In the Warrawoona Syncline (11.1) a spot 80 ppm Cu value is present over Salgash Subgroup and Wyman Formation. Au-Cu mineralisation is present within the basin.

In the southern central portion of the sheet, Cu is enhanced over granitic phases of the Shaw Batholith. A distinctive 400 ppm high (12.1) is present over stanniferous Coondina Granite (Agc) and early Shaw batholith phase Agm. The Bamboo Springs Adamellite (Agp) is spottily enhanced by 150 to 200 ppm Cu (12.2), as is the southern portion of the Cooglegong Adamellite (Agc) by an 80 ppm Cu (12.3) value.

Cu enhancements (13.1 to 13.5) are present over the Yule Batholith. Some of these enhancements reflect rafts of mafic and ultramafics within the granite. The peak Cu value, a spot 400 ppm high (13.1), is underlain by the Woodstock (Agp) and Abydos Adamellites (Agm).

A 150 ppm spot Cu high (13.2) to the northeast is present over the first lithology as is the nearby southern 70 ppm Cu pattern (13.3). A general, northeast-southwest Cu enhancement of 80 to 90 ppm (13.4), is present over Yule Batholith phase (Agm) and Abydos Adamellite (Agp). Sn-Ta mineralisation is recorded in the southern basinal high of 90 ppm. In the northwestern corner of the sheet, a 90 ppm high ...72.
(13.5) is recorded over Kangan Granite (Agp) of the Yule Batholith and regionally sheared Wodgina Subgroup. Sn-Ta-Be and some Cu mineralisation are associated with pegmatitic activity in the area.

6.3.6 Lanthanum

Breakpoints are recognised on the cumulative frequency curve in Figure C29 at 400, 800, 1500 and 5000 ppm which correspond respectively to the 66, 84, 90.5 and 96.8 percentiles of the range of values encountered. Some 36% of all samples fall below the 100 ppm detection limit for the analytical method. As expected the Archaean granites are highlighted with respect to the greenstone belts. In particular the La content increases in concentrates from basins underlain by the late phase stanniferous granites such as the Numbana Granite (Agc), Cooglegong Granite (Agc) and Moolyella Adamellite (Agy).

Within the Yule and adjacent Turner Batholiths prominent 2000 to 10,000+ ppm La highs are present. Of note is the La high (1.1) on the southern and eastern portion of the stanniferous Numbana Granite (Agc) stock in the Yule Batholith. Peak values of 10,000+ ppm are found over the fractured eastern portion of the stock. Tin mineralisation is recorded within the high. These peak values also extend northwards over the Nardoopiquithanna Adamellite (Agb) and in part over the western portion of the Puncunnah Adamellite (Agp) (1.2). Southwards, the La high extends, albeit spottily, over the northern portion of the Abydos Adamellite stock (Agb) where values range from 3000 to 9000 ppm (1.3). Basinal values over the central portion of the Abydos Adamellite stock are noticeably enriched at 4000 to 8000 ppm La (1.4). The northern and southern adjacent portions of the Yule and Turner Batholiths respectively have a general La enrichment of 1500 to 8000 ppm. The 6000 to 8000 ppm La high here (1.5) is associated with the prominent regional northeast - southwest trending fault structure which cuts the Turner Batholith, remnant greenstones of the Wodgina Belt, and the Kangan Granite (Agp) stock of the Yule Batholith. Extensive Sn-Nb-Ta-Be pegmatitic mineralisation is present within the high. A La high of 4000 ppm (1.6) is present within a pattern over main Yule Batholith phase Agm to the south of the Numbana Granite stock. Further south, a 2000 ppm La high (1.7) is again underlain...
by the same Yule Agm phase. The northern and central portions of the Woodstock Adamellite stock (Ag1) of the Yule Batholith are enhanced by 1000 (1.8) and 500 ppm (1.9) La highs.

Two La patterns are prominent over the Shaw Batholith. An east-west central La enrichment of 1000 to 10,000+ ppm highlights the northern portion of the stanniferous Cooglegong Adamellite (Agc) and the adjoining Eley Adamellite (Agp). The 10,000+ ppm value (2.1) is underlain by faulted Cooglegong Adamellite. Sn-Ta-Be mineralisation is present within the pattern. The second pattern is a 500 to 900 ppm La enrichment in the southwestern portion of the batholith (2.3), underlain by stanniferous Coondina Granite (Agc), Shaw Batholith phase (Agm) and remnant rafts of Talga Talga Subgroup.

The Mt Edgar Batholith is highlighted by the general low order La enrichment of 400 to 600 ppm in the central portion of the batholith over granitic phase Agm (3.1), and the prominent La high of 1000 to 10,000+ ppm (3.2) over the faulted stanniferous Moolyella Adamellite (Agy).

Spot highs, (4.1, 4.2, 4.3), in a general La enhancement, are found over the northern and western central portions of the Corunna Downs Batholith. The majority of the enhancements are present over the main granitic Agm phase of the Corunna Downs Batholith though, the 8000 ppm (4.2) and 1500 ppm (4.3) highs respectively, are in part underlain by some Talga Talga Subgroup, Carbanna Pool Adamellite (Agp) and a large felsic dyke. The Mondana Adamellite (Agc) is not highlighted by La as are the other late phase stanniferous granites.

The western area (5.1) of faulted Carlindi Batholith granite phase Agm is highlighted by a 900 to 1000 ppm La enhancement.

The La results over the Archaean greenstone belts are generally low. In particular of note, is the southern portion of the Soanesville Belt, which has prominent base metal patterns. The extreme northern portion of the belt and adjoining Strelley Batholith however, have relatively high La values of 500 to 700 ppm (6.1) over Gorge Creek...
and Warrawoona Group, and Strelley Batholith phases Agp and Ags.

Two La patterns are present over the northern (7.1) and southern (7.2) sheared western portion of the Western Shaw Belt and the Yule Batholith. Lanthanum results over the northern portion of the belt (7.1) range from 500 to 2000 ppm and are underlain by sheared Salgash Subgroup and Tambourah Granodiorite (Agm). The southern pattern of 400 to 600 ppm La (7.2) is underlain by the same faulted and sheared units with some Talga Subgroup.

The North Shaw Belt has two enhancements of note; a southern spot 400 ppm value over Salgash Subgroup, Corboy Formation and intrusive ultramafic (8.1); and a northeastern pattern of 500 ppm La (8.2) underlain by Soanesville and Salgash Subgroups and portion of the Shaw Batholith.

Miscellaneous highs are found in the Pilgangoora Syncline, Lallah Rook Syncline and North Pole Dome. The southwestern portion of the Pilgangoora Syncline (9.1) has a prominent La high of 1000 ppm over Salgash Subgroup, Corboy and Paddy Market Formations. A spot 400 ppm La high is present in the northwestern portion of the adjacent Lallah Rook Syncline (10.1) over Salgash Subgroup and faulted Lallah Rook Sandstone and Budjan Formation. The eastern adjacent North Pole Domes has two areas of slightly enhanced La of 200 to 300 ppm (11.1, 11.2) over highly fractured Salgash Subgroup northeast and southwest of the North Pole Mining Centre.

A north-south trending belt of high La of 2000 to 3000 ppm (12.1) is present over the north western portion of the Coongan Syncline, Shaw Batholith and Proterozoic cover. Felsic and ultramafic dyke activity is present in the batholith with Mount Roe Basalt and Salgash Subgroup in the Syncline. The southern portion of the Syncline is also accentuated by, a spot 2000 ppm La high (12.2) over Salgash Subgroup and Corboy Formation, and an area of 400 to 800 ppm (12.3) underlain by the same lithologies with Mt Roe Basalt.

The adjacent Kelly Belt is noticeably low in La with the exception
of the 4000 ppm high (13.1) over Duffer Formation, Salgash Subgroup and the Wyman Formation.

A 500 ppm La value (14.1) in the Marble Bar Belt is underlain by Duffer Formation. Extensive Au, Au-Pb mineralisation is present in the basin.

The Proterozoic Fortescue Group cover is highlighted, albeit spottily, in the lanthanum results. In the southwestern corner of the sheet, two areas underlain by the Tumbiana Formation have spot 500 and 800 ppm highs (15.1) while the Kylena Basalt is accentuated by a 700 ppm high (15.2). Values of 300 to 900 ppm La (15.3), are present over the sandstone unit of the Kylena Basalt to the southwest of the Marble Bar Belt. The 500 ppm value to the north is underlain by Mt Roe Basalt. A 2000 ppm high (15.4), in the southeastern corner of the sheet, is in part underlain by Kylena Basalt and the Hardey Sandstone, while the 500 ppm value to the northwest of the high is present over the latter lithology.

6.3.7 Lead

Breakpoints at 35, 75, 130, 230, 500 and 900 ppm are recognised on the cumulative frequency plot in Figure C30. These breakpoints correspond to the 37, 74, 88, 92, 97.75 and 99 percentiles of the range of values encountered. Only 13.5% of the values fall below the detection limit of 10 ppm for the analytical method.

The Archaean granites as expected are highlighted in the Pb results. As a generalisation Pb values increase in basins underlain by younger granitic phases of the batholiths. A marked Pb enrichment is present over the late phase stanniferous granites, e.g. Cooglegong Adamellite (Agc). The Spear Hill Adamellite (Agc) and Mondana Adamellite (Agc) are exceptions to the generalisation.

In the Yule Batholith, Pb enrichment is prominent over the late phase stanniferous Numbana Granite (Agc) stock. Values range from 80 to 1500 ppm. In the eastern portion of the stock a pattern of highly anomalous Pb values of 1500 ppm are present over fractured and faulted...
granite (1.1) while a lesser east-east trending 200 to 300 ppm Pb high is found over the southern portion of the stock. Sn-Be-Ta-Nb mineralisation is recorded in the general enhancement over the granite. To the south, over the Abydos Adamellite (Agp), Pb values range from 80 to 800 ppm. The northern and central portions of the stock are respectively preferentially enriched by 500 to 800 ppm Pb (1.2) and 300 to 400 ppm Pb (1.3). North of the Numbana Granite, Pb values over the Nardoopiquithanna Adamellite (Agp) range from 80 to 1000 ppm. A pronounced high of 500 to 1000 ppm Pb is present within the northeastern portion of the stock and overlaps the adjoining Pincunnah Adamellite (Agp) stock. Spotty enhancements of 200 to 400 ppm Pb are present over the major northeast-southwest trending shear structure (1.5) which transects the Turner Batholith, Wodgina Belt and Yule Batholith. Extensive Sn-Ta-Nb-Be pegmatitic mineralisation is associated with this structure. A spot 200 ppm Pb high (1.6) is present over faulted Turner Batholith granitic phase (Agm) east of the structure. A 300 ppm Pb pattern (1.7) is present over the central portion of the Woodstock Adamellite (Agi) stock in the Yule Batholith. The northern portions of the stock (1.8) also has a low order Pb enrichment of 80 ppm. In the southern portion of the same stock, a spot 80 ppm Pb value (1.9), is present over the granitic phase and adjoining faulted Yule Batholith phase Agm and greenstones of the Western Shaw Belt. A spot 80 ppm Pb high (1.10) is also present over the latter granite phase in the southern area of the batholith.

A pronounced east-west trending Pb enrichment of 80 to 1000 ppm is present over the central portion of the Shaw Batholith. The central and southern portions of the stanniferous Cooglegong Adamellite (Agc) stock and adjoining stocks of Eley Adamellite (Agp) are particularly enriched in Pb. Highs of 1000 and 900 ppm Pb (2.1, 2.2) are found over faulted Cooglegong Adamellite in a 200 to 400 ppm Sn enhancement. Sn-Ta-Nb-Be mineralisation is recorded in the area. South of the general Pb enrichment spot enhancements of 300 (2.3) and 150 ppm Pb (2.4) are present. The 300 ppm Pb (2.3) is underlain by faulted Cooglegong Adamellite (Agc) and Eley Adamellite (Agp). The 150 ppm Pb high (2.4) is present over a northwest-southeast fault structure in Shaw granite phase Agm and Eley Adamellite (Agp). The eluvial-...77.
alluvial Eley Tinfield is present in the northern adjacent basin. Southwards, Pb peaks at 300 ppm (2.5), as a small areal enhancement over Shaw granite phase Agm on the northern periphery of the Coondina Tinfield. Within the southern portion of the batholith, the eastern faulted portion of the Bamboo springs Adamellite stock (Agp) and the unnamed stock containing phase Agl is highlighted by 150 ppm Pb values (2.6). A minor Pb enhancement of 90 ppm (2.7) is also present in the area over the late stanniferous Coondina Granite (Agc).

Lead values over the Mt. Edgar Batholith range from 20 to 800 ppm. Pb values over the main granitic Agm phase area are low, ranging from 20 to 40 ppm and contrast with the 80 to 800 ppm values over the faulted stanniferous Moolyella Adamellite (Agy) (3.1).

Lead values over the Corunna Downs Batholith range from below detection to 400 ppm. Unexpectedly Pb values over the late phase Mondana Adamellite (Agc) are low ranging from below detection to 60 ppm, in contrast to the general 30 to 50 ppm Pb over the Carbana Pool Adamellite (Agp) and the main Corunna Downs Batholith phase Agm, which has a pronounced enrichment of 80 to 400 ppm Pb (4.1) on the central western margins of the batholith. Dispersion from the Warrawoona Group in the adjacent Coongan Belt is influencing the enrichment. A spot 120 ppm Pb high (5.1) is present over granitic phases Agp and Ags in the southern portion of the Strelley Batholith.

Lead values over the Carlindi Batholith are generally low ranging from below detection to 50 ppm. However, a spot 90 ppm value is present southeast of McPhee Mining Centre (6.1). The basin here is underlain by faulted granitic phase Agm and some Talga Talga and Salgash Subgroups.

The greenstone belts are not accentuated by definitive Pb patterns as are the granite batholiths. Generally the Pb geochemistry is characterised by spotty highs. The peak Pb value in the greenstone belts is found in the southwestern portion of the Soanesville Belt. Here, a spot 500 ppm Pb value (7.1) is found in an area of 20 to 50 ppm Pb underlain by Soanesville Subgroup. Cu mineralisation is reported in the basin.
The northern cum western portion of the Western Shaw Belt and Tambina Complex however, have high Pb values ranging from 90 to 200 ppm. Most prominent are the two adjacent 200 ppm Pb basinal areas (8.1), and the 150 ppm Pb basin (8.2) over the Tambina Complex. The larger pattern (8.1), is underlain by sheared Tambourah Granodiorite (Agm) Complex is underlain by Paddy Market Formation of the Soanesville Subgroup and Salgash Subgroup. The majority of the recorded Au mineralisation here is found within the enhancements rather than the discussed highs. The south western portion of the Western Shaw Belt and adjacent Yule batholith (8.3) have enhanced Pb values of 80 to 400 ppm. This area is underlain by highly sheared Tambourah Granodiorite (Agm) and Salgash Subgroup. A local 80 ppm Pb high (8.4) is present over northeasterly sheared Corboy Formation and Salgash Subgroup in the central southern portion of the belt.

An east-west Pb enhancement of 80 to 90 ppb Pb is present in the central portion of the North Shaw Belt (9.1). The pattern overlaps in part, the northern portion of the Shaw Batholith. The peak value of 90 ppm is underlain by Salgash Subgroup, in particular acid volcanics of the Panorama Formation and North Shaw Tonalite (Agd). Minor Au and Au-Ag-Cu occurrences are present within the pattern. The southwestern portion of the Pilgangoora Syncline is highlighted by an enhancement of 80 to 100 ppm Pb (10.1). Pb values in the Syncline generally range from below detection to 60 ppm. The Pb high is underlain by Gorge Creek Group and Salgash Subgroup. Banded iron formation is prominent in the pattern. Some Au mineralisation is also present.

A spot 300 ppm Pb high (11.1) is found in the central portion of the North Pole Dome, over North Pole Adamellite (Agm), Talga Talga and Salgash Subgroups. The area is in the vicinity of the North Pole Mining Centre and is extensively mineralised in Cu-Bi-Ba-(Pb-Zn). Pb values over the North Pole Dome generally range from below detection to 40 ppm.

Lead values over the Coongan Syncline, Marble Bar, Warrawoona and Kelly Belts are low generally ranging from below detection to 50 ppm. However, a prominent Pb pattern of 150 ppm (12.1), is present over both the Coongan Syncline and adjoining Shaw Batholith lithologies ...79.
which belong to the Salgash Subgroup, Duffer Formation, Talga Talga Subgroup, Corboy and Paddy Market Formations, and the Cooglegong Adamellite (Age) respectively.

Lead values are low over the Lower Proterozoic Fortescue Group cover, generally ranging from below detection to 50 ppm. However, a spot high of 100 ppm (13.1), is present in a basin containing the Meentheena Carbonate Member of the Tumbiana Formation in the southwestern corner of the sheet, while in the southeastern corner of the sheet, an 80 ppm high (13.2), is present over Spinaway Porphyry and Hardey Sandstone.

6.3.8 Molybdenum

With the exception of two molybdenum values, all are below the 5 ppm detection limit for the analytical method. Figure C31. The peak value of 10 ppm (1.1) is found in the Corunna Downs Batholith in a basin containing Carbaña Pool Adamellite (Agp), Corunna Batholith granite phase Agm and large felsic intrusive dyke. The remaining 5 ppm Mo value (2.1) is found in the Pilgangoora Syncline. The basin is underlain by faulted Salgash Subgroup and Paddy market Formation.

6.3.9 Nickel

Seven breakpoints are recognised on the cumulative frequency plot for nickel in Figure C32. The breakpoints at 40, 75, 95, 130, 230, and 460 ppm correspond to the 30.0, 52.5, 60.0, 71.0, 87.0, 94.2 and 98.3 percentiles of the range of values encountered. Some 10% of the samples fall below the 10ppm detection limit for the analytical method.

As expected, the majority of Ni patterns fall over the greenstone belts. However, some Ni enhancements occur in basins underlain by the early migmatitic Archaean granite phases of the batholiths.

A north-south trending Ni pattern (1.1) is present over greenstones in the Pilgangoora Syncline. The pattern is found over lithologies belonging to the Talga Talga and Salgash Subgroup and members of the Gorge Creek Group. Ni values within the pattern decrease in a southerly direction from 600 ppm to 400 ppm. The peak basinal value of 600 ppm is underlain by highly sheared ultramafics of the Talga ...
Talga Subgroup. To the southeast of the above pattern, a basinal area of moderately enriched Ni of 350 ppm (1.2) occurs, and is underlain by Salgash Subgroup mafic and ultramafics.

A prominent northeast trending Ni enhancement (2.1) containing distinctive Ni highs is present in the southern portion of the Soanesville Belt. The two highest values, 800 ppm and 600 ppm, are underlain by highly folded and sheared ultramafics of the Soanesville Subgroup. Within the peak 800 ppm basinal area Cu, Ni-Cu and asbestos mineralisation are recorded. The eastern basinal high of 600 ppm is also underlain by ultramafics of the Salgash Subgroup. The pattern extends southwards over the northern portion of the Tambina Complex which is underlain by intrusive ultramafics. Ni peaks here are 400 ppm (3.1).

With the exception of the two Ni patterns on the western-central periphery (4.1), and over the southern-central portion (4.2) of the Western Shaw Belt, Ni values are low. Ultramafics and mafics of the Salgash Subgroup here are highly folded and regionally sheared, especially those in contact with the Tambourah Granodiorite (Agm) of the Yule Batholith. Ni values within these patterns range from 200 to 300 ppm. Au mineralisation is present in the area of 4.1.

The central-northwestern portion of the North Shaw Belt has a prominent Ni pattern (5.1) with basinal Ni values of 400 to 500 ppm underlain by Salgash Subgroup and intrusive ultramafics. Minor Au and Au-Cu mineralisation is present in the area.

In the Coongan Syncline Belt four areas of Ni enhancement (6.1 to 6.4) are underlain by greenstones belonging to the Gorge Creek and Warrawoona Groups. The most prominent Ni values in the belt fall in area 6.1, where Talga Subgroup ultramafics have been highly sheared and serpentinised. Values peak here at 800 and 500 ppm. Chrysolite asbestos has been prospected in the area. The peak 600 ppm Ni value in the southern enhancement (6.4), may be influenced by Mt. Roe Basalt of the Fortescue Group. Little comment can be made on the remaining 400 ppm Ni enhancements with the exception of the Au mineralisation occurring within the western basin of 6.3.

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The central portion of the Kelly Belt underlain by acid volcanics and clastic sediments is low in Ni (10 to 60 ppm), and contrasts with the higher Ni values of 100 to 200 ppm in the northern and southern portions of the belt which are underlain by mafic and ultramafics of the Wyman Formation and Salgash Subgroup. A spot Ni high of 250 ppm (7.1) is present in the southern portion of the belt.

On the southern and northern portions of the Marble Bar and Warrawoona Belts, a 350 ppm enhancement (8.1), lies within a general Ni pattern underlain by Warrawoona Group (Duffer Formation basalts and rhyolites, Salgash Subgroup ultramafics), and the Fortescue Group Mt. Roe Basalt.

The central portion of the North Pole Dome mafic pile (9.1) has moderately high Ni values which range from 150 to 200 ppm. Salgash Subgroup lithologies mainly underlie the area.

Moderately high Ni values of 150 to 200 ppm are underlain by the Kylena Basalt and Mingah Tuff members of the Fortescue Group volcanics, west of Marble Bar (10.1), and in the south west corner of the map sheet (10.2).

As mentioned previously, some Ni enhancements occur in basins underlain by the early migmatitic Archaean granite phases and reflect mafic dyke activity and semi-ingested rafts of mafic material. The Ni content of the granite phases of the Yule Batholith containing mafics are a good example. Ni values over the Woodstock Adamellite (AgI) stock range from 80 to 350 ppm (11.1), while Ni values over the Abydos Adamellite stock (Agp) in the centre of the batholith range from 200 to 300 ppm (11.2). Similar situations are present in the Strelley Batholith (12.1), and central western (13.1) and southwestern (13.1) portions of the Shaw Batholith. The 300 ppm Ni high (14.1) in the Kangan Granite (Agp) in the northern portion of the Yule Batholith is influenced by dispersion from the greenstones of the Wodgina Belt. It should be mentioned that the main late stanniferous granites (Cooglegong, Numbana, Spear Hill (Agc) and Moolyella (Agy) suites) are characterised by low Ni values of less than 20 ppm.
6.3.10 Niobium

Since the majority of samples (95%) fall below the 100 ppm detection limit for the method, three arbitrary groupings are recognised based on the 100, 200 and 300 ppm values. The majority of the responses occur over known tin-tantalite-columbite bearing areas and are annotated on Figure C33.

In the northwestern corner of the Sheet, four Nb patterns of interest are present over the Turner Batholith/Wogina Belt and Yule Batholith. The two adjacent 300 ppm Nb values east of Wodgina (1.1) are underlain by faulted Wogina Subgroup and Turner Batholith granite phase Agm. Cassiterite, beryl, tantalite, columbite mineralisation is present in pegmatites in the area. A spot 150 ppm Nb (1.2) is present in the southwestern portion of the Turner Batholith.

A pattern of 100 to 200 ppm Nb is present (2.1) over an area of Nardoop-iquithanna Adamellite (Agb), Pincunnah Adamellite (Agp) and Numbana Granite (Agc) in the Yule Batholith. Tin mineralisation is present in the area of the peak 200 ppm Nb value. Further south, a spot 100 ppm Nb value (2.2) is present over stanniferous Numbana Granite (Agc). A spot 200 ppm high (2.3) is present in the southwestern portion of the Yule Batholith over Tambourah Granodiorite (Agm) and highly sheared Salgash Subgroup.

In the northeast corner of the Sheet, two distinct Nb patterns are present in the Mt. Edgar Batholith to the northeast (3.1) and southwest (3.2) of the Moolyella Tin Mining Centre. The northern 100 to 200 ppm Nb pattern (2.1) is underlain by the stanniferous Moolyella Adamellite stock (Agv). The 200 ppm high within the pattern occurs over the southern fractured margin of the stock. The larger southern 200 ppm Nb pattern (3.2) is underlain by early Mt Edgar Batholith granite phase Agm.

An east-west Nb pattern is present over the central portion of the Corunna Downs Batholith and in part the greenstones within the Coongan Syncline. Nb peaks at 200 ppm (4.1) within the pattern, over Corunna...
Downs Batholith phase Agm, and Warrawoona and Gorge Creek Group lithologies in the Coongan Syncline (4.2).

A spot 200 ppm Nb (5.1) is found in the southern portion of the Shaw Batholith and is underlain by early Shaw Batholith granite phase Agm, Bamboo SpringsAdamellite (Agp) and the late stanniferous Coondina Granite (Agc).

6.3.11 Silver

With the exception of three spot silver values over the Yule Batholith on Figure C24, all samples fall below the detection limit of 0.1 ppm for the analytical method. The peak value of 0.2 ppm (1.1), is found in the centre of the batholith, in a basin underlain by Yule Batholith granitic phase Agm and Abydos Adamellite (Agp). Some tin-tantalite mineralisation is recorded in a northwest-southeast trending fault structure which cuts the basin. The remaining basins containing 0.1 ppm Ag values, are underlain by Yule Batholith granite phase Agm (1.2) and by highly faulted Nardoopiquithanna Adamellite (Agp) (1.3).

6.3.12 Tin

Some 66% of the values fall below the 5 ppm detection limit for the analytical method. Five break points are recognised from the cumulative frequency plot in Figure C34. These are 35, 75, 190, 380, 660 and 1250 ppm which correspond to the 79, 89, 93.5, 98.2 and 99.2 percentiles for the range of Sn values encountered. As expected, Archaean granites are highlighted, in particular the late stanniferous phases of the Shaw, Yule and Mt Edgar Batholiths, i.e. Cooglegong and Numbana Adamellites (Agc), and Moolyella Adamellite (Agy).

The most prominent Sn patterns noted on Figure C34 are present over the Shaw Batholith. The eastern faulted portion of the stanniferous Cooglegong Adamellite stock is particularly highlighted by tin values of 250 to 3000 ppm (1.1). Less prominent basinal highs in the general batholith are; (1.2), a 500 ppm Sn underlain by faulted Shaw granite phase Agm and Eley Adamellite (Agp); (1.3), a 200 ppm Sn underlain...
again by Shaw granite phase (Agm); and (1.4), a 300 ppm Sn underlain by granite phase Agm, North Shaw Tonalite (Agm) and greenstones of the North Shaw Belt.

In the northwest corner of the Sheet, the area underlain by the regionally sheared Wodgina Subgroup, Turner Batholith and the Yule Batholith Kangar Granite (Agp) is highlighted by highs of 800 (2.1) and 200 ppm Sn (2.2) in a general 40 to 60 ppm Sn enhancement. Extensive Sn-Ta-Nb-Be pegmatite mineralisation is associated with the major northeast-southwest regional shear.

In the central portion of the Yule Batholith three spotty Sn highs of 500, 2000 and 3000 ppm (2.3 to 2.5) are present over the northern half of a stock of Abydos Adamellite (Agp). The two spot basinal Sn values of 3000 (2.4) and 2000 ppm (2.5) are especially prominent and are related to a northwesterly Sn-Ta mineralised shear which transects the basins. Northwards, a general 80 to 90 ppm Sn enhancement is present over the eastern and western portions of the Nardoopiquithanna (Agb) and Pincunnah Adamellites stocks (Agp) (2.6), while the southern adjacent 400 ppm spot Sn high (2.7) is underlain by the fractured eastern portion of the stanniferous Numbana Adamellite stock (Agc).

On the eastern portion of the Yule Batholith a Sn pattern with values ranging from 60 to 500 ppm (2.8) is present over Woodstock Adamellite (Ag1), Abydos Adamellite (Agp), and Yule phase Agm. To the northeast, a Sn pattern with values of 100 and 300 ppm Sn (2.9) is underlain by Woodstock Adamellite (Ag1) and extends eastwards over faulted Salgash Subgroup in the Pilgangoora Syncline. Spot 60 ppm Sn values (2.10) are present to the south of the Numbana Granite stock over Yule granite phase Agm. Likewise, a spot 100 ppm Sn value (2.11) is present over phase Agm in the Turner Batholith.

In the northeastern corner of the sheet, the Mt. Edgar Batholith is highlighted by a prominent enhancement of 90 to 1000 ppm Sn. The peak value of 1000 ppm (3.1) is underlain by faulted Mt. Edgar Batholith phase Agm. To the northwest, over the area of eluvial/alluvial Sn workings at Moolyella a 300 ppm Sn value (3.2) is recorded. The stanni-
ferous Moolyella Adamellite stock (Ag) itself is highlighted by a peak value of 400 ppm in a general 90 ppm high (3.3).

A general low order Sn enhancement of 40 to 50 ppm is noted over the central western margin of the Corunna Downs Batholith (4.1) and the adjacent Coongan Syncline. The area is underlain by Mondana Adamellite (Ag), Carbana Pool Adamellite (Agp), Duffer Formation and Salgash Subgroup lithologies.

A spot 300 ppm Sn value is found in the Carlini Batholith in a basin underlain by faulted granite phase Agm, and minor Talga Talga and Salgash Subgroup lithologies.

Spot 50 and 300 ppm Sn values (6.1) are present in the Strelley Batholith and are underlain by granite phase Ags.

The greenstone belts are in part highlighted by Sn values. A large Sn pattern with values ranging from 40 to 200 ppm Sn is present over the northern portion of the Soanesville Belt and adjacent North Shaw Belt over a variety of lithologies of the Salgash Subgroup, Gorge Creek Group and Fortescue Group. Distinctive highs of 150 ppm (7.1), 200 ppm (7.2) and 100 ppm (7.3) are present within the pattern. The 200 ppm high (7.2) has an equivalent highly anomalous stream sediment result.

Two patterns are present within the greenstones in the northeastern quadrant of the sheet. An 80 to 300 ppm Sn pattern (8.1) in the Marble Bar Belt is underlain by Warrawoona Group lithologies, while the inexplicable prominent 450 to 1000 ppm Sn pattern (9.1), is underlain by faulted Fortescue Group Mt. Roe Basalt, Hardey Sandstone and Kylena Basalt cover.

The Coongan Syncline is accentuated by two minor patterns of 40 to 90 ppm Sn (10.1), and 60 to 150 ppm Sn (10.2), which are underlain by Warrawoona Group, Corboy Formation and the Shaw Batholith. In the Western Shaw Belt and northern Tambina Complex, two tin patterns (11.1, 11.2) are present. Both patterns are underlain by Tambourah...
Granodiorite (Agm) and highly sheared Salgash Subgroup. Sn peaks at 500 ppm in a general area of 40 to 60 ppm Sn over the central portion of the Tambina Complex and the central western portion of the Western Shaw Belt (11.1). Au mineralisation is present in the southern portion of the pattern over the Western Shaw Belt. Southwards a small area of 80 ppm Sn (11.2) is again present over the western sheared portion of the Western Shaw Belt.

6.3.13 Vanadium

Breakpoint at 30, 70, 130, 225, 355 and 450 ppm are recognised on the cumulative frequency plot in Figure C35. These breakpoints correspond respectively to the 3, 22, 50, 71, 89 and 98.2 percentiles for the range of values encountered. Less than 1% of the values fall below the 10 ppm detection limit of the analytical method. Generally as expected, enhanced vanadium values are found over the Archaean greenstone belts and Proterozoic cover rather than the granites. Within the granites however, the early migmatitic phases in contrast to the late tectonic stanniferous granite phases, such as the Numbana Granite (Age), Cooglegong Adamellite (Age) and Moolyella Adamellite (Agy), are enriched in vanadium.

A prominent V enrichment of 400 to 800 ppm is present over the central-southern portion of the greenstone belt within the Coongan Syncline. Of the four distinctive basinal highs two are found within a northeast-southwest trending 400 to 800 ppm high. The peak 800 ppm value (1.1) is underlain by Talga Talga Subgroup and Duffer Formation whilst a 500 ppm value (1.2) is underlain by Salgash Subgroup (the Corboy Formation in particular). Northwards, a spot 400 ppm V high (1.4) occurs in a basin underlain by Duffer Formation and Salgash Subgroup.

The southeastern adjacent Kelly Hills Belt, has a central V low with northern and southern highs of interest. These are; a 500 ppm basinal high (2.1) in the southwestern portion of the belt underlain by Mt. Roe Basalt, Lalla Rook Sandstone and Budjan Creek Formation, and a 300 ppm basinal high (2.2) in the extreme east of the belt at Copper Hills, underlain by Duffer Formation, Salgash Subgroup containing Kelly
Formation and Corunna Downs Batholith phase Agb.

A general V high of 400 to 900 ppm is present over most of the Warrawoona Syncline. The southern adjacent peak values of 500 and 900 ppm V (3.1) are underlain by Warrawoona Group and extensive Corunna Downs Batholith granite phase Agm.

A central north-south trending V enhancement of 400 ppm (4.1) is found within the Marble Bar Belt which is principally underlain by Duffer Formation and some Salgash Subgroup.

The central area of the North Pole Dome has a prominent V enrichment of 400 to 450 ppm over faulted Taiga Talga and Salgash Subgroups. The peak value of 450 ppm (5.1) lies in a basin to the south of the North Pole Mining Centre.

The North Shaw Belt has two areas of V enrichment; a small northeastern 400 ppm basin (6.1) underlain by Salgash Subgroup, North Shaw Tonalite (Agd) and some Kylena Basalt; and a larger 400 ppm pattern (6.2) in the northwestern portion of the belt underlain by Salgash Subgroup, Wyman Formation, Paddy Market Formation, North Shaw Tonalite (Agd) and some Fortescue Group (Kylena Basalt and Mt. Roe Basalt).

The southern portion of the Soanesville Belt is highlighted by a 300 ppm enhancement and a spot 400 ppm V high (7.1) in the central western portion of the belt. The basin is underlain by Soanesville Subgroup with some Salgash Subgroup.

An extensive east-west V enhancement of 300 to 400 ppm is present across the northern portion of the Pilgangoora Syncline. The 400 ppm highs are separated by an area of 200 ppm and are underlain by Salgash Subgroup, Corboy and Paddy Market Formation (8.1), and Gorge Creek Formation and Turner Batholith granitic phase Agm (8.2). In the extreme southern portion of the belt, a local 300 ppm high (8.3) straddles both the Soanesville and Pilgangoora Belts and is portion of a larger enhancement extending westwards over the Yule Batholith.

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The sheared western portion of the Western Shaw Belt and the Yule Batholith is highlighted by a general 300 ppm V pattern. A spot 400 ppm high (9.1) on the northern extremities of the belt is underlain by Salgash Subgroup and Woodstock Adamellite (Ag1) of the Yule Batholith, while the 400 ppm high (9.2), in the southern central extremity of the belt is mainly underlain by sheared Corboy Formation.

A spotty north-south 300 ppm enhancement is present in the west central portion of the Lalla Rook Syncline (10.1). The enhancement is dominantly underlain by Corboy and Paddy Market Formation with some Lalla Rook Sandstone and Budjan Creek Formation. The southern 300 ppm basin extends westwards over the Strelley Batholith.

The lower Proterozoic Fortescue Group cover generally shows prominent V enrichment, especially basins underlain by the Mt. Roe and Kylena Basalt. An extensive V pattern of 400 to 500 ppm is present in the northeastern quadrant. The peak 500 ppm value (11.1), is underlain by Mt. Roe Basalt and some Warrawoona Group. A spot 800 ppm high (11.2), is present in the south eastern corner of the sheet over Kylena Basalt. Highs of 350 and 400 ppm V (11.3, 11.4) are also present over Kylena Basalt in the southwestern corner of the sheet. A 400 ppm V value here (11.5) is underlain by Tumbiana Formation.

As previously mentioned, concentrates from basins containing the early Archaean migmatitic granitic phase Agm generally have high V contents in contrast to basins containing the late tectonic stanniferous granitic phases Age and Agy. However the Mondana Adamellite (Age) and Coondina Granite (Age) are exceptions to this generalisation.

The western portion of the Carlindi Batholith is enhanced in V with values ranging from 200 to 350 ppm. The 350 ppm high (12.1) is underlain by highly faulted Agm with some Talga Talga Subgroup.

Within the large Yule Batholith concentrates from basins containing the late stanniferous Numbana Granite (Age) are noticeably low in V which range from 30 to 60 ppm, whilst basins containing the early migmatic phase Agm to the south are sporadically high in V. The majority ...89.
of the 150 to 200 ppm V highs (13.1 to 13.4) are partly inexplicable. The presence of regional mafic dykes may be the cause of the highs. The eastern high (13.3) is in part underlain by Abydos Adamellite (Agp) as is a spot 200 ppm high (13.4) to southeast. The northern and southern portions of the stock of Woodstock Adamellite (Agl) is also highlighted in the V results. The northern and southern portions of the stock are spottily enhanced by 200 to 400 ppm values. Both areas have been referred to in part above as 8.3 and 9.1. In the extreme northwestern corner of the sheet a prominent V enrichment of 80 to 300 ppm (13.5) is present over the sheared Kangan Granite (Agp) and Wodgina Subgroup in the Wodgina Belt.

In the Shaw Batholith granite phases show similar V depletion or enrichment as the Yule Batholith. Low V values, ranging from 30 to 80 ppm, underlie the centrally located late stanniferous Cooglegong Granite stock (Agc). In contrast the southern adjacent Eley Adamellite stock (Agp) is highlighted by 300 to 800 ppm V values (14.1). Likewise, in the southwestern portion of the batholith an extensive 300 ppm V pattern (14.2) is underlain by Shaw Batholith granite phase Agm, Coondina Granite (Agc) and remnant mafics of the Talga Talga Subgroup, all intruded by regional mafic dykes. A 500 ppm V basinal high (14.3) contains ingested mafics in granitic phase Agm.

Basins containing the early migmatitic Agm phase of the Corunna Downs Batholith are generally enriched in V and range from 80 to 900 ppm. This is illustrated by the previously mentioned 500 and 900 ppm basinal highs (3.1) which are underlain by both the granite phase Agm and greenstones of the Warawoona Syncline. It is interesting to note the high V values associated with the late tectonic Mondana Granite stock (Agc), especially the western portion of the phase where V values range from 100 to 300 ppm (15.1). The Agc phases are elsewhere stanniferous. Spot highs of 300 ppm (15.2) are also present over both Agm and Carbana Pool Adamellite (Agp) in the eastern portion of the batholith.

Concentrates from basins underlain by the early migmatitic Agm phase of the Mt. Edgar Batholith also have a 100 to 400 ppm V enrichment, especially in the western portion of the batholith where 800 ppm ...90.
(16.1) and 400 ppm highs (16.2) are present. In contrast concentrates from basins containing the late stanniferous Moolyella Adamellite phase (Agy) have low V values of 40 to 50 ppm.

6.3.14 Yittrium

Breakpoints at 35, 125, 450, 750, 1300, 3500 and 7000 ppm are recognised on the cumulative frequency plot in Figure C37 and correspond to the 9.5, 46, 77, 88, 93, 97.8 and 99.5 percentiles for the range of values encountered. Only 1% of values fall below the detection limit of 10 ppm for the analytical method.

The Archaean granites in contrast to the greenstones are highlighted in the yittrium results. In particular, a marked Y enrichment is noticeable in basins underlain by the late stanniferous phases of the batholiths, e.g. the Numbana Granite (Agc), Coolegong Adamellite (Age) and Moolyella Adamellite (Agy). However, some enrichment is also noted in basins containing early migmatitic phases of the batholiths.

In the large Yule Batholith, Y values over the stanniferous Numbana Granite stock (Agc) range from 200 to 8000 ppm. An enrichment of 2000 to 7000 ppm occurs in the southern and eastern portions of the stock. The eastern 7000 and 8000 ppm high (1.1) extends northwards over the southeastern portion of the adjoining stock of Nardoopiquithanna Adamellite (Agb). A prominent 5000 to 10,000+ ppm Y high (1.2) is underlain by this granite phase and the adjoining Pincunnah Adamellite stock (Agp). South of the Numbana Granite, the Abydos Adamellite stock (Agp) is also highlighted. The northern portion of the stock is highlighted by a general 2000 to 5000 ppm Y enrichment, within which is a prominent high of 4000 to 5000 ppm Y (1.3). The central portion of the stock has a lower order enhancement of 1500 to 2000 ppm Y (1.4). The northern portion of the Coorong Creek Adamellite (Ag1) (1.5) has a local high of 300 to 400 ppm.

Spotty highs within a general enhancement of Y values, ranging from 500 to 6000 ppm, are present over the major northeast-southwest fault structure (1.6) which cuts the Yule Batholith (Kangan Granite (Agp)),...91.
Turner Batholith and Wodgina Subgroup. The peak values of 3000 to 6000 ppm are found over an area of known Sn-Be-Nb-Ta pegmatitic mineralisation.

Elsewhere within the Yule Batholith spot 2000 to 3000 ppm Y highs (1.7) are present to the south of the Numbana Granite over batholith granite phase Agm. Further south, four spotty high of 500 to 800 ppm Y (1.8) are underlain by the same granitic phase.

An east-west trending belt of high Y values of 500 to 6000 ppm, is present in the central portion of the Shaw Batholith. The eastern central area of the stanniferous Cooglegong Adamellite stock (Agc) is especially highlighted by high Y values. Two prominent highs of 6000 ppm (2.1) and 5000 ppm (2.2) are present here. The first high is underlain by Cooglegong Adamellite and the adjoining stock of Eley Adamellite (Agp). The latter 5000 ppm high (2.2), is found in a basin containing extensively faulted Cooglegong Adamellite. The Eley Adamellite (Agp) is not highlighted by Y concentrate values as is the Cooglegong Adamellite, with the exception of spotty 800 to 1000 ppm values on the northern portion of the stock. In the southern portion of the batholith, values ranging from 500 to 600 ppm Y (2.3) are underlain by the stanniferous Coondina Granite stock (Agc) and batholith phase Agm containing rafts of Talga Talga Subgroup.

A marked central Y high of 600 to 800 ppm (3.1), contrasts the 60 to 300 ppm Y values underlain by granite phase Agm in the Mt. Edgar Batholith. A spot 3000 ppm Y high (3.2) is present over the fractured stanniferous Moolyella Adamellite stock (Agy). Yttrium values over this phase generally range from 60 to 400 ppm.

Scattered spotty Y highs are present over the eastern and central portions of the Corunna Downs Batholith. The peak values of 2000 (4.1) and 1000 ppm (4.2) are underlain by Carbana Pool Adamellite (Agp). Concentrates from basins underlain by the Mondana Adamellite (Agc), a supposedly late non-stanniferous granite, have low Y values, ranging from 30 to 300 ppm. An exception appears to be the 800 ppm basin (4.3).
The Strelley Batholith has low Y values ranging from 20 to 100 ppm. The central portion of the batholith (5.1), has spot Y highs of 600 and 900 ppm underlain by mainly granitic phases Agp and Ags.

A 400 to 500 ppm Y high (6.1) is present in the Carlini Batholith over faulted granite phase Agm. Some Talga Talga and Salgash Subgroup are also present in the basin. The general level of Y values over the batholith is 20 to 150 ppm.

The Western Shaw Belt has two prominent areas of Y enrichment. In the northern portion of the belt (7.1), 500 to 800 ppm Y values are underlain by faulted Tambourah Granodiroite (Agm) and Salgash Formation. The south-west portion of the belt has a spot 500 ppm Y high (7.2) over sheared Tambourah Granodiorite (agm) and Talga Talga Subgroup.

Within the North Shaw Belt, Y values generally range from 10 to 100 ppm. However, three spot highs occur; a 500 ppm Y (8.1) in a large basin underlain by Soanesville Subgroup and North Shaw Tonalite (Agd); a 900 ppm Y (8.2) in a basin underlain by Salgash Subgroup, Paddy Market Formation and intrusive ultramafic; and a 600 ppm Y (8.3) underlain by Paddy Market Formation, Wyman Formation, Salgash Subgroup and some Mt Roe Basalt. Au and Au-Ag-Cu mineralisations are present in the 500 ppm Y high (8.1).

The Soanesville Syncline highlighted previously in the concentrate base metal results is characterised by low Y values ranging from 10 to 90 ppm.

Yttrium values in the Pilgangoora Syncline generally range from 30 to 200 ppm. However, a spot 800 ppm high (9.1) is present within these values over faulted Salgash Subgroup.

The southwestern portion of the Lalla Rook Syncline is highlighted by 300 and 1000 ppm Y values (10.1) over faulted Gorge Creek Group and some Salgash Subgroup. Cu mineralisation is recorded in the peak 1000 ppm basin.
Little can be said about the North Pole Dome, with the exception of the 300 ppm high (11.1) underlain by Salgash Subgroup containing felsic volcanics of the Panorama Formation in the southwestern portion of the dome. Likewise, the Warrawoona Syncline, where a 500 ppm spot high (12.1) is present over Duffer Formation, Salgash Subgroup and some Corunna Batholith granite phase Agm.

Low Y values of 40 to 150 ppm generally characterise the Coongan Syncline. However, two area of Y enrichment emerge. Two adjacent 200 and 900 ppm Y values (14.1) are present in the western central portion of the belt underlain by Corboy and Paddy Market Formations, Talga Talga Subgroup and some Cooglegong Adamellite (Age). Southwards, two semi-adjacent basinal Y highs of 150 and 200 ppm (14.2) are present. Duffer Formation and Talga Talga Subgroup underlie the 150 ppm Y basinal high, while Salgash Subgroup, Duffer Formation, Wyman Formation and Corboy Formation underlie the 200 ppm Y basinal high. Au mineralisation is present in the latter basin.

Two highs are present in the Kelly Belt. A western 500 ppm high (13.1) is surrounded by 20 to 60 ppm Y values and is underlain by Salgash Subgroup and Kelly Formation. The eastern portion of the belt has a pronounced high of 600 to 3000 ppm Y (13.2). Duffer Formation, Salgash Subgroup and some granite (Agt) underlie the 3000 ppm basin while Salgash Subgroup (mainly Kelly Formation and Wyman Formation underlie the 600 ppm Basin.

The majority of Y responses over the Lower Proterozoic Fortescue Group cover are underlain by the Mt. Roe and Kylena Basalts, and Hardy Sandstone; e.g. the northern spot 800 ppm Y high (15.1) over Mt. Roe Basalt; the pattern of 200 to 300 ppm Y (15.2) over Kylena Basalt and Hardey Sandstone; the spot 150 ppm Y high (15.3) over Kylena Basalt (locally sandstone); and the pattern of 400 to 600 ppm Y (15.4) over Mt. Roe Basalt and Hardey Sandstone.

6.3.15 Zinc

Thirty two percent of the zinc values fall below the 10 ppm detection
limit for the method. From the cumulative frequency plot in Figure C37 five break points are recognised. There are 35, 70, 95, 150 and 230 ppm which correspond to the 65, 85, 89, 95.5 and 98.9 percentiles of the range of values encountered. Mixed zinc responses are present over both the greenstone belts and granites.

The highest and most prominent Zn responses are found over the southern portion of the Soanesville Belt (1.1, 1.2). Both the eastern and western 500 and 400 ppm Zn highs (1.1, 1.2) are underlain by Soanesville Subgroup. Au, Cu and Ni-Cu mineralisation are recorded within the highs. A northern 100 to 200 ppm enhancement (1.3) is underlain by Salgash Subgroup and Wyman Formation and straddles the southern portion of the Pilgangoora Syncline. Extensive Cu and Cu-Pb-Zn mineralisation are recorded within the enhancement.

Three spotty high zinc responses are present in the general 40 to 80 ppm background over the Pilgangoora Syncline. The 400 (2.1) and 200 ppm highs (2.2) are underlain by faulted Salgash Subgroup. Some Turner Batholith granite phase Agm is also present in the latter high. Sn-Ta-Be and Au mineralisation is also recorded within (2.2). The 150 ppm Zn pattern (2.3) on the southeastern flanks of the Syncline is underlain by Turner Batholith granitic phases Agm, Agp and Gorge Creek Group lithologies. Au mineralisation is recorded within the southern portion of the pattern.

Four zinc patterns are present in the Coongan Syncline (3.1 to 3.4). The highest Zn value of 250 ppm, falls in the southeastern portion of a 200 to 250 ppm Zn pattern (3.1) over the central portion of the Syncline. Au mineralisation is recorded within the pattern. Salgash Subgroup and Corboy Formation of the Soanesville Subgroup underlie the peak value. Southwards, a 150 to 200 ppm Zn (3.2) pattern is present over the same lithologies, but with the addition of some Mt Roe Basalt. In the north of the Syncline, a 200 ppm Zn pattern is present over Warrawoona Group, Paddy Market and Corboy Formations, and some Cooglegong Adamellite (Agc). A spot 150 ppm Zn high (3.4) is present within an enhancement on the eastern portion of the Syncline and Corunna Downs Batholith. It is underlain by Salgash Subgroup and Mondana Adamellite (Agc).
The Kelly Belt is marked by a central Zn low of 10 to 30 ppm, in contrast to the 40 to 60 ppm Zn enhancement in the northeastern and southwestern portions of the belt. Within the southern western enhancement, a Zn high of 150 ppm (4.1) is present over Salgash Subgroup, Lalla Rook Sandstone, Budjan Formation and some Mt. Roe Basalt. Zn enhancement (4.2), falls over Duffer and Wyman Formations, and Salgash Subgroup containing felsic volcanics of the Kelly Formation. Cu-Ag mineralisation is present in the felsic volcanics.

In contrast with the surrounding 10 to 20 ppm Zn low, a 100 to 150 ppm Zn high (5.1) is present in the central portion of the Marble Bar Belt over Salgash Subgroup and Duffer Formation. Extensive Au, Au-Pb and Ag-Cu mineralisation is present within the high.

The northeastern portion of the North Pole Dome is enhanced by 50 to 60 ppm Zn values. Of interest is the fact that the extensive Au-Ag-Cu, Bi-Cu and Ba-(Pb-Zn) mineralisations are found in a Zn low of 20 ppm to the south of the enhancement. However, the spot Zn high of 90 ppm (6.1) to the south of the mineralisation underlain by faulted Talga Talga and Salgash Subgroups may be of direct interest.

The north-central portion of the North Shaw Belt is enhanced by a Zn pattern of 40 to 200 ppm which is underlain by Warrawoona Group, some Mt. Roe Basalt, North Shaw Tonalite (Agd) and Shaw Batholith phase Agm. Zn peaks at 200 (7.1) and 150 ppm (7.2) within the pattern. Au and Ag-Au-Cu mineralisation is found within the highs.

Within a general pattern of 40 to 50 ppm Zn over the northwestern portion of the Lalla Rook Syncline, Zn peaks at 200 ppm (8.1) over sheared Gorge Creek and Warrawoona Group. Cu mineralisation is recorded in the basinal high. A Zn value of 100 ppm (8.2), is present over Strelley Granite and Salgash Subgroup, south of the Lalla Rock Syncline.

In contrast to the general Zn low over the northern portion of the Western Shaw Belt, two Zn highs are present in the central and southern portions of the belt. The central high of 80 to 100 ppm Zn (9.1) occurs over the prominent western sheared contact of the belt and
adjacent Yule Batholith. The pattern is underlain by Tambourah Granodiorite, Salgash Subgroup and Corboy Formation. Extensive Au mineralisation is present within the high. Southwards, a spot 100 ppm Zn high (9.2) is present in the south-central portion of the belt and is underlain by sheared Corboy Formation.

Zinc enhancements are present over the granite batholiths. Many of these enhancements are inexplicable, but some are due to the presence of rafts of mafic and ultramafic rocks within the granite phases. For example, the northern portion of the Woodstock Adamellite (Agp) within the Yule Batholith is especially enhanced in zinc. Values here range from 40 to 400 ppm in contrast with values elsewhere which range from below detection to 30 ppm Zn. The peak Zn value within the high is 400 ppm (10.1). The 90 ppm Zn value (10.2) on the south-eastern portion of the Woodstock Adamellite probably reflects dispersion from intrusive ultramafic and Salgash Subgroup within the basin. The Abydos Adamellite (Agp) is also in part enhanced by Zn of 100 to 200 ppm (10.3). A similar granitic phase in the same area, the Pincunah Adamellite (Agp) also shows Zn enhancement of 60 to 180 ppm (10.4). Sn mineralisation is present within the 180 ppm high.

An explicable spot Zn high of 250 ppm (10.5) is present over Yule Batholith phase (Agm), in the western portion of the sheet. Likewise two spot 50 ppm Zn highs are underlain by the Kangan Granite and Wodgina Belt (10.6), and the stanniferous Numbana Granite stock (Agc) (10.7). However, extensive Sn-Ta-Nb-Be pegmatitic mineralisation is present in the first basinal area.

The Shaw Batholith has three (11.1 to 11.2) pronounced regional Zn patterns. The most prominent of which is a pattern of 80 to 150 ppm Zn (11.1) over faulted stocks of Eley Adamellite (Agp) and stanniferous Cooglegong Adamellite (Agc). The two remaining areas of Zn enhancements of 50 to 60 ppm (11.2, 11.3) appear to reflect extensive mafic dyke activity and rafts of mafics in the Shaw Batholith phase Agm. Bamboo Springs Adamellite (Agp) and granite phase (Agl) are also prominent in the area of 11.2.

...97.
A Zn high of 100 ppm (12.1) is present within a general 60 ppm enhancement in granite phase (Agm) in the Mt Edgar Batholith.

The central portion of the Corunna Downs Batholith is enhanced in Zn. The three most prominent patterns 80 to 200 ppm Zn (13.1), 80 to 100 ppm Zn (13.2) and 80 ppm Zn (13.3) are underlain by granite phase Agm and rafts of mafic material, though the first contains a large felsic dyke and some Carbanna Pool Adamellite.

The most prominent Zn patterns over the Proterozoic Fortescue Group cover are underlain by Mt. Roe Basalt. For example, the 40 to 60 ppm Zn pattern (14.1) in the northeastern quadrant of the sheet. Spotty Zn values of 40 to 50 ppm are present elsewhere, e.g. in the southwestern and southeastern corner of the sheet over Nymerina Basalt and Tumbiana Formation (14.2) and Kylena Basalt (14.3).

6.3.16 Stream Concentrate Exploration Target Summary

In a similar manner to the stream sediments the following three elemental suites Ag-Bi-Be-Mo-Nb-Sn-Y-La; Ag-Bi-Cu-Co-Pb-Zn and Cu-Ni-Co-Zn-V attempt to summarise in a qualitative manner the observed elemental highs and enhancements over the greenstone belts and batholiths that comprise the sheet geology. The suites again attempt to cover the main spectrum of economic mineralisations in the regional geological setting. For example, the first grouping (Figure C38), attempts to cover the hydrothermal mineralisations associated with granitoids (Sn-Mo; Nb-Be-Sn), the second (Figure C39), sulphides of sedimentary and volcanogenic affinities (Cu-Pb-Zn-Co) in the greenstone belts, and the latter (Figure C40), sulphides and oxides of interest (Cu, Ni-Co-V) in the mafic and ultramafic portions of the greenstone belts. Some overlapping of elements occur between associations. The maps are again best examined with the aid of the geology (Figures C3, C4) and mineral occurrence maps (Figure C5).

6.3.16.1 Shaw Batholith

The known "tin" granites (Cooglegong Adamellite, Spear Hill Adamellite)
and in part areas of extensive eluvial-alluvial Sn mineralisation are highlighted. Generally the northern central portion of the "tin" granite, the Cooglegong Adamellite, is highlighted by coincident Sn-Be-Pb-Y patterns with spot Bi and La. A Zn pattern with spot coincident La and Pb-Sn is present over faulted Eley Adamellite and the southern tongue of Cooglegong Adamellite. Pegmatites carrying Ta-Nb-Sn, Be and W are known in the latter granite.

Of unknown significance and possible interest is the Cu pattern over the Bamboo Spings Adamellite in the extreme southern portion of the batholith.

Concident Ni-Co patterns in the southeastern portion of the batholith may reflect remnant ultramafics of the Talga Talga Subgroup. The true significance of these patterns are unknown.

6.3.16.2 Yule Batholith

There is a general prominence of multi-elemental patterns in the northern portion of the batholith over the younger granite phases in particular the "tin" granite. Pb is the most outstanding of the elements in the patterns. A prominent accurate Pb-Be-La-Y pattern is present over the southern and eastern fractured portions of the Numbana Granite, a so called "tin" granite. The coincident Sn over the eastern portion of the "tin" granite extends northwards over the adjacent Nardoopithanna Adamellite where it is part coincident with a generally fringing Nb-Bi-(Ag) pattern. Some Zn is coincident with the southern arcuate portion of the Pb-Be-La-Y pattern. The northern portion of the Be pattern extends westwards over the fractured margins of the Numbana Granite. Nardoopithanna Adamellite, regionally sheared and pegmatite mineralised Wodgina Belt and Kangan Granite. Some Pb-La is in part coincident with the extension of the Be pattern. Pegmatitic Sn-Ta-Be mineralisation is recorded within the above discussed patterns. However, the significance of the Nb pattern is not known and bears investigation as a possible lead into Ta mineralisation in large scale zoned pegmatites. Eluvial and alluvial Ta-Sn possibilities also exist here, albeit of a small scale.

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Outside the Numbana Granite, the Sn pattern extends spottily southwards over the Abydos Adamellite. Sn is generally coincident with a larger Pb pattern with accompanying spotty Ag-La-Y-Zn and a large extensive northeasterly trending cross cutting Cu pattern. Sn-Ta pegmatitic mineralisation is present within the eastern most anomalous Ag-La-Y basins and may explain the patterns. The northern portion of the Woodstock Adamellite has a prominent Sn pattern which overlaps the adjoining greenstone belts (Pilgangoora Syncline, Soanesville Belt). The Sn is coincident with Bi-La-Cu-Ni-Co-Zn. Some contribution from mafics is possible, but the significance of the Sn-Bi is unknown.

The cause of the above previously mentioned large, northeasterly, trending Cu pattern, with spotty accompanying though not necessarily coincident Sn, Bi, Ag, Zn is unknown. Likewise the Zn-Y pattern over the Pincunnah Adamellite which extends southeasterwards over the northern portion of the Woodstock Adamellite.

A Sn pattern, with in part coincident Nb-Pb-Co, is present in the southeastern corner of the batholith and is underlain by sheared Talga Talga Subgroup and migmatitic granite. Pegmatitic mineralisation is again probably present within the pattern and may bear investigation.

The Pb-Zn-Bi-La-Y high, south of the Numbana Granite, is probably in part related to the southern portion of the major regional northeasterly trending shear that transects the Wodgina Belt. A similar assemblage is noted over the northern portion of the shear in the Turner Batholith.

6.3.16.3 Corunna Downs Batholith

The northern portion of the Corunna Downs Batholith underlain by the early migmatitic suite is marked by a large inexplicable mono-elemental Nb pattern which extends westwards across the northern portion of the adjoining Coongan greenstone belt. Nb-Ta bearing pegmatites may be present in the pattern, but to date no occurrences have been recorded.
Spotty, generally non coincident Cu, Bi, Be are found over the Mondana Adamellite and appear to be part of a larger Cu-Bi-Be province in the southeastern corner of the map sheet. The significance of these patterns is unknown.

A coincident Mo-La-Zn response underlain by Carbana Pool Adamellite (Agp) transected by a large felsic dyke is present in the western central portion of the batholith. Spotty Mo responses were also noted in the stream sediment data over the adamellite.

A prominent Zn-Pb-La pattern over a small synclinal trough of Salgash Subgroup sediments and volcanics in the mid western portion of the batholith may have some base metal potential.

6.3.16.4 Mt Edgar Batholith

Large semicoincident Sn-Nb patterns are present over the Mt. Edgar Batholith, especially in the area of the "tin granite", the Moolyella Adamellite. Spotty Be, more extensive Y-La-Pb, are also in part coincident with Sn-Nb. The geochemistry well reflects an area of pervasive Sn-Ta-Nb-Be bearing pegmatites associated with the tin granite. Eluvial-alluvial concentrations of Sn-Ta are currently being worked here.

6.3.16.5 Strelley, Carlindi Batholiths

Little comment can be made about the Strelley and Carlindi Batholiths with the exception of spot Sn values of no particular significance.

6.3.16.6 Turner Batholith

The Turner Batholith has a large La pattern with semicoincident Nb-Y, Pb and Sn. The bulk of the elemental patterns, in particular Nb, are associated with the known northeast-southwest trending regional shear, which in the Wodgina Belt to the southwest, is associated with Ta-Nb-Sn mineralisation in large zoned pegmatites. The coincident Nb-Sn-Pb-Zn here may thus reflect similar pegmatite mineralisation.
Investigations here would therefore be warranted for both alluvial-eluvial Ta-Nb-Sn and large scale zoned pegmatite mineralisation of the Bernic Lake type.

The northern most Bi-Pb pattern over the regional shear may also bear investigation as Bi-Ag anomalism was noted in the sediment summary.

6.3.16.7 Soanesville Belt, Tambina Complex.

A coincident Cu-Ni pattern with accompanying semi-coincident Zn, spot Pb, and Co highlights the southern portion of the Soanesville Belt containing extensive mafic- ultramafic rocks. As with the sediment geochemistry attention is focused on the Ni-Cu-Co possibilities. Cu, Cu-Ni occurrences are known in the southeastern and southwestern portions of the belt respectively. The discrete Cu-Ni anomalism of the southern most basin straddling the Tambina Complex and containing intrusive ultramafics would bear detailed investigation.

6.3.16.8 Western Shaw Belt

Two areas of interest are present in the Western Shaw Belt. Both of these areas are prominent in the stream sediment data.

In the southern portion of the belt, the distinctive Ni-Co pattern with in part coincident Cu-Zn is underlain by sheared Corboy Formation (chemical sediments) and Salgash Subgroup (ultramafics, felsic volcanics). Ni-Cu-Co and possibly Cu-Zn-Co targets again bear investigation.

The central western periphery of the belt in sheared juxtaposition with the Yule Batholith has a prominent coincident Cu-Co-Zn pattern with accompanying semicoincident northern Pb-La and southern Sn-Ni responses. The southern portion of the pattern contains extensive Au mineralisation in sheared mafic-ultramafics and was highlighted by prominent As-Sn anomalism in the stream sediments. The possibility of Ni mineralisation may also exist here.

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6.3.16.9 Pilgangoora Syncline

As with the stream sediment data the northern portion of the Syncline, has for the most part coincidental Cu-Ni-Co-Zn in an area underlain by ferruginous sediments of the Paddy Market Formation and ultramafic-mafics of the Salgash Subgroup. Of interest is the spot coincidence of Mo in the southern portion of the belt. A similar, but more pervasive Mo response was noted in the stream sediments. The significance of the above pattern is unknown.

An east-west trending Cu pattern, with in part coincident Ni, is present in the central portion of the syncline over ultramafic-mafic rocks of the Talga Talga Subgroup. The Cu-Ni pattern bears investigation.

A Cu-Ni-Co-Zn-Sn pattern straddling the syncline and the adjacent northern portion of the Soanesville belt appears to reflect extensive Cu mineralisation in mafic volcanics of the Salgash Subgroup.

6.3.16.10 Lalla Rook Syncline

A distinct Cu-Co-Zn basinal high appears to reflect minor Cu mineralisation associated with a prominent regional shear. This feature was also noted in the stream sediments and suggests that the shear zone should be subjected to further research.

6.3.16.11 North Pole Dome

The general environment of the mafic pile of the North Pole Dome is reflected in the extensive V-Ni pattern with in part coincident Cu, Co and Zn. The northern Cu-Bi basinal high appears to reflect known Ag-Au-Cu and Cu-Bi mineralisation. Stratiform mineralisation within the pile is a possibility besides the recorded vein mineralisation associated with radial faulting in the pile.

6.3.16.12 North Shaw Belt

The central portion of the belt has in part coincident V-Co-Ni-Zn.
Little significance is attached to this high background regional pattern which appears to reflect mafic volcanics of the Salgash Subgroup and Talga Talga Subgroup. The Co-V pattern at the northern extremity of the belt probably reflects a similar geological environment.

The Sn-Zn basinal high in the northeastern portion of the belt is underlain by mafics of the Talga Talga Subgroup and North Shaw Tonalite and may reflect minor recorded Au and Ag-Au-Cu mineralisation.

The northeastern monoelemental Cu response is underlain by felsic volcanics and North Shaw Tonalite. The felsic volcanics and granite here have been highlighted previously in the stream sediment data for their respective possible Cu-Zn and Cu-Mo potential.

6.3.16.13 Marble Bar Belt

Little can be said about the belt as the Co-Zn-V and Ni-Zn-V patterns generally reflect the mafic environment of the Talga Talga Subgroup though the Co-Cu-Sn-V basinal high may be of significance. Some influence from the Proterozoic Mt. Roe Basalt cover is however suspected. The spot Bi adjacent to the Cu-Co-Sn-V high is found in a basin containing extensive Ag-Au mineralisation.

6.3.16.14 Warrawoona Belt

Little comment can be made of the general Co-V pattern though the basinal response having accompanying Cu contains recorded showings of Cu and Ag-Au-(Cu). The monoelemental Zn response on the sheared margins of the belt and the Corunna Downs Batholith focuses attention on an area of interest delineated in the stream sediment geochemistry.

6.3.16.15 Coongan Belt

The striking feature of the geochemistry of the Coongan Belt is the extensive southern Cu pattern overlapping the Mondana Adamellite of the Corunna Batholith and the adjacent southeastern Kelly Belt. Much of the pattern over the Coongan Belt has accompanying V and
in part semicoincident Ni, Zn and Co, and probably reflect mafic volcanics. However, of possible economic interest is the southeastern portion of the belt where Cu is coincident with Bi. This Cu-Bi pattern overlaps the Kelly Belt especially the acid volcanic Kelly Formation of the Salgash Subgroup. The feature was also recognised in the stream sediment data and commented upon.

The southern central Cu-Ni-Co-Zn basinal high may have some Cu-Ni-Co potential, as it is underlain by a majority of the component formations of the Warrawoona Group which are composed of mafic-ultramafic lithologies. Extensive Au mineralisation is also present in the basin.

In the north of the belt, the Cu-Co-Zn-Ni basinal high underlain by mainly Soanseville Subgroup (chemical sediments), Wyman Formation (felsic lavas), Salgash Subgroup (mafics, chemical sediments) and Duffer Formation (felsic lavas) is of interest. Inexplicable patterns for a number of elements are present here in the stream sediment data and have previously been commented upon.

6.3.16.16 Kelly Belt

Remarks made above pertaining to Cu-Bi anomalism in the adjoining western Coongan Belt apply here. Anomalism is found over felsic volcanics of the Kelly Formation in both the southern and northern portion of the belt. Vein Ag-Cu mineralisation is known in the area, as per the basin containing the Cu-Be high, and is associated with fracturing in the volcanic pile. The area of the pile may have potential for both Ag-Au-Bi and Cu-Bi-(Zn) mineralisation.

6.3.16.17 Wodgina Belt

This small greenstone belt is transected by a prominent northeast-southwesterly trending regional shear which appears to have been a locus for widespread pegmatitic Ta-Nb-Be-Sn mineralisations. Previously discussed patterns associated with the Turner and Yule Batholiths in part overlap the Wodgina Belt and reflect this highly mineralised environment.

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6.3.16.18 Proterozoic Volcanic Cover

Unlike the stream sediment data, elemental patterns over the Proterozoic volcanic cover are not as enigmatic or prominent, with the exception of a central Cu in a larger Co-Ni-(V) pattern over faulted Kylena Basalt in the southwestern quadrant of the sheet. Isolated Cu, Cu-V highs occur over the same unit in the extreme southeastern corner of the sheet. Similar highs, but larger in areal extent were noted in the sediment data. Co-V responses on the eastern and western side of the North Shaw Belt are influenced by Mt. Roe Basalt.

A Be-Bi-La pattern highlights the area of the Hardey Sandstone and intrusive Spinaway Porphyry in the southeastern corner of the sheet. An As enhancement was noted over the area in the sediment data.

6.4 Discussion

Strong similarities are noticeable in the patterns generated by the elements common to both sample media over the various geological entities comprising the sheet geology. Where differences exist in the level of response, analytical methodology (acid digestion - atomic absorption spectrophotometry versus emission spectrography) and/or dominance of a mode of dispersion (chemical versus clastic) would appear to explain the variations. Strong geochemical differentiation is noticeable at three levels in the macro-regional data and reflects geological environment. These are:

(i) Gross differences in general terms between the batholiths and greenstone belts. For example, basins over the former in both media generally have lower order Cu, Ni, Co, V and Zn results.

(ii) Gross differences between and within the batholiths. Differences noticeable between the batholiths are really only evident with the "tin" granites within the batholiths. For example Nb patterns characterise only the Moolyella Adamellite of the Mt. Edgar batholith. However, within each of the major batholiths, basins over the "tin" granites with respect to
the older gneiss have distinctly high Sn and Pb and low Co, 
Cr, Cu, Mn, Ni and Zn stream sediment values while Sn, Pb, 
La, Y and Be are high and Cu, Ni, V and Zn are low in the 
stream concentrates.

(iii) Gross differences between and within greenstone belts. For 
example, the elemental responses in both media over the Pilgan-
goora Syncline are obviously different from than that of the 
Western Shaw Belt. Within both belts further differences are also 
obvious.

The detailed geochemical reviews of both media data, subsequent summation 
and target analysis in terms of the respective geological entities 
and environments has revealed a number of minor geochemical provinces, 
some of which contain known minor mineral occurrences. However, in 
some of these cases the minor, generally polymetallic provinces are 
far more extensive with inferred zoning, which may reflect a number 
of possible hitherto unrecorded styles of mineralisation in the geo-
logical environment.

The macro-regional geochemical data in its own right has therefore 
indicated a variety of targets of exploration interest in both favourable 
and unfavourable conceptual geological environments in the 17,420 
km$^2$ sheet area. The results of further work, entailing literature 
research on past exploration work in the Western Australian Mines 
Department, photogeology and ground checks, if favourable, would lead to 
ground acquisition and detailed evaluation of the upgraded target.

7. MULTIVARIATE SUMMARY

7.1 The Problem

The writer has shown from the univariate work and summaries that 
at a macro-regional level of sampling, distinctive elemental associations 
characterise different geological units and mineralisations. However, 
when drainage samples are collected and scanned for a large number 
of elements difficulties arise in the search for these distinctive
metal associations because of the physical task of examining a voluminous number of different elemental analytical results and interrelating the elemental patterns generated, e.g. the univariate summaries. From the writer's observations of regional geochemical exploration in industry in general, a number of elements are often analysed including the commodity metals of interest. The commodity elements are examined in some depth, with hopefully straightforward results emerging, of the identification of samples which contain large components of a single element, or simple metal associations related to a particular influence such as lithology or mineralisation.

As previously discussed and illustrated, the recognition of simple metal associations in a geological setting is an important attack in the writer's brief company reviews of the onfile 1: 250 000 map sheet elemental data, but at times it is difficult to choose what associations are important. It is obviously even more difficult to identify at macroregional densities, or a albeit at times, in normal high sample density circumstances, the mineralisation component in stream sediments, where the camouflaging effects of other influences prevail; e.g. when mineralisation is a minor component of the geological environment in the basin or is remote from the drainage channel. Thus, the remaining elemental results of the multielemental scan are often left to be superficially examined even though their information content may be considerable. It is therefore somewhat of a fallacy to analyse samples for a great number of elements if the data generated is not used, i.e. if the maximum amount of information is not extracted.

Multivariate statistical methods offer a way of attempting to maximise the amount of information in such data sets. A large number of individual special programs are available, e.g. factor analysis, discriminant analysis and cluster analysis. However, the user in industry is faced with the problem of these programs being often, not readily available, accessible for immediate usage, or if available may need modification to handle large data sets commonly encountered in exploration geochemistry. Thus, for most companies reliance is placed on existing statistical packages that were not developed for the earth sciences, e.g. IMSL (IMSL Inc.), SSP (IBM Corp.), BMD (Dixon 1972). However these package programs are to an extent limited by their low user orientated structure,
i.e. their data manipulation capabilities and the compartmentisation of programs. The advent and increasing world wide availability of another non earth science program library SPSS, (Statistical Packages for the Social Sciences, Nie et al (1975)) appears to overcome the previous low level of user orientated package programs.

The most common applications of multivariate methods to exploration geochemistry can be classified into the following categories:

(i) Exploratory usage - where data is explored and patterns among elements are sought (i.e. elemental associations) with a view to data reduction and summary, and the bonus of a possible discovery of a new concept (i.e. a possible hidden elemental "ore" association that can be related to a meaningful geological entity).

(ii) Confirmatory usage - where hypotheses are tested about the structure of the elemental data in terms of an expected number of groups of significant elemental associations based on a priori information.

(iii) Quantitative usage - where scores representing elemental associations can be constructed for the particular multivariate statistic (e.g. factor, regression, discriminant analysis) so that these new variables can be used in subsequent spatial analysis.

Generally multivariate statistical applications in exploration geochemistry are based on the data summarising capabilities of various methods. One such multivariate statistical technique is factor analysis. This is in part explored here through experimentation with the concentrate data via the previously mentioned non earth science computer program library of SPSS.

As a precursor to exploration of the data by factor analysis an experiment was first carried out in using the computer line printer over a pen plotter to produce for areal analysis the summary multivariate maps.

...109.
7.2 Line Printer Mapping

As all regional studies are based on some form of areal classification, the correct representation and subsequent analysis of the spatial arrangement of the areal distribution of variables, both in the univariate and multivariate sense through mapping is of prime importance. However, time (cost) and effort become limiting factors when the scope of a mapping problem is large. For example, the writer's plotting and subsequent summation of the individual elemental data for stream sediment and concentrate media of the Marble Bar Sheet in their respective outlined basins is extremely time consuming and error prone. It is in the production of such maps for comparative analyses that the power of computer mapping is realised, the mapping being effected by pen plotters or less commonly the line printer.

The latter technique (line printer mapping) is becoming both highly advanced and common as evidenced by pop art characteratures such as "Snoopy" or more formal computer outputs of old masters, e.g. Leonardo de Vinci's "Mona Lisa" and Michelangelo's "David". The line printer is more readily accessible than the pen plotter and amenable to high speed production runs, and as previously stated very cost effective. In some respects it is graphically inferior and less accurate than the pen plotter since a typewriter character of 1/6" x 1/10" or 1/8" x 1/10" is used rather than a pen point of say 3/100". However the result is generally aesthetically pleasing, as evidenced by the acceptance of computer "pop art".

Coppock (1973) reviews the history of computer line printer mapping or thermatic cartography since its primitive beginnings in the early 1950's and evolution in the 1960's. The initiative for the development and the resulting widespread use of line printer maps and their derivatives has come from regional research studies by botanists, economic geographers, meteorologists and town planners who are devoted to practical map making with usable interpretable results. The best known line printer mapping programme, the SYMAP package, was developed in the USA by Northwestern University and latter the Harvard Laboratory
of Computer Graphics founded in 1963. Many programs and refinements have been developed in parallel from the basic ideas in SYMAP for other machines, because of difficulties in compatibility of machine storage capacity, software language level and machine language. All line printer mapping programs are however, characteristically simple, efficient, and cheap to operate on their respective hardware.

Usage of the computer line printer for mapping is derived from the fact that the print characters are as on most typewriters printed with a rectangular space of constant size. This grid of character locations provides a regular framework for the construction of maps, while the characters themselves provide the symbols for mapping. The computer can therefore be programmed to output via the line printer strings of alphabetic, numeric and symbol characters or print layers of varying tonal density made up of permutations of characters overprinted in a defined area. Spatial patterns of variation in data are more rapidly visualised and absorbed by the latter method of data display, i.e. by arranging data in ascending order of increasing visual density or greyness. A maximum of 10 grey intervals can be used, though 3 to 6 grey levels would appear to be appropriate for most mapping.

In geology, crude maps resulting from trend surface and harmonic analysis of spatial data have long been generated by the line printer, Agterberg and Kelly (1971), Davis (1973), but few examples of line printer maps of regional geochemical data are seen in the literature with the exception of Howarth (1971), David et al (1974), Chapman (1975), Govett et al (1974), Webb (1973), Chapman (1975), Govett et al (1975), Topping (1976). This may be a result of the reluctance of some workers in using a method that at times is not always aesthetically pleasing, but in practical terms appears to highlight satisfactorily regional patterns of variation in geochemical data.

7.2.1 Line Printer Mapping Experimentation

The writer investigated the following mapping methodologies, GREY a modified program already on hand after Howarth (1971) and, SYMAP,
Version 5.20 (Dougenik and Sheehan 1975). The latter program was investigated through the link up of the University of Leicester Computer Centre with the University of Manchester Computer Centre. Three basic mapping procedures, chloropleth (conformant), isopleth (contour) and proximal mapping, are contained within the SYMAP package while GREY is a simple example of the chloropleth procedure.

Chloropleth (conformant) maps are used to depict values given to predefined data zones, where a zone may be a point, a line, or an area. A unique character symbol is assigned to each value interval and the data is displayed by character representation. This is the simplest of the three procedures.

Isopleth (contour) maps are based on the technique whereby all points having the same numeric value within a search area are connected by a contour line. Between any two contour lines a continuous surface is assumed. The surface is determined mathematically by computing weighted average of points based on the inverse distance model within the search radius, i.e. data points furthest away from the centre of the search area are suppressed in the computations. Other corrections are made to account for special configurations of data points. Interpolated points on the surface are assigned to an interval. A unique character symbol is used to represent each interval and the computed surface is displayed using the appropriate symbol at each print location.

Proximal maps are a special case of isopleth mapping. Zones are constructed around each data point using the nearest neighbour criterion. Each constructed zone is assigned the value of the enclosed data point and a character symbol is printed through the zone. Proximal maps do not interpolate between known data values though they do compute distance between data points.

distribution of Mo, Pb, Zn, Cd and As in stream sediments over England and Wales though this was not produced by SYMAP. This latter work forms part of the macro-regional geochemical research work of the Applied Geochemical Research Group, Imperial College, (refer Section A) and was produced from programming developed by the group.

The 88 stream sediment sample coverage of the Shaw batholith were selected for the following trials:

(1) Accepting the data as co-ordinated at the sample collection site and producing Sn maps via GREY and the isopleth package of SYMAP.

(2) Modifying the co-ordination of the data to the approximate basin centroid and repeating the above runs. The reason for modifying the co-ordination to the approximate basin centroid was to check on bias brought about by an irregular sample grid. For example at 1:500 000, with GREY, adjacent samples on stream junctions will be averaged, the geometric mean of the two points calculated and the appropriate class interval character symbol plotted. Information is thus distorted as values may be downgraded into lower class intervals. A very irregular sample grid will also cause distortion of the plotted surface in isopleth mapping. Machine digitised basin centroids was thus thought to give better representativity of sample distribution since the basin areas are of comparable size.

Input to SYMAP Version 5.2 is given in a series of "packages" of up to 35 options, each of which describes one type of feature of the area to be studied, e.g. the outline of the map area, location and value of data points, location and content of map ancillaries (legends, titles, special features) characteristics of the map output (size, scale, contents, number, range and symbolism of data intervals). The generalised package is user orientated, allowing user input format and having options for the user to tailor the output to his requirements so that an adequate map can be produced with as little effort as possible. Documentation is well referenced in a SYMAP users manual (Dougenik and Sheehan 1975). Isopleth mapping only was carried out...
Prior to running both GREY and SYMAP the data was subjected to program FREQUENCIES from the SPSS library to choose suitable meaningful class intervals. Default options exist in SYMAP for placing data in class intervals but are not meaningful if extremes of data are present. A default option exists within GREY via the incorporation of the percentile version of the program.

7.2.2 Results and Conclusions from Line Printer Mapping Comparisons

The outputs for normal field co-ordination and basin centroid co-ordination for GREY and SYMAP are compared with normal basinal outlines with values and geology in Figures C41 and C42 respectively.

Patterns generated for both printer outputs for normal field co-ordination are not as representative as the basin centroid printer outputs when compared with the yardstick, the hand plotted basinal values and geology, especially over the outline of the tin granite phases. The chloropleth map (GREY) suffers from the previously discussed averaging of points while the isopleth map (SYMAP) suffers from the effects of an irregular sampling network. With the latter the greatest deviation is towards areas of low sample density especially towards the sides of the map. However, the map edge effect here is not as gross as an earlier output because the writer has chosen to construct a barrier around the sampled area of interest by using option A-OUTLINES, so that the sample points positioned externally to the area still influence the interpolation process, but are excluded from the output map.

In terms of cost of production, the simple chloropleth GREY output compared with the isopleth SYMAP output is less than a cent a point compared with 2 to 4 cents a point if a commercial rate is applied to the computer time units. Costing is a reflection of the sophistication of the algorithm. The multiple choice and usage of options in SYMAP is the reason for the increased cost. However, the product is superior to the GREY chloropleth output. Points are still symbolised in class interval terms by a numeric character in the shaded contour map.
BASIN CENTROID COORDINATION

SYMBOL

LEVEL

FREQUENCY DISTRIBUTION OF DATA LEVELS VALUES IN LAW LEVEL

SCALE 0 25 50 75km

"TIN" GRANITE Aq PHASES UNDIFFERENTIATED
(Spear Hill Adamellite, Coolegong

Adamellite, Coombe Granite)

PHASES Aq PHASES UNDIFFERENTIATED
(Bley Adamellite, Bamboo Springs

Adamellite)

PHASES Aq 1 UNDIFFERENTIATED

Migmatitic Phase Aq

LINE PRINTER COMPARISONS:
SYMAP OUTPUT - SHAW BATHOLITH

FIG. C 41
BASIN CENTROID COORDINATION

BASINAL VALUES-GEOLoGY-MINERALISATION

NORMAL COORDINATION

"TIN" GRANITE Agc PHASES UNDIFFERENTIATED
(Spear Hill Adamellite, Googlegong Adamellite, Coondoom Granite)

PHASES Agp UNDIFFERENTIATED
(Eley Adamellite, Bamboo Springs Adamellite)

PHASES Agi UNDIFFERENTIATED

MIGMATITIC PHASE Agm

SCALE 0 25 50 75km

TIN MINERALISATION

ALUVIAL TIN WORKING

LINE PRINTER COMPARISONS:
GREY OUTPUT - SHAW BATHOLITH

FIG. C 42
It should be stressed that patterns related to mineralisation can be recognised in both chloropleth and isopleth maps except that the visual effect and ease of pattern recognition by maps of the latter type is greater. However, the results for isopleth mapping are dependent on a regular sampling grid. To optimise the procedure recoordination of stream sites to basin centroids by machine digitising is recommended. Where basin areas are of a comparable size an even sample network will result from basin centroid coordination.

In conclusion the two "off the shelf" computer programme packages used, SPSS-FREQUENCIES and SYMAP, although not developed for exploration geochemistry appear to adapt well to the requirements of simple data analysis and spatial representation.

7.3 Factor Analysis

The multivariate statistical summary technique employed belongs to the large variety of procedures slotted under the term factor analysis. Factor analysis was developed by psychologists in the 1930's as a model for explaining responses to intelligence tests in terms of a small number of underlying "factors", i.e. groups of variables from the tests that could be interpreted as representing "intelligence", "adaptability", and so forth. The technique was one of the first multivariate analytical methods to be used by geologists (Krumbein et al (1963)) and geochemists (Nichol et al (1967)). It appears to have been helpful in a number of cases, but from personal observation the technique has been abused and misapplied. This has, in some respects also served to being computer applications in exploration geochemistry into disrepute with some of the older members of management in industry instead of promoting the positive aspect of the computer as an aid to problem solving.

A general classification of the techniques and decision levels involved, in factor analysis can be seen in Figure C43. The writer's classification shows the complexity of the flow path through the many alternatives now available at each of the three customary steps of factor analysis.
Figure C43 General flow diagram for styles and decisions in Factor Analysis. Note: Dotted outline and flowpath are not part of the SPSS computer package FACTOR.
The flow path is now in part becoming readily available worldwide through the Statistical Packages for the Social Sciences (SPSS) computer program library, (Kim (1975) in Nie et al (1975)). The three steps in the flow path are, (1) the preparation of a correlation or equivalent matrix, (2) the exploration of possible data reduction by the extraction of initial factors, and (3) the final search for simple and interpretable factors that best summarises the data through rotation to a terminal solution. Major options at each stage may be summarised by three dichotomies, i.e. R-type versus Q-type factor analysis in step 1, defined versus inferred factor analysis in step 2, and orthogonal versus oblique rotation in step 3.

The basic factoring process is carried out through the standard techniques of matrix algebra, i.e. the extraction of eigen values and eigen vectors from a correlation or variance–covariance matrix obtained from a set of multivariate observations. Harman (1967) provides an in depth explanation of the factoring processes which are not examined in detail here. A simplistic view in the geological rather than psychometric context can be found in Davis (1973).

Due to the number of subjective decisions that can be made at the various levels in the main steps of the factor analytical flow path in Figure C43, experimentation was carried out with the concentrate data through the computer program package facilities of the SPSS library in an attempt to arrive at a final flow path to a valid summary. This flow path would be followed in the analysis of the stream sediment data. Packages used were CONDESCRIPTIVE, COMPUTE, NONPAR CORR, PEARSONS CORR, FACTOR.

7.4 Experimentation Along the SPSS Factor Analytical Flow Path

7.4.1 Choice of Variables

All the concentrate elemental data was not accepted for analysis. The elements Ag, Bi, Mo and Nb were deleted because they were outliers, i.e. 96 to 99% of the respective results lay below their spectrographic analytical detection limits. The remaining 10 elements subjectively...
appeared satisfactory in that "wild" data, outliers in the individual elemental data, are absent. Scatter diagrams for elemental pairs could have been constructed through SPSS program SCATTER to check the presence of wild data. However some 40 plots would be needed to check all 10 elemental combinations.

7.4.2 Choice of Data Transforms

The overall statistical distribution of the stream concentrate elemental data has been previously shown to be generally highly positively skewed, leptokurtotic and polymodal (i.e. mixed populations representing the probable effects of the major lithological subdivisions, mineralisation, possible environmental and physiographic factors). Statistical distributions of the individual component populations of the various elemental distributions however have not been investigated, but other workers note that a variety of individual distributions are possible in a data set, Malmgren (1979). Prior to multivariate statistical analysis similar data sets are often subjected to transformations, especially of the log base 10 variety, in the belief that the transformation will lead to the conditions of/or approximating that of multivariate normality, i.e. to reduce skewness and make the elemental data follow a normal distribution, stabilise variance and obtain additivity, these conditions being the theoretical requirements for parametric statistical procedures, (Koch and Link (1970)).

Reyment (1971) emphasised that the question of multivariate normality is one where theoretical statisticians and practicians (in this reference palaeontologists) tend to drift apart. Whereas normality is desirable from a statistical viewpoint deviations from normality may reveal significant information about the geological history of the sample. For example, in the geochemical sense, positively skewed elemental distributions may disguise the fact that the data is not homogenous, i.e. the tail of the distribution is due to an anomalous population (mineralisation) or to some spatially discrete background population.

Differing views on the appropriateness or nonappropriateness of transformations exist, especially of the commonly applied log base 10 transformation, (Govett et al (1975), Link and Koch (1975), Chapman (1976,
The crux of the matter for the exploration geologist is the recognition of anomalous populations and the interpretability of the results gained from any transformation. For example, Chapman (1976) reports that R-mode factor analysis is sensitive to log transformation, in that it suppresses populations representing mineralisation and enhances background populations, which is contrary to the exploration geologist's aims. In some cases the effect of a log base 10 transformation on a variable is also not helpful in that original negative or positive skewness may become markedly enhanced leading to erroneous loadings in subsequent factor analysis (Lindquist (1976)). Generally negative skewness is induced which is not usually as severe as the original skewness. Kurtosis is also reduced.

Lindquist (1976) proposed individual variable transformations through an algorithm called the SELLO transformation, which is an automatic best choice between no transformation, log base 10 transformation and a log transformation with a computed optional constant for each variable in order to minimise skewness. He demonstrated that usage of the SELLO transformation before the computation of the correlation matrix leads to reliable factors being obtained in factor analysis. Howarth and Earle (1979) advocate the usage of the Box-Cox transform. This is a more general power transform for which the log normal distribution is a special case:

\[ Z = \begin{cases} \frac{\lambda - 1}{\lambda} & (\lambda \neq 0) \\ \log x & (\lambda = 0) \end{cases} \quad x > 0 \]

The value of \( \lambda \) is chosen to minimise skewness, or skewness and kurtosis from that of the normal distribution. A variety of computer methods exist through a program LAMTRAM to optimise \( \lambda \). Howarth and Earle (1979) indicate that this transformation as a preprocessor to carrying out principal component or factor analysis is also superior to the log base 10 transformation, because of the better definition of multielemental associations on the component or factor axes. Transformations can be carried out in SPSS through subprogram COMPUTE. The user writes in FORTRAN notation the desired transformation of a variable on a control card.
No one method is ever a panacea. One could probably extend this saying to transformations, as per Miesch's (1977) statements, "there are many situations in geochemistry where a log transformation of the data is inappropriate, .... log transformations are helpful far more often than not". Even though there is much conjecture on the subject of transformations it would appear that transformations if correctly applied should improve the statistical reliability of the result by meeting or approximating theoretical parametric conditions. Skewness and kurtosis of the gross individual elemental distributions for raw and transformed data should thus be calculated and examined before proceeding with this multivariate technique. The parameters of skewness and kurtosis previously calculated for both normal (SPSS – program CONDESCRIPTIVE) and log base 10 transformed elemental concentrate data (SPSS – programs COMPUTE, CONDESCRIPTIVE) in Table C7 were plotted against each other and compared (Figure C45). The two data sets were also subjected to R-mode principal component (PCA) and factor analysis (CFA) (see below 7.4.3) and the correlation matrices, proportion of variance explained by the principal components and factors, and their corresponding unrotated loadings are compared (Tables C9 to 11) to gauge the effects of transformation.

An alternative approach was tried, that of using nonparametric statistics because of the uncertainty of the distributions and polymodal nature of the elemental data. This is distribution free and also avoids bias in computations involving squaring of extreme values. Ranked data was therefore used in the computational steps, i.e. a Spearman rank correlation matrix was calculated (input from NONPAR CORR) for subsequent R-mode factor analysis. The correlation matrix, proportion of variance explained by the principal components and principal factors, and their corresponding unrotated loadings for the data are compared in Table C8 and C9 with outputs via the parametric pathway using raw and log base 10 transformed data.

There is also no algebraic reason why factor analysis cannot be based on a variance-covariance matrix of unstandardised data. In fact, the correlation matrix is the same as the variance-covariance matrix of standardised data. By standardising variables, so that each has
a mean of zero and standard deviation of unity, variables having mixed measurement, e.g. Cu ppm, Total Heavy Metals ml Dz, or variability in range of measurement, e.g. Ag 0.1 to 10 ppm, Cr 100-10 000 ppm, can be given equal weighting in the analysis. The data being analysed here is of the latter type. Standardisation however may affect the weights given to error in the data, (Davis (1973), Duff (1975)). The process of standardisation is however fixed in the factor algorithm of SPSS and raw data runs cannot be made for comparison.

7.4.3 Choice of Mode of Analysis

A number of factor methods can be seen to be available in Figure C43. These methods can be generally divided into those methods using defined or inferred factors. This is a result of a conscious decision to replace the unities of the main diagonal of the correlation matrix with estimates of communality. If this is not done the method is defined and called Principal Component Analysis (PCA). Replacing the main diagonal of the correlation matrix leads to the method of Classical Factor Analyses (CFA) where inferences are being made about the variables. The remaining methods in the SPSS flow path, Rao, Image and Alpha Factor Analysis are mainly of the latter type.

PCA is really a mathematical manipulation not a statistical procedure in that nothing is said about probability, hypotheses or testing and that its usefulness is judged by performance and not by theoretical considerations. It is a method where an exact linear transformation of a set of geochemical data is effected giving rise to a new set of variables or components. Each new variable or component is a linear combination of the old and by definition uncorrelated to orthogonal to each other, and accounts successively for the greatest possible amount of unexplained variance in the data. The solution provides as many components as there are elements. All of the original variance will be accounted for when all components are calculated. The PCA model may be written:

\[ Z_j = \sum_{i=1}^{n} a_{ij} F_i \]

...120.
where $Z_j$ is the value of the $j$th element in standardised form,

$a_{jn}$ is the "loading" or standardised multiple regression coefficient

of the $j$th element of the $n$th component

and $F_n$ is the value of the $n$th component, which is defined as a linear

combination of the $n$ original elements.

The analytical result is a value of each component ($F$) for each sample,
a set of loadings ($a$) for each element on each component and the

variance of each component (i.e. the eigen values of the variance-
covariance matrix of standardised variables on which the analysis

is performed).

The loadings ($a$) of elements on components provide information on

associations between elements. High loadings of the same sign for

a number of elements on the same component means that the elements

are strongly correlated. These associations can usually be seen from

the matrix of correlation coefficients between the elements though

it becomes difficult for a large number of elements in the matrix.

As the aim is to examine spatially the regional variation of the

centration of the $n$ elements in the data set, "scores" for each

component will describe exactly the same total data variability as

$n$ plots of the raw values for each element. However, the plot of scores

for the first component will be the best possible summary of the

variability of all the elements and will be completely uncorrelated

with plots for successive components. Likewise, the plot of scores

for the second component will be the next best summary etc. In SPSS

scores are based on standardised elemental values. Scores are in

standard deviation units and lie above and below the zero mean of

the score.

In contrast CFA is a statistical technique relying on a set of assump­
tions about the nature of the parent population from which the samples

were drawn. It is assumed that the relationship within a data set of

variables is such that each variable is dependent on one or more

uncorrelated underlying factors and that the number of factors to account

for the observed relations in the data is smaller in number than the
variables. Variance in the variables is therefore derived from variance in the factors (i.e. the "common factors"), but in addition a contribution is made by unique sources which independently affect the original variables. The independent contribution is referred to as a "unique factor". The CFA model may be written as

\[ Z_j = a_{j1} F_1 + a_{j2} F_2 + \ldots + a_{jn} F_n + d_j U_j \]

The symbols have the same meaning as per the PCA equation, but with the addition of:

- \( U_j \) is the unique factor for element \( j \)
- \( d_j \) is the "loading" or standardised multiple regression coefficient of the \( j \)th element on the unique factor \( j \).

It is assumed that the unique factor \( U_j \) is both uncorrelated with any other unique factor and any of the common factors. Therefore any observed correlation between elements is assumed to be due to the common factors.

If the data is standardised the variance of an element is unity, and for the above model the variance can be split into:

(a) variance due to the common factors which is called the "communality" of the element and denoted \( h^2 \), and

(b) its complement \((1-h^2)\) the variance due to the unique factor.

Before a CFA solution can be reached the communality of each element and the number of factors must be estimated – a difficult and seemingly subjective task. With a PCA solution the number of components and variables are equal and communality is unity. In the same manner as PCA, "scores" for each factor can be calculated and the spatial variation of the various factor loadings (elemental associations) mapped.
In regional geochemical studies both R-mode PCA and CFA have been used with varying success by many workers; e.g. stream sediments (Armour-Brown and Nichol (1969)); lake sediments (Jaquet (1975), Hornbrook and Garrett (1976)); lithogeochemistry (Saager and Esselaar (1969), Garrett (1973), Hesp and Rigby (1975)); pedogeochemistry (Farrell et al (1976)). The major use of factor analysis in general in mineral exploration is to separate different patterns of influence, resulting on one hand from two or more styles of environment, (Nilsson (1970), Brundin et al (1972)) and on the other hand two or more styles of mineralisation, (Saager et al (1974)).

It is also possible to look for patterns between samples, through Q-mode analysis and sequential samples through P-mode analysis. The former is an old and well used technique in sedimentological studies, (Krumbein and Imbrie (1963), Imbrie and Purdy (1962)). It has also been used in a variety of geochemical studies, on small data sets of no more than 150 samples and 20 variables. Generally the data sets are 30 to 60 samples with 8 to 14 variables, - e.g. stream sediments (Nichol et al (1969)); pyrites (Dawson et al (1974)); lake sediments (Jaquet (1975)); drill cores (Turek et al (1976)); hydro-geochemistry (Ashley et al (1978)). Q-mode analysis is not a feature of the SPSS library. However, a package was investigated, the Q-mode package of Davis (1973). Q-mode analysis was not pursued and the flow path of R-mode analysis via SPSS studied.

Little is known by the writer on the applicability of P-mode analysis to geochemical data. Page et al (1978) reports that the method is being applied to UK funded and manned (ICS personnel) regional stream sediment geochemical programmes in Indonesia. It is not a part of the SPSS utility.

As previously mentioned PCA and CFA have been used in this study through SPSS option PA1 and PA2 in FACTOR. From this point the general descriptor term of factor analysis is used at times by the writer in an equivalent sense to the definitive terms PCA and CFA.
7.4.4 The Terminality of the Solution

One of the primary uses of any factor analytical technique is to reduce the number of variables necessary to describe variation in the data set. Factors or principal components therefore may be employed as a minimum number of totally independent variables needed to describe the data. This step in the flow path is the most subjective. The subjectivity is based principally on the question, "has a final solution been obtained?". Initial solutions often have loadings which may be difficult to interpret and clarification of the loadings is needed by carrying out a suitable rotation of the axes. However, there is no reason why the initial unrotated solution, if not complex, should not be accepted and used. Some workers argue that this is the only acceptable case, (Temple (1978). If uncertainty exists about the initial solution the questions, "how many factors or components should be rotated?" and "what rotation should be employed?" are asked.

The choice of the number of components or factors to be used in the actual rotation and initial or terminal interpretation is subjective. Three choices are apparent:

(1) Harman (1967) suggests that only factors associated with eigen values greater than unity be used. However, if this approach is used 1 to 2 or 3 factors are isolated which are general factors expressing only the major source of variability in the data, i.e. major lithological or environmental control. In contrast, associations reflecting mineralisation in regional geochemical data often have a minor contribution to the overall data variability and would be overlooked. This classical solution is the default option in all rotational methods of programme FACTOR.

(2) Some workers, (Drapeau (1973)), have applied the "scree" test of Catell (1965, 1966); i.e. plotting eigen value versus cumulative percent variability or cumulative percentage of eigen values versus number of factors and employing only the factors associated with eigen values above the most distinctive break in the pattern of decreasing eigen values.
(3) Perhaps the most objective choice is to employ as many factors as are necessary to simplify the data to a predetermined degree of simplicity or use as many factors as one can confidently interpret in terms of the local environment. Examples of this approach are the works of Church et al. (1976) and Garrett et al. (1969). In the latter example 6 factors were expected on geological and environmental grounds from a 13 factor model of stream sediment data from Sierra Leone. In actual fact the metal associations of the first 9 factors appeared interpretable and significant with regard to the geology. The loadings on the first 9 factors appeared interpretable and significant with regard to the geology. The loadings on the first 9 factors were subsequently rotated and scores for each sample on each of the 9 factors computed, plotted and interpreted with respect to geology and environment.

Rotation be it by orthogonal or oblique means is the final step in the search for simple and interpretable factors. The effect of rotation on clarification of the loadings is illustrated by the orthogonal rotation case in which four elements Cu, Ni, Co, Zn are depicted in two-dimensional space in Figure C44. On the unrotated first factor all the elements load high, while on the unrotated second factor Cu, Co are moderately high in a positive sense and Ni and Zn are low in the negative sense. Every element is thus accounted for by two common factors. The approximate unrotated and rotated loadings are tabulated in Figure C44. A point of interest from the unrotated solution is that there are two spatial clusters of variables, Cu and Co go together as do Ni and Zn. If the original axes are now orthogonally rotated, factor clarification occurs. Ni, Zn now load high only on factor 1 and Cu, Co load high only on factor 2. In some respects if one was looking for Cu, Ni mineralisation in mafic-ultramafic rocks both solutions are valid; factor 1 being representative of lithology and factor 2 mineralisation, though factor 1 when rotated is definitely lithological. This simplistic theoretical example also illustrates the power of data reduction and summation of the technique of factor analysis. The same general principles apply to the oblique rotation as apply to the orthogonal rotation. However, because the factor axes are not orthogonal clustering of elements is accentuated because each axis is
THE EFFECT OF ROTATION ON FACTOR CLARIFICATION

UNROTATED

ORTHOGONAL ROTATION

OBlique ROTATION

ORTHogonal Rotated Factors

Oblique Rotated Factors

<table>
<thead>
<tr>
<th>Elements</th>
<th>Unrotated Factors (U)</th>
<th>Rotated Factors (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>80(+)</td>
<td>10(+) 90(+)</td>
</tr>
<tr>
<td>Co</td>
<td>80(+)</td>
<td>20(+) 90(+)</td>
</tr>
<tr>
<td>Ni</td>
<td>80(+)</td>
<td>30(+) 80(+)</td>
</tr>
<tr>
<td>Zn</td>
<td>90(+)</td>
<td>30(+) 80(+)</td>
</tr>
</tbody>
</table>

Fig. C44
closer to the respective group of elements and information on the amount of correlation between factors is obtained. Figure C44 again illustrates these points. The two factors can in this case be seen to show correlation between each other.

In SPSS orthogonal rotation can be effected through subprograms VARIMAX, QUARTIMAX, and EQUIMAX. The VARIMAX method is the most widely used rotational method, and a number of factors may result in the terminal solution. This is especially important when one is trying to summarize elemental associations in a real geological setting in which a number of types of mineralisation may be expected and possibly the effects of masking environments need to be partitioned. VARIMAX, centres on the method of Kaiser and involves the simplification of the columns of a factor matrix so that loadings of elements on each factor are either high or low, i.e. tending to unity or zero respectively. The method maintains the orthogonal (uncorrelated) relationship between factors or components, but the proportion of variance explained by each factor of component may change.

In contrast, the QUARTIMAX solution principle is to make the complexity of a variable a minimum by simplifying the rows of a factor matrix, that is to rotate the initial factors in such a way that a variable loads high on one factor, but almost zero on all others. The maximum possible simplification is reached if every variable loads only on one factor. The EQUIMAX criteria is a compromise between QUARTIMAX and VARIMAX.

Since a certain amount of correlation might be expected between factors, as geological processes are rarely mutually exclusive of each other in nature, a more realistic approach is to relax the orthogonal relationship. This is termed an oblique rotation. In principle the axes are allowed to rotate freely to best summarise any clustering of variables and the factors are allowed to be correlated if such correlations exist in the data. For example, the previously discussed Figure C44. Sub program OBLIQUE in SPSS can be used to carry out the oblique rotation. However, the terminal solution with an oblique rotation is very subjective. It can be made extremely oblique (correlated)
or nearly orthogonal (uncorrelated) by altering a value called delta (option DELTA) in the oblimin criteria equation governing the rotation. Some workers, such as Garrett et al (1969), Nichol (1970), have used dual rotations, i.e. varimax followed by an oblique rotation to reach a terminal solution. Dual rotations however, are not a feature of the SPSS package.

The terminality of the initial PCA and CFA solutions were investigated for both parametric (raw and log base 10 data) and nonparametric (raw ranked data) pathways. Comparisons of the available rotations in the SPSS package to reach a terminal solution were also made and are discussed below.

7.5 Results of Experimentation Along the Flowpath

7.5.1 The Effects of Transformation

The effects of skewness and kurtosis on the 14 element stream concentrate raw and log base 10 transformed data was examined by graphical means. Figure C45. The raw data can be seen to be generally highly skewed and leptokurtotic. For elements such as Nb, Bi, Ag and Mo this is not surprising as they exhibit truncated distributions because the majority of their elemental concentrations (96 to 99%) fall below the detection limit for the spectrographic analytical method. The effect of a transformation is dramatic in reducing skewness and kurtosis. For the log base 10 transformation, Pb, Y, Sn, La, Zn and Co are still slightly positively skewed and evenly divided between being slightly positive and negative in kurtosis while Cu, V, Ni and Be have slightly negative induced skewness and are evenly divided between being slightly positive and negative in kurtosis. The elemental data for Nb, Bi, Ag and Mo in gross terms were not normalised. This is not surprising as explained above. There has been, with the possible exception of V, a marked improvement in skewness and kurtosis by carrying out a log base 10 transformation. However, if the applicability condition of the normal distribution is applied in the gross sense, (i.e. $A/(6/N)^{1/2} < 3$ and $E/2(6/N)^{1/2} < 3$, where A and E are respectively skewness and kurtosis, Refer Appendix II), skewness for Sn, Y and
THE EFFECT OF DATA TRANSFORMATION ON SKEWNESS AND KURTOSIS FOR 14 ELEMENTS MARBLE BAR STREAM CONCENTRATE DATA SET.

FIG. C45
La, and kurtosis for Sn and Cu in Table C7 are statistically significant and the individual elemental distributions in gross terms do not conform to pseudo log normality. In all probability multivariate normality is also not approached. From the above formula log skewness and log kurtosis should not exceed 0.36 and 0.72 respectively for the individual elemental distributions to be statistically insignificant, i.e. conform to gross log normality.

Because the conclusions drawn from the effects of transformation on correlation are similar to those drawn from R-mode factor analysis discussion of the results is incorporated into the next section.

7.5.2 Evaluation of Different Factoring Procedures

Comparison of the correlation matrices, proportion of the variance explained by the principal components and principal factors and their corresponding respective unrotated loadings for each factor type for the parametric (raw and log base 10 transformed data) and nonparametric pathways are found in Tables C9, C10 and C11. As a generalisation, from the correlation matrices in Table C9 one can see that log base 10 transformation of data induces higher correlations between 77% of the elemental pairs in both the positive and negative sense. Likewise, in 80% of the cases higher correlations were obtained between elemental pairs by ranking. There appears to be a greater similarity in the correlation coefficients obtained by the parametric pathway after log transformation and the nonparametric pathway though in 62% of the cases correlation coefficients were higher by the latter pathway.

Comparisons of the proportion of variance explained by the PCA and CFA and their corresponding unrotated loadings (Tables C10 and 11) for the parametric treatment, (i.e. raw and log base 10 transformed data) and nonparametric data, (i.e. ranked data) indicates that for PCA and CFA there is a greater closeness in the proportion of total variance extracted and in the actual solutions obtained by using parametric statistics (after first log base 10 transforming the data) and nonparametric statistics except where low loadings predominate, i.e. PCA factors 5 to 10 and CFA factors 3 to 10. Loadings are higher and perhaps a little clearer in their tendency towards ± 1.0 and zero. However, the interest—
<table>
<thead>
<tr>
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<th>Sn</th>
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<th>Be</th>
<th>Cu</th>
<th>Ni</th>
<th>La</th>
<th>Co</th>
<th>V</th>
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<td>Zn</td>
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<td>1.000</td>
<td>0.0296</td>
<td>0.3810</td>
<td>0.2145</td>
<td>0.3617</td>
<td>0.2314</td>
<td>-0.0268</td>
<td>0.0561</td>
<td>0.0415</td>
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<td>1.0000</td>
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Table C9 A comparison of correlation matrices on raw and log base 10 data.
<table>
<thead>
<tr>
<th>A. Parametric Solution</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
<th>Factor 6</th>
<th>Factor 7</th>
<th>Factor 8</th>
<th>Factor 9</th>
<th>Factor 10</th>
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</thead>
<tbody>
<tr>
<td>FV</td>
<td>3.33</td>
<td>3.47</td>
<td>0.99</td>
<td>0.78</td>
<td>0.66</td>
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<td>0.21</td>
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<td>0.15</td>
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<tr>
<td>CV</td>
<td>37.3</td>
<td>34.7</td>
<td>9.9</td>
<td>7.2</td>
<td>0.8</td>
<td>4.5</td>
<td>2.5</td>
<td>1.1</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Cv</td>
<td>37.3</td>
<td>62.1</td>
<td>72.0</td>
<td>79.9</td>
<td>91.3</td>
<td>94.8</td>
<td>94.9</td>
<td>98.5</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>B. Parametric Solution</td>
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<td>4.06</td>
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<td>40.9</td>
<td>40.9</td>
<td>40.9</td>
<td>40.9</td>
<td>40.9</td>
<td>40.9</td>
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</tr>
<tr>
<td>CV</td>
<td>37.7</td>
<td>37.7</td>
<td>37.7</td>
<td>37.7</td>
<td>37.7</td>
<td>37.7</td>
<td>37.7</td>
<td>37.7</td>
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<tr>
<td>Cv</td>
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<td>76.6</td>
<td>76.6</td>
<td>76.6</td>
<td>76.6</td>
<td>76.6</td>
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<td>76.6</td>
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Table C10 A comparison of the unrotated factor loadings for parametric (raw and log base 10 transformed data) and non-parametric (raw data) PCA pathways.
<table>
<thead>
<tr>
<th>A. Parametric Solution</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
<th>Factor 6</th>
<th>Factor 7</th>
<th>Factor 8</th>
<th>Factor 9</th>
<th>Factor 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Raw Data) EV</td>
<td>3.73</td>
<td>2.47</td>
<td>0.99</td>
<td>0.78</td>
<td>0.68</td>
<td>0.45</td>
<td>0.35</td>
<td>0.21</td>
<td>0.15</td>
<td>0.13</td>
</tr>
<tr>
<td>CVL</td>
<td>37.3</td>
<td>62.1</td>
<td>72.0</td>
<td>79.9</td>
<td>86.7</td>
<td>91.2</td>
<td>94.8</td>
<td>96.9</td>
<td>98.5</td>
<td>100</td>
</tr>
<tr>
<td>B. Parametric Solution</td>
<td>Factor 1</td>
<td>Factor 2</td>
<td>Factor 3</td>
<td>Factor 4</td>
<td>Factor 5</td>
<td>Factor 6</td>
<td>Factor 7</td>
<td>Factor 8</td>
<td>Factor 9</td>
<td>Factor 10</td>
</tr>
<tr>
<td>(Log 10 Data) EV</td>
<td>4.06</td>
<td>7.63</td>
<td>0.77</td>
<td>0.64</td>
<td>0.48</td>
<td>0.32</td>
<td>0.26</td>
<td>0.19</td>
<td>0.13</td>
<td>1.0</td>
</tr>
<tr>
<td>CVL</td>
<td>40.6</td>
<td>26.3</td>
<td>7.8</td>
<td>6.5</td>
<td>4.6</td>
<td>3.7</td>
<td>3.6</td>
<td>3.2</td>
<td>6.7</td>
<td>100</td>
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<tr>
<td>C. Non Parametric Solution</td>
<td>Factor 1</td>
<td>Factor 2</td>
<td>Factor 3</td>
<td>Factor 4</td>
<td>Factor 5</td>
<td>Factor 6</td>
<td>Factor 7</td>
<td>Factor 8</td>
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<td>EV</td>
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<td>78.6</td>
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<td>91.0</td>
<td>94.1</td>
<td>96.9</td>
<td>98.7</td>
<td>100</td>
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</tbody>
</table>

Table C11: A comparison of the unrotated factor loadings for parametric (raw and log base 10 transformed data) and non-parametric CPA pathways.
ing point is that the general structure of virtually all components on all PCA runs are the same up to factor 5, while in the CFA runs there are only minor differences up to factor 3. For example, the raw data in factors 1 and 3. There is also a general similarity between PCA and CFA factors up to factor 3. From this observation it is inferred that the general factoring procedure is robust and appears to work well even for a data set whose individual members are not exactly normal or log normal in distribution. Furthermore, the advantage of using parametric statistics to produce a matrix of Pearson's correlation coefficients is that it involves little computational effort even for large data sets. On the other hand the calculation of a matrix of correlation coefficients by Spearman's or Kendall's ranking method is difficult for large data sets because of the problem of tied ranks. An increase in computational time and hence cost by a factor of 20 was observed for the Marble Bar data set. However, a correlation matrix of any type once calculated can be saved within SPSS for further calculations thereby reducing the costs of subsequent computer runs, e.g. rotation experimentation. Nevertheless, if scores are required for any factor analysis raw data must be resubmitted for their calculation.

7.5.3 The Initial Solution

The unrotated solution for log base 10 transformed data was investigated for its terminality. The following questions arise. "Is the initial solution valid, simple and interpretable?" "Is there cause to rotate to the conventional terminal solution?" From Table C10 the 10 components of the initial PCA solution can in part be intuitively given a name which reflects geological process-response groupings. These are as follows:

**Factor 1** High positive Ni-Co-V-Cu-Zn loadings versus moderate negative Pb-Y-Be-La loadings which probably reflects the two general geological entities "greenstone belts" versus granitoid batholiths.

**Factor 2** High to moderate positive loadings of La-Sn-Y-Pb which probably reflects the granitoid batholiths with perhaps accentuation of the specialised young "tin" granite phases.
Factor 3  A high positive loading of Be dominates this factor. The significance is unknown, but may reflect areas of pegmatitic mineralisation.

Factor 4  A high negative loading of Sn dominates this factor. This perhaps reflects tin mineralisation.

Factor 5  A moderate positive loading of Cu dominates with some contribution from Pb. The significance of the factor is unknown.

Factor 6  A moderate negative Zn loading with a low Pb contribution in turn offset by a low positive La loading of similar magnitude. The significance of the factor is unknown.

Factor 7  A low to moderate positive Pb loading with a low order positive Ni and Co low contribution offset by a low negative Cu loading of similar magnitude. The significance of the factor is unknown.

Factor 8  A low to moderate positive V loading with low order positive contributions from Pb and Y, offset by a low negative La loading of similar magnitude. The significance of the factor is unknown.

Factor 9  A low negative Y loading offset by a low positive V, La loading of similar magnitude. The significance of the factor is unknown.

Factor 10 A low to moderate positive Ni loading offset by a low negative Co loading of similar magnitude. The significance of the factor is unknown.

Close examination of the 10 eigen values in Table C10 reveals that the first two factors dominate and account for 67.0% of the total data variance. Inclusion of a further three eigen values leads to five factors of possible significance which accounts for 85.9% of the total data variance. Low antipathetic loadings on factors 6 to 10 make recognition of elemental associations difficult and the conclusion that these factors are possibly trivial is reached.
STREAM CONCENTRATES:
SCREE TEST UNROTATED PCA AND CFA SOLUTIONS

*1 = PCA Factor
x1 = CFA Factor

HIGH MULTIELEMENTAL LOADING OF FACTORS

MODERATE TO HIGH MONOELEMENTAL LOADINGS ON FACTORS

LOW TO MODERATE MONOELEMENTAL LOADINGS ON FACTORS — DUBIOUS OR TRIVIAL FACTORS

FIG. C46
The selection of the number of factors that are possibly significant in the factor matrix has been carried out with a modicum of geological objectivity. Intuitively, the association on the first factor appears to express the regional geological environment; the second, a specialised (?) geological environment (the young "tin" granitoids) of economic interest; while factors 3 to 5 which are monoelemental in character probably have no greater information content than a plot of the raw data. However, factor 4 (monoelemental Sn) considered with factor 2 may be important in clarification of possible mineralisation associated with the young granitoids. The remaining factors, as previously mentioned, appear trivial, being antipathetic in elemental character and have interpretable, but dubious low loadings. If a "scree test" is applied to the data, by plotting eigen values versus cumulative percentage of eigen values as in Figure C46, three groupings occur which can be related to the above objective assessment. A very distinctive break in the plot at an eigen value of 1.75 separates factors 1 and 2 from the remaining factors. A lesser break on the plot at an eigen value of 0.42 separates factors 3 to 5 from 6 to 10.

The same process of reasoning can be applied to the CFA data. If the equivalent initial CFA solution (i.e. log base 10 transformed data) is examined factors 1 to 5 appear to be important. (Table C11, Figure C46) Factors 1 and 2 are again dominant expressing greenstones and granitoids respectively and are strongly separated from factors 3 to 5 which have monoelemental antipathetic loadings. However, Be(+), Sn(−) and V(+) respectively, dominate the loadings of factors 3 to 5. The interesting point is that low loadings predominate from factor 3 in the case of CFA, in contrast to factor 6 in the PCA. In general terms there appears to be little ambiguity in the initial CFA and PCA solutions, though the effects of antipathetic loadings would be reduced, especially in the CFA case.

The writer has been hypothesising on the basis of statistical computations. Unfortunately, the spatial relationship of where a set of values forms a pattern in geological space has not been taken into account. Thus to ascertain the true significance of the above factors and the validity of the conclusions made to date, the following was carried...
out; (1) the scores of each factor in the unrotated PCA matrix were calculated (SPSS - subprogram FACSCORE); (2) histograms of the scores for each factor generated (SPSS - programs COMPUTE, CONDESCRIPTIVE, FREQUENCIES); (3) from the resulting frequency distribution of scores for each factor class intervals of variable size were selected; and (4) maps of scores of each individual factor produced by the computer line printer using isopleth mapping by SYMAP (Figure C47 to 56). Machine digitised basin centroid co-ordinates of the Marble Bar sheet were merged with the factor scores prior to isopleth mapping as the basinal centroid co-ordinates appear to give a better sampling grid with minimal distortion of the geochemical surface.

Factor 1 + Ni-Co-V-Cu-Zn versus - (Pb-Y-Be-La) Figure C47.

As suspected this factor i.e. high positive loadings of Ni-Co-V-Cu-Zn versus moderate negative Pb-Y-Be-La loadings reflects the two main geological entities greenstone belts and granitoid batholiths. High positive scores outline the greenstone belts and greenstone remnants in the batholiths. In particular, high positive scores of 1.5+ outline the more mafic and ultramafic areas within the greenstone belts.

This can be seen by comparing Figure C45 with Figure C4. The Coongan, Soanesville, central Pilgangoora and North Pole Dome Belts are particularly highlighted. Extreme negative scores (2.0-) highlight the "tin" granite phases in the Yule (Numbana Granite), Shaw (Cooglegong Adamellite) and Mt Edgar (Mooyella Adamellite) Batholiths.

Factor 2 + La-Sn-Y-Pb Figure C48.

Factor 2 is dominated by moderate to high positive loadings of La-Sn-Y-Pb. The resulting map of the high positive factor scores (1.0+) in Figure C48 is similar to the qualitative summary of Sn, Y, La (Figure C22) with the addition of Pb from the qualitative summary of Figure C23.

The northern portion of the "tin" granite phase in the Shaw Batholith is highlighted, as is the same phase in the Yule Batholith and Mt Edgar Batholith. The pattern in the Yule Batholith however is dominantly underlain by the northern adjacent Nardoopithana Adamellite. The
**Figure C47** MARBLE BAR CONCENTRATES FACTOR 1

**Value Extremes Are**

-2.37  
2.84

**Value Range Applying to Each Level**

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<th>Maximum</th>
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**Distribution of Data Point Values in Each Level**

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**Scale**

- 0  
- 25  
- 50  
- 75  
- 100 km

**Marble Bar Concentrates Factor 1**

**Ni-Cu-W-Cu-Zn**

**Maximimum Included in Highest Level Only**

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**Figure C47** MARBLE BAR CONCENTRATES FACTOR 1
FIGURE C 48  MARBLE BAR CONCENTRATES FACTOR 2
Turner Batholith and to a lesser extent the Wodgina Belt are also highlighted and the patterns probably reflect the mineralised environment of the northeast trending regional shear. There are differences between the univariate summaries and the factor 2 map. The northern portion of the North Shaw Belt and eastern periphery of the sheared Yule Batholith and Western Shaw Belt in particular, are highlighted better in the map of Factor 2 scores. Both areas contain extensive mineralisation, the first Ag-Au-Cu-Pb while the second Au mineralisation. The northwest trending feature across the northern portion of the Corunna Downs Batholith in the factor 2 map is also of interest, as an extensive Nb pattern was recorded here in the univariate analysis.

Factor 3 +Be Figure C49.

Factor 3 is dominated by a high positive Be loading with a very minor component from low negative La-Zn loadings. However, the latter has not affected the strong correspondence between the patterns of positive scores in the factor score map and patterns highlighted in the raw data map of Figure C25. Known areas of pegmatitic mineralisation are evident. For example; in the Wodgina Belt, the north western portion of the Pilgangoora Syncline, and in the Shaw and Mt Edgar Batholiths, associated with the "tin" granites. Patterns commented upon in the raw data analysis over the Fortescue Volcanics (especially in the southeastern corner of the map), Kelly Belt and in the southern Shaw and Yule Batholiths respectively, are also prominent. However, no extra information appears to have been gained from the map of the factor scores.

Factor 4 -Sn Figure C50

Factor 4 is dominated by a moderately high negative Sn loading and minor lower positive Y-La-Cu loadings. Again, there is a noticeable strong correspondence of the patterns of negative scores in the factor score map to the patterns discussed in the Sn raw data map of Figure C34. The Shaw and Mt Edgar Batholiths are especially prominent. Areas containing the "tin" granite phases and known elluvial/alluvial Sn mineralisation are highlighted. The "tin" granite in the Yule Batholith...
FIGURE C49  MARBLE BAR CONCENTRATES FACTOR 3

DATA VALUE EXTREMS ARE -3.02  2.78

VALUE RANGE APPLICABLE TO EACH LEVEL
MINIMUM  1.50  2.00  2.50
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DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

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SCALE 0  25  50  75  100 km
I……………………I……………………I……………………I……………………I

MARBLE BAR CONCENTRATES FACTOR 3 + Be

DATA VALUE EXTREMS ARE -3.02  2.78

VALUE RANGE APPLICABLE TO EACH LEVEL
MINIMUM  1.50  2.00  2.50
MAXIMUM  -3.00 -2.00 -1.00  0.00  0.50  1.00  1.50  2.00  2.78

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FIGURE C49  MARBLE BAR CONCENTRATES FACTOR 3
FIGURE C 5 0  MARBLE BAR CONCENTRATES FACTOR 4

VALUE EXTREMES 4-L  -3.67  2.35

VALUE RANGE APPLYING TO EACH LEVEL

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DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

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FIGURE C 5 0  MARBLE BAR CONCENTRATES FACTOR 4
is only spottily enhanced in a minor way. It is of interest to note that high positive scores here, depicting Y-La-Cu enrichment. Strong regional Y-La anomalism was evident in the La and Y raw data (Figure C29, C36). The remaining prominent patterns of high negative factor scores of less than 1.0 are the same as those that were commented upon in the raw Sn data analysis. As with factor 3, no extra information appears to have been gained from the map of factor 4 scores.

Factor 5  +Cu(Pb) versus (-Zn)  Figure C51

Factor 5 is dominated by a moderate positive loading of Cu with a supporting low positive loading of Pb. However, a low negative Zn loading is just greater and offsets the positive loading of Pb. High positive factor scores (1.0+) outline areas of Cu (Pb) enrichment, e.g. southern Shaw Batholith, while high negative factor scores (1.0-) outline areas of Zn enrichment, e.g. western central Yule Batholith. The raw data maps of Cu, Pb and Zn (Figures C28, 30, 37) have a much greater informational content than the factor 5 map.

Factor 6  -Zn(Pb) versus +(La)  Figure C52

Factor 6 is dominated by a moderate negative Zn loading supported by a low negative loading of Pb which in the numeric sense is slightly greater than a positive La loading. High negative scores (1.0-) outline areas of Zn(Pb) enrichment in the eastern Yule Batholith/adjacent Soanesville Belt/Shaw Batholith, Pilgangoora Syncline Belt and Kelly Belt. High positive scores (2.0+) outline La enrichment in the Proterozoic Fortescue Volcanics cover, Marble Bar and North Shaw Belts and Turner Batholith. The raw data maps of Zn, Pb and La (Figures C29, C30, C37) are more informative than the factor 6 map.

Factor 7  +Pb (Ni-Co) versus -(Cu)  Figure C53

Factor 7 is dominated by a moderate positive loading of Pb supported by low positive Ni and Co loadings which are offset by a negative loading of Cu. Patterns of high positive scores (2.00+) reflecting increased Pb, Ni, Co content of concentrates are especially prominent over the Tambina Complex, southwestern portion of the Soanesville
DATA VALUE: CATACOMBS ARE -3.61 3.71

VALUE RANGE APPLYING TO EACH LEVEL

MINIMUM  -2.20 -1.59  -0.99  -0.49  -0.01  1.00  1.99  2.99  3.99  4.99  5.99

MAXIMUM   5.00  5.99  6.99  7.99  8.99  9.99  10.00

ILLUSTRATION OF DATA POINT VALUES IN EACH LEVEL

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FIGURE C 51 MARBLE BAR CONCENTRATES FACTOR 5
MARBLE BAR CONCENTRATES FACTOR 6

DATA VALUE EXTREMES ARE

VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM -3.00  -2.00  -1.00  0.00  1.00  2.00  3.00
MAXIMUM  5.00  7.00  7.00

DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

SYMBOLS

FREQ.

FIGURE C52 MARBLE BAR CONCENTRATES FACTOR 6
MARBLE BAR CONCENTRATES FACTOR 7 + Pb-(Ni-Co) versus -(Cu)

DATA VALUE EXTREMES ARE: -3.62 3.41

VALUE RANGE APPLYING TO EACH LEVEL:
MINIMUM -1.93 -1.00 -1.00 -1.00 0.00 1.00 2.00 3.00 1.00
MAXIMUM -3.43 -2.00 -1.00 0.00 1.00 2.00 3.00 1.00

DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL:

SYMBOLS

FREQ.

FIGURE C53 MARBLE BAR CONCENTRATES FACTOR 7
Belt, North Shaw Belt and central North Pole Dome, while patterns of high negative scores (1.00-), reflecting areas of Cu enrichment, are found in the Shaw and Corunna Downs Batholiths, Coongan, northwest Soanesville, and northwest Pilgangoora Syncline Belts. The individual raw data maps for Pb, Ni, Co and Cu (Figures C27, 28, 30, 32) have a much greater informational content than the map of factor 7 scores.

Factor 8 $+V(Pb, Y)$ versus $-(La)$ Figure C54

Factor 8 is dominated by a moderate loading of V with a contribution from lower positive loadings of Pb and Y. These lower positive loadings are offset in the numeric sense by a slightly higher negative loading of La. The patterns of high factor score (2.00+) are similar to the areal V highs noted in the V raw data (Figure C35). For example, highs are evident over the northern Soanesville Belt and adjacent Proterozoic cover, the western periphery and northwestern portion of the Coongan Belt and the Marble Bar Belt – adjacent Mt Edgar Batholith. High negative scores (2.00-) outline in part areas of high La noted in the raw data (Figure 29); for example, the northwestern corner of the Turner Batholith. However, where high La, Pb and Y values are coincident in the raw data they generally cancel each other in the factor score map. For example, the previously cited high La area on the factor score map in actual fact is far more extensive in the raw data. The factor map also has only in part, given a map of the V patterns of interest in the raw data.

Factor 9 $(V-La)$ versus $-Y$ Figure C55

Factor 9 is dominated slightly by a low Y loading which is offset by lower (in the numerical sense) positive loadings of V and La. As with previous maps of factor scores the high negative scores (2.00-) highlight areas of Y enrichments noted in the raw data in Figure C36. For example, the Yule Batholith. In turn, high positive scores (2.00+) principally highlight areas of La enrichment noted in the raw data in Figure C29. For example, the high scores over the Cooglegong Adamellite in the Shaw Batholith is most prominent. However, the factor map has only in part factually represented the Y patterns of interest noted from the raw data map.
FIGURE C54 MARBLE BAR CONCENTRATES FACTOR 8 + V-(Pb-Y) versus -(La)

VALUE EXTREMES =+5  3.09

VALUE RANGE APPLYING TO CAM LEVEL
MINIMUM  -4.64  -3.00  -1.60  0.30  1.00  2.00  3.00  3.69
MAXIMUM  -3.00  -2.00  -1.00  0.00  1.00  2.00  3.00  3.69

DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

SYMBOLS

FREQ.

FIGURE C54 MARBLE BAR CONCENTRATES FACTOR 8
Figure C55: Marble Bar Concentrates Factor 9 + (V-La) versus -Y

Value ranges applying to each level:

Minimum: -3.72
Maximum: 5.05

Distribution of data point values in each level:

Symbol:

Freq.

---

Scale 0 25 50 75 100 km

Marble Bar Concentrates Factor 9 + (V-La) versus -Y

Data Value Extremes Ape

Minimum: -3.71
Maximum: 5.05

Range applying to each level:

Min: -3.72
Max: 5.05

Distributing Data Points Values in Each Level:

Symbols:

Freq.
Figure C56: Marble Bar Concentrates Factor 10 + Ni versus Co

Data Value Extremes are

Maximum Included in Highest Level Only

Minimum

Maximum

Value Range Applying to Each Level

Scale

0

25

50

75

100 km

Factor 10
Figure C56

A moderate positive Ni loading just offsets in the numeric sense a lower negative Co loading in factor 10. Unfortunately, high positive scores (1.00+) outline only in part areas of high Ni noted in the raw data in Figure C32. Likewise, high negative scores (1.00-) outline only in part areas of high Co noted in the raw data in Figure C27. Areas having coincident patterns of high Ni and Co in the raw data as in southern portion of the Soanesville Belt can be seen to be suppressed in the map of the factor scores. The information content of the raw Ni and Co data maps (Figures C27, 32) is far superior to the map of factor 10 scores.

7.5.4 A Comparison of PCA and CFA Rotated Solutions

From the preceding section 7.5.3, no further clarification of the initial solution appeared to be necessary, because the loadings on the factors of interest were not ambiguous and more importantly could be explained in terms of the geological environment. Indeed factors 1 and 2 in the initial PCA and CFA solutions are the only factors having multielemental loadings suited for clarification by rotation. A two factor model is the classic solution of Harman (1967) as these two factors account for the bulk of the total data variance (up to 68%) and their eigen values are greater than unity. Nevertheless, the terminal PCA and CFA solution reached by orthogonally rotating factors 1 and 2 (two factor model) and factors 1 to 5 (five factor model) by SPSS-VARIMAX are compared for the two pathways (i.e., parametric-raw and log base 10 transformed data; non parametric-raw data) Tables C12 and C13. The results for three orthogonal rotations (through SPSS subprograms VARIMAX, QUARTIMAX, EQUIMAX) and an oblique rotation (SPSS subprogram OBLIQUE) on a five factor model from the initial PCA and CFA solutions for log base 10 transformed data are compared in Tables C14 and C15. The results of rotation experimentation carried out within OBLIQUE on the same initial PCA and CFA solutions can also be seen in Tables C16 and C17. All experimentation was effected very economically by either running previously saved correlation matrices or communality estimates - factor matrices. However, if scores are required for the factors in the terminal solution the raw data must be submitted as input.
From Tables C12 and C13, the two and five factor PCA and CFA varimax rotated models for parametric and nonparametric pathways, can be compared. For the parametric pathway the resulting PCA factors are very similar, the only noticeable difference is that the ordering of the elements on factors 1 and 2 in both models are slightly changed and that the order of importance has changed for the loadings on factors 4 and 5 in the five factor model, i.e. Sn dominates on factor 4 for the transformed and parametric data in contrast to factor 5 for the raw data. The reverse holds for the Cu factor, i.e. transformed data, factor 5 contrasting with factor 4 for the raw data. However, for the parametric data Pb is a factor instead of Cu.

Some fission and fusion can be seen respectively on raw data factors 1, Ni-Zn-Co-V-(Cu) and 4, Cu (V-Co). In all the original PCA unrotated matrices the 5 factors were identical, with the exception of the strong antipathetic nature of factor 4 (-Sn/+Be) for the raw data, and factor 5 (Pb) for the nonparametric data. The nonparametric and transformed data rotated PCA solution are near identical to their unrotated solutions with the exception of, the greater clarity of loadings (i.e. tendency to + unity or zero), a reduction of antipathy on factor 1, some fusion and fission of loadings in factor 2 for the two and the five factor models respectively, and a reversal of sign for the Sn factor. Cu as a factor has also been deleted from importance in the subsidiary important grouping of factors 2 to 5 and has been replaced by Pb.

Similar observations can be made with regard to the CFA pathway. The two factor models are essential the same though the loadings have altered slightly in importance on the factors causing some fusion on the transformed and parametric runs. However, with the five factor model differences are apparent. Firstly, the CFA nonparametric solution is invalid. The iterative procedure stopped after 13 rotations because the communalities exceeded unity. Factors for the previous (acceptable) iteration were retained and are displayed in Table C13. Factors 4 and 5 are very similar being dominated by V in this incomplete solution. The parametric CFA outputs are very similar in the content of the important factor loadings except the order of importance of the Sn and Be factors are reversed. The trivial nature of factor 5 is accentuated and indicated by low antipathetic elemental loadings. Indeed, after...
Table C12 A comparison of PCA terminal solutions for the parametric and non-parametric pathways through rotation by SPSS FACTOR subroutine VARIMAX.
Table 13 A comparison of CFA terminal solutions for the parametric and non-parametric pathways through rotation by SPSS FACTOR subroutine VARIMAX.
factor 3 lower loadings are present on the factors than in the PCA case, but in the case of factors 3 and 4 the loadings are still distinct. There is a great similarity in the initial and terminal transformed solutions with only minor exceptions being the reversal of sign on the Sn factor and some antipathy of loadings on factor 1. As the factor model increases some fission is noticeable in factors 1 and 2, the communality in general has increased as has the clarity of the loadings of importance. However, the communalities for Be and Sn are still low.

A comparison of the two main rotational methods, i.e. orthogonal (varimax, equimax and quadrimax rotations) versus oblique is made in Table C14 and C15, for both the PCA and CFA methods. If the previously noted difference in order of importance of the loadings on factors and the interchangeability of factors between the factor methods is neglected, for orthogonal rotations there is a greater closeness in the results for the individual PCA and CFA varimax and quadrimax rotational outputs. However, for the equimax PCA and CFA outputs there are changes in the order of importance of loadings on factors along with attendant fission and fusion, especially the former on factor 1. The general order of importance of factors 4 and 5 for both PCA and CFA outputs has also changed. Fusion is mainly restricted to factors 3 and 4 in the CFA outputs. Also in the equimax CFA output, the trivial antipathetic factor noted in the varimax and quartimax cases, is no longer evident.

For orthogonal rotations in general, loadings appear to be slightly better defined by varimax rotation, i.e. their tendency to + unity and zero.

The oblique PCA and CFA solutions which are compared with their respective orthogonal solutions in Tables C14 and C15 have been computed for a delta value of zero, which allows a well correlated solution. For the PCA oblique solution, factor 1 is similar to equimax factor 1 in the order of importance of the mafic elemental loadings, while factors 2 to 5 are similar to the varimax or equimax factors with the only exception being the reversal of sign on factor 4 Sn. The loadings on all factors are very definitive. For the CFA oblique
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**Table C14:** A comparison of PCA terminal solutions via SPSS sub-routines VARIIMAX, EQUIMAX, QUARTIMAX and OBLIQUE.
Table Cl5. A comparison of CFA terminal solutions via SPSS sub-routines VARIMAX, EQUIMAX, QUARTIMAX and OBLIQUE.
solution the results are similar to the varimax and equimax solutions with the exception again of the reversal of sign of factor 4 Sn. The triviality of factor 5 has again been confirmed. Loadings on oblique factors are better defined than their orthogonal counterparts.

The oblique solution is subjective in that the user must make the final decision on the degree of correlation required. The degree of correlation is controlled by altering a value called delta in the oblimin criteria equation governing the rotation. This is effected by using option DELTA. A number of oblique solutions were tried with DELTA set at -5.0, -2.0, -1.0, -0.5, 0, 0.25, 0.50, 1.0 in OBLIQUE for rotation of the initial PCA and CFA solutions for log base 10 transformed data. The resulting solutions obtained ranged from uncorrelated (orthogonal) to highly correlated (oblique). Refer Tables C16 and C17.

In the very uncorrelated PCA oblique solution (DELTA = -5.0, Table C16), loadings exceed unity on factors 3 and 4 and are thus invalid. However, the solution for DELTA = -1.0 is satisfactory. As the degree of correlation is increased by making delta more positive, loadings on factors 1 and 2 increase in value while loadings on factors 3 to 5 drop. Fusion on factors 1 and 2, and fission on factor 5 is noted as the solution becomes more oblique. At delta values greater than 0.25, (i.e. DELTA = 0.25, 0.50) too much correlation has been introduced to force the significant loadings to become greater than unity thereby invalidating the solution.

If the valid "uncorrelated" PCA and CFA oblique solutions in Tables C16 and C17, i.e. (respectively PA 1 OBLIQUE DELTA = -1.0, PA 2 OBLIQUE DELTA = -5.0) are compared with the equivalent orthogonal solutions in Tables C14 and C15 similarities and dissimilarities can be noted. The PCA "uncorrelated" oblique solution has some similarities to the equimax solution though the order of factors 4 and 5 have been reversed and the Sn factor (now 4 instead of 5) has become negative in sign. The "uncorrelated" oblique CFA solution lies somewhere between the equimax and varimax solutions. Oblique factors 1 and 2 can be equated with equimax factors 1 and 2 while oblique factors 3 to 5 can be equated with varimax factors 3 to 5. However, with the latter
Table C16 A comparison of PCA terminal solutions for log base 10 data via SPSS sub-routine OBLIQUE.
Table C17: A comparison of CFA terminal solutions for log base 10 data via SPSS sub-routine OBLIQUE.
FACTOR 1

FACTOR 2

PLOT OF FACTOR 1 AGAINST FACTOR 2
AFTER VARIMAX ROTATION

FIG. C 57
the loadings on factor 4 and 5 are reversed, i.e. positive instead of negative.

There is also a similarity between orthogonal and acceptable "correlated" oblique solutions (DELTA = 0) if, trivial factors, as in the case of CFA factor 5, and fission on factors are neglected. The reason for the similarity of solutions in this case can be found by plotting the loadings of factor 1 against factor 2 for the varimax rotated PCA solution. This plot is also an option in FACTOR. One can see, from Figure C57, that there are two broad distinctive clusters within which are sub-clusters, i.e. Ni-Co-V-Cu-Zn versus La-Y-Pb-Be-Sn. If a line is drawn through the middle of each broad cluster from the origin of the axis the two lines would be near orthogonal showing minimal correlation between groups. This is in fact what is observed in the factor pattern correlation matrix in Table C14 for an oblique rotation at DELTA = 0. A low negative correlation (-0.13) exists between factor 1 and 2. This should be expected as the associations represent contrasting lithological groupings, i.e. mafics versus granites. However, within each broad cluster improvement is expected in correlation between component subclusters which are themselves factors. This can also be seen in the factor pattern correlation matrix in Table C14. For example, within the granitoid cluster there are subclusters which can be equated to factors. The factor pattern correlations are Be (Factor 3) and La-Y-Pb (Factor 2) 0.32, Sn (Factor 4) and La-Y-Pb (Factor 2) -0.40 and, Be (Factor 3) and Sn (Factor 4) -0.25.

Little has been gained here by relaxing the orthogonality between factor axes and rotating by the oblique method. However, the strong antipathy of factor 2 and 4 is contrary to, what was expected, i.e. factor 2 ("tin" granites) correlating in the positive sense with factor 4 (tin mineralisation (?)), and for the most part with what was observed in the analysis of the patterns of the scores of the respective factors.

7.6 Discussion

Instead of contributing the same and possibly new information, the
R-mode factor analysis has accomplished the opposite, i.e. it has led to data redundancy though some data redundancy occurred in the beginning by the non-inclusion of outlier elements which in the univariate summaries did contribute information. Major geological environments were summarised. The map of PCA factor 1 scores gave an excellent outline of the greenstone belts while factor 2 to an extent highlighted the "tin" granites. Factor 3 and 4 maps, Be and Sn respectively, reiterated the information content of the raw data. However, the remaining factor maps were trivial, in part due to low to moderate antipathetic elemental loadings, more information being contained within the raw elemental plots.

A weakness of the entoto multivariate statistical approach with respect to the simplistic univariate approach has also been highlighted. Data values are being summarised statistically without regard to their geological position in space. The effect is in part to see the dominance of elemental associations representing the major geological entities, i.e. greenstones versus granites. Little of significance from the exploration viewpoint appears to have been gained from the entoto PCA data run, with the possible exception of the relationship between factors 2 and 4. Some correspondence is found between top scores for factor 2 and 4 over the "tin" granite phase in the Mt Edgar and Shaw Batholiths. However, high factor 2 scores over this geological entity in the Yule Batholith have low factor 4 scores. The factor correlation matrix in a subsequent PCA oblique rotation accentuated this latter point, i.e. a strong antipathetic correlation exists between factor 2 and 4.

An a priori subdivision of samples into the two major geological entities was therefore attempted as it was thought it would be helpful for a more meaningful analysis, i.e. seeking associations within the major groupings. However, it was recognised from the univariate analysis that there was still dichotomity within these two subdivisions though, superficially it did not appear to be as great as the entoto approach.

As PCA seems more objective, the two data sets were analysed by this pathway. Prior to PCA analyses through PA1, skewness and kurtosis
were again plotted and examined for raw and log base 10 transformed data. A decision was taken to use transformed data as input to FACTOR because of the optimisation of data skewness over the raw data. The elements Ag, Bi, Mo and Nb were again deleted from analysis because of the paucity of data. Basins containing mixtures of groupings, i.e. granite and greenstone however were included in both groups.

The initial solutions of the PCA were again examined objectively to ascertain if rotation was necessary. These initial solutions are summarised in Table C18. They can be seen to be similar in character up to factor 4 to the entoto PCA run. The first two factors in each run are again dominant, i.e. mafic and granitic associations respectively while the third and fourth are Be and Sn. Clarification of factors appeared advisable especially for factor 1 of the granite grouping.

The first four factors of each run were thus subsequently orthogonally rotated (VARIMAX) to see if further clarification could be obtained and factors due to mineralisation partitioned. The result can be also seen in Tables C18 and C19.

Clarification occurred, but the component loadings on factor 1 and 2 for granite and greenstone groupings respectively are essentially the same, though their order of importance on the factors have changed. Factor 3, Be dominates over factor 4, Sn, in the granite grouping while in the greenstone grouping factor 3, Sn, dominates over factor 4, Be. No further work seemed advisable due to the similarity of the results with the "entoto" PCA runs.

The non helpful side of R-mode factor analysis has been previously noted, Cameron and Hobbs (1970), Saager and Esselar (1969). In the latter reference an R-mode analysis was performed on 9 variables for 109 samples from the Basal Reef of the Orange Free State goldfield, R.S.A., in order to determine factors which might indicate a different metallogenic process in the formation of this orebody. The three factor solution obtained which confirmed current theories could equally well have been extracted by inspection of the correlation coefficient matrix.

Likewise, little was gained here, even by the separation of the data
Table C18 A comparison of the unrotated and rotated PCA solutions for granite and greenstone groupings, Marble Bar sheet.
into the main lithological groupings. For the subdivided data the factor structure appeared to remain fairly constant. Similar processes are perhaps operating on the same variables in the groups which is quite beyond the ability of the factor procedure to resolve. It was of interest to note the dominance of the mafic over the granitic associations even though granite batholiths have a greater areal extent than greenstones. This may reflect the nature of the batholiths. They evolved by intrusion into an early greenstone crust, Glikson (1979). Greenstone xenolith trains are readily evident within the batholiths. In some respects the user of factor analysis does not know what he is looking for except that is is indicative of mineralisation. The correlation matrix should, and does, give some information about element associations to form hypotheses, though in the actual factor analysis process here, inter- and intra-population effects within the major lithological groupings have not separated, and if any associations did result, were severely modified or, if minor, (e.g. representing mineralisation) swamped and lost.

A difficulty was also apparent in the SYMAP greyscale produced factor score maps. The scale of production at 1:1 000 000, and perhaps the number of class intervals used, has restricted the contouring in the isopleth mapping and has subsequently made pattern recognition difficult. This is apparent when factor 1 was rerun at 1:500 000 (Figure C58) and compared with the original 1:1 000 000 product (Figure C47). In some respects inattention to scale of presentation defeats the purpose of basin centroid co-ordination for isopleth mapping. As a generalisation the cost of production of SYMAP produced maps increases near exponentially as the size of the map increases.

The SPSS flowpath of factor analysis was explored through R-mode PCA and CFA though options PA1 and PA2 respectively in program FACTOR. As the data was polymodal, skewed and leptokurtotic and conjecture exists on the subject of transformations factor runs were carried out on raw and the common log base 10 transformed data via the conventional parametric pathway, (i.e. input to a Pearson's correlation matrix within FACTOR), and on raw data via the nonparametric pathway, (i.e. through a Spearman rank correlation matrix as input to FACTOR).
graphically. Neglecting elements with truncated distributions, skewness and kurtosis was seen to be dramatically reduced. However, skewness for Sn, Y, La and kurtosis for Sn and Cu were found to be statistically significant in that the elemental distributions in gross terms do not conform to log normality. It was subsequently found, that if trivial factors are neglected, virtually all components on all individual unrotated PCA and CFA runs were similar, though there was a closeness in the greater proportion of total variance extracted and the actual solutions obtained by using parametric statistics (after a log base 10 transformation of the data), and nonparametric statistics.

A few comments can thus be passed on the explorationist's dilemma as noted by Chapman (1976), i.e. by not transforming the data the analysis will be effectively weighed in terms of populations relating to mineralisation - the main object of the explorationist, but by not transforming the data, fundamental mathematical assumptions may not be satisfied to the point of invalidating the analysis. Firstly, as stated previously above, the data appears to be representative of a complex geological environment that factor analysis is not capable of effectively breaking down. However, from the similarity of the results the general factoring procedure is robust and appears to work well for a data set whose individual members are not normal or log normal in their gross distributions. No advantage is seen in using nonparametric statistics over parametric statistics because of the greater computational time (cost) involved. Indeed, in a subsequent comparison of rotations, it was seen that the nonparametric five factor model for CFA was invalidated due to the iterative procedure stopping after 13 iterations because communalities exceeded unity. Perhaps to circumvent the situation noted by Chapman raw and transformed data factor runs should be compared. This can be done cost effectively by saving the matrices within SPSS for further manipulation and not generating immediately the factor scores.

The SPSS unrotated factor matrices for either factor method for the entoto and subdivided data could be interpreted and 4 possibly 5 significant factors could be determined and given a name which reflected geological processes. Significant factors can be chosen on the basis...
of geological objectivity and the scree test. The chosen factors in these cases were not ambiguous, though the effects of antipathetic loadings especially in the case of the CFA initial entoto and subdivided data solutions were reduced by varimax rotation and factor 5 confirmed in the entoto case as being trivial. Examination of the entoto plots of PCA scores also confirmed the triviality of factor 5. Thus, rotation is important and should be carried out to clarify solutions.

The effects of rotations through VARIMAX were examined for two and five factor models, the former being the only model with solely multi-elemental factors for valid clarification. Generally with respect to the unrotated matrices factor models with a small number of factors (2) exhibit some fusion of the factors. As the number of factors increases (5) minor fission occurs. If all factors were rotated each factors would probably be dominated by one element which would defeat the purpose of factor analysis, i.e. its data summary capability. The effects of antipathy were reduced and the loadings were better defined, i.e. in their tendency to unity or zero by rotation. Communality also improved for Sn and Be for the CFA five factor model rotation.

Factors were also rotated, orthogonally by VARIMAX, EQUIMAX, QUARTIMAX and obliquely by OBLIQUE. For the orthogonal rotations the varimax and quartimax solutions show a greater similarity than equimax. The subjective, oblique solutions tended to lie somewhere between equimax and varimax. In this case the orthogonal and oblique solutions are similar because there is natural orthogonality between the main component associations on the factors. This was revealed by a scatter plot of the loadings on varimax rotated factors 1 and 2, a useful option of FACTOR.

8. SUMMARY DISCUSSION AND CONCLUSIONS

The primary aim of the work undertaken in this section was a very detailed interpretation of macro-regional, multi-elemental stream sediment and concentrate geochemical data for a typical 1:250 000 sheet on the Australian continent. The information content of the
Onfile data from the Marble Bar sheet was maximised to its limits in order to determine in the macro-regional sense, (1) which elements or groupings of elements are most strongly associated with known mineralised environments, (2) whether any such elemental groupings cluster in similar geological favourable areas outside known mineralised environments and, (3) whether any elemental groupings exist which are possibly representative of hitherto unrecorded styles of mineralisation in both favourable and unfavourable conceptual geological environments.

Data presentation was first accomplished by tracing the individual elemental values from Calcomp produced maps onto basinal overlays which could be registered with geological and mineral occurrence compilations.

Simple univariate statistics were run with the aid of EDP processing via VSTAT and the facility of the SPSS package library. Cumulative frequency plots of the elements were constructed by plotting intervals set by the analytical reading for the elements. It became evident that elemental distributions were polymodal, overlapping and in gross terms obeyed at times neither normal or log normal distribution laws due in part to truncated distributions.

Consequently, the correlation matrices obtained by classical statistics via VSTAT were rerun. Nonparametric statistics were favoured using ranked data for the computational steps via NONPAR CORR of the SPSS library. This approach is distribution free and also avoids bias in computations involving squaring of extreme values. The correlation matrices resulted in a large number of correlations. Frequency distributions of the correlation coefficients resulted in the separation of groupings within which elemental associations drew ones attention to geological environments of possible economic interest. Many of these correlations were also seen when the individual elemental maps of the data types were compared. For both data types the majority of elemental associations appear to be associated with the greenstone belts even though the granite batholiths dominate the sheet geology.
Elemental populations for the data types were determined from obvious break points on cumulative frequency plots and were subsequently annotated on their respective elemental drainage base plan. These geochemical maps were complimented by summary geological and mineral occurrence plans. Resulting elemental patterns and spot responses falling over the simplistic geological subdivisions from the summary geological map were recorded. The individual detailed elemental interpretations were subsequently cross referenced to each other and to the geological and mineral occurrence maps. After "living with" the data for some time a geochemical synthesis was built up using process-response criteria.

Strong geochemical differentiation which reflected geological environment was noticeable at three levels in the macroregional data of both media. Fundamental gross differences were noticed between the batholiths and greenstone belts. Differences could be extended further to between and within the individual batholithic and greenstone entities. The data sets of both media were subsequently summarised in a qualitative manner by elemental suites covering the main spectrum of economic mineralisations in the regional geological setting.

The summation and target analysis in terms of the respective geological entities and environments, revealed a number of minor geochemical provinces some of which contain known minor mineral occurrences. In some cases the same minor, but generally polymetallic provinces fall over similar geological entities which do not contain recorded mineralisation, and on conceptual grounds are targets of immediate exploration interest. However, some of the minor polymetallic provinces are far more extensive with inferred zoning and fall over both favourable and unfavourable conceptual geological environments. These situations may reflect a number of possible hitherto unrecorded styles of mineralisation in both overlooked minor and major geological environments.

The multi-elemental data for the concentrates was subjected to factor analysis, to determine if further information remained hidden and had not been extracted. The pathway of factor analytical techniques was in part explored through a now available non-geological computer...
package library called SPSS. Line printer programmes GREY and SYMAP, the latter another non geological development of social scientists, were investigated for rapid, cost effective, spatial presentation of factor scores for subsequent areal analysis.

Line printer outputs of chloropleth (GREY) and isopleth mapping (SYMAP) for normal and basin centroid co-ordination were compared for the Sn stream sediment data coverage over the Shaw batholith. For each of the line printer runs "grey scale" geochemical maps were produced using successively darker symbols for nominated class intervals previously obtained from a SPSS - FREQUENCIES run. It was found that there is a substantial difference between the patterns generated using normal field co-ordinated data and basin centroid data, when compared with a yardstick, hand plotted basinal values and geology. With normal field co-ordinated points the chloropleth GREY mapping suffers from overprinting with subsequent averaging of points while the isopleth SYMAP mapping suffers from the effects of both overprinting and an irregular sampling network. Patterns resulting from both types of mapping of basin centroid co-ordinated data outlined the distribution of the main "tin" granite phase of the batholith. The visual effect and ease of pattern recognition by SYMAP was far superior to GREY. However, both algorithms are scale dependent and consideration of a suitable plotting scale with the number of classes to be plotted is advised, otherwise the effects of basin centroid co-ordination are negated. The conclusion was reached that SYMAP, a non geological developed package, performed better than GREY in the spatial representation of geochemical data for subsequent areal analysis.

The flow path of factor analysis through SPSS was examined and in part explored. R mode PCA and CFA (sub programs PA1 and PA2 of FACTOR) were chosen for comparison. The previous univariate work had shown that the gross distributions of the individual concentrate elemental data were generally positively skewed, leptokurtotic and multi-modal, leading to the conclusion that some form of data transformation was needed if the conventional parametric pathway was to be followed. Nonparametric statistics was an alternate choice and had been previously favoured in the univariate analysis. As much conjecture was found...
to exist on the subject of the application of transformations, SPSS - FACTOR runs were tried on raw and log base 10 transformed data via the parametric pathway (Pearson's correlation matrix) as well as the nonparametric pathway via Spearman's rank correlation matrix from SPSS - NONPAR CORR as input to FACTOR. However, before running FACTOR, via the parametric pathway, skewness and kurtosis were examined graphically for raw and transformed data. Skewness and kurtosis were seen to be reduced to both slightly positive or negative values for elements which did not have truncated distributions. Furthermore, it was noted that some elements with slight positive skewness, (in particular Sn, Y, La) still did not conform to gross log normality. The elements (Ag, Bi, Mo, Nb) which had severe truncated distributions were deleted from any factor analysis as they were data outliers.

A comparison was made of the correlation matrices, proportion of variance and the corresponding unrotated loadings for each factor for both PCA and CFA factor runs via the parametric and nonparametric pathways. The following was revealed;

1. there was a greater correlation between elemental pairs in the positive and negative sense for log transformed data and ranked data,
2. there was also a strong numeric similarity between the two above correlation matrices.
3. loadings were also higher and perhaps a little clearer in their tendency to + unity or zero in the individual factors from the log transformed and ranked data.
4. If trivial factors are neglected, the general structure of the components was found to be similar within each factor method for all data runs. Likewise, there was a general similarity between each factor method.

A conclusion was reached that the general procedure appears robust and works well even for data whose individual members are not normally or log normally distributed. There would also appear to be no advantage in using nonparametric statistics on large data sets to calculate a correlation matrix as input to FACTOR, because of the computational greater effort and hence cost involved. However, the writer recognises
that optimum results with parametric statistics can only be obtained if conditions are met or if not at least approximated. In this case the common log base 10 transformation though incomplete proved adequate to advance the writer’s purposes, and little extra computational effort was involved in running COMPUTE before FACTOR (-PA1 and PA2) in the same SPSS job stream. Superior transformation alternatives have been proposed, Lindquist (1976), including a recent one of particular promise (Howarth et al (1979)) and should be given consideration as a precursor to SPSS - FACTOR to increase the reliability of the results. However, the dilemma as outlined by Chapman (1976) should not be forgotten and perhaps a comparison of raw and transformed data factor runs is advised.

The terminality of the initial solution for transformed data was investigated. In the unrotated state PCA factors 1 to 5 appeared to be valid, simple and interpretable. The remaining factors appeared trivial being antipathetic in elemental character and had dubious low loadings. A similar, though not entirely satisfactory result was reached with CFA factors on the same data type. Even though the selection of significant factors was arrived at independently by objective geological reasoning and the scree test, hypothesising on the basis of statistical computations alone does not mean the user is correct in his assumptions. The spatial relationship of where a set of values forms a pattern in geological space should also be taken into consideration. To this end scores for all unrotated PCA factors were greyscaled and plotted by SYMAP.

The trivial nature of factors 6 to 10 were confirmed. An additional factor, 5, was also considered trivial.

There appeared at first to be no point in clarifying significant factors in the initial solution by a rotation because the majority of the significant factors were mono-elemental in character. The first two though multi-elemental, expressed clearly as the mono-elemental factors did, geological processes, being in this case the environments of greenstone belts and granite batholiths. Clarification of the solution however does lead to better defined loadings by reducing...
antipathy on factors.

Two (1 and 2) and five (1 to 5) factor models were orthogonally rotated by VARIMAX to gauge the effects of rotation. Subsequently orthogonal and oblique rotational methods were compared for PCA and CFA runs through SPSS subprograms VARIMAX, QUARTIMAX, EQUIMAX and OBLIQUE. In gross terms similar solutions were noted. It was found that experimentation could be achieved economically by running the SPSS saved matrices instead of rerunning the raw data through COMPUTE and then FACTOR.

The OBLIQUE output did not differ significantly from the orthogonal outputs because there appeared to be a natural orthogonality between component associations on the factors. This was revealed in a scatter plot of the VARIMAX loadings of factors 1 and 2. These plots, an option in FACTOR, are useful and recommended in that the clustering of variables and their relative position to each on the graphical plots gives information on the degree of actual correlation between factors. If correlation does exist between factors the data should perhaps be rerun by OBLIQUE as geological processes are dynamic and interacting and the information obtained may be more significant. However, it should be pointed out OBLIQUE is subjective in that the user must make the final decision on which DELTA (the oblimin criteria equation control) best fits the data and the results may be quite different from orthogonal rotation. From the writer's experimentation the SPSS default value of 0 is best accepted as it gives a fairly oblique correlated solution. In all cases rotation caused loadings (elemental associations) on factors to be better defined.

Factor analysis in this case was a step backwards and grossly inferior to the univariate interpretation carried out by a mental synthesis of the individual elemental maps referenced to each other and the geology. This failure is thought to be due primarily to the statistical computations not taking into account where a set of values forms a pattern in geological space, correlations being biased by value rather than pattern recognition within a geological entity as is done visually. The effects of inter-populations and intra-populations in the main geological entities in this case to, are possibly too
complex to be separated and any resulting associations are the major geological environments which is contrary to the writer's aims.

The SPSS computer program library is extremely user orientated and satisfactorily performs descriptive and inferential statistical analyses economically while the SYMAP package effectively creates for minimal cost, regional surfaces of any raw data or SPSS statistical outputs for pattern recognition and analysis. The negative aspect of factor analytical methods should not deter the user. Use of the more objective PCA SPSS pathway may reveal an elemental association (a factor) which when related to geology by plotting the factor scores by SYMAP and noting their distribution may generate a new exploration idea which could lead to an ore deposit.
SECTION D

ASPECTS OF INVESTIGATIONS OF LOCAL ANOMALIES AND REGIONAL PATTERNS

INTRODUCTION

Follow-up investigations of anomalies vary in both the level and scope of activity. These investigations are broadly:

(1) Confirmation and determination of the source of local and regional anomalies in line with conceptual target thinking on secured and unsecured ground.

(2) Prospecting for a specific commodity.
   This aspect being based in part on the recognition of geochemical/metallogenic provinces.

Aspects of the first investigations are discussed in this section through a series of case studies. Some old methods of geochemical prospecting are shown still to have a valid place in a modern integrated exploration programme. The latter investigation is discussed in Section E where an experiment is carried out to investigate the validity of drawing inferences from gross spatial patterns in macro-regional geochemical data and satellite photography.

1. FIELD INVESTIGATIONS

The actual physical process of follow-up was accomplished by sampling teams under the direction of professional staff (a geologist or the geochemist). The function of the teams was originally threefold:

(1) the follow-up of local and regionally anomalous patterns
(2) to provide internal contractual geochemical sampling services, and
(3) further sampling in areas of poor regional coverage.

After experimentation by the writer methods were evolved for the teams and this was applied to the field investigations.

...2.
1.1 Field Analytical Work

With the development of rapid analytical procedures amenable to mass production (e.g. atomic absorption spectrophotometry) field analytical procedures are no longer in vogue. However, a decision was taken to revamp well tried methods of geochemical prospecting because of the time limitations brought about by: project budgetary restraints, the great number of anomalies to examine in the field over a geographically large area, the short field reasons in areas of climatic extremes together with, in some cases, governmental regulations on tenancy of properties. The primary requisition of investigations is that a positive result should be obtained (i.e. the upgrading or downgrading on an anomaly) by the team before leaving the area.

The fundamental requirements of any field analytical technique that is going to be used by both trained geologists and semi-skilled field personnel alike are:

1. The method must be simple and have clear, step by step analytical instructions, which provide data that can be logged by the operator;

2. Must have inbuilt controls for precision and accuracy;

3. Must have non-bulky components for the field analytical work, i.e. having a kit format to fit into a small box of no more than 1.0 \( \times \) 0.5 \( \times \) 0.5m in dimensions.

Optional analytical schemes were designed to meet these objectives for the basic "bread and butter" commodity elements Cu, Ni, Pb and Zn. However the method for Pb is difficult due to the fading of dithizone and the use of considerable quantities of KCN, and since Pb generally occurs with Cu and Zn a specific method for this element was not deemed necessary. The following schemes were therefore adopted:

1. "Total" Heavy Metals (THM)
2. Hot acid extractable copper and zinc (Hx Cu, Hx Zn)
3. Hot acid extractable copper and nickel (Hx Cu, Hx Ni)
4. Cold acid extractable copper and zinc (cx Cu, cx Zn)
5. Cold acid extractable copper and nickel (cx Cu, cx Ni)
For simplicity all of the above are based on acid or buffer digestions rather than fusions. Fusions with alkali (KOH, NaOH), carbonate (Na$_2$CO$_3$), nitrate (KNO$_3$) or bisulphate (Na$_2$HSO$_4$) are difficult in that, correct mixing and proper fusion must be effected between the flux and sample. A separate pyrex tube is used for each fusion and often, from the writer's experience, this is troublesome in that a large proportion of the tubes shatter during cooling rendering solution of the "cake" a difficult task.

The analytical methods actually adapted are based on those published by Hawkes (1957); Gilbert (1959); Stanton and Coope (1958) and Ward, Larkin and Canney (1963). However, the methods have been simplified and a common digestion method based on 25% nitric acid adopted for "total" Hx Cu, Hx Ni and Hx Zn.

Near total extraction was obtained in certain cases by leaching samples overnight in cold 25% HNO$_3$. Cold extractable techniques using 2.5% nitric acid (cx Cu, cx Ni) and specific buffer solutions (cx Zn, cx THM) were also used. Appendix III.

A simple sheet on which to log the analytical work was evolved. In practice if an analytical scheme is selected, the log on completion of the analyses will look like Figure D1. Where possible duplicate and replicate analyses of samples are carried out. The bracketed results are tubes re-read at random after an analytical run of 50 samples. Precision (sampling and analytical, overall analytical, reading) is monitored by the simple graphical method of Thompson and Howarth (1973). Sampling and analytical precision (PSA %), overall analytical precision (PA %) and analytical reading precision (PAR %) can be quickly calculated graphically. Figure D2 compares the results of precision calculations for a typical batch of field and laboratory Hx Cu determinations.

The levels of precision for the field data (PSA 45%, PA 35%) are satisfactory when compared with the laboratory results. From experience, analytical reading is the greatest source of error in the field determinations and is at least half of the analytical precision. As an example, an analytical reading precision of 18% is cited for the preceeding Hx Cu determinations. For the "total" Hx Cu analytical reading precision results cited, interference of the colour of the organic phase by the high Fe content of
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<td>23</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>GA 7368</td>
<td>24</td>
<td>24</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>GA 4950</td>
<td>25</td>
<td>25</td>
<td>2</td>
<td>1.6</td>
</tr>
</tbody>
</table>

**CONCENTRATION (ppm) = \text{weight of matching standard (g)} \times \frac{\text{volume of sample solution (ml)}}{\text{ml aliquot taken (ml)}}**
**ANALYTICAL PRECISION**

- Field Analytical Precision
  - Cu, P<sub>A</sub> = 35%
- Laboratory Analytical Precision
  - Cu, P<sub>A</sub> = 12%

- In a set of duplicate measurements on many samples, 90% of the points will fall below the diagonal appropriate to the precision of the measurements at the 95% confidence limits.

**SAMPLING-ANALYTICAL PRECISION**

- Field Sampling-Analytical Precision
  - Cu, P<sub>LA</sub> = 45%
- Laboratory Sampling-Analytical Precision
  - Cu, P<sub>LA</sub> = 18%

**PRECISION CONTROL CHART**

*After Thompson and Howarth (1973)*

Fig. D2
FIELD ANALYTICAL FLOW SHEET

SIEVED SEDIMENTS
or
SOIL SAMPLES

DIGESTED SAMPLES
25 gms - 175 mm
2 ml 25% HNO₃
1 hour digestion
Top to 10 ml's with H₂O

Cu
READING TUBES
2 mls sample solution
5 mls Cu buffer
1 ml Biquinoline

Ni
READING TUBES
1 ml sample solution
5 ml Ni buffer
1 ml furilidione

COMPARISON WITH
Cu STANDARDS

COMPARISON WITH
Ni STANDARDS

RECORD RESULTS ON SHEET
CALCULATE Cu & Ni VALUES IN ppm
If results greater than standards repeat procedure with half aliquots of sample solution

ANALYSES OF DUPLICATE SAMPLES
(10% of samples for Sampling Precision)

PLOTTING ON PRECISION
CONTROL SHEETS

Cu &/or Ni ANALYSES
REPLICATE ANALYSES
of SIEVED SEDIMENTS
or SOIL SAMPLES
(10% of samples for Analytical Precision)
(Graphical method of Thompson B Howarth)
1) Sampling Precision read off
2) Analytical Precision read off
3) Reading Precision read off

REREADING ANALYSIS
(for Reading Precision)

VISUAL PRESENTATION OF RESULTS
By sized circles for ranges of values on overlays to sample location sheet

CORRECTION OF TECHNIQUES
WHERE NECESSARY

FOLLOW UP OF OBVIOUS
ANOMALIES

Fig. D 3
the samples was probably the major cause of the imprecision. This effect was found to be critical below 30 ppm Cu when high Fe caused the shades of pink to become grey and reading accuracy was therefore impaired. Masking and interference of colours in the organic phase is a common problem. Other factors contributing to the general overall analytical precision are the substitution of a measured volume of sample by using a scoop for an actual sample weight, and the variable strength and amount of reagent solutions caused by inaccuracies in volumetric measurement at various stages in the determination.

The sampling team members (two persons) were generally chosen on their past capabilities in mineral exploration work. The individuals in the team were semi-skilled and of average intelligence, education was generally to the third or fourth year level of secondary schooling. The ideal team is composed of a person with a leaning towards the direct physical prospecting side of the work, and a "book keeper", who can accurately and diligently record field and analytical results in note and map form. Both individuals should be competent and practical in mechanical and bush matters. The teams received their initial tuition in geochemical prospecting by analysing "training sets" of minus 175 micron stream sediment material gathered from active or defunct exploration projects. Besides learning the rudiments of field analytical work they were taught to plot their analytical results in terms of simple ranged circles, to recognise dispersion trains, and spot high results. Recognition of either of these two features imply that more detailed sampling (streams, bank, soil, rock) coupled by a search for mineralisation (i.e. gossans) would be required before leaving the area for work elsewhere. Figure D3 summarises the established procedure for field analytical work. Geochemical staff working with the team in the field completed the training. It should be noted that all samples collected and subjected to field analytical work are later analysed by a custom laboratory under standardised conditions.

1.2 Case Studies

The following 5 case examples attempt to illustrate the effectiveness of a variety of field analytical work conducted under differing physiographic and climatic regimes.
Climatic zones are based on the map Climatic Regions in the Atlas of Australian Resources (Dept. of National Development 1954). Coastal Zones are not shown.

AUSTRALIA
CLIMATIC ZONES AND CASE STUDY AREAS

Fig. D4
Case 1: Hot Dry Tropical Interior - cx Cu/Hx Cu
Case 2: Dry Temperate Interior - Hx Cu/Hx Ni
Case 3: Temperate Highlands - Hx Cu/Hx Zn
Case 4: Coastal Highlands - Total Heavy Metal
Case 5: Alpine Mountain Type - Total Heavy Metal

The disposition of the study areas may be seen in Figure D4. This figure, and the definitions of climatic regions as shown, was compiled by the Department of Meteorology, Commonwealth of Australia and is not intended to replace those existing systems which classify the Australian climate according to world wide subdivisions.

CASE 1: HOT DRY TROPICAL INTERIOR

The area of interest lies in the Hamersley Ranges in the Pilbara Region of northwest Western Australia.

A dry, hot tropical climate of the interior prevails. Figure D5 outlines typical climatic statistics for the area. The mean annual rainfall is less than 400 mm falling, on average, on 41 days of the year. Heavy falls of rain occur during the summer months from northern tropical cyclonic systems. A small amount of rain falls in the winter months as the region is mildly under the influence of the southern systems which bring winter rains to the southern portion of the state. Evaporation far exceeds precipitation and is greater than 2300 mm per annum. Temperatures are high all year round. In the summer months, mean daily temperatures peak in January at 40°C maximum and 26°C minimum. Winter months are milder with the lowest mean daily temperatures of 24°C maximum and 11°C minimum falling in the month of July.

The major topographic features have resulted from differential erosion of folded sediments and volcanics. Relief, from plain to hilltop, may be as much as 600m with the plain area usually lying about 200m above sea level. The immediate area of interest is highly dissected, with the course of the largest "river" Turee Creek traversing gorges. Rivers and creeks are ephemeral in nature and flow intermittently during the west season, and for the remainder of the year are generally dry. Occasionally the larger "rivers" such as Turee Creek have isolated pools and rock holes separated by sand and shingle during the dry period. (Figure D6).
**WITTENOOM**  
**ELEVATION 460.2 M**

Data compiled from Raw Data, Bureau of Meteorology.

**TROPICAL INTERIOR CLIMATIC STATISTICS**

*Fig. D5*

**TYPICAL SCENERY IN THE CASE STUDY AREA**

*Fig. D6*
**CASE STUDY I**

**SKETCH MAP**

- **Marra Mamba iron formation**
- **Jeerinah formation**
- **Original regional sample**
- **Stream sediment sample - follow up (~175mm³)**
- **Rock chip sample**
- **NA** No analytical result

**ORIENTATION AREA**

**TROPICAL INTERIOR**

**Fig. D7**
OUTCROP - Block mineralized pod

OUTCROP - Cherty laminated shale

Mineralized and bleached shale zone - 120 m.

LEGEND

- Marra Mamba iron formation
- Jeerinah formation
- Original regional sample
- Stream sediment sample - follow up (175 mm³)
- Rock chip sample

ORIENTATION AREA
TROPICAL INTERIOR
CASE STUDY I

Hx Co / Hx Pb / Hx Zn Lab. A.A.S.
Vegetation is confined to spinifex grass and shrubs with larger eucalypts and acacias confined to the water courses. Soils in the area are thin and skeletal.

The general area of interest is underlain by the Proterozoic Marra Mamba Iron Formation (Hamersley Group) which rests conformably on cherts and pyritic shales intruded by doleritic sills of the Jeerinah Formation (Fortescue Group). Remnants of the old Tertiary Hamersley Surface are represented by laterite which is underlain by the sediments and volcanics.

From the interpretation of a number of 1:250,000 sheets covering the region, distinct Cu anomalies were noted to be associated with the Jeerinah Formation in the Hamersley Basin. It was therefore decided to investigate ten regional anomalies, to assess the potential of the formation as a target for detailed exploration for copper mineralisation. The writer's investigation was carried out by reconnaissance geological mapping of anomalous basins and further stream sediment sampling guided by field analytical work.

At this stage field analytical work had not been carried out. From a published map a small Cu showing was noted to occur in the general area in a geological environment that was similar to that in which the regional anomalies occur, thereby making it an ideal location for a geochemical orientation survey with the field analytical kit. Geological information from observations on the mineralisation would lead to implications being made on both the style and possible exploration targets in the area.

The copper mineralisation was examined before carrying out the geochemical orientation. Stratiform mineralisation was found in a 120 m wide kaolinised zone in cherty shale containing spheroidal limonite after pyrite. Malachite, sooty pyrolusite, haematitic limonite and gypsum were present. The mineralisation was best seen in a few old prospecting pits and was probably the result of the oxidation of a primary pyrite-chalcopyrite assemblage with the attendant release of sulphuric acid causing chemical alteration of the shale. Gypsum and calcrite products at the surface pointed to the strong possibility that the shale was calcareous or dolomitic in depth. The occurrence itself appeared to be both stratigraphically and structurally controlled, with the mineralisation present on bedding planes.
while the occurrence itself was localised in a small flexure. Figure D7 outlines the geological setting and the original Cu geochemical results over the occurrence. From Figure D7 it can be seen that the mineralisation is expressed in the original regional data, albeit rather subtly. A value of 60 ppm Cu is recorded on the southern arm of Turee Creek which cuts the mineralised zone compared with a background value of 39 ppm Cu some 500 m north of the occurrence. Both creeks are of the same size and stream order.

Seventeen samples were collected in the area and covered both mineralised and background situations. Cold extractable 2.5% HNO$_3$ and hot 25% HNO$_3$ extractable field colorimetric copper determinations were made on the minus 175 micron fractions of the active stream sediment sample collected as per the field analytical methods outlined in Appendix B. These samples were subsequently analysed by a custom laboratory for Cu, Co, Pb, Zn by atomic absorption spectrophotometry (AAS) after a hot 60% HClO$_4$ digestion at 180°C for one hour. The laboratory Cu is compared with the field results in Figure D7 while the remaining Co, Pb, Zn results are found in Figure D8.

A good correspondence is evident between both the field and laboratory data. The anomalous values from the very small creek draining the mineralisation are quickly drowned by the large southern arm of Turee Creek. The original subtle anomaly on the major drainage noted in the original data is again evident in both the field and laboratory determinations. A reasonable reproducibility of the original regional site values is also evident in the subsequent laboratory analyses of the resampled "original" sites.

After verification of the applicability of the field kit, an anomalous basin some distance from the orientation area was investigated. From aerial photographs extensive dolerite sills were suspected to intrude the sedimentary sequence in the basin. It was therefore decided to extend the orientation and use both the cold extractable and hot Cu field analytical work to ascertain which method best differentiated mineralised pyritic sediments from the interbedded doleritic sills. The remaining 9 basins in the field programme would be investigated by using the most effective digestion method.
REGIONAL ANOMALY
TROPICAL INTERIOR
CASE STUDY I

LEGEND

- Colluvial and laterised gravels
- Robe pisolite
- Morra Mamba iron formation
- Jeerinah formation - undifferentiated
- Original regional sample
- Stream sediment sample - follow up (−175mm)
- No analytical result
- Rock chip sample

Field Hx Cu/Field Cx Cu/Lab Hx Cu A.A.S.

SKETCH MAP
Colluvial and laterised gravels
Robe pisolite
Marra Mamba iron formation
Jeerinah formation - undifferentiated
Original regional sample
Stream sediment sample - follow up (-175mm*)
Rock chip sample

REGIONAL ANOMALY
TROPICAL INTERIOR
CASE STUDY I

Fig. D10
In the regionally anomalous 80 km$^2$ drainage basin, severe dissection of the Jeerinah Formation and Marra Mamba Iron Formation had produced a rugged terrain of overhanging cliffs and gorges. The Jeerinah Formation as suspected was dominated by large dolerite sills with some interbedded sediments. Erosion of areas underlain by sediments had produced steep sided amphitheatre "breakaway" topography. The 42 stream samples taken in the follow-up were limited to the southern two thirds of the basin because of inaccessibility due to the extensive dolerite sills (refer Figure D9).

Anomalous field cx and field Hx Cu values were found on creeks in three breakaway areas. Figure D9. The floors of the "breakaways" are areas of white kaolinised shales containing brown iron oxides in remnant pyrite pits. However, further detailed prospecting led to the find of malachite float in scree at the foot of the wall of one of the western breakaways. A small pit was dug into the scree and revealed malachite mineralisation in kaolinised sediment. A grab sample ran 5.5% Cu. At a nose in the breakaway further Cu mineralisation was found in cherty shale containing spheroidal limonite pseudomorphs, in partly silicified black carbonaceous shale and grey red siltstone. The mineralisation in the siltstone was present along the bedding planes and in small pisoliths. A sample of the siltstone over 0.3m ran 3.0% Cu. Above the flat dipping siltstone, a thick gossanous ironstone was present. This gossanous material was thought to represent the oxidised expression of a massive pyrite bed. Two samples ran 780 and 1 500 ppm Cu. Investigations of the other anomalous areas failed to reveal further copper mineralisation.

The laboratory results for hot perchloric Cu, Co, Pb and Zn confirmed the field analytical work and the original interest in the area. (Figure D10). Of interest again is a comparison of the original Cu, Co, Pb and Zn results with the resampling data. Cu originally ran 115 ppm compared with 120 ppm, Co ran 35 ppm compared with 64 ppm, Pb ran 30 ppm compared with 42 ppm and Zn ran 195 ppm compared with 210 ppm. With the exception of Co, and to some extent Pb, sample site reproducibility is good.

Both cold extractable and hot field Cu similarly satisfactorily discriminate mineralised pyritic shale from dolerite by two orders of magnitude. The same feature applies to the laboratory Cu results. The decision to use...
the cold extractable copper technique for the rest of the programme was made based upon the rapidity of the cold extractable method in comparison with hot determinations.

CASE 2: DRY TEMPERATE INTERIOR

This example comes from the Eastern Goldfields Province of Western Australia and illustrates aspects of the search for copper-nickel mineralisation in a "greenstone" belt.

The case area experiences a dry temperate climate of the interior with a maximum rainfall in the winter months. The climatic figures summarised in Figure D11 are typical of the area. The mean annual rainfall of 279 mm falls on an average of 68 days per annum with a distinctive maximum in the winter months of June and July. Evaporation far exceeds precipitation and is greater than 2,200 mm per annum. Temperatures vary markedly with the seasons. In the summer, the average monthly temperatures peak in January at 35°C maximum and 18°C minimum. Winter months are cooler and milder with the lowest mean daily temperatures occurring in July at 16°C maximum and 4°C minimum.

The topography is subdued being part of the physiographic subdivision of Western Australia called "Salinaland". One of the characteristics of the area is the occurrence of remnants of an "old" plateau surface which stands as a series of north-south trending hills and ridges rising to 400m above sea level. Steep cliffs ("breakaways") up to 40 m in height separate the old plateau surface from a new land surface, the "new" plateau. A great number of small salt encrusted playa lakes (salinas) form a part of the landscape of the new plateau. These are prevalent in the southern portion of the study area. Drainage over the case area is restricted to intermittent ephemeral streams that only run from the upland areas after heavy rains, and then diffuse themselves on the surrounding plain, or enter local basins of internal drainage, (i.e. the playa lakes).

Salmon gums and sandalwood strands are found on the open country while mulga scrub dominates the upland area. Grass is usually absent, but due to the unseasonal weather at the time of sampling, grass had sprung up in the bare spaces between the xerophytic shrubs and trees. (Figure D12).
DRY TEMPERATE INTERIOR CLIMATIC STATISTICS

SOUTHERN CROSS  356.6M

Complied from Raw Data - Bureau of Meteorology

TYPICAL SCENERY IN THE CASE STUDY AREA
Soils are variable, ranging from lateritic podsol to solonised brown soils on the old and new plateau surfaces respectively.

The geology of the "greenstone" belt consists of two rock associations, mafic to ultramafic extrusive and intrusive volcanics (I) and sediments (II) (Figure D13). Tholeiittic basalts and ultramafics of the high magnesian suite (serpentinite, chlorite-tremolite rocks) dominate the mafic-ultramafic association, while shale, siltstone, minor conglomerate, banded iron formation and chert comprise the sedimentary association. The two associations have probably stratigraphic significance because most workers in the Eastern Goldfields Province have placed the mafic-ultramafic association beneath the sediments, (Williams 1970). Regional metamorphism of lower amphibolite facies has affected the belt.

Small scale gold mining activity has occurred at Baker, Ryans Find, Little Nipper and Boucher in the southern portion of the area.

From the gross 1 : 250,000 sheet statistics for the stream sediments, two regional anomalous areas were recognised. These were a copper, nickel rich location in the Norton Dam area (A) and a copper, nickel, lead, bismuth, manganese, cobalt location in the Mt. Walter area (B). Both of these areas are annotated on Figure D13. The copper-nickel anomaly was thought to be probably associated with gabbroic rock types in the "greenstone" belt and was given an A rating for follow-up work. The remaining anomaly at Mt Walter was thought to be related to drainage effects and was not afforded a rating for follow-up. From research of company files in the Western Australian Mines Department little could be ascertained on past base metal exploration in the area. Past activity as previously stated was restricted to small scale gold mining.

In the course of the follow-up investigation a decision was taken to examine the belt more closely with further regional drainage sampling, and prospecting by seeking gossans in the magnetic anomalies in the mafic and ultramafic volcanics of the sequence. These are marked MM on the total intensity magnetic map in Figure D13. A linear block of country of some 700 km$^2$ was subsequently examined and sampled. Stream samples at a density of one sample per 8 km$^2$ were taken in the course of prospecting. Field hot copper and nickel determinations were carried out on the minus ...11.
AREA A

ultramafic rocks

AREA C

ultramafic float 220/825/470/455

laterite 95/75/20/35

Norton Dam

100/100

148/91/21/41

117/100/20/34

95/410

Track

0  2  3  4 km

O Original Regional site . . . . . . . . . . . . . . . Laboratory Cu/Ni ppm
O Stream sediment sample, first scan . . . . Field Cu/Ni ppm
● Stream sediment sample, follow-up . . . Laboratory Cu/Ni/Pb/Zn ppm
X Rock chip sample . . . . . . . . . . . . . . . . Laboratory Cu/Ni/Pb/Zn ppm

REGIONAL ANOMALIES
DRY TEMPERATE INTERIOR - CASE STUDY 2

Fig. D14
175 micron fraction to guide further sampling and systematic prospecting. All samples collected and analysed in the field were subsequently analysed by a custom laboratory for Cu, Ni, Pb and Zn by atomic absorption spectro-photometry following a hot 60% perchloric acid digestion. The results of the regional field hot Cu and Ni analytical work, and the laboratory Cu and Ni, Pb and Zn may be seen in Figure D13.

The Norton Dam copper and nickel anomaly was confirmed by the field results in the course of the regional sampling. Further follow-up work is presented in Figure D14. Deeply weathered, and in part lateritised, serpentinite and amphibolite were noted in the area. A careful gossan search revealed no evidence of mineralisation. One sample collected appeared gossanous, but subsequent petrographic and chemical analysis confirmed it to be lateritic in origin. Rock chips collected and analysed adequately demonstrated both this regional anomaly, and one to the southwest, as being due to high background situations in the volcanic pile.

In the course of prospecting, further attention was drawn to the interesting magnetic anomaly MM by the coincidence of the anomalous Cu and Ni results marked C in Figure D13. Field Hx Cu and Hx Ni values of 95 and 410 ppm respectively were recorded here. The laboratory results of 108 and 329 ppm Cu and Ni confirmed the area's interest. Unfortunately much of the regional magnetic anomaly's strike could not be covered due to the lack of drainage. However, the anomalous area itself was prospected and the source of the anomaly found to be a weakly mineralised mafic-ultramafic contact situation which had previously been systematically gridded and percussion drilled. (Area C Figure D14). Panning of cuttings revealed the presence of pyrite and pyrrhotite. The concentrates, assayed in the field, ran 200+ ppm Cu and 1000+ ppm Ni. Subsequent laboratory analysis of selected chips ran 205 ppm and 3200 ppm Cu and Ni respectively. Ground search in the thick mulga scrub along the southern strike portion of the magnetic anomaly, which is devoid of drainage cover, revealed further old gridding and costeaming. The contact area appeared to have been adequately tested and no further work was carried out.

One copper anomaly (D) was examined before leaving the area. The results of field Cu and Ni peaked here at 90 and 100 ppm respectively. The source of the anomaly was underlain by rocks of the sedimentary association. Follow-up revealed that the drainage basin was underlain by weathered ...D12.
<table>
<thead>
<tr>
<th>Original Regional Site</th>
<th>Resampled Site</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
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<td>Cu  95  Ni  209 Pb  16 Zn  35</td>
<td>Original regional anomaly</td>
</tr>
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<td>50  70  24  27</td>
<td>54  119  19  41</td>
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<td>55  135  30  43</td>
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</tbody>
</table>

Table DJ Regional Resampled Sites - Case Study Two
pyritic shale, chert and iron formation. The source of the anomaly was suspected to be the weathered pyritic shale. Zinc is enhanced with Cu in the laboratory results and supports this opinion.

The drainage anomaly noted in the Mt Walter area (B), and considered a probable drainage effect, is prominent again in the laboratory Pb results. Pb peaks at 40 ppm in a poorly defined wash in granitic terrain.

The analytical results of resampling at the approximate regional sampling sites can be seen in Table D1.

From these few resampled sites, there appears to be a fair comparison between the data sets obtained even though another commercial laboratory (using the same digestion and analytical method) had analysed the new data set. Generally speaking, the gross regional pattern that drew attention to the area, and gave rise to the follow-up programme is well reflected in the new data set.

CASE 3: COASTAL HIGHLANDS

This example comes from northeastern Tasmania and illustrates a field investigation of a polymetallic anomaly. From very early limited spectrographic scan data a Cu, Pb, Zn, Sn, W anomaly of 800, 200, 200, 2000 and 800 ppm respectively was present in the stream sediment results. The high order results suggested a local origin in an immediate area of 300 km² and did not appear to reflect contamination from mineralisation being mined some 30 km to the northeast of the anomaly.

The case area experiences a cool mild temperate climate. Climatic figures summarised in Figure D15 are typical of the area. The mean annual rainfall approximates 950 mm with precipitation falling throughout the year. However, a distinctive maximum rainfall (with occasional snow) occurs in the winter months of June and July. Evaporation is less than precipitation and averages 850 mm per annum. Temperatures are cool to mild the year round. Summers are short, and cool with maximum and minimum average monthly temperatures peaking at 21°C and 8°C respectively in January, while average monthly maximum and minimum temperatures in the cold wet winters are 9°C and 0.5°C in the month of July.
The area rises steeply from the South Esk River Valley at 200m above sea level to a highly dissected plateau at 800m above sea level. The present topography is a result of major block faulting in late Tertiary times. A youthful drainage pattern has incised the underlying geology. (Figure D16).

Various types of large eucalypts with, in parts, an undergrowth of ti-tree, wattle and scrub cover the area. Thin brown podsolic soils are present.

The area of geochemical interest is mainly underlain by Devonian granite of a similar type to the Ben Lomond Batholith to the north of the case area. The granite is a potassic leucogranite, and is generally coarse grained, porphyritic and pale cream to pinkish in colour. Masses of tourmaline are common in the granite, especially in the vicinity of the tongues and sills of microgranite and aplite that intrude the granite. These intrusives appear to be late differentiates of the main batholith and outside the area are frequently greisened and carry cassiterite, wolframite and miscellaneous sulphides. Remnants of basement Silurian (?) siltstone, greywacke and shales (Mathinna Beds) are present. Regionally the basement was folded along northwesterly axes during the Tabberabera Orogeny and intruded by the Ben Lomond Granite. Peneplanation occurred followed by the deposition of Permian and Triassic sediments and Jurassic sheet dolerite. The remnant outcrop areas of Permian (?) sediments are only found in the immediate area of interest.

The anomaly was examined initially in two stages because of natural work breaks in the summer field season. This feature is reflected in the geochemistry (See Figure D17). Stage one samples were collected and analysed by the field team and the writer for their total heavy metal contents, in order to confirm the original anomaly. This work was successful and defined three basins as anomalous with peak values originating from the central drainage, Rosier Creek. While the team was on leave, Cu, Pb, Zn, Sn and W analyses were carried out on the minus 175 micron fraction by a custom laboratory and these data confirmed the anomaly. Cu, Pb and Zn peaked at 660, 32 and 640 ppm respectively on Rosier Creek and Sn, W at 1120 and 343 ppm respectively on Gilligans Creek. Cu, Pb and Zn were determined by atomic absorption spectrophotometry after a hot 60% perchloric acid digestion, while Sn and W were determined on a pressed powder mount by x-ray fluorescence.
A return visit was later made to the area to examine the anomalies more closely. Rosier Creek was investigated first by both taking and testing active stream sediments at approximately 400m intervals for the 4 to 5 km of the drainage and by noting the geology. The field kit did not at first confirm the original findings until halfway up the drainage. A highly anomalous area was eventually defined in the headwaters of Rosier Creek and sulphide float was found. Similar situations were found in the adjacent eastern (Gilligans Creek) and western drainage basins. A drainage basin northwest of Avoca which had a laboratory Cu high was also investigated. The original field work had shown this to be background. Field investigation here reconfirmed the original work.

The follow-up field samples were again sent to the same laboratory for Cu, Pb, Zn, Sn, W analyses. These results in general confirmed the stage two field work. There is though an explainable difference in the base metal and total heavy metal patterns. The total heavy metal pattern reflects the Pb, Zn geochemistry and the possible presence of sulphides (Rosier Creek), while on Gilligans Creek low order heavy metal results are coincident with peak Sn and W results suggesting a different type of mineralisation (cassiterite). Of concern, however, is the obvious difference in the results between the original first and second stage samples. The grossly higher first scan samples were reanalysed and the original results confirmed. To eliminate laboratory bias, the samples were checked by another laboratory. The results were again confirmed. The initial high Cu results and highly anomalous Sn and W results on Rosier, Gilligans and Western Creeks are inexplicable. It is suggested that incorrect sampling by the field team (taking slumped bank material) may be the cause of the enigma. An exploration licence was granted by the Mines Department and further detailed work carried out by the operating division.

CASE 4: ALPINE MOUNTAIN

The case originates from the follow-up of one of a series of regional base metal anomalies noted in southeastern Victoria in the lower portion of the rugged Snowy Mountains.

...15.
BENDOC FORESTRY STATION  
ELEVATION 914.4 M

ALPINE MOUNTAIN CLIMATIC STATISTICS

Fig. D18

TYPICAL SCENERY IN THE CASE STUDY AREA

Fig. D19
FIELD
TOTAL SAMPLE - COLORIMETRIC
- Total Heavy Metals in dithizone
- Cu 25% HNO₃
- Hx 25% HNO₃
- Cu ppm

LABORATORY
- 175mm HClO₄ AAS
  - Cu ppm
  - Pb ppm
  - Zn ppm

REFERENCE
- Manganiferous Ironstones
- Alteration Zone - strong
- Alteration Zone - weak
- Quartz-rhombohedral diorite
- Mudstones, Shales
- Lochian Coves
- Snowy River Volcanics
- Wombat Creek Group
- Shale, Sandstone
- Total Heavy Metals in dithizone
- Cu/Pb/Zn - HClO₄ Digestion / AAS
- Original regional anomalous sample
- Soil Traverse
- Mine

ALPINE MOUNTAIN
CASE STUDY 4

Fig. D20
Climatically, the Alpine area within short distances experiences a great diversity of climate because of the extremes in topography. The area of direct interest is really sub-alpine in nature (See climatic statistics Figure D18). Snow does occur, but falls persist only for a few days. Frosts are common and the area is subjected to cloud and fog. Low pressure systems from the southeast bring rainfall at any time throughout the year, though there is a distinct peak in the summer months. Snow falls are only brought from cold fronts of western origin.

The area averages some 815 mm of rainfall per annum. In the summer months maximum and minimum temperatures peak in February at 25.4°C and 13.2°C respectively, while in the winter month of July maximum and minimum temperatures of 9.1°C and -2.4°C are recorded.

The area is covered in wet open eucalypt forest containing stringybark, silvertop and mountain gum with heath, shrubs and wattle on the forest floor. "Jungle" filled water-courses are common. Soils in the area are stony red-yellow loamy podsol. (Figure D19).

Topographically the area ranges from 600 to 1100m in elevation and is characterised by rounded ridges and spurs that rise from well incised valleys.

The case area is underlain by a faulted sequence of sediments and volcanics belonging to the base metal prospective early Palaeozoic Lachlan Geosyncline. (Refer Figure D20). The oldest mapped unit in the area is the Silurian Wombat Creek Group (sandstone and shale) which is, in turn, overlain by Devonian Snowy River Volcanics (tuffs, pyroclastics, rhyodacite), Buchan Group (fossiliferous limestone and dolomite) and Taravale Formation (mudstone, shales). A quartz, hornblende diorite of Devonian age has intruded the sequence.

Due to access a regional Cu, Pb anomaly (105, 160 ppm) was followed up by the writer using on-site heavy metal analytical work with regional mapping. Confirmatory laboratory analytical work was again carried out on the minus 175 micron fraction for Cu, Pb, Zn after a hot 60% perchloric acid digestion. (See Figure D20). The anomalous creek was quickly discerned with reference to two adjacent background situations (10 ml Dz versus 4, 3 ml Dz) and was followed to its first major junction.

...16.
Here both drainages were still anomalous (8, 13 ml Dz). The western drainage (8 ml Dz) was followed up first as float of "ironstone" gossanous material was found in the creek. The drainage led to a series of exotic manganiferous ironstones in limestone. The headwaters of the creek still appear to be high in the field results (12, 9 ml Dz), but these values after prospecting were thought to reflect a fault and underlying tuffs. Subsequent laboratory analyses of the samples confirmed these field observations.

The remaining anomalous drainage (13 ml Dz) was also followed up. The intensity of the anomaly increased and readings went off scale (i.e. greater than 16 ml Dz) as the headwaters were approached. A visual comparison of colour intensity was made until a cut-off was obtained in the drainage, i.e. a value of 16+++ falling to 6 ml Dz. A bank search was initiated in the dense scrub and a large alteration zone in pyritised tuffs and rhyodacite was recognised. Gossanous looking rhyodacite assayed for Cu, Pb and Zn, 240, 38 and 76 ppm respectively.

A 480 m soil traverse line was run across the alteration zone. Samples of the C horizon were taken at 30 m intervals with a mattock and the unsieved material analysed in the field for total heavy metals (T.H.M.). Four T.H.M. peaks were discernible along the traverse. This was later verified by the field hot 25% HNO₃, and cold extractable 2.5% HNO₃ Cu work carried out that night, and the subsequent laboratory analysis for Cu, Pb, Zn on the minus 175 micron soil fraction after a hot 60% HClO₄ digestion (See Figure D20). There appear to be distinctive metal/alteration associations with the peaks, i.e. at peak A, field T.H.M. -Hx Cu-cxCu is coincident with laboratory Zn-Cu and weak alteration; at peak B, field T.H.M. is coincident with laboratory Cu and fringe alteration; at peak C, field T.H.M. -HxCu-cxCu is coincident with laboratory Pb-Cu-(Zn) and strong alteration; and at peak D a field T.H.M. coincident with laboratory Pb and no alteration. Prospecting was therefore initiated along strike north and south of the elongate alteration zone cut by the stream.

A very small adit was found to the south of the stream, hidden in scrub near the top of a ridge. Mineralisation noted in dump material was fine grained chalcopyrite, pyrite and galena in quartz veining. The mineralisation appeared to be of hydrothermal origin, and located in a west-northwest shear in altered tuff-rhyodacite. Granite was located a further 600 m south...
of the adit. Selected rock samples collected and identified at the adit environs assayed as follows:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineralised quartz</td>
<td>3400 ppm</td>
<td>1700 ppm</td>
<td>560 ppm</td>
</tr>
<tr>
<td>Quartz veined rhyodacite</td>
<td>1300 ppm</td>
<td>280 ppm</td>
<td>920 ppm</td>
</tr>
<tr>
<td>Silicified tuff</td>
<td>18 ppm</td>
<td>24 ppm</td>
<td>4 ppm</td>
</tr>
</tbody>
</table>

The evidence of the style and tenor of mineralisation located near the top of the ridge, together with the soil traverse results, pointed to another possible hydrothermal mineralised vein situation related to shearing as being the source of the regional anomaly. The anomaly as such was therefore downgraded as a target for further exploratory work.

However, while prospecting north of the alteration zone further stream sediments were discovered to be anomalous in total heavy metal, and on subsequent laboratory analysis for Pb and Zn. Detailed field examination here revealed massive manganiferous lenses in tuffs containing the minerals pyrolusite and psilomelane. This manganiferous material had weak Cu (< 106 ppm), strong Zn (< 1%) and Pb (< 400 ppm) values thereby adequately explaining the drainage response. The lenses probably represented bog ores precipitated in shallow lakes formed on the exposed tuff bed.

CASE 5: TEMPERATE HIGHLAND

The final case comes from north-central Victoria and illustrates a geochemical failure in the sense that the regional anomalous value could not be repeated or explained.

The area experiences a temperate highland climate with a distinct winter rainfall. Annual precipitation is some 570 mm falling on an average of 90 days of the year. Summers are warm, with mean monthly maximum and minimum temperatures peaking in February at 29.0°C and 14.4°C respectively. Winters are generally mild with the lowest mean monthly maximum and minimum temperatures occurring in July at 12.5°C and 2.3°C respectively, (Figure 21).

Where the land is not cleared for pasture, medium to scattered dry eucalypt forest composed of ironbark, box gum and wattle cover the area. Heath, small shrubs and grass undergrowth are found on the forest floor. Generally
HEATHCOTE P.O.  ELEVATION 220.1m

Compiled from Raw Data - Bureau of Meteorology

TEMPERATE HIGHLAND CLIMATIC STATISTICS

Mean Monthly Maximum Temperature °C
Mean Monthly Minimum Temperature °C
Mean Monthly Rainfall (mm)
Mean Monthly number of rainy days

Mean Annual
20.2
7.6
573
90

TYPICAL SCENERY IN THE CASE STUDY AREA
the crowns of the hills have the densest vegetational cover. Greybrown podsolic soils are present in the area away from the alluvium filled valleys.

Topographically the area is one of rolling hills with wide, alluviated main valleys. Extremes of elevation are not present. Elevations range from 180 m in the valleys to no more than 300 m on the highest hill top. (Figure D22).

The geology of the area is shown in Figure D23. The oldest formation in the sampled area is the Silurian (Llandoverian) Costerfield Formation. The formation is confined to the Costerfield Dome and consists characteristically of black siltstones and mudstones. Rocks of the Silurian (Ludlovian) Dargile Formation surround the dome and consist of sandstones and mudstones. The Lower Devonian Broadford and Puckapunyal Formations are in faulted contact with the Silurian sediments in the eastern portion of the area, while the McIvor Formation in the west is conformable with the Dargile Formation. These formations consist of siltstones and interbedded sandstones, with occasional greywacke and conglomerates. Pliocene-Pleistocene silts of the Shepparton Formation are preserved along the flanks of the drainages east of the Costerfield Dome. The creeks here have recently down-cut into the formation to expose up to 10-12 m of silts. The silts resemble loess deposits and a reddish brown soil profile has developed on the formation.

The major structural features are the Costerfield and Moorimbool Faults which occur to the east of the Costerfield Dome and form two arcs which are convex towards the west.

Antimony and gold has been mined from small structurally controlled quartz reefs at Costerfield, South Costerfield, and in the Red Castle area 10-14 km to the north.

A regional sample collected on Wappentake Creek ran 200 ppm Cu, 30 ppm Pb and 270 ppm Zn. The sample appeared to have its source from the old antimony-gold mining area. However, the simple mineralogy of the ore possibly excluded the anomalous values (especially the Cu) being derived from the old workings. As the anomaly was confirmed by reanalysis, field investigations were instituted by regional mapping and collecting active stream sediments at a density of one sample per 2.5 km² and analysing the minus 175 micron
fraction in the field for HxCu and HxZn by colorimetry. The field results are compared with the subsequent laboratory total (hot 60% HClO₄) Cu and Zn results in Figure D23. Unfortunately in this case the new Zn standard solution obtained was too acid and bleached the dithizone making a standard Zn colour series impossible to read. Therefore all HxZn results are based on ml of dithizone (Dz) added to a 2 ml aliquot of digestant.

The HxCu and HxZn field results are generally low. Difficulty was experienced in reading the colours of the low Cu results because of the high iron content of the samples. The only copper responses were obtained in seven samples. Three of these (4, 6, 18 ppm) were taken at Costerfield from the creek below the old mining area, while on Wappentake Creek a value of 10 ppm Cu coincides with low order zinc.

The highest Zn values have been marked on Figure D23. Two samples to the north in Garden Hut Creek ran 9 and 7 ml Dz respectively. One was located immediately downstream from workings, while the other was taken from below a gossanous quartz bar which is possibly associated with the Moorimbool Fault. Minor diggings occur adjacent to the creek. A sample at Costerfield itself ran 5 ml Dz. High results for both copper and zinc were expected for this sample as it was collected immediately downstream from tailings and old mine plant. In Wappentake Creek itself samples show enhanced values of 4 to 10 ml Dz. Geological structure and outcrop in the area are favourable for mineralisation and are possibly a cause for the enhanced Zn geochemical values. A swarm of parallel quartz veinlets individually up to 20 mm wide were observed here striking at 160° Mag. and dipping to the east at 59°.

The 10 ml Dz value and the generally higher than background values obtained in the vicinity have not as yet been really satisfactorily explained. There is no Devonian or Silurian outcrop in the creek in the immediate area, the creek being flanked by the Pliocene-Pleistocene Shepparton Formation. The high values could possibly be derived from this source.

Samples taken at the site of the original anomalous sample did not show any significant result, though there is general enhancement of Zn in the immediate vicinity.

The laboratory values confirm the generally low order field results, and the observations made. The highest Cu and Zn results are related to tailings,
1.e. Cu 20-25 ppm and Zn 70-410 ppm. The values for zinc and copper for the original regional sample site were in this case not confirmed, even though the original sample, when reanalysed, was still highly anomalous. No indication of a source for the anomaly could be found. Devonian and Silurian sediments do not outcrop in the vicinity of the sample site.

Copper and zinc values showing a higher than background level of response in both field and laboratory results were obtained from samples downstream from mining activity, and from possibly favourable mineralised structural features. The presence of diggings on these structural features indicates that the loci for Au, Sb mineralisation in the area have previously been tested. The cause of the anomaly was inexplicable and no further work was recommended.

2. DISCUSSION

Fifteen to twenty years ago, before atomic absorption spectro-photometry became readily established, most exploration companies had at least one person experienced in a few of the simpler field analytical methods. A published example by Lissman et al (1965) outlines geochemical prospecting by North Broken Hill Pty. Ltd. for low grade molybdenite deposits in northern Queensland and New South Wales, Australia. A caravan equipped as a mobile field laboratory enabled prospective areas to be geochemically prospected for Mo and Cu by simple colorimetric methods after a hot 6N HCl digestion. Today because of expertise and economics which the centralized custom geochemical laboratory offers, many companies lack or have lost the expertise to arrange for or understand the full value of field analytical methods. This is regrettable as the simplest of field methods have great applicability. To the writer these applications are in the field of "on-site" decision making and personnel motivation.

The applicability of field analytical methods to "on-site" decision making are:

(1) To guide in much the same manner as the previously discussed case studies, the direction of exploration parties in the follow up of particular drainage basins at the reconnaissance or detailed level in a programme where the exploration season is short and/or the original anomalous is poorly accessible.
<table>
<thead>
<tr>
<th></th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>CPZ</th>
<th>THM</th>
<th>Sn</th>
<th>SCPZ</th>
<th>W</th>
<th>WSCPZ</th>
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<tr>
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<td>0.43</td>
<td>0.91</td>
<td>1.00</td>
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<tr>
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<td>0.54</td>
<td>0.45</td>
<td>0.90</td>
<td>0.99</td>
<td>0.60</td>
<td>1.00</td>
</tr>
</tbody>
</table>

CPZ = Cu + Pb + Zn  
THM = Total Heavy Metal  
SCPZ = Sn + Cu + Pb + Zn  
WSCPZ = W + Sn + Cu + Pb + Zn

Table D2 Case Study Three - Elemental Correlation Matrix
Pt .10 ppm D.L., Kothiny (1974); As 1 ppm D.L., Marshall (1978). It should be pointed out that these detection limits apply to more sophisticated analytical methods in which spectrophotometers and not the human eye are used for comparison of samples with standards. Field analytical methods are versatile, especially those having a common digestion. They appear to be able to provide at a reasonable cost a useful amount of data of acceptable precision. The latter point has been illustrated on page D3.

With the hot extractable nitric acid digestion used by the writer two elements can be determined on 80 samples plus 10% repeats in a working day. Productivity is greater (120 to 150 samples/day) if cold extractions (e.g. 2.5%/25% HNO₃ or THM buffer) are used and read. For hot and cold extractable work cost per sample for two elemental determinations is A$0.80 and A$0.50 respectively.

The field analytical results for case studies 1, 2 and 3 are compared graphically with the respective elemental laboratory results of interest in Figure D24. This again illustrates the general strong correlation between the independent analytical data sets. Graphical comparisons of field analytical data and laboratory data is also at times useful and may lead to extra information and inferences being made on possible mineralisation in the area of interest.

For example if the tabulated correlation matrix (Table D2) for the variables THM, Cu, Pb, Zn, Sn, W from Case Study 3 is examined THM is most strongly correlated with Cu+Pb+Zn (0.86), Pb (0.80) and Zn (0.74) and is poorly correlated with Sn (0.11), Cu (0.22) and W (0.45). The graphical plots (Figure D24) confirms this observation, but Sn and to some extent W can be seen to be obviously different. A population of extractable and Dz reactable Sn is present. Sn purely derived from an oxide source would not be expected to be extractable and Dz reactable. A sulphide source could also be present here.

The methodology adopted by the writer is not a panacea but there are obvious advantages as outlined above in using it. There are disadvantages but these disadvantages in some cases can be overcome by adhering to established procedures. Disadvantages to cite are:

(1) Fickleness of reagents. This really only applies to dithizone, and...
centres on the user being aware of; the ease of Zn contamination especially from the fingers and not using demetallized water and buffer solutions, and when the dithizone solution is unusable. To some extent the fickleness of the reagents is brought about by lack of standardisation in methodology. E.g. Not using new solutions and standards at regular intervals; and more importantly the realisation that the reactions of the reagents are strength and time dependent. Samples should be subject to the same acid strength and digestion time to optimise metal extraction, while shaking time should be kept constant to optimise color development of the organic phase with the metal in solution. Clean, strict, working habits and to some extent experience should minimise the problem of "fickle" reagents.

(2) The method is less quantitative. This is true but the writer has shown that even though the absolute laboratory values are not reproducible the patterns are.

(3) Eagerness of field staff to participate. This should not be a problem but has been experienced by the writer!! Occasional less significant anomalies were followed up when stronger and more significant anomalies were found. This was solved by insistence of the team following strictly the "modus operandi", i.e. Plotting the data, rating dispersion trains over spot highs and referring results to the writer.

(4) Use of toxic chemicals. Most chemicals in the laboratory are poisonous as well as combustable. How to handle chemicals is solved by education. E.g. The toxic effect of organic reagents is reduced by using them outdoors or in a well ventilated space. Gloves should be worn when handling chemical if the handler suffers a skin allergy. Hands should be washed before eating and food should not be stored near chemicals. Organic chemical should not be exposed to naked light.

(5) Visual reading problems. Less than 5% of the male population are color blind and can't differentiate color. The writer has only met one color blind person - non professionally. From personal observation the average person is able to discriminate color in favourable concentration range where organic-metal complexing is at an optimum and a standard series is obvious, e.g. as with biquinoline over the range 10 to 250 ppm. With practice difference in reading color for a Cu series between persons is no more than 10% and generally can be comfortably read ...24.
at 5 to 10 ppm intervals or better. Problems however occur at low levels in arid climates where Fe may mask color as per the previously discussed example on page D3, or in wet cool climates where organic humic material causes bleaching of the organic reagent. Retinal fatigue with continual reading is a problem especially with the cold extraction technique, but to some extent avoided by changing partners with similar "eyes" and check readings. Photometers amenable to a 12V battery system could be used and would lead to better precision, but the emphasis is on the extreme portability of the equipment which fits neatly into a chest measuring 1.2 x 0.5 x 0.5 metres and not a caravan equipped solely as a mobile laboratory.

It is again stressed that any samples collected and analysed in the field are still sent to a custom laboratory to be analysed under standardised conditions.

3. CONCLUSIONS

It has been shown through the above case studies and discussion that under certain conditions old tried field analytical methods can make a valuable contribution from both the technical and personnel aspect to an ongoing modern integrated exploration programme. Indeed, even though they appear not to be in vogue an awakening of interest is currently being experienced in aspects of field analytical techniques. New field analytical techniques of importance are in the field of Hg analysis, Jerome Mercury Detector, Phelps et al (1977), Wu et al (1977); U analyses through solid and solution fluorimetry, Barringer and Scintrex UA-3 equipment respectively; specific ion-electrodes with the emphasis on the anion F, Carlson et al (1977) and EDA Instruments RDU 200 Rn equipment. Portable isotope, X-ray fluorescence analysers hold promise for onsite analyses. However, the sensitivity of the method is poor, restricting analysis to elements which can be concentrated by onsite panning, such as Sn in concentrates or are industrial minerals of high concentration, e.g. Rb, Sr, Ball et al (1979).

Recent advances have also been reported in updating old field geochemical methods through spot paper tests. Delavault (1977), Merk (1976). The former described a simpler than current procedure using two liquids (acetic acid/ sodium acetate digestion, dithio-oxamide (rubeanic acid) reagent) that is less subject to errors in the hands of persons with little or no training...
in field chemistry. The latter manufactures impregnated papers that are specific to an element and concentration range in much the same manner as their limited range pH papers.

In conclusion the writer wishes to reiterate his observation from involvement in follow up and confirmation and determination of local and regional anomalies, that a successful programme is an integrated one in which the explorationist must use effectively all data sources and methods at his disposal to maximise the probability of success. Field analytical methods though not currently in vogue are just one tool.
SECTION E

THE SEARCH FOR EXPLORATION TARGETS FROM AN OVERVIEW OF MACRO-REGIONAL GEOCHEMICAL DATA

INTRODUCTION

This section builds on from Section C and consists of two experiments in the search for the granitoid commodity elements, tin and tantalum, in a 100,000 km$^2$ portion of the Precambrian Pilbara region of Western Australia.

(1) The objective of the first experiment is to determine if a simplistic overview of univariate macro-geochemical data integrated with satellite imagery and geological data can generate new exploration targets.

(2) The second experiment is to determine if a multivariate pattern recognition technique at the overview level, combined with the same satellite imagery and geological ideas would generate similar, but preferably better defined exploration targets. The concentrate data from Section C is used as both a training and testing set for preliminary pattern classification.

1. GENERAL SETTING

The Pilbara region of Western Australia lies within latitudes $19^\circ\ 39'\ S$ and $23^\circ\ 30'\ S$ and longitudes $116^\circ\ E$ and $126^\circ\ E$ and occupies an area of some 375,000 km$^2$. The direct area of interest in this study is the 100,000 km$^2$ coastal Pilbara hinterland north of the Fortescue River to Port Hedland, the major iron ore export hub of the Pilbara. (Figure E1).

The climate is arid, with hot summers and mild winters prevailing. The annual evaporation rate of some 2500mm far exceeds the average annual rainfall of 200 to 350 mm. Spinifex grass and associated shrubs are common with eucalypts and acacias confined to the watercourses.
The general hinterland of the area of interest lies between 150 and 400m above sea level and consists of sand plain and extensive ranges of low razor back hills. It forms what is called "Pilbaraland", a dissected "old" plateau of which remnants are still preserved, (Jutson 1950). The major river systems, the Sherlock, Peawah, Yule, Turner, Strelley, Shaw, Coongan, De Grey, Nullagine and Oakover are ephemeral, superimposed northerly flowing drainages which have been responsible for the erosion of the "old" plateau. Major river capture of the Nullagine-Oakover systems by the westerly flowing De Grey River and minor river capture in the headwaters of the Shaw River in Quaternary times has not affected the general northerly drainage direction of the system. Hickman and Lipple (1975).

2. REGIONAL GEOLOGY

The area of interest, consists of an Archaean cratonic shield intruded by Lower Proterozoic to Archaean granitoids. Intensely deformed layered Archaean volcanics and metasediments intruded by mafic and ultramafic sills occupy synclinal structures between the large batholithic masses. Lower Proterozoic flood basalts and andesites, with thickly intercalated sediments, rest unconformably on the Archaean and probably once covered the majority of the area. Erosion during the Phanerozoic has removed much of the Proterozoic cover to expose the underlying "greenstones" and granitoids. Figure E2, page E6, outlines the general geological environment of the hinterland.

The batholithic regions of granitoid rocks occupy more than 60% of the 320 x 240 km hinterland of interest. The older tonalite-trondhjemite portions of the multi-domal batholiths are gneissic and more mafic with wide textural variations and contrast with the younger, intrusive and transgressive granitoids which are massive, even grained porphyritic biotite muscovite adamellites. Published ages range from 3.5 to 3.2 b.y. for the older granites to 2.7 to 2.6 b.y. for the younger granites, de Later et al (1972). Glikson (1979) comments that the published Rb/Sr and U/Pb dates in contrast to Pb/Pb dates reflect thermal and cooling imprints younger than the actual igneous event.
The young granites in particular the Coolegong Adamellite, Spear Hill Adamellite, Numbana Granite, Coondina Granite and Moolyella Adamellite on the Marble Bar 1:250 000 sheet are associated with tin mineralisation, Blockley (1970), Hickman and Lipple (1975), while the Cooke Creek Granite on the Nullagine 1:250 000 sheet is associated with tungsten mineralisation, Hickman (1975). These granites designated as the "young" or "tin" granites, Maitland (1919), Blockley (1970), probably occupy no more than 15% of the batholiths along west to northwest and minor northeast trends. The geological summary of the Marble Bar 1:250 000 sheet in Section C (Figure C3) illustrates this point.

The "tin" granites are more resistant to erosion than the older gneissic granite they intrude. Consequently they form areas of rough hilly country marked by tors and domes and contrast with the flat, sandy plain underlain by the older granites.

3. MINERALISATION

Two main types of primary Sn, Ta mineralisation are present and are both related to pegmatites. Figure E3 based on Blockley (1970), Taylor (1979) illustrates the type settings.

Lithium rich pegmatites which contain appreciable quantities of lepidolite, zinnwaldite, spodumene, cassiterite, tantalite, columbite and beryl constitute the first type of mineralisation. These are related to the older gneissic granitoids and are usually found cutting "greenstones" some distance from any possible source granites. The pegmatitic masses are large, irregular bodies, at times exceeding 1.5 km in length, and are up to 100m in width, and occupy well defined faults and tension fractures. Many are zoned, with a central core of blue-grey quartz surrounded by shells of pegmatitic material of varying quartz-albite-microcline-muscovite composition. The outer shell is often mostly albite. These pegmatites have been mainly worked for their tantalite and beryl content rather than for cassiterite. Pegmatites of this type are present at Pilgangoora, Strelley, Tabba Tabba and Wodgina and have been described by Anon (1953), Blockley (1969), (1973), Ellis (1950), Hill (1975), Knight (1979).
(a) Diagrammatic illustration of settings for large zoned pegmatites (Type 1) and pegmatitic vein swarms (Type 2).

(b) Selected sections to illustrate the structure of Type 2 tin-tantalite bearing pegmatitic swarms, the source of the eluvials at Moolyella.

Figure E3 General setting of large zoned pegmatites (Type 1) and pegmatite swarms (Type 2). After Blockley (1969), Taylor (1979).
Pegmatites of the second type are essentially cassiterite bearing and are related to the "tin" granite phase. Blockley (1970), describes them as flat dipping swarms around the edges of the "tin" granite cutting across the older granite gneiss and migmatite. The pegmatites range from 3m to no more than 100m in length and from less than 1m to no more than 4m in width. Typically they are layered, being made up of alternations of coarse grained quartz-microcline-biotite and fine grained quartz-albite-spessartite-green muscovite. Cassiterite is associated with the latter assemblage with minor tantalite, columbite and monazite. Very rarely are lepidolite, zinnwaldite, beryl and fluorite present.

The main economic significance of the above pegmatitic mineralisation, especially the latter type, is that they are the parent "protore" from which alluvial and eluvial deposits of economic grade have resulted by the processes of weathering and erosion. Production of cassiterite concentrates to date has been some 16,076 tonnes, the majority of which (15,697 tonnes) has come from the area of the Marble Bar 1:250 000 sheet. The majority of the production of concentrates has come from Moolyella (7800 tonnes), Cooglegong (5000 tonnes) and Eley (1900 tonnes), Western Australia Mines Department Annual Reports (1976, 1977). Older possibly Tertiary deposits have been mined from dissected kunker and clay cemented gravels at Friendly Creek, Coondina and Cooglegong, (Blockley (1970), Hickman and Lipple (1974)). Present annual concentrate production in the Pilbara is of the order of 450 tonnes, less than 4% of Australia's total production. The largest individual producer, Pilbara Tin Pty Ltd at Moolyella is currently expanding production to 480 and 32 tonnes of tin and tantalite concentrates respectively from a series of eluvial and alluvial deposits grading 0.86 kg SnO₂/m³ and 0.34 kg Ta₂O₅/m³.

The Pilbara region once accounted for the majority of Australia's tantalite production, but since the 1950's the Greenbushes area in southwestern Western Australia has produced 95% of the total. Production in the Pilbara mainly came from small scale mining of zoned pegmatites of the above mentioned first type of primary mineralisation in the Wodgina district. Some 380 and 112 tonnes of cassiterite and tantalite concentrates have been produced here, Blockley (1971). Reserves of 500,000 tonnes of 0.14% Ta₂O₅ are said to remain at Wodgina itself in a 670m long, 3 to 9m wide zone of pegmatite, Goldrim Mining Annual Report (1979).
In the past Pilbara concentrate buyers were paying for Sn and claiming the now valuable Ta. Recent data, Knight (1979), suggests that concentrates from Pilbara Tin Pty. Ltd.'s Moolyella mine averages 3.5 to 4.0% \( Ta_2O_5 \) approximately half is molecularly combined with cassiterite while the remainder can be recovered as a columbite-tantalite concentrate assaying 40-45% \( Nb_2O_5 \) and 28-30% \( Ta_2O_5 \). A possible 640 tonnes of the above cited Sn concentrate production figure could therefore be columbite-tantalite concentrates. However some record of production has been kept which when compiled from Western Australian Mines Department Annual Reports amounts to approximately 500 tonnes.

Production of columbite-tantalite from eluvial-alluvial sources in the Pilbara is increasing in response to rocketing prices. An estimated 47 tonnes of the 163 tonnes produced in Western Australia in 1979 came from the Pilbara. Interestingly, Australia produced 13% of the world's primary Ta (\( Ta_2O_5 \) in concentrates) production of 513 tonnes in the 1974-76 period. With increases this figure would now approximate 15%, half of the current rated production of TANGO, the world's largest producer from a zoned pegmatite situated at Bernic Lake in Manitoba, Canada.

4. **EXPLORATION TARGETS**

Tin deposits older than 600 m.y. are rare and are considered from a company viewpoint unimportant. This unimportance is due to the sporadic and seemingly limited nature of the mineralisation in large pegmatites and the occurrence of associated exotic elements of low demand and moderate price e.g. Ta, Nb, Li, Be, Cs, Rb. The former element has now become an exception, due to demand and the diminishing ore reserves of TANGO at Bernic Lake, Canada. Eluvial-alluvial concentrations associated with the pegmatites have thus provided most of the production (as exemplified above), because hard rock mining has generally required both a high grade and the presence of the exotic rare metals. However, large scale working of pegmatite for Sn does occur, as at Greenbushes in southwestern Western Australia and the Kitalolo and Manona pegmatites of central Africa. This only occurs where the pegmatite is large (up to 5km long, 50 to 300m wide) and importantly, have a deep weathering profile which allows economic extraction of the resistant cassiterite and associated exotic minerals. Such deposits are low grade, as exemplified by Greenbushes production...
E6.

figures $1.5 \times 10^6$ m$^3$ for 420 tonnes cassiterite (0.28 kg/m$^3$) and 108 tonnes tantalite (.07 kg/m$^3$). (Greenbushes Tin N.L. Annual Report 1980). However, in the last few years, due to increasing scarcity and demand, Sn, but moreover Ta concentrate prices, have rocketed to over A$4$ kg and A$200$ kg respectively making such deposits very profitable and turning them into Ta rather than Sn producers. The increase in price particularly for Ta (refer Figure E4) has given impetus to the re-evaluation of pegmatites.

Thus, the statement "to hunt for elephants one looks in elephant country" would certainly apply to the Pilbara in the search for these commodities especially in view of, past and present production (a sign of elephant tracks!), and perhaps the limited work carried out to date on pegmatites by companies. It would be easy to superficially overlook an important zoned pegmatite (minimum target $3 \times 10^6$ tonnes of 0.15% SnO$_2$; 0.10% Ta$_2$O$_5$). The reason being that, while the mostly barren central quartz core is often exposed at the surface due to its resistance to weathering and erosion, the mineralised outer sheets may be scree covered. An eluvial placer as entry into a bulk open cut or underground room and pillow Sn-Ta situation (with emphasis being placed on the larger zoned type of pegmatites), and possibly Sn from disseminations of cassiterite in quartz stockworks and cassiterite bearing greisens would appear valid targets in the Pilbara Precambrian terrain in today's economic climate.

5. EXPERIMENT ONE - THE SIMPLISTIC UNIVARIATE OVERVIEW

5.1 Methodology

The Sn data for stream concentrates covering the area was originally generated by computer chloropleth mapping via GREY at a scale of 1:1 000 000, and then traced for reproduction. Intervals were selected from a previous SPSS (FREQUENCIES) computer run which generated histograms for the elemental data. Figure E5.

Unfortunately Ta geochemical data is not on-file. However Nb in stream concentrates is on-file in the data bank and can be used as a pathfinder for Ta mineralisation in granitoids, since Ta and Nb form an isomorphous series of minerals—tantalite (Fe, Mn) Ta$_2$O$_6$ and columbite (Fe, Mn, Nb$_2$O$_6$) being end members of the series and neither end member is found in nature
Figure E4 Historical tantalum pentoxide prices 1955 to 1980, in constant US$. From Greenbushes Tin N.L. Annual Report 1980.
in the pure state, Dana (1932). Ta : Nb ratios in concentrates from Wodgina and Moolyella range from 4:1 to 1.5:1 respectively, (Knight et al (1979)). The Nb data does suffer a handicap in that the spectrographic limit of detection is 100 ppm. Nevertheless, the Nb data was treated in the same manner as the Sn data and a map produced to overlay a complimentary granitoid mineral occurrence - regional geological map. Figures E6, E2.

A geological base map was compiled with a bias to recognition of the young "tin-tantalite" bearing phases in the batholiths. This was accomplished by using Landsat imagery and current geological mapping. (Figure E2.) In the last four years work has begun in unravelling the stratigraphy of the Pilbara granite batholiths through the Geological Survey of Western Australia (G.S.W.A.) regional 1:250 000 updated mapping programme. The key adjoining 1:250 000 sheets, Marble Bar and Nullagine, have been remapped respectively by Hickman and Lipple (1975) and Lipple (1975). Satellite imagery (Landsat 1 and 2 scenes) have also become available for the Pilbara through the Commonwealth Scientific Industrial Research Organisation's (CSIRO), Division of Mineral Physics. The writer obtained coloured slides of these scenes and as a precursor to the simplistic univariate geochemical analysis engaged in mapping the "tin-tantalite" granite phases over the Pilbara using the Marble Bar-Nullagine scene as a reference. Some difficulty was however, experienced with the two Landsat scenes covering the Roebourne, Port Hedland and Yarrie 1:250 000 sheets. The quality of these two scenes was not on par with the southern adjacent Pyramid-Marble Bar and Marble Bar-Nullagine 1:250 000 sheet scenes.

The Marble Bar-Nullagine Landsat scene covers the western and eastern halves respectively of the same named 1:250 000 sheets. The geology of the Marble Bar sheet was briefly reviewed in Section C and Figure C3 after the G.S.W.A. summarised the geology. Figure E7 is the eastern half of the G.S.W.A. geological summary while Figure E8 is the equivalent relevant portion of the Marble Bar-Nullagine Landsat scene. This portion of the scene illustrates what can be gained from visual pattern recognition of quality Landsat photography. Firstly, what can be seen is the characteristic photo pattern of the "tin" granites, i.e. in particular the Cooglegong Adamellite and the Moolyella Adamellite in the Shaw and Mt. Edgar batholiths respectively. The outline of the Cooglegong Adamellite...
STRATIGRAPHIC AND STRUCTURAL INTERPRETATION

From Geological Survey, Western Australia, Explanatory Notes of Marble Bar 1:250,000 Sheet

MARBLE BAR SF50-08

STRATIGRAPHIC AND STRUCTURAL INTERPRETATION

PORTION MARBLE BAR SHEET

COMPARATIVE INTERPRETATIONS - "TIN" GRANITE PHASES Figure E-7
MARBLE BAR SF50-08

STRATIGRAPHIC AND STRUCTURAL INTERPRETATION

PORTION MARBLE BAR SHEET
COMPARATIVE INTERPRETATIONS — "TIN" GRANITE PHASES

Figure E 7
PORTION MARBLE Bar - NULLAGINE LANDSAT SCENE - INTERPRETATION "TIN" GRANITE PHASES

MT EDGAR BATHOLITH
1. Moolyella Adamellite

SHAW BATHOLITH
1. Spear Hill Adamellite
2. Coolegagou Adamellite
3. Coondina Granite

CORUNNA DOWNS BATHOLITH
1. Mondane Adamellite
may be more extensive than what has been outlined by reconnaissance mapping of the G.S.W.A. It should be pointed out that the minor Spear Hill Adamellite and Coondina Granite can only be outlined with difficulty in the Shaw Batholith. Of interest however is a new feature, the subdivision of a G.S.W.A. designated "tin" granite, the Mondana Adamellite, in the Corunna Downs Batholith. The eastern half has both the distinctive photo colour and texture which is comparable with the Cooglegong and Moolyella Adamellites. It is suggested that this eastern portion of the granite intrusion is perhaps the true "tin" granite phase. The macro-regional stream sediment data for Sn, Mo(?), Bi(?), Pb and V (low) appears to validate this point though the stream concentrate data is equivocal. Refer Section C.

In a similar manner, the remainder of the Landsat scene and surrounding scenes were examined to compile Figure E2. Undoubtedly much more information would come to light from usage of the actual Landsat computer tapes. Pattern recognition algorithms now being developed and used in satellite imagery processing could be applied to mapping the young "tin" granite phases in the Pilbara. However, as a "cost effective" first pass, new useful information can be gained from visual examination of quality Landsat photography (albeit they being raw or computer enhanced imagery).

5.2 General Univariate Overview

From Figures E2, 5 and 6 (a comparison of the Sn, Nb and mineral occurrence-geological maps) a good correlation can be seen between areas of known mineralisation, "tin" granite and Sn-Nb geochemistry. For example, the producing Moolyella, Eley and Cooglegong areas stand out. Other geochemically high areas of interest stand out which are in part associated with inferred "tin" granite. For example, the strong Sn and Nb pattern on the southern and northern portions of the Nullagine and Balfour Downs sheets highlights an inferred young phase within the Kurranna Batholith.

Nb with accompanying subordinate Sn in the southeastern portion of the Port Hedland sheet, northwestern and central northeastern portions of the Marble Bar sheet, and smaller spot highs on the Roebourne, Port Hedland and northern portions of the Pyramid and Roy Hill sheets are found in older granite terrains. Some of these patterns may represent possible ...
zoned pegmatite targets. The Marble Bar patterns have been commented upon previously (Refer summary Section C 6.3.16) as being worthy of investigation. However, not all patterns are related to granite batholiths. For example, the northeast trending series of Nb(Sn) patterns extending from approximately the southwestern corner of the Nullagine Sheet are also related to even younger porphyroids (Spinaway Porphyry) and the highs in the southeastern corner of the same sheet are associated respectively with the Fortescue Volcanics, Hammersley Group sediments and Lower Proterozoic granite; the Sn patterns north of the Oakover River on the Yarrie Sheet could be related to basal Mesozoic sediments of the Canning Basin.

5.3 An Interesting Inference from the Overview

An interesting aspect of the overview arises, which when integrated with other data, points to a possible exploration target concept that merits research. This is the distinctive concentrate Sn trains leading into the major river systems and thence into the De Grey area in the central portion of the Port Hedland Sheet. Attention is thus drawn to the concept of the possibility of heavy mineral accumulations, principally tin, tanto-columbite, gold, chromite, ilmenite, rutile, zircon and monazite in river and deltaic/palaeo-strandline environments.

Besides tin and tanto-columbite, the hinterland has also seen minor gold production from small scale workings in the greenstone belts. Approximately 16000 and 850 kg respectively have come from primary and alluvial sources. The majority of production, 11,146 kg, has come from the Marble Bar sheet. (Western Australian, Dept. of Mines statistics Annual Report 1977). Figure E2 outlines the gold occurrences of the area. Primary gold mineralisation of economic importance is confined to small high grade auriferous quartz veins which occur in sheared Archaean mafic-ultramafic and sedimentary rocks. Erosion of the Archaean primary deposits during Proterozoic times has resulted in the formation of limited "deep leads" in Proterozoic conglomerates. Quaternary alluvial and eluvial deposits also contain gold in the vicinity of primary deposits.

Two main ingredients are needed for deposits of alluvial minerals. These are:

(1) An extensive source area of the economic minerals of interest and,
(2) Suitable large sedimentary environments in which the economic minerals released from their host by the processes of weathering and erosion under humid conditions can be accumulated and concentrated.

The railway line from Port Hedland to the southern iron ore mines approximately separates the hinterland area into an eastern and western regime in terms of provenance. From Figure E2, the eastern regime, in particular its western subdivision, can be seen to have the most favourable provenance situation with respect to major commodity elements, i.e. the production of Sn and Au and to an extent Ta-Nb. This is related to the greater development of young "tin" granites, with attendant Sn-Ta bearing pegmatites, in the Shaw Batholith (Cooglegong and Spear Hill Adamellites, Coondina Granite) on the Marble Bar Sheet, the Kurranna Batholith on the Nullagine Sheet, the Mt. Edgar Batholith (Moolyella Adamellite) on both the Marble Bar and Nullagine Sheets and an unnamed phase in the Carlinidi Batholith on the Port Hedland Sheet. With respect to Au, the provenance situation is related to the greater extent of gold occurrences in the Archaean "greenstone" belts. The geochemical overview for Sn and Nb (Figure E5 and E6) also reinforces the general favourable provenance situation of the eastern regime.

The sedimentological situation in the eastern regime too seems to be more favourable than the western regime, especially in the De Grey area. As previously mentioned the river systems appear to have maintained a northerly flow for a considerable period of time, i.e. since mid Tertiary times. Epeirogenic movements and Pleistocene eustatic changes due to glacial periods have caused repeated rejuvenation of the river systems. This repeated rejuvenation of the river systems is evidenced by the deep incision and superimposed nature of the drainages, and the recognition that the present land surface is the product of multiple erosion cycles. Remnants of at least three land surfaces, the Hamersley, Intermediate and Yule exist within the hinterland area. The Shaw, Coongan, Strelley, De Grey river systems here appear to have maintained a constant flow of sediments seawards over a long period of time before the westerly flowing De Grey captured the separate northerly flowing Nullagine-Oakover system with its perhaps dilutant sediment input. Indeed fossil Tertiary tin bearing leads are associated with the Shaw system at Coondina and Cooglegong.
With reference to the Landsat scene covering the De Grey area on the Port Hedland sheet, the physiography of the area can be divided into predeltaic riverine and deltaic sections (Figure E9). This predeltaic riverine subdivision is a sediment "sump" which consists of the confluences of the De Grey-Strelley, De Grey - Shaw and De Grey - Coongan Rivers. These confluences have braided alluvial flats up to 22 km wide and 45 km long. The rivers themselves before the confluence are braided and up to 600m wide. Within the sump the present rivers are now at grade. Northwards, the sump, now the De Grey - Ridley River system, passes through a narrow water gap in the Ord Ranges and forms an extensive rounded delta on the northwestern (seaward) front of which are lines of dunes and tidal flats. Low (1965) reported alluvial clay, sand, gravel and boulder beds in excess of 20m thick and 20 km long occupying the drainage channels and flood plain of the delta.

Hydrological work has been carried out in the predeltaic riverine section by the Western Australia Mines Department on behalf of the Public Works Department to investigate water supplies for Port Hedland, 80 km to the west. Davidson (1976) summarises the data accumulated from bore census, exploratory drilling and geophysics (seismic refraction and resistivity) in the predeltaic "sump" environment of the De Grey, Strelley and Shaw Rivers. The work reveals:

(1) Alluvium to weathered bedrock or sometimes fresh bedrock occurs at depths ranging from 18 to 120m.

(2) The water table ranges from 4 to 28m below surface with a probable average of 15 to 17m. A shallow water table is an important consideration in a possible dredging situation.

(3) The lower most sediments of the De Grey valley are Coongan and Shaw alluvium overlain by Oakover and Nullagine River sediments deposited after river capture by the westerly flowing De Grey in Pleistocene times. The upper most sediments consist of Recent alluvium from all four rivers that are now at grade.
Buried channels are evident in the limited seismic traverse data. The present course of the De Grey no longer coincides with the axis of the "sump". In its downstream tract the river has migrated several km southwestwards and further upstream it has moved to the northeast. Numerous old channels as yet buried are also evident in the modern Strelley, Shaw and De Grey Rivers.

Possible targets therefore emerge in the De Grey area for prospecting for alluvials. These targets are:

1. The pre-deltaic riverine environment i.e. the alluvial sumps before the present river system were at grade.

   From the above, a large thickness of alluvials is evident over a considerable area and coupled with the provenance situation (especially the nearby Carlinidi Batholith for Sn, Ta) plus indications in the geochemical overview, a possibility exists for the accumulations of placer minerals. The older deeper Tertiary sediments of the Shaw, Strelley and Coongan systems are probably more prospective than the dilutant De Grey and recent mixed sediments of the river systems because they reflect erosional products from a more humid climate than the present.

2. The palaeo strandline/deltaic environments.

   Extensive heavy mineral accumulations are present in the seaward extension of modern deltaic environments. An example is the ilmenite-monazite deposits of the Nile delta. The actual ilmenite and monazite here is reported to have their source in Sudan and Ethiopia, 1200 to 1700 km distant, (Meleik et al. 1978)). By analogy a similar situation may be present in the De Grey delta which is the seaward extension of the alluvial sump. A marine influence would be necessary for the concentration of the heavy minerals of interest. The concentration of heavy mineral would need not be great, i.e. 0.5 to 1% by weight for the area to be of economic interest provided the economic minerals of interest are the majority constituents.

The geological notes of the Port Hedland 1:250 000 sheet, Low (1965), indicate that in Pleistocene times, probably predelta times, a palaeostrandline was present. The description of the Pleistocene Boosut Formation is as follows:
"The Boosut Formation is a shoreline deposit consisting of sandy calcarenite, minor oolitic limestone and calcilutite. It includes lithified dunes, beach and offshore deposits. It may be up to 23m thick in the Port Hedland area."

The sedimentological environment though not indicative of a particularly high energy environment because of the carbonate content, is nevertheless very similar to the Pleistocene to Recent Quindalup and Spearwood strandlines in the Capel area in southwestern Western Australia which carry minor but still mineable economic concentrations of ilmenite, (rutile, zircon, monazite), Welch (1964).

The products of both, local marine erosion of basal Mesozoic sediments of the Anketell Shelf of the Canning Basin, (a possible intermediate host for heavy minerals), and the products of regional weathering and erosion of the favourable Pilbara hinterland brought to the coast by the northward flowing river systems, were probably dispersed and sorted by current and wave action along the paleo-coastline abutting the craton to develop beach and frontal dune deposits which may host heavy mineral deposits. The building up of the coast in the De Grey delta area probably took place by accretion in longitudinal portions each of which was formed by an off-shore submarine spit or bar. Alluvial advance of the coast is attributed to the in-filling of swales behind the spits to eventually form solid land. Long-shore drift would be responsible for sorting, distribution and concentration of material along the foreshore area. Indeed if the Port Hedland Landsat scene is re-examined a chronological series of events is indicated in the formation of the delta with the western embryonic portion being most favourable for heavy mineral accumulation (Figure E9). A strong longshore northerly drift up the present coastline is evident in the scene from spit, and bar features. The heavy mineral products from the mineralised headwaters of the large Turner River system on the boundary of the eastern provenance regime may have also been carried by strong northern longshore drift up the coast and contributed to the sediments in this site.

The inferences being made here are themselves a topic for research and subsequent validation. Many questions arise such as; if from the above hypothesising, heavy mineral deposits are present in both sedimentological situations, what percentage of the heavy mineral accumulation would be cassiterite, tanto-columbite and gold, the prime economic minerals of...14.
Emergent present day coastline = shallow depositional coastline extending seaward. Longshore drift is evidenced by bars, cusps and strandlines.

Raised beach with prominent strandlines.

Port Hedland Mt Goldsworthy

Original estuarine coastline

Tin granite shore Carboniferous

Sites of possible heavy mineral accumulation

DE GREY LANDSAT INTERPRETATION
Figure E10 Decrease in grain size of heavy minerals with increasing distance from source. Modified after Zenschke (1961). Metals Exploration data from AIMM field excursion notes (1980) and Melbourne stock exchange reports 1978 to 1980.
interest? The major and minor commodity placer minerals, (cassiterite, tantalite, gold versus zircon, monazite, ilmenite, chromite and rutile) appear to differ markedly in placer forming properties (density, tenacity, cleavage and hardness). Indeed from broad observations, economic placer deposits of these major commodity minerals appear to be located no more than 40 km from primary source and occur very rarely in marine environments. However, the Carlindi Batholith is within the required sphere of influence and may have contributed Sn, Ta heavy mineral.

Another point for thought also arises. Figure E10, modified after Zeschke (1961), shows the decrease in grain size of heavy minerals with increasing distance of transportation. A fair "guesstimate" of the decrease in grain size of gold with distance based on the comparative properties (SG, hardness, tenacity) with the species Zeschke studied has been added to the original graph along with actual exploration data for cassiterite grain size and grade with distance from source. (Metal Exploration's Queensland (Ruxton) tin mining operations; AIMM notes of field visit 1980, miscellaneous stock exchange reports). The following points arise. Firstly, if gold and cassiterite do occur in the heavy mineral concentrates at favourable sites of accumulation in the area, the grain size may be such that economic recovery would be difficult (less than 50 microns(??)) in contrast to the minor commodity minerals of interest as illustrated in the graph for chromite. Secondly, from the Metals Exploration data economic grades fall dramatically from 1630 gm Sn/m³ at Ruxton 15 km from source to a grade of 860 gm Sn/m³ at Dinner Creek, 35 km from source.

Even though placer targets could be inferred from the geochemical overview, nearby provenance and sedimentological regimes, caution should be urged. Many questions arise. The subject of placer formation in one that needs to be thoroughly researched and is beyond the scope of this thesis. However superficially offsetting the negative aspects for the exploration geologist is the excellent infrastructure of the area. For example the road, rail, power, harbour facilities 90 km distant at Port Hedland and nearby housing at Goldsworthy, an iron town. Importantly, in our increasingly conservation conscious world, if dredging took place, there would be a low environmental impact on the area. These two latter points could perhaps outweigh the negative aspect of the hypothesising to allow land
acquisition and a subsequent limited reconnaissance drilling programme to prove or disprove the theory.

5.4 Conclusions

The generalised overview of macro-regional concentrate Sn, Nb data integrated with a simplistic regional geology map in part derived from Landsat photography and a compilation of granitoid mineral occurrences has allowed the recognition of a number of anomalous areas. However, in terms of target assessment for Sn-Ta, anomalous areas of interest can be reduced to areas within the older gneissic terrain in the search for zoned pegmatites, or areas associated with the young granite phases, e.g. within the Kurrana Batholith.

Landsat photography is demonstrated as being able to distinguish features which have been overlooked in government regional mapping. For example, the subdivision of the "young" Mondana Adamellite of the Corunna Downs Batholith into two phases. The eastern most phase is inferred by the writer as being the probable true "tin" granite as some support is found in the macro-regional stream sediment geochemistry.

An inference made from the Sn, Nb macro-regional data gives, an impetus for further research in a target area for placer mineral accumulation, even though some reservation exists for accumulations of the major minerals of interest, i.e. gold, cassiterite, tantalite over the lesser economically important minerals rutile, monazite, zircon, ilmenite, chromite and magnetite. The value of Landsat photography is again highlighted when integrated with other geological data.

6. EXPERIMENT TWO - MULTIVARIATE PATTERN RECOGNITION

6.1 The Problem

Detailed interpretations have been carried out on the stream sediment and semi-quantitative emission spectrographic stream concentrate geochemical data over the Marble Bar 1:250 000 Sheet in Section C. Granite batholiths containing young phases associated with tin-tantalite
mineralisation are prominent and are especially distinguishable in the semi-quantitative concentrate data. Similar phases are present in batholiths elsewhere in the Pilbara. The writer has hopefully outlined all these phases from a study of Landsat photography in Experiment 1. Indeed, from this work, it has been shown that the eastern portion of the Mondana Adamellite in the Corunna Downs Batholith possibly only belongs to the young "tin" phase. Thus, here it is hoped to confirm and more readily distinguish through discriminant analysis, a multivariate pattern recognition technique:

1. areas containing the young "tin" granite phase with associated areas of peripheral pegmatitic mineralisation, and

2. areas within the older granite terrain which may contain important zoned pegmatite mineralisation.

The semi-quantitative concentrate data in contrast to the stream sediment data appears more diagnostic and will be used in the analysis.

6.2 General Principles of Pattern Recognition and Classification

In sections throughout this thesis the word "pattern" has been stressed. What is, a pattern, and how can a pattern be recognised? The definition of a pattern is interesting. With reference to both the Oxford and Chambers dictionaries the following varied explanations emerge:

- ornamental design e.g. on a carpet
- a model
- way in which objects are arranged
- distribution of shots on a target
- a particular disposition of form and colour

From the above a pattern in the geochemical sense could be said to be a distribution or arrangement of values (highs and lows) over a geological entity. However, the ingredient of colour must be added, which in the exploration geochemical sense, relates to characteristic elements that are spatially and causally related to known mineralisation.
Generally in a geochemical programme for base metals the characteristic elements examined are the commodity elements being sought and one or two pathfinder elements. As there are probably no more than 5 to 7 elements per sample point a simplistic univariate approach is taken with pattern recognition. As demonstrated in Section C this is often the most effective because:

(1) The results are easier to interpret in relation to the geochemical behaviour and known mineralogical-petrological characteristics of an area and,

(2) Most important, nothing is lost by mathematical manipulation.

From the writer's viewpoint the two most important reasons for applying multivariate pattern recognition techniques are:

(1) To combine and summarise established features and,

(2) To detect additional features related to those already known.

The general process of pattern recognition usually denotes a discrimination or classification of a set of processes or events. In practice the set of processes or events required to be classified can be diverse ranging from physical objects (e.g. in this case drainage samples) to mental states. When dissected there is nothing mystical about the process of pattern recognition, because we as human beings perform the task of pattern recognition in almost every instant of our daily lives. For the mineral explorationist, with particular reference to exploration geochemistry bracketed, the process of pattern recognition could be defined as, the extraction and recognition of features (characteristic elements) in a data set that typify a mineralised environment (i.e. elemental enrichments or depletions) and the search for similar situations in a new, but geologically comparable area by using these now established recognised features.
Three distinctive phases with natural decision points are present in the pattern recognition flowpath. The phases can be identifiable with any scientific experimentation or new industrial undertaking. These phases are (1) an exploratory (learning) phase; (2) a pilot or controlled experimental phase, and (3) the main recognition and classification phase.

(1) Exploratory (learning) phase

In the exploratory phase, which is essentially one of learning, facts are assembled on the defined problem. Hopefully our knowledge is such that training sets can be created which consists of perhaps a number of recognisable groups for subsequent classification of samples of unknown types to one of these groups. This process is called supervised learning based on a priori information. The converse, unsupervised learning, involves no a priori information and groups of samples must first be sought on the basis of data analysis using ordination or cluster seeking methods.

Once groups are defined the major problems of pattern recognition must be considered. These are inter-related, being feature selection and classification. Feature selection is the critical question concerning the existence of a possible set of distinctive characteristics that typify the group in a training set. The second and inter-related critical question is how good are the characteristics in assigning individual samples to these groups? The fundamental aim in the exploratory phase is to find an acceptable rule to satisfactorily classify all unknown sample data into one of several (but usually two) groups.

(2) Pilot or controlled experimental phase

A pilot experimental phase is important in that the stability and reliability of recognition can be tested. Some modification of our a priori knowledge of members of the groups in the original training set or discriminantary features may be necessary for subsequent classification of unknown samples. Ultimately a result is obtained which is hopefully both, statistically, but more importantly, geologically significant, allowing progression to the more extensive and, in a real world industrial situation, expensive main phase.
(3) Main recognition and classification phase

Using the knowledge of the learning and pilot phases, data over an unknown, but geologically similar area can be classified with the aim of establishing prospective target areas for further exploration work.

6.3 Discriminant Analysis

The writer has chosen to investigate the problem through the classification tool discriminant analysis. The reason for this decision is that a priori knowledge of the groups in which we are interested exists, and thus the aim is to find a decision rule which discriminates these groups well on the basis of the observed features. Application of this decision rule to the regional data will assign each sample member to one of the categories purely on the basis of these characteristic features.

The decision rule used for classification could come from a now extensive library of statistical, metric and hypergeometric decision functions developed by mathematicians. However, as a general statement one wishes to find a decision rule or discriminant function (D) that separates groups on the basis of an observed set of features (X). Application of this discriminant function to an unknown data set will assign each new sample to one of the categorised groups purely on the basis of its measurements. The value of a discriminant function D(X) associated with the ith group will be a maximum for all samples belonging to that group. That is:

\[ D_i(X) > D_j(X) \quad i, j = 1, \ldots, n, \quad i \neq j \]

The decision boundary between the two groups will be expressed by the equation:

\[ D_i(X) - D_j(X) = 0. \]

The most accessible classification methods for the exploration geochemist are various programmes involving linear discriminant analysis, IBM (1968), Davis (1973), BMD (1975), SPSS (1975) and non linear discriminant analysis, Howarth (1973). These respectively involve statistical and hypergeometric decision functions.

...20.
(1) Linear Discriminant Analysis

Linear discriminant analysis has been used extensively in other branches of the earth sciences, Griffiths (1966), but has not been widely used in exploration problems to date with the exception of lithogeochemistry (see below). The reason for this is presumed to be the practical difficulties associated with obtaining adequate data for formulating the training sets. In many geochemical exploration problems there is a difficulty in obtaining known target and background populations of relevance to the survey area in the sample medium being used. Samples related to a commodity element being sought are often not available because that commodity element is not yet known in the survey area, or in the extreme case, mining operations in the area have adversely contaminated the medium being employed. However, the latter situation is at least a starting point. The background populations are also important, careful selection of members being needed to match the geological and geochemical variations in the survey area.

The majority of the applications cited in the literature have used the Fisher linear discriminant function (FLDF) because of the availability of suitable package programmes. For example:


Davis (1973); - stream geochemistry

BMD-07M Stepwise Method (Dixon 1975); - regional target prediction using integrated data sets composed of geological, geophysical and/or geochemical data; Rose (1972), Prelat (1977).

SPSS (Nie et al 1975); - hydro-, pedo-, lithogeochemistry; Feiss and Ragland (1979); lithogeochemistry; Divi et al (1979), Fox (1979, 1980), Sopuck et al (1980).
The FLDF method is both robust and simplistic (Davis, 1973) and excellent results have been reported especially in lithogeochemical studies on volcanogenic deposits, where subtle differences between various mineralised and background elemental populations have been maximised, allowing target halos to be considerably broadened in both the areal and vertical senses, Whitehead and Govett (1974).

The FLDF objective is to weigh and compare variables from two or more groups, and to then linearly combine the weighings in a manner, such that, the groups are forced to be as statistically distinct as possible. This operation then acts to transform the measured values for the variables of interest of a sample, into a single discriminant score that is located on the resulting discriminant function. Mathematically, the transformation maximises the ratio of the squared differences between the multivariate means and their pooled variance. The Mahalanobis distance ($D^2$) represents the measure of the separation between the two multivariate means, expressed in units of pooled variance. Its magnitude can be statistically tested by the F test. This test gauges how effective the variables are in separating the groups in question.

The transformation can also be visualised as a search for an orientation in multivariate space where the two (or more) groups show the greatest separation and least dispersion. This is illustrated in Figure E11 for a three variable, two group situation. Assuming that Cu, Pb and Zn have been determined on each sample for two different groups and that these were then plotted in mathematical three dimensional space, a distribution of points as shown in Figure F11 might result. If the points were projected orthogonally onto either of the three axes (say Cu on the diagram) an extensive amount of overlap would occur between groups, leading to the conclusion that the two groups cannot be differentiated using the three variables, Cu, Pb and Zn. However, by finding a new orientation for an axis (the discriminant function) a location can often be found that allows the groups to be differentiated when the discriminant scores of the group samples are plotted on this line.
Figure E11 Representation of the relationship between the discriminant function and the distribution for groups 1 and 2.
The resulting linear discriminant functions calculated are of the type:

\[ D_i = C_0 + C_{i1}X_1 + C_{i2}X_2 + \ldots + C_{in}X_n \]

where, \( C_{ij} \) are the weighed constants for the \( n \) elements used in the analysis.

\( D_i \) is the value of the discriminant function for the \( i^{th} \) group, a sample being assigned to the group for which \( D \) is a maximum.

The maximum number of discriminant functions to be derived is either one less than the number of groups or equal to the number of discriminating variables whichever is smaller. The relative importance of each discriminant function is measured by; the relative percentage of the eigen value associated with the function, canonical correlation and Wilks Lambda.

The adequacy of the derived discriminant function is also tested by classifying the cases used to derive the functions in the first place and comparing predicted group membership with actual group membership. One can thus empirically measure the success in discrimination by observing the proportion of correct classifications.

Classification equations are derived from the pooled within groups covariance matrix and the centroids for the discriminating variables. Each group has separate equation of the type:

\[ C_i = C_{i0} + C_{i1}X_1 + C_{i2}X_2 + \ldots + C_{in}X_n \]

where \( C_{i0} - in \) are weighted classification coefficients with \( C_{i0} \) being the constant of the \( n \) elements in the analysis for group \( i \).

\( X_{1 - n} \) are the values of the \( n \) elements

\( C_i \) is the classification score for group \( i \)

Under the assumption of a multivariate normal distribution the classification scores can be converted into probabilities of group membership.

...23.
The rule of assigning a sample to the group with the highest score is then equivalent to assigning the case to the group for which it has the greatest probability of measurement. A Bayesian adjustment of this probability is possible when; one desires to take advantage of \textit{a priori} knowledge of group membership probabilities; when groups are of different size, or when the cost of misclassification into certain groups is very high. The mathematics of SPSS-DISCRIMINANT are not given in Nie \textit{et al} (1975), but are similar to the flowpath in BMD-07M, Dixon (1975).

(2) Non-linear Discriminant Analysis

An alternative discriminant method which is perhaps more attractive, is the non-linear decision rule PDM (polynomial discriminant method) of Specht (1967) and its subsequent variants such as EDFM (empirical discriminant function method) of Howarth (1973), Donker \textit{et al} (1978). The method does not depend on the assumptions of multivariate normality and equal covariance matrices being present as in FLD. Indeed in a comparative study by Howarth (1971) of sedimentary rock classification, no adjustments for non-normality or unequal dispersion in the seven classes studied were made, and when using the EDFM an overall 80\% success rate in classification was obtained. This contrasted with a maximum of only 27\% success over the seven classes obtained with FLD using the same training and testing sets via the IBM package programme. As in the case of many multivariate techniques, the situation covered by FLD is in reality rare. Although Fisher's original approach is distribution free it provides an optimal assignment rule in the sense of minimising the probability of misclassification only if multivariate normality is present or approximated and equal covariance matrices are also assumed.

The non-linear discriminant rule in part overcomes also the problem of training set sparseness which is so often the encountered norm. This is the writer's problem of having few, but hopefully representative data, comprising the groups in the training set. (See below). Most importantly the problem that can be now resolved is the partition of non-linearly separable groups.
The mathematical basis for the non-linear (Polynomial) discriminant method is based on the non-parametric estimation of a probability density function for each category to be classified, so that the Bayes decision rule may be implemented, Specht (1967). The basic mathematics has been given in a geochemical context by Howarth (1971), (1973).

In simplistic terms the probability density function is estimated from the values occurring in the training set samples by extrapolation using a smoothing parameter, sigma (σ). In one dimension in an unsmoothed state the function is composed of a series of overlapping distributions. As sigma increases (i.e. the degree of smoothing) the function in one dimension takes on the appearance of a continuous distribution. Refer Figure E12. An unknown sample is assigned to that group for which its probability is a maximum.

The Bayes rule may also be used, weighing these probabilities by the *a priori* probability of the occurrence of each group P(i). Thus for the ith group the product P(i), i.e. P(i) P(i/X), is considered, assigning the unknown sample to the class for which this is a maximum. A gate is set so that, if P(i) is less than this value the sample is classified as "unknown" and as such would also become candidates for investigation.

The method to date, upon adaptation to the earth sciences has appeared to be successful in regional geochemical surveys for multi-group classification problems, Howarth (1971, 1972, 1973), Castillo-Munoz and Howarth (1976), and is being used in other exploration geochemical problems, e.g. pedogeochemistry, Gustavsson et al (1976), lithogeochemistry, Howarth (1971), Rehder and van den Boom (1980). The method has also been extended to other fields where large data sets prevail as in satellite imagery classification, Donker et al (1978).

6.4 Pattern Classification

6.4.1 General Introduction

The writer has opted to use both the above discussed linear and non-linear discriminant functions in the learning phase to first gauge their effectiveness on a difficult data set, i.e. semi-quantitative ...25.
Figure E12 Representation of probability density functions in one dimension for seven samples in a two group training set after application of a large value of sigma for smoothing.
emission spectrographic concentrate data. The linear discriminant function algorithm used is DISCRIMINANT which is readily available through SPSS (Nie et al 1975), and as noted above appears to have been successfully applied to discrimination problems in lithogeochemistry, e.g. Fox (1980), Sopuck et al (1980). The non-linear discriminant function used is the EDF algorithm of Howarth (1973). This algorithm has been successful in obtaining satisfactory discriminant functions on small training sets. Also subsequent good classification results have been obtained on difficult regional data sets, in particular stream sediment samples from an area having geological, pedological and environmental (cultural and geochemical) complex characteristics, Castillo-Munoz and Howarth (1976).

6.4.2 **Learning Phase (Problem Definition)**

From Section 6.2 the writer has summarised in table form, the salient steps in any classification problem. Refer Table E1. Each of the steps has an element of difficulty and have been commented upon by a number of workers. However, from the literature the writer feels that a great deal of success in pattern recognition should be measured by the skill used in selecting meaningful features. Not enough attention has generally been paid to the estimation of the best measurement set.

Elements that are outliers (i.e. having few values above the detection limit of the analytical method) are obviously omitted, but there appears at times to be an air of subjectivity and automation in choosing the remaining elements to enter into the discriminant function.

With the SPSS DISCRIMINANT programme feature selection for inclusion in the discriminant analysis can be controlled by the user through a method specification. Assuming as a starting condition, multivariate normality, all features can be entered concurrently through the direct method regardless of the discriminating power of each of the features, or features may be entered singularly or, in specified groups through five stepwise methods. The latter results in an optimal set of features being selected on the basis of their discriminating power for final entry into a discrim-
1. EXPLORATORY (LEARNING) PHASE

(1) Problem definition.

(2) Training set creation - choosing representative samples of the groups. Problem of supervised and unsupervised learning.

(3) Feature selection.

(4) Classification.

2. PILOT (CONTROLLED) EXPERIMENTAL PHASE

(1) Testing the stability and reliability of recognition-classification through an independent testing set whose members have a known group assignment.

(2) Problem of the unknown category, i.e. non enforcement of group assignment as per the training set if samples have insufficient response to the defined group.

(3) Possible modification of training set and features with retesting.

3. MAIN RECOGNITION AND CLASSIFICATION PHASE

Table E1 Summary of steps in classification flow path.
inant function. Generally stepwise procedures are an efficient way of approximately locating the best set of features. The true solution would require testing every possible subset to determine which would produce the very best results. If there are too many features this process would consume an inordinate amount of computer time. Of interest, is that at times the sequence in which the features are selected are not necessarily the same as their relative importance as discriminators. The importance of variables can also be monitored and controlled internally, and hence gauged within the DISCRIMINANT run, by statistics such as the F test entry and deletion criteria, Rao's V, and from the resulting discriminant function coefficients themselves. From the computed discriminant function, the importance of variables can be ranked according to the magnitude of the standardised discriminant coefficients.

Feature selection via the EDF pathway in exploration geochemistry has generally involved preselection of variables by simple inspection of group data or line profile comparison of variables (i.e. mean, standard deviation comparisons of variables between groups). Feature selection though, could possibly be accomplished more meaningfully by modifying the EDF algorithm so that individual univariate probability density functions for groups themselves are first calculated iteratively by doubling sigma intervals commencing at 0.25, for the raw data or at .02 for logarithmic transformed data until a steady classification is attained. A listing of the percentage of samples assigned to each group against sigma for each element would be line printer output. Optimum sigma for each element could then be chosen for subsequent calculation of the univariate probability density functions. Line printer plots would display in one dimension the univariate probability density functions for the groups. From this computer run elements revealing good separation of groups would be selected as being features to retain for the calculation of multivariate probability density functions for the groups.

What ever the discriminant pathway the law of diminishing return must also apply, i.e. there must be an optimum number of elements after which the percentage overall recognition success rate will not significantly increase or, if too many elements are present the overall recognition success rate may actually decrease. In the latter case "noise" is being added which suppresses the "signal", and hence decreases...27.
the recognition success rate. Castillo-Munoz (1973) illustrates this point. In the case of both algorithms the optimum number of variables is important in computational terms.

Firstly, consider the use of the Mahalanobis distance \((D^2)\) in DISCRIMINANT as a classifier. Its effectiveness will be related to the significance of the Mahalanobis distance between groups. For the case of a normal distribution for the total sample size \((N)\), groups \((g)\) and \(p\) variables \((p)\), the significance of the difference between two groups \((1\ and\ 2)\) is distributed as \(F\) with \(p\) and \((N-g-p+1)\) degrees of freedom on the null hypothesis.

\[
F = \frac{n_1 n_2 (N-p-g+1)}{n_1 + n_2 p(N-g)} D^2
\]

As the number of variables increase, the power of this test and thus the significance of the estimated Mahalanobis distance \((D^2)\) decreases unless the true distance between populations is increased by more than a certain minimum amount. The dimensionality of the problem is however reduced by stepwise discriminant analysis.

In the case of the EDF algorithm the optimum number of variables is also important in computational terms. Howarth (1973), points out that for a given number of training patterns and constant \(\sigma\), the estimated density function will decrease as the number of variables increases. In the event that a very small density function arises, computer truncation errors on some hardware may produce zero values for the function which could result in misclassification. The worker's aim when using the EDF algorithm should therefore be to reduce the original variables to those of significance such that the information loss is minimal and the estimated density function values will tend to be maximised. Concern over the truncation error in the writer's case is trivial as the data set is composed of only 14 elements and in the actual process of classification probably no more than 5 would be used in the discriminant function.
Of practical importance to the exploration geologist is that the identification of significant variables, i.e. elements, should be known as a reduction in the cost of subsequent analytical work may be possible in a large ongoing geochemical programme.

From the writer's viewpoint feature selection can be carried out in perhaps both a more simplistic and meaningful manner by resorting to:

(1) The, previously well used cited technique of line comparisons of group features, i.e. simple elemental ranges, means and standard deviations to first assess the problem, and

(2) Quantification of observed group separation by the various elements through the non-parametric Kolmogorov-Simirnov (KS) test.

The above can be carried out quickly and effectively through the facilities of SPSS, i.e. CONDESCRIPTIVE, NONPAR TEST – KS. The classification run, especially the stepwise method in DISCRIMINANT with its ancillary statistics and the EDF algorithm if modified, could act as a check on the significance of the chosen features for the discriminant function.

The problem of target and background population mentioned previously is real in this exercise. From the detailed univariate work in Section C obvious differences were noted in the geochemistry over the young granite and gneissic phases in the batholiths of the Marble Bar sheet. Thus, superficially, it would seem that one of the writer's aims "to confirm and more readily distinguish areas containing the young granite phases with associated areas of mineralisation" is fairly simple. However, the results of the detailed univariate work also showed variation between young granite phases in the batholiths. This is not entirely unexpected because of the varying composition of the young phases, e.g. Moolyella Adamellite in the Mt Edgar Batholith versus the Numbana Granite in the Yule Batholith. It would also appear that the young phases have varying degrees of associated recorded pegmatitic mineralisation. For example, the
extreme case of the prolific pegmatitic mineralisation associated with the Moolyella Adamellite in the Mt Edgar batholith versus the barren(?) Mondana Adamellite in the Corunna Downs Batholith. Coupled with this problem, is the one of paucity of basinal numbers over the individual young granite phases. Thus, for a meaningful discriminant analysis, only an average young granite phase can be considered. This is especially so with FLDF, because returning above to the F test of significance of the Mahalanobis distance; if a very small number of samples are present in the training set groups and a variable is added which increases the Mahalanobis distance by only a very small amount, the significance of the distance between the groups is reduced and hence the effectiveness of the subsequent classifier based on this measure. As a rule of thumb, ten times the number of measurements per group should be used. For example five elements, fifty samples.

The problem of a background population also exists. This, however, is not a problem of numbers, but whether or not greenstone and gneiss be considered as two entities. The gneiss is essentially ingested old proto-greenstone crust. Relict greenstones have been mapped in the gneissic portions of the batholiths (Hickman and Lipple (1975)), and can be discerned on quality Landsat photography, Glickson (1979). As some Sn highs were noted in the actual Archaean greenstone belts and are representative of pegmatitic mineralisation (e.g. Wodgina, Strelley) a true background population should be best chosen from areas of gneiss containing ingested greenstone and remnant Lower Proterozoic cover.

Principally because of the nature of the medium (semiquantitative concentrates), analytical data (semiquantitative spectrography) and the previously discussed availability of numbers to form an adequate training set, the writer has endeavoured to limit the discriminant analysis to a simple two class problem, i.e. "tin" granite/mineralisation versus gneiss/greenstone. Discriminant analysis even under idealised conditions also becomes increasing complex interpretationally as the number of classes increases.

...30.
After a few trials, 30 samples were finally selected for the "tin" granite/mineralisation class from over the Numbana Granite (17 samples), Cooglegong Adamellite (10 samples) and Moolyella Adamellite (3 samples). No samples were selected over the Mondana Adamellite because of the writer's contention that only the eastern portion is the young phase and verification of this in the testing run is of prime interest.

Simple statistics (range, mean and standard deviation) were calculated for these three sub groups and the 30 samples as a whole. Likewise, for the gneiss/greenstone class 30 samples were selected from the Yule Batholith (18 samples), Shaw Batholith (9 samples) and Mt Edgar Batholith (3 samples). These gneissic areas contain relict greenstone protocrust and in the case of the first and last respectively, some Lower Proterozoic Fortescue Group volcanics and Archaean Gorge Creek Group greenstones. Again simple statistics were calculated for the sub-groups and the group as a whole. These data are summarised in Figure E13 as a series of line comparison for the various elements and listed in Tables E2 to E4.

From Figure E13 can be seen the amount of individual elemental discrimination between the two classes for the grouped and component subgroup elemental data. Mo and Ag are below the limit of detection and have been deleted from the work. Pb, Sn, Y, La, Be, Bi and Nb are excellent and unambiguous positive discriminators in terms of enrichment with respect to the "tin" granite/mineralisation class. Subjectively too, one could say that there appears to be greater between group variability than with group variability for certain elements. Nb however, suffers from a paucity of data and is considered an outlier. Bi is also of possible interest, but unfortunately also suffers from a paucity of data. From the remaining elements (Cu, Ni, Co, V, Zn) no useful discrimination between the two classes is seen in the grouped data for Cu and Zn, but Ni, Co and perhaps V, are useful in terms of reflecting depletions of these elements with respect to the "tin" granite/mineralisation class. The overall discriminating power of these latter elements though has been somewhat reduced by the adverse "positive" contribution from the Shaw Batholith "tin" granite/mineralisation sub-group. This is due to the presence of major mafic dyke activity in the drainage basins underlain by the Cooglegong Adamellite in the Shaw Batholith.
| B1 | F1 | PH | SN | SH | SN | Y | RE | MO | BR | CE | NF | LA | AG | CO | V |
|----|----|-----|----|----|----|---|----|----|----|----|----|----|----|----|----|----|
| H 1877F086E227122356 | 0 | 45 | 60 | 0 | 0 | 60 | 5 | 0 | 0 | 30 | 10 | 0 | 0 | 0 | 50 |
| H 1877F086E227122357 | 0 | 45 | 60 | 0 | 0 | 60 | 5 | 0 | 0 | 30 | 10 | 0 | 0 | 0 | 50 |
| H 1877F086E227122358 | 0 | 45 | 60 | 0 | 0 | 60 | 5 | 0 | 0 | 30 | 10 | 0 | 0 | 0 | 50 |
| H 1877F086E227122359 | 0 | 45 | 60 | 0 | 0 | 60 | 5 | 0 | 0 | 30 | 10 | 0 | 0 | 0 | 50 |
| H 1877F086E227122360 | 0 | 45 | 60 | 0 | 0 | 60 | 5 | 0 | 0 | 30 | 10 | 0 | 0 | 0 | 50 |
| 1877F086E227122361 | 0 | 45 | 60 | 0 | 0 | 60 | 5 | 0 | 0 | 30 | 10 | 0 | 0 | 0 | 50 |

**Table 22** Data listing "tin"-enriched mineralization (Group 1) and "quartz-sulphitites" (Group 2) training sets.
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<th></th>
<th>N</th>
<th>R</th>
<th>X</th>
<th>SD</th>
<th>CV%</th>
<th>S</th>
<th>K</th>
<th>Log X</th>
<th>Log SD</th>
<th>Log S</th>
<th>Log K</th>
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Table E3 Statistics for "Tin" Granite/Mineralisation Group of training set.
|    | Cu  | Co  | Ni  | La  | Ce  | Pr  | Nd  | Sm  | Eu  | Gd  | Tb  | Dy  | Ho  | Er  | Tm  | Yb  | Lu  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 18 | 10  | 47  | 73  | 11  | 1.5 | 0.8 | 0.9 | 0.3 | 0.1 | 0.1 | 0.2 | 0.4 | 0.3 | 0.1 | 0.1 | 0.0 |
| 9  | 20  | 20  | 20  | 0.0 | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   | -   |
| 30 | 3   | 30  | 30  | 18.1 | 1.2 | 0.6 | 0.9 | 0.9 | 0.3 | 0.1 | 0.1 | 0.2 | 0.4 | 0.3 | 0.1 | 0.1 |

Table E4 Statistics for Gneiss/Greenstone Group of training set.
Looking at the tabulated results (Table E2) for the two groups, the usefulness of Co is suspect because of the number of values in both groups below the limit of detection for the analytical method. Ni to some extent also shows spottiness of data, but not to the same degree as Co.

Quantification is needed on the observed group separation of the whole training set. From the above La, Pb, Y, Sn, Be, V and Ni(?) are of definitive interest while Co is suspect. Due to the nature of the data use of the non-parametric Kolmogorov-Smirnov test would appear to be appropriate.

The Kolmogorov-Smirnov (K-S) two sample test is a test whether two independent samples have been drawn from the same population (or from populations with the same distribution). This two sample test is concerned with the agreement between two cumulative distributions of two sets of sample values. If the two samples have in fact been drawn from the same population distribution then the cumulative distributions of both samples may be expected to be fairly close to each other, in as much as they both should show only random deviations from the population distribution. If the two sample cumulative distributions strongly deviate at any point this suggests that the samples come from different populations and the original hypothesis (H₀) is rejected. The two tailed test is sensitive to any kind of difference in the distributions from which the two samples were drawn, i.e. central tendency, dispersion, skewness.

To apply the K-S two sample test, one makes a cumulative frequency distribution of each sample of observations using the same intervals for both distributions. For each interval the cumulative frequency is subtracted from one another. The largest of the observed deviations (D) is focused upon and its significance is assessed by resorting to a probability table, i.e. the probability associated with the occurrence of a value as large as the observed D under the null hypothesis that the two samples have come from the same distribution. Our alternative hypothesis (H₁) is simply that there is a difference, i.e. the two samples are from different populations.
As certain elements show enrichment and depletions over the target population the writer is principally interested in a two tailed test, i.e. testing the maximum deviation irrespective of direction. Thus, from the writer's viewpoint the test offers a way of objectively selecting elements which show differences for further investigation by univariate or multivariate methods. The data was subjected to the K-S test through the facility of NONPAR TEST-KS in the SPSS library. For small data sets (less than 100 cases) the significance of the answer must be assessed by resorting to a probability table. This was done by reference to Table L in Siegel (1956).

The results of the test are found in Figure E14. At the .01 confidence level Pb, Y, La, Be and Sn are significant in a positive direction (i.e. representing enrichment in these elements for the "tin" granite/mineralisation class), while V is significant in a negative direction (i.e. representing depletion of the element in the "tin" granite/mineralisation class). At the .05 confidence level Ni is significant in a negative direction representing once more depletion of the element in the "tin" granite/mineralisation class.

Features of real interest in order of importance for discriminating between "tin" granite/mineralisation and gneiss/greenstone are thus, Pb, Y, La, Be, Sn, V, Ni. The next important step is to find an acceptable rule to satisfactorily classify all unknown sample data into the two groups. This aspect has been combined with the pilot testing phase because of the extrapolatory nature of the EDF algorithm.

6.4.3 Pilot Testing Phase

The pilot testing phase as mentioned above has become a training-testing phase. The remainder of the Marble Bar concentrate geochemical data has become the testing set, to test the stability and reliability of recognition of the discriminatory rule as other areas of "tin" granite and mineralisation are well known. Some modification of group membership of the original training set or combination of the above features of interest may again be necessary for subsequent satisfactory classification of regional unknown samples. Hopefully, a statistically,
Figure E14 Results of Kolmogorov - Smirnov Test showing discriminatory elements for tin granite/mineralisation and gneiss/greenstone groups.
but more importantly, a geologically significant result will be found to allow confident progression to the main phase.

Group membership has already been objectively modified from 32 to 30 samples each in the training phase. Any further modification would reduce the small groups comprising the training set. At present the individual groups are each 7% of the testing set (30 each in 418 samples). If a satisfactory discriminant rule can be found, this percentage would reduce drastically to 1% in the main phase, (30 in 1800 + regional samples). So much dependence on so few samples! Some misclassification must therefore be tolerated. A perfect training set is in the writer's situation unattainable and in reality undesirable. Nothing in life is "black and white", a grey zone is always present. When a satisfactory discriminant rule can be found using the established features or a combination of the established features, an arbitrary band on the probability of group membership can be enforced to in-part remedy misclassification. For example, samples having a probability of 50 to 60% for the "tin" granite/mineralisation or gneiss/greenstone classes should be scrutinised with respect to their geological setting. If for example, two "just failed" gneiss/greenstone samples cluster with a "well passed" "tin" granite/mineralisation sample, the area deserves thought as a possible exploration target.

In contrast to SPSS-DISCRIMINANT, an unknown category is present in the EDF pathway. If at a required known smoothing parameter, the sample cannot be classified it is placed into this category and will not be forced into the "tin" granite/mineralisation or gneiss/greenstone classes. Samples in the unknown class are odd and their spatial distribution with respect to geology should also be examined to determine their significance. Generally smoothing is determined iteratively until the maximum rate of classification takes place. This sigma value is used in the subsequent calculations as per the method of Howarth (1973). There are disadvantages in this approach. These are:-

(a) The problem of training set crossover and misclassification as illustrated by Castillo-Munoz and Howarth (1976). In some respects this can also be caused by the user being too demanding
in requiring all samples to be classified into the assigned groups. This can be overcome by the user objectively examining the sigma classification table of the output.

(b) Problem of computational time. A factor of 10X can be assigned to calculation time involving iterative determinations. This has been said to be not really prohibitive in real world costs with modern high speed computers. From the writer's experimentation it is a real world cost to the explorationist using a bureau. This cost is however trivial if it leads to a mine. Reduction in computational time (and cost) can be effected however through a data transformation (log base 10) within the EDF algorithm. For example a job run execution time was reduced to 43.6 seconds from 1046.8 seconds by first transforming the data.

Computer runs for comparative studies in the pilot testing phase were thus effected through the facility of, SPSS-DISCRIMINANT, stepwise method MAHAL, (refer Nie et al (1975) for details) and the EDF algorithm (refer Howarth (1973)). Both data sets were internally log base 10 transformed in the same computer run prior to the calculation of the discriminant and classification functions. Log base 10 standardised data runs were also carried out. Standardisation was effected through the Z-score option (mean of zero, standard deviation unity) in SPSS-CONDESCRIPTIVE. This file was only subjected to the EDF algorithm, because the process of standardisation of data is inbuilt into the SPSS-DISCRIMINANT algorithm in the same manner as SPSS-FACTOR previously discussed in Section C.

It should be mentioned that recognition of group membership within the training set for analysis by the two algorithms differs. Prior to running SPSS-DISCRIMINANT, the groups in the training set must be defined. This is carried out by the insertion of a numeric character, i.e. 1 = Sn granite/mineralisation; 2 = gneiss/greenstone; 3 = ungrouped to be classified into 1 or 2, in a free field of the individual physical sample records of the data file through a simple Fortran programme DISC or through the text editing facility (XEDIT) of the computer system. The groups are now defined on the VARIABLE LIST card of the internal SPSS job control. In contrast, group membership in the training set
in the EDF algorithm is defined by designated map areas (training areas). Thus, in the writer's experimentation, the 30 samples for the "tin" granite/mineralisation group can be placed into seven map areas. Likewise, for the 30 samples for the gneiss/greenstone group. Any number of areas can define a group. However, the algorithm makes allowance for only a total of 26 training areas. The outline of the entoto sampled area must also be defined as the area remaining outside the training areas contains the samples to be classified to either of the two groups.

For the SPSS pathway the following was carried out after first subjecting the data to a log base 10 transformation:—

(1) All elements were entered into the stepwise analysis regardless of the presence of outriders to see how effective the algorithm is in handling obvious redundant variables. The outputs can be found in Table E6 while the resulting classification map can be seen in Figure E15.

(2) The obvious outsiders were deleted (Bi, Nb, Mo, Ag) and the ten remaining elements Pb, Zn, Sn, Y, Be, Cu, Ni, La, Co, V, were entered in the stepwise analysis. The output can be found in Table E7 while resulting classification map can be seen in Figure E16.

SPSS-DISCRIMINANT, Version 6.0, was used initially, but lacks some of the statistical refinements of the update, Version 8.0, now available at Leicester. Tabulated outputs refer to work done using both SPSS packages.

For the EDF pathway the following was carried out:—

(1) All seven significant elements, Pb, Be, Sn, Y, La, Ni, V, were entered in the analysis. The smoothing parameter was iteratively determined and the results of the subsequent classification are found in Table E8 and in Figure E18.

...36.
(2) The five significant granitoid elements only, i.e. Pb, Be, Sn, Y, La, were entered in the analysis. The smoothing parameter was again iteratively determined and the results of the subsequent classification are found in Table E9 and in Figure E19.

(3) The tabulated results of the above seven and five element classifications for various smoothing parameters were examined graphically mainly to ascertain if any group cross-over was present. Refer Figures E20, E21. As significant breaks in the plots were noticed at 0.04 sigma and corresponded with a large unknown grouping (27.9 and 18.7% respectively) both the seven and five element combinations were rerun at 0.04 sigma smoothing, to ascertain the membership of the unknown group category in terms of the regional geology. Figures E22 and E23 outlines the spatial distribution of the members of the three groups, i.e. "tin" granite/mineralisation, gneiss/greenstone and unknown groups, at this smoothing parameter.

(4) The above seven and five element runs were repeated with Z-score data, smoothing once more being iteratively determined. Refer Tables E10 and E11; Figures E24 and E25.

6.4.3.1 Results of Pilot Testing Phase

(1) SPSS - all data

From Table E6 elements in order of final importance in the summary are La, Ni, Be, Bi, V and Sn. This can also be seen from the change in Rao's V and its associated test of significance from the output of SPSS version 6.0. Refer Figure E26, Table E5. Unexpectedly, Bi has been entered at the expense of Pb and Y which were two elements that should have featured prominently in the discrimination. From the initial statistics, the univariate F ratio between groups and its equivalent in Step 0, tells us that Mo and Ag which are below detection are constants and will not be entered in the analysis, while for Zn, Cu and Bi variation between groups is insignificant. Surprisingly, Nb is significant. Note the significance has been added from a duplicate table in the output. Discriminating power in the
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Table E5 Summary SPSS-DISCRIMINANT outputs for all elements (top) and with elemental outliers deleted (bottom) from SPSS-Version 6.0
Figure E26 Change in Rao's V and significance stepwise discriminant analysis
SPSS-DISCRIMINANT Version 6.0
Outline of training oreo: Eluvial or alluvial working

- Copper
- Tin
- Silver
- Lead
- Beryl
- Gneiss/greenstone
- Bismuth
- Uncoloured

Discriminant score: -1.6

- 0.995% probability of Tin ore/greenstone class
- Marginal probability of class/variate: 0.60-65%; 0.02-60%

N.B.: In order of importance from standardized discriminant function coefficients
After La has been entered in Step 1 there is a notable drop in significant F and $D^2$, especially for Y, Sn, Nb, whereas Bi rises in significance. Bi continues to rise at each succeeding step as Ni, then Be is entered into the equation. Finally, at Step 4 Bi itself is entered leaving V to be entered at Step 5. It is not until V has entered that Sn regains significance to be entered at Step 6, after which the analysis ceases, because F to enter for the remaining elements are below the statistical gate of 1.0000. F to remove is set at 1.0000 and one can see at Step 6, Sn is just in the analysis. The remaining elements are insignificant in their contribution to the discrimination. If the superseded SPSS Version 6.0 is run at its default F values of .01 to enter and .005 to remove, all elements are obviously entered in the final equation. A comparison of final eigen values, canonical correlation between the two SPSS versions reveals how insignificant are the contributions of the remaining elements to the discriminant equation, e.g. eigen value 2.276 c.f. 2.350, canonical correlation 0.835 c.f. 0.837, the last figure in each case being from the SPSS, Version 6.0 output (Table E5, E6). The validity of the solution is however, doubtful from the results of the failure of the test for equality of group covariance matrices based on the six discriminating variables. Four members of the "tin" granite/mineralisation group can also be seen to have been reclassified in the training set. Three of these cases have been strongly reclassified while the fourth is of marginal classification. Because the classifications into the two groups appeared to be definitive from both the tabulated group probability estimates and the frequency distributions of group discriminant scores (Table E6), it seemed advisable to examine the areal distribution of group membership even though the validity of the solution is doubtful.

The areal distribution of the membership of the two groups can be seen in Figure E15. Basins containing discriminant scores of less than -1.6, which is a greater than a 99.5% probability of membership of the "tin" granite/mineralisation group, are accentuated. Some 13.4% of the testing set has been classified into the "tin" granite/
mineralisation group. The efficiency of the classification is only fair. In the Shaw Batholith, the main Eley and Cooglegong eluvial-alluvial mineralisation is not expressed though this is reflection of the original semiquantitative quality of the analytical data. Also, the Coondina area in the same batholith is not expressed in the data as is neither the Moolyella eluvial mineralisation in the Mt Edgar Batholith. These latter areas are prominent in the univariate geochemistry. (Refer stream concentrate target summary from Section C, Figure C38, included overleaf.) Other areas of significance reported in Section C 6.3.16 and summarised on Figure C38 are also not highlighted. However, the north eastern-eastern and south eastern flanks of the Numbana Granite in the Yule Batholith are prominent, and as previously mentioned in Section C 6.3.16, would bear investigation. Likewise, the basins containing the sheared Yule Batholith in juxtaposition with the Tambina Complex and Western Shaw Belt would also bear investigation for pegmatitic mineralisation. The pattern in the Corunna Downs Batholith over sheared Coongan Belt in juxtaposition to Carbana Pool Adamellite and G.S.W.A. mapped Mondana Adamellite is however inexplicable and its significance is debatable. The outline of the writer's defined "tin" phase in the Mondana Adamellite is notably missing. The significance of the remaining scattered basins which have a marginal probability of membership to the "tin" granite/mineralisation group are also debateable.

(2) SPSS - outriders deleted

The obvious outriders were all deleted. Zn and Cu, because of their lack of significance could also have been deleted, but were left in the analysis. As with the previous all element SPSS run, the elements in order of importance from the univariate F ratio between groups (Step 0 in Table E7) anticipated to feature in the analysis, should be La, Pb, Y, Be, Ni, Sn, V, Co. Zn and Cu are insignificant. From the final summary in Table E7, the most important elements in the final discriminant are La, Ni, Be and V. After Step 4, no further significant information is added to the discrimination. This can also be seen by the change in Rao's V and its associated test of significance from the SPSS Version 6.0 output. Refer Table E5, Figure ...39.
Outline of training areas

Member of training set

"Tm" = granite/mineralisation class

Discontinuity score 0-1-8

Levels 30-50% probability of Tm granite/mineralisation class

Marginal probability of classification > 70-50% ; 50-30%

Unprepared bore holes described 0

TRAINING TESTING PHASE

SPSS - ALL OUTLIERS DELETED

Le - Ni - Be - V Significant

NB: in order of importance from
standardised discriminant function coefficients
E26. Sn and Y are present, but at 0.212 and 0.517 significance levels. Pb has not even been entered into the analysis because of its low F to enter. As remarked above, version 6.0 is particularly generous too, in its default F to enter (0.01) and remove (0.005) criteria as compared with version 8.0 both being set at a more realistic level of 1.000.

Tracing through the analysis in Table E7, with the exception of Ni and Zn, all the elements F to enter drop when La is entered at step 1. In particular Sn and Y drop spectacularly while Zn rises. Ni, Y, Co, Be, Pb and Zn are still significant. After Step 2 when Ni is entered, there is a further notable drop in F to enter, particularly for Zn, Co and Pb, with Be and V remaining significant. At Step 3, Be is entered leaving V. F to enter with the exception of V and Co drops further. Co though, is still not significant. After V is entered at Step 4, the remaining elements are far from being significant though the F to enter for Sn and Co has risen. The contribution of these remaining elements to the final discrimination can again be shown to be insignificant from a comparison of the final eigen values and canonical correlations from the superseded SPSS Version 6.0 outputs in Table E5 with Table E7, i.e. eigen value 2.040 c.f. 2.107, canonical correlation 0.819 c.f. 0.823 the last figure in each case from the SPSS, Version 6.0 output.

The same four members of the "tin" granite/mineralisation training set group can be seen to have been reclassified in Table E7. Two of these cases have been strongly reclassified while two are marginal. A marginal case is also present in the gneiss/greenstone group. The overall percentage of the grouped cases of the training set correctly classified was 93.32%. Classifications into the two groups was again seen to be definitive from both the tabulated group probability estimates (Table E7) and a frequency distributions of the discriminant scores.

The areal distribution of the membership of the two groups can be seen in Figure E16. Basins again containing discriminant scores of less than -1.6 which are greater than a 99.5% probability of membership...
TABLE 50 - 08

Locality map

- Mines or Prospects
- Eolian or alluvial working
- Ac. Abnormally
- Kg. Silver
- Ss. Arsenic
- Au. Gold
- Be. Beryl
- B. Barium
- Cr. Chromite
- L. Copper
- N. Nickel
- P. Lead
- Sn. Tin
- W. Tungsten
- Zr. Zircon

Outline of training areas

Training set

"The granite formation class"

Discriminant score c<1.6

Significant La = Be

NB: In order of importance from standardised discriminant function coefficients

TRIAL TESTING PHASE

SPSS - GRANITIC ELEMENTS (Pb-Sn-Be-La-Y)

Significant La = Be

NB: In order of importance from standardised discriminant function coefficients

Figure E17
of the "tin" granite/mineralisation group are accentuated. Some 13.4% of the testing set has also again been classified into the "tin" granite/mineralisation group. Marginal members of the group have disappeared or become marginal members of the gneiss/greenstone group. Some new members of the "tin" granite/mineralisation group have appeared, notably in the south eastern corner of the sheet where areas of intrusive Spinaway Porphyry of the Fortescue Volcanics, and an area of Mondana Adamellite-Boobina Porphyry-copper mineralised Kelly Formation acid volcanics are accentuated. Overall the efficiency of classification is again judged fair. The problem of non-recognition of areas of tin mineralisation at Moolyella and Coondina is still present.

If only the five granitoid elements, Pb-Sn-Be-La-Y, are considered and subjected to analysis, La-Be, are of importance which is to be expected. Figure E17 outlines the areal distribution of group membership of this analysis. From Figure E17, greater misclassification has been introduced into the training set, and secondly a great many new areas emerge much of which is "noise". However, some areas have Be and associated Sn-Ta pegmatitic mineralisation. Basins over the Moolyella and in part Cooglegong tin field have also become marginal members of the gneiss/greenstone group. Generally though, more "noise" has been introduced into the analysis and a similar distribution to the classified "tin" group members would probably result from plotting the distribution of populations of Be and La produced.

(3) EDF - seven elements

Table E8 is the output for all seven significant elements, i.e. Pb, Be, Sn, Y, La, Ni, V which were entered in the analysis. The smoothing parameter was iteratively determined and the result of the subsequent classification at a final sigma value of 0.20 on the testing set was: 20.670% "tin" granite/mineralisation, 79.330% gneiss/greenstone and 0.000% for the unknown group categories. Membership of the "tin" granite/mineralisation group can be seen to rise rapidly with smoothing and peaks at 0.08 sigma, i.e. 21.229% with the remaining 61.453% classified gneiss/greenstone and 17.318% unknown. Membership of the
Figure E21 Graphical representation of iterative EDF seven element classification. Marble Bar testing set until terminal classification.
Figure E27 Graphical representation of the probability of group membership for EDF seven element data classification.
"tin" granite/mineralisation group drops very slightly (0.559%) with subsequent increased smoothing, while the unknown group becomes depleted, its members being gradually assigned to the gneiss/greenstone group. (Refer Table E8, Figure E21.) The small loss from the "tin" granite/mineralisation group also appears to have been assigned to the gneiss/greenstone group. The terminal classification was accepted over the classification at 0.08 sigma, because it appeared that the unknown is essential part of the gneiss/greenstone and "noise" had been eliminated at minimal cost of membership to the "tin" granite/mineralisation group, i.e. 0.559% = 2 samples. However, the question of, "what, in broad geological terms is the unknown group?", remains to be investigated to confirm the assumptions made.

The membership of the two groups in both the training and testing sets can be seen to be definitive from Table E8 and Figure E27. In contrast to the SPSS runs, no misclassification or marginal probability of membership has occurred in the training set. Indeed, in the testing set only a few samples have marginal group membership, i.e. occurring in the writer's defined 40 to 60% zone of marginal probability of group membership in Figure E18. Samples having greater than 99.9%, 99.0% and 95.0% probability of membership to the "tin" granite/mineralisation group have been annotated along with those having a marginal classification of group membership.

The resulting classification via EDF is judged to be far better than SPSS. The training set can be seen to be strongly classified to the "tin" granite/mineralisation class in the main batholith of interest. Peripheral areas associated with tin mineralisation are present in the testing set. For example, in the Yule Batholith; the Wodgina Belt; extension of the Wodgina shear into the Turner Batholith; the environs of the Pilga Shear mineralisation, southeast of the Numbana Granite in the Abydos Adamellite; and south and northeast of the Numbana Granite. The latter area is of particular interest because of the prominent Nb pattern commented upon in the univariate data analysis. Other "tin" granite/mineralisation classified areas accentuated in the Yule Batholith are generally associated with its sheared margins, a locus for hydrothermal mineralisations some of which are pegmatitic. For example, Yule...
Batholith/Pilgangoora Syncline - Be and Au; Yule Batholith/Soanesville Belt - Au; Yule Batholith/Tambina Complex - Ta, in the shear just outside the pattern; and Yule Batholith/Western Shaw Belt - Au.

In the Shaw Batholith some patterns are related to tin mineralisation outside the training area, such as to the south of the Cooglegong Adamellite. Other areas are present to the east of Coondina and in the extreme northern portion of the batholith and the North Shaw Belt. In the Mt Edgar Batholith, the Moolyella mineralisation is discernable, south of the Moolyella Adamellite training set.

Three general areas of interest are present in the Corunna Downs Batholith. With the exception of the basin straddling the batholith and the Kelly Belt the patterns are not strongly classified to the "tin" granite/mineralisation group. The basin in the southeastern corner is underlain by Mondana Adamellite, Boobina Porphyry and contains Cu mineralisation in the felsic volcanics of the Kelly Formation. However, the northern most pattern in the batholith is of some interest because of the presence of a Nb pattern noted in the univariate analysis.

The Fortescue Volcanics are highlighted, especially the area in the south eastern portion of the map underlain by intrusive Spinaway Porphyry. Other inexplicable patterns occur to the southwest and northwest of the Marble Bar Belt.

The remaining patterns are found in the Carlini Batholith and the Strelley Batholith. The former may have associated pegmatitic mineralisation.

(4) EDF - five elements

Table E9 is the output for only the five granitoid elements, i.e. Pb, Be, Sn, Y, La, which were entered in the analysis. The smoothing parameter was again iteratively determined and the result of the subsequent classification at a final sigma value of 0.20 on the testing set was; 22.067% "tin" granite/mineralisation, 79.933% gneiss/greenstone and 0.00% for the unknown group. Final membership of the "tin" granite/
Table E9 Portion Testing set KGF output—Five Granitoid Elements
Figure E20 Graphical representation of iterative EDF five element classification. Marble Bar testing set until terminal classification.
Figure E28 Graphical representation of the probability of group membership for EDF five element classification.
TRAINING TESTING PHASE
EDF - FIVE GRANITIC ELEMENTS
Pb-Sn-Be-La-Y

- Mines or Prospects
- Ores or alluvial working
- Antimony
- Silver
- Arsenic
- Au Gold
- Bi Bismuth
- Cr Chrome
- Co Copper
- Ni Nickel
- Pb Lead
- Be Beryl
- Sn Tin
- W Tungsten
- Zn Zinc

- Outline of training areas
- Member of training set
- To granite/mafic-ultramafic class
- 99% probability
- 99% probability
- 99% probability
- Unannotated: 60-94%
- Marginal probability of classification: 40-50%
- 50-60%
- 60-90%

Figure E19
mineralisation group has became slightly larger than the above seven element case (1.39% = 5 samples). Membership of the "tin" granite/mineralisation group was seen to rise much rapidly with initial smoothing and peaked at 0.04 sigma, i.e. 22.346%, with the remaining 58.939% assigned to the gneiss/greenstone group and 17.318% assigned to the unknown group (Refer Table E9, Figure E20). In contrast with the unknown group whose membership was being reassigned to the gneiss/greenstone group with increased smoothing a virtual steady state existed for the "tin" granite/mineralisation group until smoothing with a sigma value of 0.16 caused a slight drop in classification (0.279%) and a further gain to the gneiss/greenstone group. It would again appear that the unknown group is essentially part of the gneiss/greenstone group. However, this remains to be substantiated. The terminal classification at 0.20 sigma was once more selected, because of the yet proved assumption that "noise" had been eliminated at minimal cost of membership to the "tin" granite/mineralisation group, i.e. 0.279% = 1 sample.

Group membership in both the training and testing sets can be seen to be definitive from Table E8 and Figure E28. Again, in contrast to the SPSS runs, no misclassification or marginal probability of membership has occurred in the training set. Likewise, in the testing set only a few samples have marginal group membership. An areal distribution of group membership is given in Figure E19. Samples having greater than 99.9, 99.0 and 95.0% probability of membership to the "tin" granite/mineralisation group have been annotated along with those having marginal classification of group membership.

The resulting classification based on only the five granitoid elements is basically similar, but shows some improvement over the above reported seven element classification. Even though some weakening of the probability of classification has occurred in the training set members over the Numbana Granite and Moolyella Adamellite, patterns are better defined elsewhere. For example, in the Carlindi Batholith; southeastern corner of the Yule Batholith and western Corunna Downs Batholith. Most important, is the appearance of a pattern over the Coondina Granite and in part the mineralisation in the Shaw Batholith.
Outline of training areas

Minerals or Prospects
- Chrome
- Copper
- Nickel
- Tin
- Terrane
- Tungsten
- Zinc

Mines or Prospects
- Asbestos
- Silver
- Pb: Lead
- Ag: Silver
- Sn: Antimony
- Bi: Bismuth
- Zn: Zinc

Outline of training areas

Mineral of training area

Tol' / granite / regional basement crises

Smooth/ transparent class

Marginal probability of classification

Coloured basin classified

Training phase

EDF - Seven elements

Pb - Sn - Ba - La - Y - V - Ni

Smoothing parameter set at 0.04

Figure E.22
M A R B L E BAR
SF50-08

• Mines or Prospects
- Eluvial or Alluvial working
- Adits
- Rivers
- Arsenic
- Salt
- Beryllium
- Barium

- Outline of training areas
- Number of training set
- Training/evaluation sites
- Unknown sites
- Marginal probability of classification
- Uncovered basin classified 6
(5) EDF - classification at 0.04 sigma

The answer to the question, "what, in broad geological terms is the unknown group?" was solved by running EDF for both five and seven element combinations at 0.04 sigma smoothing. At 0.04 sigma smoothing, group classification for the five element combination was; 22.346% "tin" granite/mineralisation, 58.939% gneiss/greenstone and 18.715% unknown, while for the seven element combination, 18.715% "tin" granite/mineralisation, 53.352% gneiss/greenstone and 24.022% unknown. The distribution of the three groups for both runs can be seen in Figures E22 and E23.

A comparison of these figures with those of the previously discussed five and seven element terminal solution (Figures E18 and E19) reveals that the unknown group principally outlines areas of mafic volcanics in the greenstone belts and remnant mafic xenolithic rafts in the batholiths. Of particular note, are areas underlain by the Fortescue Volcanics, Coongan Belt, North Pole Dome and the southern portion of the Shaw Batholith. It should be pointed out that at this smoothing parameter areas belonging to the gneiss/greenstone group in the actual greenstone belts are also underlain by mafic volcanics, but the emphasis would appear to be areas underlain by volcano-sedimentary rocks, e.g. Western Shaw Belt, Pilgangoora Syncline Belt. In contrast the areal distribution of the "tin" granite/mineralisation group is much the same as the respective terminal classifications. It is thus not surprising that with subsequent increased smoothing the unknown group has become reclassified entirely to the gneiss/greenstone group.

(6) EDF - Z-score runs

The seven element combination Z-score data run result can be seen in Table E10, while the areal distribution and a frequency distribution of group membership can be seen in Figures E24 and E29. These data, the latter in particular, should be compared with Table E8, Figure E18, E21 and E27. At a final sigma of 0.20; 20.112%, 79.888% and 0.000% are respectively classified "tin" granite/mineralisation, gneiss/greenstone and unknown groups in the testing set. An insignificant...
Figure E29 Graphical representation of the probability of group membership for EDF normalised seven element data classification.
TRAINING TESTING PHASE
EDF - SEVEN ELEMENTS
Pb - Sn - Be - La - Y - V - Ni
Z - SCORE DATA

Outline of training area
Boundary
Member of training set
99.9% probability
99.0% probability
95.0% probability
Unannotated 60 - 94.9% probability
Marginal probability of classification: 60 - 50%; 50 - 60%
Marginal probability of classification: 40 - 50%; 50 - 60%
Uncoloured basins classified G
<table>
<thead>
<tr>
<th>Sample</th>
<th>Fe</th>
<th>Cu</th>
<th>Pd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample A</td>
<td>0.2</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>Sample B</td>
<td>0.24</td>
<td>0.19</td>
<td>0.09</td>
</tr>
<tr>
<td>Sample C</td>
<td>0.26</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>Sample D</td>
<td>0.28</td>
<td>0.22</td>
<td>0.11</td>
</tr>
<tr>
<td>Sample E</td>
<td>0.3</td>
<td>0.23</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Table: El Portion Testing Set EDF output-Five Granitoid Elements Normalised Data
Figure E30 Graphical representation of the probability of group membership for EDF five element normalised data classification.
Outline of training area

Member of training set

99.9% probability

99.0% probability

95.0% probability

Marginal probability of classification:

60-65%

65-70%

60-70%

Marginal probability of classification:

60-70%

60-70%
drop in classification to the "tin" granite/mineralisation group has occurred, i.e. 0.558% = 2 samples, in the testing set. However, a marked increase in the probability of group membership can be seen in Figure E24 and E29. Also, no samples fall within the writer's zone of marginal probability of group membership. Patterns have become more distinct, e.g. the Moolyella mineralisation, western Corunna Downs Batholith and the Spinaway Porphyry in the southwestern corner of the sheet. Off setting this is some loss of information, e.g. basins in the tin mineralised areas of the Shaw Batholith (Coordina) and Turner Batholith.

The five element combination Z-score data run result can be seen in Table E11, while the areal distribution and a frequency distribution of group membership can be seen in Figures E25 and E30. These data, in particular the latter, should be compared with Table E9, Figures E19 and E20. In contrast to the raw log data run, a substantial increase in classification to the "tin" granite/gneiss group has occurred in the testing set at a final sigma of 0.20. Final classification to the respective groups is, 25.140% "tin" granite/mineralisation, 74.860% gneiss/greenstone and 0.000% unknown. An increase of 3.073% (= 13 samples) has occurred in the "tin" granite/gneiss group of the testing set. As with the original raw data run no misclassification has occurred in the training set and a marked increase in the probability of group membership has resulted. A marked increase in the probability of group membership has again occurred in the testing set. However, it is not as pronounced as the above seven element combination. The same number of samples can be seen to fall within the writer's zone of marginal group membership, but one less is present in the probable "tin" granite/mineralisation category of the zone.

Patterns are similar to the raw data run, but are more pronounced. They also, in part, have become enlarged, e.g. Moolyella Tinfield, Coordina Tinfield, north eastern flanks of the Numbana Granite and the western portion of the Corunna Downs Batholith. Of importance and not seen in previous classification runs are areas containing minor Sn occurrences, e.g. in the southern part of the Yule Batholith and to the northeast...
of the Numbana Granite. Of further relevance is the fact that when Figure E25 is compared with the summary concentrate univariate map, Figure C38, an excellent coincidence is seen between patterns. More information is however, present in the classification map. Besides highlighting the previous mentioned minor Sn occurrences, it has given substance to the Nb pattern in the northern portion of the Corunna Downs Batholith and highlighted the faulted Yule Batholith/Western Shaw – Soanesville – Tambina Complex greenstone belt contacts as a possible locus for pegmatite mineralisation. However, the writer’s inference that only the western portion of the Mondana Adamellite is the true "tin" granite has not been substantiated by the concentrate data. Nevertheless, the basin straddling the adamellite, Boobina Porphyry and Archaean felsic volcanics containing Cu mineralisation is highlighted. The mineralised quartz vein system here is recorded as extending into the granite and may be genetically related to the young granite.

6.4.3.2 Conclusion from Pilot Testing Phase

A rigorous training phase has led to the formulation of a simple two class discrimination-classification, i.e. "tin" granite/mineralisation versus gneiss/greenstone, in an attempt to accomplish the aims of the experiment. The availability of population numbers to form an adequate training set and the semiquantitative nature of the data have dictated this approach. An extensive testing phase using the Marble Bar Sheet data, has led to the conclusion that the nonparametric EDF performs much more satisfactorily than the conventional parametric FLDF. FLDF like CFA in Section C is robust and can stand limited abuse when the conditions for parametric statistics are not entirely met. In this case, where the conditions were probably met (i.e. the individual participating elements are in gross terms, log normal, (refer Tables E3 and E4) the analysis failed, not in the statistical sense, but in a geological sense. The SPSS – DISCRIMINANT algorithm was effective only to the point that, when the outrider elements in the data set were deleted, the seven important elements and their probable order of significance in a possible subsequent discriminant equation could be seen from the univariate F ratios. This confirmed previous
independant determinations of the discriminatory elements and their significance. However, in the final analysis there was a failure to include Sn, Pb and Y, elements that showed significant discrimination in the univariate sense between the two groups. It is concluded that, a linear equation here is probably not appropriate to represent and summate the discrimination showed by the entire seven elements or the five "granitoid" elements.

Seven element (Sn, La, Be, Y, Pb, Ni, V) and five element (Sn, La, Be, Y, Pb) log base 10 and log base 10 standardised data runs were carried out with the EDF algorithm using the Marble Bar Sheet data as a testing set. The classifications were iteratively determined and the "terminal" classification at a smoothing parameter of 0.20 were selected in each case. At this sigma value, all samples are assigned to either the "tin" granite/mineralisation and gneiss/greenstone groups and the unknown group category does not exist. It was shown from the examination of the distribution of group samples from a classification using a smoothing sigma of 0.04, that the unknown group is effectively a subdivision of the gneiss/greenstone group. Even though five element classifications generally resulted in more samples being assigned to the "tin" granite/mineralisation group than the seven element classifications, (i.e. 22.07% c.f. 20.67% in the case of the log base 10 data and, 25.14% c.f. 20.11% with the log base 10 standardised data), the resulting patterns of the classified samples of the "tin" granite/mineralisation group, are similar to the seven element classification, but are more meaningful and diagnostic in their probability of group membership. Indeed, with the five element classification using standardised data, patterns have become enlarged and more pronounced. Besides highlighting "tin" granite phases and major areas of known Sn-(Ta) mineralisation, areas containing minor Sn occurrences were seen for the first time; substance given to a Nb pattern in the old granite terrain in the northern portion of the Corunna Downs Batholith; and the Yule Batholith/Western Shaw - Soanesville – Tambina Complex greenstone belt sheared contact is highlighted as a possible locus for hydrothermal (pegmatitic?) mineralisation.
The satisfactory outcome of the testing phase, especially with the EDF algorithm, has led to the decision to proceed with the regional experiment.

6.4.4 Regional Phase

A statistical, but of more relevance, a geological satisfactory result was obtained from the pilot testing phase using the EDF algorithm on standardised data for the five granitoid elements Pb, Sn, Be, Y and La. This result means that a more extensive regional classification phase can now confidently proceed using these five elements over the 100,000 km$^2$ area of interest in the Pilbara.

A data base of 1880 stream concentrate geochemical results was assembled for classification. The data included the Marble Bar testing set, but excluded detailed second stage infill regional sampling over the southern portion of the Nullagine Sheet. This raw data was standardised and then subjected to classification through the EDF algorithm using the granitoid elements Pb, Sn, Be, Y and La. The areal distribution of group membership is given in Figure E31 along with a probability of group membership to the "tin" granite/mineralisation group.

6.4.4.1 Results from the Regional Phase

At a final sigma of 0.20; 16.48%, 83.52% and 0.00% of the sample results were respectively classified "tin" granite/mineralisation, gneiss/greenstone and unknown. Refer Table E12. From Figure E31 the distribution and probability of group membership can be seen.

On the Roebourne Sheet, in the northwest corner of the area of interest, scattered strongly classified members of the "tin" granite/mineralisation group are found over Pleistocene gravel covered granite and granite gneiss. It is of interest to note some Nb responses have been previously reported in the area of these "tin" granite/mineralisation classified samples. To the east, a prolific pattern of "tin" granite/mineralisation group members can be seen on the Port Hedland Sheet, especially in the western third of the map area. This mainly reflects dispersion...
Table 3.2: Regional Distribution of Granitic Elements (ppm)
from a young "tin" granite phase of the Carlindi Batholith which has associated Ta-Sn mineralisation. Recent remapping and updating of the original mapping (Low (1965)), by the G.S.W.A. confirms the presence of the tin granite, Lipple (1979). Areas annotated A, B and C from the classification are of interest in the search for Ta-(Sn) deposits, especially when combined with the updated geology and Nb data. The main rivers in the central portion of the sheet area are again prominent with their "tin" granite/mineralisation group member dispersion trains. In the remainder of the sheet, areas annotated D and E may also be of interest. These are underlain by Archaean greenstones.

On the Yarrie Sheet, north of the Oakover River, is a semi-contiguous area of "tin" granite/mineralisation classified samples. The majority of the area is underlain by Fortescue Group volcanics, Archaean granite-gneiss and basal Mesozoic sediments of the Anketell Shelf subdivision of the Canning Basin. In the univariate analysis, Sn was noted as being highly anomalous in the western portion of the area. This could represent dispersion from accessory cassiterite in the basal sediments of the Canning Basin, which were in turn were locally derived from a hidden young "tin" phase in the Muccan Batholith. This batholith is now only in part exposed on the Yarrie and the western adjacent Port Hedland Sheets. South of the Oakover River, a spotty distribution of "tin" granite/mineralisation classified samples is underlain by Archaean and Proterozoic granite.

On the Pyramid Sheet there appears to be a prominent cluster of "tin" granite/mineralisation group samples in the northeastern corner of the sheet. From the Pyramid 1:250 000 Geological Sheet the bulk of this pattern, annotated A, corresponds to an area of sparsely outcropping Archaean porphyritic granite. This pluton is poorly defined on the Pyramid-Marble Bar Landsat scene. However, early mapping describes this pluton as consisting of a medium to coarse grained leucocratic granite with potash feldspar phenocrysts, Kriewaldt and Ryan (1968). This could possibly be a young "tin" granite. Portion of the area also has an associated Nb pattern. The pattern annotated B to the east of A, is the Sn-Ta centre at Friendly Creek. A pattern annotated C is unusual, being...
centred over the locus of two major fault structures in Fortescue Group volcanics. Some Archaean granite is however, present in the southern portion of the pattern.

No comment is passed on the Marble Bar Sheet as this has been previously discussed in detail above in Section 6.4.3.

"Tin" granite/mineralisation group classified samples outline predominantly intrusive and partly extrusive Proterozoic Spinaway Porphyry and associated Fortescue Group volcanics and sediments on the Nullagine Sheet. Of prominence are the patterns labelled A and B. In the univariate analysis, the area of pattern A had an equivalent Nb response, while pattern B had an interesting Sn response. The significance of the patterns are not known, but the extrusive nature of the Spinaway Porphyry downgrades any economic potential. It is also of interest to note that these patterns are poorly classified as belonging to the "tin" granite/mineralisation group. On the border of the southern adjacent Balfour Downs Sheet, classified samples annotated C, outline the "tin" granite phase of the Kurranna Batholith. In contrast, pattern D, over the Mt Edgar Batholith in the northwestern corner of the sheet probably only reflects reported areas of localised Sn, Ta mineralised pegmatite swarms in the granite gneiss. A response is missing over the "tin" granite phase in the southern central portion of the sheet area. This is however, a function of the original analytical data and is discussed below.

Nothing can be said about the few samples that lie in the area of interest on the Mount Bruce Sheet. However, on the eastern adjacent Roy Hill Sheet, three patterns of interest, A, B and C, lie in the older granite of the Yule Batholith. Their significance is unknown, but pattern B may be of interest as a Nb response was noted in the univariate analysis and is coincident. The remaining classified samples fall over colluvium covered Fortescue Group volcanics.

The Balfour Downs Sheet is marked by the extension of the prominent "tin" granite/mineralisation pattern from the northern adjacent Nullagine Sheet over the Kurranna Batholith. A "tin" granite phase is present...
in the batholith and has associated Ta, Be mineralisation. The area was previously noted as having a definitive Nb response. The remaining "tin" granite/mineralisation classified samples are underlain by Fortescue Group volcanics and sediments. Some of these classified samples also have an accompanying Nb response.

6.4.4.2 Conclusions from the Regional Phase

The satisfactory outcome of the testing phase led to a regional classification phase over a 100 000 km² area of interest over the Pilbara inclusive and peripheral to the testing area, using the EDF algorithm on standardised data, for the five granitoid elements, Pb, Sn, La, Y and Be. Further "tin" granite phases were highlighted, within the Carlindi Batholith (Port Hedland Sheet), the Kurranna Batholith (Nullagine and Balfour Downs Sheets) and an unnamed batholith on the Pyramid Sheet. The latter was of particular interest, in that it is poorly defined on the Pyramid-Marble Bar Landsat scene. The first pattern was very extensive and may reflect a "halo" of hydrothermal activity with attendant pegmatoid mineralisation. In some respects it bore similarities to the pattern in the Yule Batholith, in the southern adjacent Marble Bar Sheet. The southern portion of the pattern from ancillary evidence, involving some Ta-(Sn) mineral occurrences, coincident Nb geochemistry and structure, would bear investigation for Ta-(Sn). A possibility of interest in the Proterozoic Spinaway Porphyry on the western portion of the Nullagine Sheet was briefly raised from the regional classification map. However, there is a general poor probability of membership to the "tin" granite/mineralisation group, and the in part extrusive nature of the granitoid excluded it from further interest.

Other areas of known mineralisation were also highlighted, such as at Friendly Creek (Pyramid Sheet) and Tabba Tabba (Port Hedland Sheet). On the other hand there were some in part inexplicable spottily distributed "tin" granite/mineralisation group classified samples. For example on the, Roebourne, Port Hedland, and Yarrie Sheets. Spottiness on the eastern portion of the Port Hedland Sheet may however, be due to reported small localised pegmatites in the older granite gneiss terrain. Some
speculation is introduced with the pattern in the north of the Yarrie Sheet. This pattern may reflect dispersion from the basal Mesozoic of the Anketell Shelf of the Canning Basin, which in turn may reflect erosional products from a buried "tin" granite phase in the underlying and part exposed Muccan Batholith. Structure again appeared prominent with a "tin" granite/mineralisation group pattern underlain by a major cross-cutting feature on the Pyramid Sheet.

As a general conclusion, discriminant analysis, through the EDF algorithm appears to have been an aid in meeting the writer's objective of confirming and more readily distinguishing:

(1) areas containing the young "tin" granite phases,

(2) areas of possible exploration interest within the older granitic terrain and as a bonus,

(3) highlighting structural situations which may be locii for hydrothermal mineralisations.

7. SUMMARY DISCUSSION AND CONCLUSIONS

The primary aim of the work undertaken in this section was the search for exploration targets for the granitoid commodity elements Sn and Ta, over a 100 000 km² area of the Pilbara region in northwestern Western Australia, using the macro-regional geochemical data integrated with satellite imagery. Two experiments were conducted. The first being a simplistic overview, using the Sn and Nb stream concentrate data integrated with satellite imagery and geological data, to see if exploration targets can be generated. The second involved the testing of the applicability of two contrasting discriminant analysis algorithms to a semiquantitative data set; and depending on applicability and performance, to use one of these multivariate pattern recognition algorithms on the same stream concentrate data base, coupled with the above ancillary data, to see if similar, but better defined exploration targets for Sn and Ta emerge.

...53.
Landsat scenes in coloured slide form for the area of interest were visually examined with the aid of a slide projector to compile a geological map with a bias to the so called young "tin" granite phases in the batholiths. The Marble Bar-Nullagine scene was used as a reference for what essentially was a "visual pattern recognition" exercise of granites having a similar photo texture to the Moolyella Adamellite in the Mt Edgar Batholith and Cooglegong Adamellite in the Shaw Batholith. Difficulty was experienced in the compilation, due to the varying quality of adjacent scenes. For example, the possible "tin" granite phase highlighted on the Pyramid Sheet in subsequent multivariate pattern recognition work was missed. Nevertheless, a new feature, the subdivision of the G.S.W.A. designated "tin" granite, the Mondana Adamellite, in the Corunna Downs Batholith emerged. It was suggested by the writer that the eastern portion of the granite is the true "tin" granite, even though confirmatory evidence from the macro-regional data is equivocal.

Granitoid mineral occurrences were also compiled from a variety of sources and added to the geological base map so that separate Sn and Nb computer plotted stream concentrate data maps could be interpreted. Even though a high detection limit of 100 ppm prevailed for Nb, it was used as a pathfinder for Ta, since this commodity element was not determined on the concentrates. In part, semicoincident Sn and Nb patterns of exploration interest emerged. Some of these patterns were related to the "tin" granite phases and known mineralisation, while others occurred in the older granitic terrain and over structural situations. It is pointed out that not all the young, and called "tin" granite phases, have associated or well defined Sn patterns. For example, the Numbana Granite in the Yule Batholith. This feature is probably related to differing compositional phases, and possibly erosional levels of the so called "tin" granites phases in the batholiths. The Sn overview data was particularly useful in that dispersion trains on the large rivers of the Port Hedland Sheet gave impetus for further research into the general possibility of exploration for placer minerals, but with an emphasis on the major commodity minerals of interest such as cassiterite, gold, tantalite over the lesser economically important rutile, ilmenite, monazite, chromite and magnetite. The
value of Landsat photography was again highlighted in indicating sites of possible accumulations of placer minerals. Indeed, visual examination alone of quality Landsat photography is demonstrated as yielding new useful information, and is a cost effective precursor to more detailed regional satellite imagery studies involving computer processing of the actual Landsat computer tapes. Although the placer possibilities have exploration merit from the environmental, infrastructure and land tenure positions, further research is needed. Some evidence was advanced, from the point of view of provenance and differing placer forming properties of the major and minor commodity minerals, that suggests that if placers have formed, the minor commodity minerals would have accumulated at the expense of the more economically attractive minerals, gold, cassiterite and tantalite.

The general principles of pattern recognition and classification as applied to geochemical data were outlined as a precursor to the second experiment. As demonstrated in Section C the writer favours a simplistic univariate approach to geochemical interpretation as nothing is lost by mathematical manipulation and the results are often easier to interpret. Multivariate pattern recognition techniques are useful tools enabling one to combine and summarise established geochemical features and to detect additional features to those that are already known from univariate studies. The applicability of linear (FLDF) and non linear (EDF) discriminant analysis to the semiquantitative concentrate data was investigated through available proprietary (SPSS Inc.) and published (Howarth, (1973)) algorithms.

In many exploration geochemical problems there is a difficulty in obtaining known target and background populations of relevance to effect discrimination and subsequent classification. It is thought that this is the reason why this pattern recognition technique has not been widely used in exploration geochemical work to date, especially with media associated with the hydrosphere. Even though some a priori knowledge was available here on groups to be discriminated, paucity of sample numbers over possible groups, led to the formulation of a two class problem to advance the aims of the writer, i.e. discrimination...
and subsequent classification to, either a general "tin" granite/mineralisation group or a gneiss/greenstone group. Indeed, where quality data is not available, as in this case, it is not prudent to make the analysis too complex. The detailed knowledge gained in Section C of the Marble Sheet concentrate geochemistry, enabled a final training set of 60 samples to be assembled that was considered representative of the two groups and the remaining 358 sample members of the sheet to be considered as a testing set. Feature selection in the training phase was made independently of the two algorithms even though this could be carried out automatically in the FLDF algorithm being tested. Line profile comparisons of individual elemental means and standard deviations for component subgroups and groups a whole were made, with subsequent quantitative estimates of elemental group discrimination through the nonparametric Kolmogorov-Smirnov Test. The former was an aid in confirming what elements were outliers and that discrimination-classification should be considered as a two class problem; while the latter, showed that five elements, in order of importance La, Pb, Y, Sn and Be and a further two, Ni and V, were statistically significant as discriminators, and respectively indicative of enrichment and depletion in the "tin" granite phase. Nb and Bi could have been important discriminators, but were considered as outliers because of the paucity of the data. From this work an independent approach to feature selection, rather than an inbuilt choice in an algorithm in a testing phase is recommended, as it allows one to be more objective about the classification problem at hand, and increases the probability of attaining a successful and meaningful result. The inbuilt choice within the algorithm used in the testing phase should only be regarded as a check, confirming the correctness of the selected discriminatory features.

An extensive training cum testing phase led to the conclusion that the nonparametric EDF performed more satisfactorily than the conventional and generally robust parametric FLDF, because a linear discriminant function was not appropriate for the problem at hand.

Five and seven element raw and standardised data runs were carried out with the EDF algorithm. The raw data was internally log base...
10 transformed in the same run as it radically reduced computational time (and in real world terms, cost) without effecting the classification by a factor of 30X. The five element (La, Pb, Sn, Y and Be) runs resulted in more samples being assigned to the "tin" granite/mineralisation group. The difference in assignment did not involve an inordinate amount of samples, but the resulting classification maps showing the distribution of "tin" granite/mineralisation group members were clearer and the probability of group membership was more diagnostic. The five element standardised data runs produced the most meaningful classification maps. Besides highlighting "tin" granite phases, major and for the first time, minor areas of known Sn-(Ta) mineralisation were highlighted; substance was also given to both monoelemental Nb patterns in the older granitic terrain, and a structural situation on the Yule Batholith/Western Shaw-Soanesville- Tambina Complex greenstone belt contact, as a possible locus for hydrothermal mineralisation (pegmatoid as well as gold).

The EDF algorithm performed admirably in the testing phase on the macro-regional data, but the axiom, "the final product is only as good as the constituent ingredients" applies in any endeavour. A better classification could have been obtained here, if the data was not semiquantitative. Information gaps were seen (i.e. non classification to the "tin" granite/mineralisation group) and were obvious in the Wodgina Belt and in particular in the Shaw Batholith over the Eley Tinfield and are attributed to sampling – analytical problems. Data quality could be improved in the future by the laboratory reducing the semiquantitative nature of the spectrographic analysis or by using a better analytical method such as, X-ray fluorescence, especially via the new generation multielemental equipment. At substantially lower detection limits other elements such as Ta and Nb may have also had an important role in the classification.

The EDF algorithm itself could be improved; i.e. the discriminatory elements confirmed by univariate density plots before classification, and a measure of their importance in the discrimination – classification given.
The use of the EDF algorithm was extended to a regional classification phase over a 100,000 km$^2$ area of interest using the standardised data for the five elements, La, Pb, Y, Sn and Be. Further "tin" granite phases were highlighted on the Port Hedland, Nullagine and Balfour Downs Sheets. A suspected phase was highlighted on the Pyramid Sheet, that had been missed in the visual interpretation of the Landsat scene. Other known areas of mineralisation were highlighted, and some patterns of samples classified "tin" granite/mineralisation were again found over interesting structural situations on the Pyramid and Port Hedland Sheets.

In summation, if the deficiencies of the actual data are neglected, the application of the multivariate pattern recognition technique, discriminant analysis, through the EDF algorithm, has led to better defined targets in the search for Ta and Sn at the overview level. The formulation of an average "tin" granite/mineralisation group has enabled regional mapping over the area of interest of the young phases of importance, including the location of a possible phase missed in the visual Landsat interpretation. It has been pointed out previously, that these young phases do not at times have associated or well defined macro-regional Sn patterns, even though they generally have associated Sn and/or Ta pegmatitic mineralisation. Thus, their location is a starting point in the search for possible associated eluvial-alluvial mineralisation. Other classified patterns belonging to this group in the older granitic terrains (e.g. Yule and Corunna Downs Batholiths) and associated with structure (e.g. Yule Batholith and east central Pyramid Sheet) may be indicative of hydrothermal mineralisation (with the emphasis on larger zoned pegmatites). This latter point is only really highlighted if the classification is combined with the univariate overviews, in particular the censored Nb data. Nb in the multivariate sense was considered to be an outlier. However, here in the Pilbara it can be used as a useful pathfinder for Ta and is especially important when coincident with "tin" granite/mineralisation classified samples. Indeed, the spotty classifications in the eastern central portion of the Roebourne Sheet over the Pleistocene eluvium covered old granite terrain may now be of some significance.
It is not until all sources of data, i.e. geology and structure, mineral occurrence plots, satellite imagery, the univariate geochemistry, the results of a multivariate pattern recognition exercise, are used and integrated, that truly better exploration targets emerge at the macro-regional level. These defined exploration targets, will in turn, need to be looked at in closer detail, i.e. responses of the relevant important elements placed in perspective with respect to local geology and structure, other sources of data integrated, for example regional geophysics, and perhaps the results of a computer session with the actual Landsat data tapes, to lead up to target rating and final confirmation through a field validation programme.
SECTION F
THE CONCEPT OF REGIONAL GEOCHEMICAL PROSPECTING
USING "LOAM" HEAVY MINERAL CONCENTRATES

INTRODUCTION
The concept of regional geochemical prospecting using "loam" heavy mineral concentrates is introduced. Preliminary experimental work to possible ongoing prospecting programmes is discussed below and some conclusions are drawn.

1. TERMINOLOGY
Before proceeding further some basic terminology must be defined and discussed. Terminology to be defined and discussed are "heavy mineral", "loam" and "loaming".

1.1 Heavy Mineral
Heavy minerals are those with specific gravities greater than the "light" minerals, (quartz SG 2.66 and feldspar SG 2.67), and consist interalia of oxides, sulphides, silicates, a few native metals, occasional titanates, tantalates, columbates, and less frequently, carbonates, phosphates, halides and sulphates. Minerals that readily oxidize during weathering do not persist as discrete heavy mineral grains in soil. Hence, the generally unstable compounds of heavy metals such as Cu, Pb, Zn, Ni do not survive for long among the more chemically and mechanically stable oxides and silicates. Heavy minerals in soil must, therefore, be able to withstand subaerial processes during severe weathering and erosion. Their persistence is due largely to their resistance to dissolution by natural chemical processes and, to a degree, their physical stability (hardness, cleavage and tenacity).

Most primary heavy minerals that persist in soil are usually sparingly developed, but as accessory types are widespread throughout the source rocks in which they crystallized. It is a characteristic feature of heavy minerals in their original sources (i.e. principally in magmatic and associated pneumatolytic environments) that trace elements enter or replace major elements in the crystal lattice. For example, Cr in ilmenites, Cu in magnetites. Small inclusions of a variety of minerals, gases and fluids are also often found in heavy minerals.

...2.
Among these inclusions are less stable sulphide minerals that persist because of the host's mechanical and chemical stability. Where the original abundance of the mineral in the source rock is much greater than normal, significant concentrations of a heavy mineral may build up in the soil through the process of weathering. These concentrates may reach economic proportions, e.g. eluvial cassiterite, gold and diamonds.

In heavy mineral geochemical prospecting, the content of the ore elements in heavy minerals is generally of less importance than the occurrence of the actual ore heavy mineral species, though trace element analysis of specific heavy mineral species has been suggested for use in other facets of regional prospecting. For example:

(1) Tan and Yu (1970) refer to the separation of pyrite samples from stream sediments in Taiwan and their analysis for Cu. Control samples indicated that pyrite from Cu deposits in the drainage contained 110-1700 ppm Cu, pyrite from Au deposits, 40-480 ppm Cu and pyrite from coal seams 100-120 ppm Cu. The method succeeded in delineating known deposits and outlining two new anomalies.

(2) Fisher (1971) reported studies in Australia involving the use of trace elements in tourmaline as an ore indicator. This mineral is regarded as being particularly suitable for exploration purposes since its high chemical stability permits its preservation in deeply leached soils, laterite profiles and stream sediments (C.I.M. Spec. Vol. 11, p. 16-20).

(3) Magnetite taken at the surface of the stream bed by dragging a magnet through the dry bed load has been used in exploration for base metal deposits in a variety of climatic and physiographic regimes. Its use has been reported in the search for porphyry copper deposits in Arizona, Huff (1971), and Ecuador, de Gryss (1970), and volcanogenic lead-zinc deposits in South Africa, Beeson et al (1975), McLaurin (1978).

With the exception of the latter example the separation of grains of individual species in a sample, with subsequent trace element analysis is labour intensive and slow. The high cost of such work prohibits...
it's usage in general geochemical exploration using concentrates.

1.2 Loam and Loaming
The term "loam" here is used not in the strict pedological context but in the sense of a soil sample of diverse and mixed origin, having variable material components of residual, eluvial and colluvial origin.

"Loaming" is the physical process of tracing mineralisation by panning soil and/or sediment and is an extension of prospecting by visual float tracing.

Pieces of mineralisation broken from outcrop by weathering and particularly by the physical agencies and processes of erosion, such as sheet wash and soil slumping, are dispersed. The particulates may gradually work their way under gravity into streams where they may be carried long distances. Consequently, the prospector finding float on a hillside or stream can follow it back to its source. An idea of distance of travel of the float is gained from the size and abundance of float pieces and by their roughness or water worn condition. Outcrops which are the source of float may be concealed by a covering of soil, and it is here that the visual tracing of float gives way to the process of "loaming". The technique is one of the oldest methods of prospecting and though not strictly a geochemical method, was the forerunner of geochemical surveying. It still is an active competitor with geochemical surveys in prospecting for deposits containing resistant minerals such as diamonds, gold and cassiterite which are capable of appearing in the heavy fraction of soils and sediments.

The process of "loaming" is based on panning similar volumes of sample material and concentrating the heavy minerals by gravitational methods, using water or wind as separating agents. In this way a comparative visual estimate of the amount of material sought can be made between samples without resort to chemical analysis. For example; in the pioneering gold rush days in arid Western Australia, where outcrop is minimal and water scarce, a method called "dry blowing" was devised, which utilized the wind as a separating medium. A pan of sample taken from the top 5 to 10 cm of soil was repeatedly poured from a pan held at the operator's head into a similar dish on the ground. The wind blew the light fines aside leaving the coarser material and gold behind.
The gold content was estimated by panning and colour counting. In this way a map could be made, or more simply, stakes placed into the ground to outline what today is known in geochemical terms as a clastic secondary dispersion halo of a gold body. Trenches or pits would be sunk over peak values to test the area.

The "loaming" method is still in use, and as previously mentioned should not be overlooked as a possible alternative and/or supplement to geochemical prospecting. Modern examples of the method are as follows:

1. Lee (1963, 1965) outlined the results of surveys conducted by the Geological Survey of Canada in the Kirkland Lake area. Gold particles were counted in heavy mineral concentrates from tills and eskers and were found to be effective in defining auriferous glacial trains.

2. Bird (1970) outlined the location of the small Migori-Nyanza gold deposit in Kenya. The company's geological department noted a number of small gold workings located in the Nyanzian System along the fringes of the Migori Granite. A loaming programme, laid out over 8km of strike, disclosed patches of mineralised quartz bearing rubble. More detailed pitting and trenching was carried out in the mineralised quartz rubble areas. Both estimates of colour and chemical analysis were carried out on the samples collected. Trenching in the vicinity of two sample points which contained mineralised gravels assaying 27.5 and 7.7 gm/tonne Au indicated the presence of high grade eluvial gravels and the sub-outcrop of the Migori reef.

3. Barbier and Wilhelm (1978) cite a recent case in Brittany, France where soil panning has been used successfully in the exploration for cinnabar and wolframite veins.

4. In the search for a specific mineral such as diamond, concentrates produced from sediments and soils are mineralogically examined by microscope. Besides diamonds, other specific indicator minerals, (chrome pyrope, chrome-diopside and picro-ilmenite) shed from
the primary kimberlite host are sought. Recent examples of the successful usage of this technique in the search for economic diamond deposits include the Russian deposits located on the Siberian Platform, and the Botswanan deposits as exemplified by the Orapa pipe.

2. PREVIOUS AND PRESENT INVESTIGATIONS

With the proviso that the material being examined has a residual or colluvial component there is no reason why "loam" samples, untreated or treated (i.e. the heavy mineral fraction concentrated) cannot be used as a medium in conventional regional geochemical prospecting for specific commodities. Indeed, systematic regional residual soil surveys at variable densities in areas of non-existant to minimal drainage have become standard practice in most parts of the world to outline areas of mineralisation. This type of activity for the most part would be directly comparable to "loam" geochemical surveys.

In contrast to the documentation of conventional regional soil geochemical surveys, little is recorded in the literature on the use of heavy mineral separates from soils in such surveys.

Tooms and Webb (1961) record that in Zambia, in the early 1950's before the now conventional large scale soil geochemical sampling programmes became common, Short's microchemical tests for semiquantitative estimates of Cu, Co, Ni and Zn were carried out on concentrates obtained by panning large samples weighing 1½ to 3 kgs collected from termitaries and soil pits. The procedures were tedious, and although metal contents could be detected in samples collected in the vicinity of mineralisation, the results tended to be grossly erratic. This procedure was discarded in the mid 1950's for the now conventional practice of systematic soil sampling.

An unpublished and very sketchy account of regional loam concentrate geochemistry has been given by Iannello (1972). This experimental work was carried out over the Tati Concession, an area of $5400\text{km}^2$, in northeastern Botswana. The Tati concession was held and explored for base metals by Sedge (Botswana) Pty Ltd (an affiliate company of Anglo American Corporation of South Africa) between 1969 and 1972. The concession area had previously been "loam" sampled in the early 1960's by another affiliate company, De Beers Prospecting (Botswana) Pty Ltd, as part
of their general diamond exploration effort in that country. Towards the close of the major base metal exploration programme carried out by Sedge (Botswana) Pty Ltd, over the concession, De Beers was approached by that company for use of the stored regional loam concentrates collected over the area. At this stage in time, the regional geochemical coverage of the concession consisted of stream sediments at 6-8 samples/km² over the northern 1100km² portion of the concession, and soil sample coverage at 20 samples/km², (i.e. soil samples taken on lines 500m apart and at 50m intervals) over the remaining 4400km² which was devoid of drainage. The geochemical work supplemented earlier airborne electromagnetic (INPUT) and magnetic coverage of the concession.

De Beers' modus operandi over the concession area was as follows: A series of east-west base lines were cut at 15km intervals across the concession. Teams of samplers were then sent out to collect a surface soil scrape (0 – 10 cm) at 60m intervals along 7.5km long north-south traverses spaced at 1km intervals along the base line. The sampling scheme resulted in an even coverage of the concession area at one sample per 8 km². Samples collected from two adjacent half traverse lines (3.75km) were bulked together, bagged and taken to a central washing site where concentrates were produced using Wifley tables. Concentrates from the tables were bagged and sent to a central laboratory for mineralogical examination for diamonds and kimberlitic indicator minerals.

The 610 regional reconnaissance concentrate samples covering the area were released by De Beers and sent to Anglo American Research Laboratories in South Africa for chemical analysis. The work, as reported, consisted of splitting, crushing and grinding the minus 600 micron bulk concentrates to 75 microns, taking splits for fire assay Au determinations and a very semi-quantitative 15 element emission spectrographic scan. The elements in the scan were As, Bi, Cu, Li, Mo, Nb, Ni, Pb, Sn, V, Sb, W, Y, Zn. The results for Cu, Ni were hand plotted, and anomalous elements and cells "eyeballed". The conclusion reached was that the majority of areas delineated were already known geologically (e.g. old gold producing areas) or from the Cu, Ni, Pb, Zn geochemical and geological sampling programmes carried out by Sedge (e.g. the Selkirk and Tekwane copper, nickel mineralisation).
As mentioned in Section A, a method of regional prospecting based in part on heavy minerals in glacial till is being carried out by the Geological Survey of Sweden (SGU) (Brundin and Bergstrom, 1977). SGU's aim is to cover the glacial till overlying the PreCambrian shield of Sweden, regardless of geological features, in about 15 years at the low sample density of one sample/10km². This sample density is comparable to the Botswana loam experiment. The primary aim of the survey is the detection, by mineralogical and chemical means, of anomalous dispersion fans that are a product of glacial transportation from mineralisation. SGU's sampling programme is initially being based on the existing road network. Till samples are collected from road cuttings by carborne teams (2 persons) at intervals of about 3km. This method appears to satisfactorily detect regional secondary dispersion trains related to mineralisation. Brundin and Bergstrom (1977) give an example of a new scheelite region detected at Ostansjo in northern Sweden.

The two methods ("loam" and till concentrates) appear to have some marked similarities but also distinct differences. Both are capable of contributing valuable information regarding mineralisation in geologically little known regions, i.e. problem areas having maximum overburden and minimal outcrop. It should be pointed out that many of the kimberlites discovered in Botswana are concealed, or are level with, typical surrounding featureless plain. For example, the Jwaneng pipes in southern Botswana do not have any topographic expression and are concealed beneath 30 to 60m of superficial deposits. (Baldock, Hepworth and Marenga 1976). However, the area has anomalous surface concentrations of kimberlite indicator minerals in semi-residual soil, calcrete and sand. Generally the typical base metal deposit offers a small target area (say 0.2 hectares) to the exploration geologist. This can, however, be considerably enhanced in glacial terrain by the typical fan shaped dispersion train produced by glacial movement. The dispersion train can be kilometres in length and of a considerable breadth. This enhancement means that the probability of direct successful detection of mineralisation in a till concentrate regional programme as conducted by SGU is considerable. There is, however, always the probability that isolated bodies will be missed. In contrast, a "loam" concentrate has a minimal component of transportation and is generally representative of a small area of country. Therefore, detection of individual mineralisation may be some-
what fortuitous. There are, and will be, obvious exceptions such as the "porphyry" types of mineralisation or again kimberlites which have large surface areas. The latter type may have an exceptionally large surface area. E.g. The Orapa pipe, Botswana is 110 hectares in area. However it should also be borne in mind that the environment of ore can be regionally anomalous and can be detected, be it mineralogically and/or geochemically. Hence the concept of geochemical and metallogenic provinces.

In Australia, until 1975, the peripheral collecting organisation's "loam" concentrate sampling had taken place only at a close density in specific small areas under exploration licence for diamonds. This approach was instrumental in locating pipes and dykes in a number of localities in Australia, e.g. Terowie, South Australia (Colchester, 1972). Systematic loam sampling in the Botswana manner at the first stage of regional diamond exploration had been unnecessary because of the availability of adequate drainage systems. Material collected from a trap site in a drainage system has been assumed to be a representative composite of the geology of that basinal area. Sampling and concentrating the heavy mineral fraction of material from trap sites at a mean density of a sample per 75km², meant that much of the continental area of Australia could be rapidly and economically scanned for diamonds. However, as sampling progressed from all four points of the compass into the arid interior of the continent, drainage systems became scarce to non-existent finally necessitating the collecting organisation to give thought to the methodology of regional scale loam sampling under Australian conditions. The question was also raised of the utilisation of the products of regional loam programmes to obtain geochemical coverage over a possible 1.3 x 10⁶km² area of the continent having minimal and/or non existent drainage and poor outcrop.

As part of this thesis the writer has set out principally to investigate the applicability of loam concentrates in regional geochemical surveys in areas of minimal drainage. The work reported below has consisted of:

(1) As a precursor, obtaining the raw "loam" concentrate analytical data of the Botswana, Tati Concession experiment from the Botswana Geological Survey, along with current geological information,
as well as conducting a detailed hindsight examination of all
data to determine if geochemical/metallogenic provinces are discernable in concentrate data

(2) Preliminary local and regional experiments in the Eastern Goldfields
Province of Western Australia to determine the significance of
loam concentrate geochemical patterns.

3. TATI HINDSIGHT EXAMINATION
As previously outlined an unpublished and very sketchy account of regional
loam concentrate geochemistry over the Tati Concession has been
given by Ianello (1972). The raw listed analytical data with location
maps were lodged with the Geological Survey of Botswana as a condition
of reporting on exploration activities within the concession. The writer
acknowledges the help of the Geological Survey of Botswana in releasing
a copy of the raw data and location maps along with updated geological
references covering the area of interest. The objective of obtaining
these data was to conduct a detailed examination to determine, before
embarking on experimental work:

(1) If geochemical provinces are discernable in a large regional concen-
trate data set covering an area of poor to non existent drainage.

(2) The relationship of known metallogenic provinces to any discernable
geochemical provinces.

3.1 General Setting
The 5400 km² area of interest lies between the Shashe and Ramokgwebana
Rivers along the north eastern boundary of the country. Francistown,
one of the main towns of Botswana lies near the centre of the area
of interest on the main railway line to Bulawayo in adjoining Rhodesia.
Figure F1 shows the location of the area of interest in relation to
diamond prospecting ("loam sample") coverage in the country.

The climate and vegetation of the area is best described as being tropic-
al savannah. Hot "wet" summers and mild dry winters prevail. Mean maximum
and minimum temperatures for the seasons at Francistown are 31.4, 18.8°C
respectively in December; 22.9 and 5.5°C respectively in June. The
LOCATION OF STUDY AREA
(after Baldock et al. 1976)

Fig. F1

TYPICAL JIGGED LOAM HEAVY MINERAL CONCENTRATE

Fig. F2
average rainfall of 419mm occurs during violent thunder storms in the
period October to April. (Botswanan government statistics). The topograp­hy is reported to reflect the nature of the underlying lithologies,
Keys (1976). Areas underlain by granitoid rocks are flat sand covered
pediments broken by occasional inselbergs lying between 900 and 1000m
above sea level. In contrast, greenstone relics provide a more positive
relief because of the greater variety of lithologies. In particular
banded iron formation forms prominent ridges (eg Matsiloje Hills) which
rise to a few hundred metres above the pediment.

The area is underlain by two geological entities, both Archaean in
age, the Rhodesian craton and the Limpopo mobile belt. (Figure F3).
The Rhodesian craton is represented by mainly granitised sediments
(paragneiss) and deformed intrusions (orthogneiss) of amphibolite-facies
metamorphic grade, as well as later post tectonic granitoid bodies.
Within the sea of granite gneiss are two relict greenstone belts, the
northern Vumba and southern Tati belts. The greenstone belts comprise
a two tier volcanosedimentary sequence of mafic to felsic volcanics
and sediments of Bulawayan age, which have been variably metamorphosed
to greenschist and lower-amphibolite facies. The Limpopo mobile belt
occupies a minor portion of the area of interest, being only developed
along the Shashe River in the south. High metamorphic grade (upper
amphibolite and in places granulite facies) gneisses with associated
metasediments and metavolcanics are present here. Baldock (1977).

Significant gold, nickel-copper, iron mineralisation is restricted
to the Tati belt. As in other Archaean greenstone belts in Canada,
Australia and Rhodesia, mineralisation here is related to the thick
sequence of volcanic rocks and to later felsic to mafic-ultramafic
intrusions. The volcano-sedimentary sequence of interest as typified in
the Tati belt commences with the Lady Mary Formation, (amphibolites and
actinolite schists of mafic to ultramafic volcanic origin with minor
metasediments, iron formation and marble); followed by the Penhalonga
Formation comprising dominantly clastics, meta-andesites and rhyolites
and minor limestone. Succeeding the Penhalonga Formation at the top of
the sequence are extrusive felsic meta-volcanics (rhyolites and dacites)
and meta- quartzites with minor penecontemporaneous mafic to ultramafic
layered intrusions of the Selkirk Formation. The belt has been subjected

...11.
to at least four major deformations and six metamorphic events. Keys (1976).

There is evidence that gold was worked by the "ancients" at 200 sites prior to modern activity between 1866 and 1964. Keys (1976). "Ancient" prospecting was so thorough that only the Rainbow Mine was discovered by Europeans. Recent production is an estimated 6,265,000 and 610,000 grams of gold and silver respectively. The latter was an important co-product in both the Tati and Vumba belts. Total gold-silver production including the ancients is perhaps double these figures. Keys (1976) op. cit. Molyneux (1971). Over 60 small mines and prospects are recorded in the more important Tati belt. These occurrences though small form a distinct metallogenic district. (Figure F3). The origin of the mineralisation is volcanogenic, but in detail many of the occurrences are fissure fillings related to late stage quartz veins controlled by intrusive granite, Baldock (1977). Solutions associated with post tectonic granites are considered to have remodelised at least part of the volcanogenic gold into structurally favourable shear zones, producing veins with typical epigenetic characteristics. Crockett (1964), Boocock (1965), classified the gold mineralisation of the Tati Belt into five groups and listed the principal occurrences of each of the main groups.

These groups are:

(1) Gold mineralisation in numerous small enechelon fissure quartz veins in metavolcanics, e.g. Bonanza Mine.

(2) Gold mineralisation in quartz reefs in shear zones close to granite-greenstone contacts, e.g. Monarch Mine.

(3) Gold mineralisation in quartz reefs near the contact with banded iron formation, e.g. Rainbow and New Zealand mines.

(4) Gold mineralisation in quartz reefs near the top of the Lady Mary or Penhalonga Formation, e.g. Map-Nora Mines.

(5) Disseminations in structurally disturbed areas, e.g. Golden Eagle Mine.
Associated with gold are the sulphides, arsenopyrite and pyrite, with minor galena, sphalerite and chalcopyrite.

Nickel-copper mineralisation found in the late 1960's at Phoenix and Selkirk and in the early 1970's at Tekwane, Cinderella and Dollar Princess in the central-south eastern portion of the Tati belt form a distinct metallogenic district. The deposits are small ranging from the largest at Phoenix of $4.5 \times 10^6$ tonnes of 2.1% Ni, 0.8% Cu, to Selkirk $3 \times 10^6$ tonnes of 0.9% Ni, 0.8% Cu; to Tekwane $0.6 \times 10^6$ tonnes of 1.2% Ni, 0.6% Cu; to drill intersected narrow widths of 0.15% Ni, 0.20% Cu at Cinderella and Dollar Princess. The sulphide assemblage (pyrrhotite - pentlandite - chalcopyrite - pyrite) is related to meta-intrusive mafic and ultramafic rocks spatially associated with the felsic volcanics of the Selkirk Formation. The Selkirk and Tekwane occurrences are located within metagabbro stocks whilst at Phoenix no primary host is exposed, the mineralisation being concentrated in intersecting shear zones in an area underlain by migmatitic and metavolcanic rocks. In the Vumba belt trace amounts of Ni and Cu have been recorded in several disseminated and massive sulphide deposits associated with amphibolites found by drilling geochemical anomalies and/or airborne INPUT electro-magnetic conductors. (Iannello 1972).

Other mineralisations are recorded in the Tati belt. These are, scheelite in quartz veins in mafic schists, especially at the Prospect and Golden Eagle gold mines; minor chrome from serpentinites at Sekukwe Kop; and low grade banded iron formation in the Matsiloje Hills, in the central and eastern portions of the belt respectively. Soil copper-zinc anomalies often related to gossans and with coincident INPUT responses are present at the top of the Lady Mary and Penhalonga Formations and in several ferruginous chert horizons. Follow-up work failed to detect significant sulphide mineralisation. However due to the limited time of the prospecting agreement the work is considered to be in an incomplete state. Keys (1976).

3.2 Geochemical Patterns

The elemental data for Au, As, Bi, Cu, Li, Mo, Nb, Ni, Pb, Sn, Sb, V, W, Y and Zn were key punched from the tabulated results and sample co-ordinates digitised. The analytical and co-ordinate data were merged ...13.
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<th>H/S</th>
<th>CVK</th>
<th>E</th>
<th>A</th>
<th>L/g</th>
<th>H/g</th>
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<td>2.398</td>
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All results below the limit of detection

Number of cases = 625. L = low, H = high, S = standard deviation, CVK = coefficient of variation

E = kurtosis, A = skewness, lg = log 10 data.

* Test for normality E/2 (6/N)^2 < 3; A / (6/N)^2 < 3

Table Fl Elemental statistics, loam concentrates, Tati concession.
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<th>Pb</th>
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<th>Mo</th>
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**S = .001**  
**S = .01**  
* S = .05

**n = 625**  
1 Strong 0.60  
2 Moderate 0.60 - 0.59  
3 Weak 0.25 - 0.39

Table F2 Rank correlation matrix, loam concentrates, Tati concession.
by computer and basic statistics run by the computer programme CONDESCRIPTIVE from the SPSS library. Table F1 summarises the statistics.

The majority of the values are highly positively skewed and kurtotic and when log 10 transformed remain so, with the exception of V and Zn which follow the log normal distribution. A correlation matrix for the data is given in Table F2. Due to the uncertainties of the distributions this was obtained by the Spearman Ranking Method through the facility of the computer programme NONPAR CORR of the SPSS library. A histogram in 0.05 intervals of the correlation matrix is also shown in Table F2. Two strongly separated groupings of correlation coefficients can be recognised. The most strongly separated and distinctive has been designated as strong (i.e. 0.60+) while the other weak (i.e. 0.25 - 0.44). The strong grouping is a Ni-V-Zn-Cu-Sn association while the weak can be broken up into Pb-Y, Bi-(Sn-Zn-V-Ni), Bi-Cu and Mo-W associations.

From the histogram plots of the individual elements up to 10 class intervals were chosen and the elemental data computer plotted at 1:500,000. Maps for As, Li, Sb were not generated as these elements were below the detection limit for the spectrographic analytical method. A geological and mineral occurrence map was compiled from the 1:500,000 geological mpa of Botswana, Bennett (1970), the 1:1,000,000 map showing mineral occurrences and metallogenic districts of eastern Botswana, and the 1:250,000 geology and mineral occurrences of the Tati Belt. Baldock (1977). Refer Figure F3. The observed elemental patterns are as follows.

3.2.1 Gold
The great majority of values fall below the detection limit of 150 ppb. However, the remaining positive values are distributed in interesting patterns some of which are obviously related to gold mineralisation in both the Vumba and Tati belts. The gold values have been outlined by the 150 and 600 ppb isopleths in Figure F5.

The largest patterns annotated, 1 to 5 are related to areas of known mineralisation in the Tati belt. These are as follows:

...14.
MINERAL OCCURRENCES & GEOLOGY
Au, Cu, Ni, Pb, Zn & V
LOAM CONCENTRATE GEOCHEMISTRY
(1) A very extensive Au pattern is found in the north-west portion of the Tati belt. The three annotated highs, 1.1 to 1.3 within the pattern, are confined to the area containing extensive quartz vein mineralisation in amphibolites of the Lady Mary Formation (Map-Nora, Golden Eagle and associated prospects (1.1, 1.2)), and to a lesser extent in the meta-andesites/rhyolites of the Penhalonga Formation, which in places, as to the north of Francistown, are in contact with felsic intrusives (Monarch, Mambo prospects (1.3)). However very few prospects are present within the annotated high 1.2.

(2) An extensive Au pattern of 600 ppb (2.1) is found in the eastern portion of the belt underlain by meta-rhyolites/dacites of the Selkirk Formation. Minor gold workings are recorded in the eastern portion of the pattern at Tekwane.

(3) To the east of the above, a small gold pattern is underlain by mainly Lady Mary and Penhalonga Formation. Within the influence of the 600 ppb high (3.1) in the pattern, gold mineralisation is present in the Lady Mary Formation at Matsiloje and Jim's Luck prospects.

(4) A spot high of 600 ppb (4.1) reflects in part the environs of the gold mineralisation of the Rainbow prospect, one of the larger workings in the belt.

(5) A 600 ppb high (5.1) is recorded in a small pattern in the southern portion of the belt over amphibolites of the Lady Mary Formation. The high reflects in part the environment of the gold quartz vein mineralisation at New Zealand and Brown's prospects.

A large gold pattern annotated 6.1 is present over the northern Vumba belt. A central high of 600 ppb within the more extensive northern pattern appears to reflect an area of known gold mineralisation in quartz veins in amphibolites. To the south of this pattern a small area of 150 ppb Au (6.2) is present over greenstones.

Minor inexplicable spot responses are present in the sampled area. These responses are usually associated with orthogneisses of the craton.
However, three of the four 600 ppb highs (7.1 to 7.4) to the south of Tati belt, are associated with greenstones. Two low order spot 150 ppb values (8.1, 8.2) are associated with the eastern and western peripheries of the northern portion of a post tectonic granite batholith in the Timbale Hills. A more extensive 150 ppb Au pattern (9.1) is found in the northwest corner of the area over the craton. No comment can be made on the remaining non annotated Au responses over the craton.

3.2.2 Copper
Patterns of interest as outlined by the 50, 75 and 250 ppm isopleths in Figure F5 are found over the Vumba and Tati belts. Cu-Ni mineralization of importance is also annotated on the figure.

The most prominent pattern (1.1) falls over the Vumba belt. Within an extensive area of 500+ ppm, Cu peaks at 2000 ppm. Conventional stream sediment sampling confirms the high copper content of the area with accompanying moderate nickel values. Massive soil grids failed to disclose any economic sulphides of interest. The conventional stream sediment patterns were surmised to reflect the abundance of mafic volcanics in the sequence, Ianello (1972).

A general copper pattern is found over the Tati belt, especially the area underlain by the more mafic units in the Lady Mary and Penhalonga Formations. However within this pattern are a series of north trending crosscutting highs. These highs may in part be related to underlying regional structure.

Nickel mineralization at Selkirk and possibly the minor occurrences at Dollar Princess, Cinderella and Tekwane are associated with regional Cu highs annotated 2.1 and 2.2. Likewise, the gold mineralization in the Lady Mary Formation at the Map-Nora and Golden Eagle mines and associated prospects, are highlighted by spot Cu highs annotated 3.1, 4.1. Generally the bulk of the anomalous Cu Ni areas from the regional soil geochemistry over the Tati belt are located within the two large central highs 2.1 and 5.1. The first of these 2.1 has been previously mentioned as containing the Selkirk mineralization. No comment can be made on 5.1 with the exception of the presence of a distinctive northern 250+ ppm high. The large Phoenix Cu-Ni deposit is found in a general area of high background Cu (2.3).
Cu highs of 500+ ppm (6.1) and 250+ ppm (6.2) are found in the western portion of the belt over post-tectonic granite and Lady Mary Formation. Little comment can be made on the large Cu patterns 7.1, 7.2, in the eastern portion of the belt with the exception that some of the highs within the patterns contain known areas of gold mineralization. E.g. the 250+ ppm high in the southern pattern 7.2. A few spot inexplicable unannotated responses of 100+ ppm are found over the craton.

3.2.3 Nickel

Patterns of interest are highlighted by the 50, 100 and 250 ppm isopleths in Figure F5. Cu-Ni mineralization of importance is also annotated on the Ni results.

The Tati belt is highlighted in the Ni results in contrast to the nickel low over the Vumba belt. As with the Cu results the environs of the Selkirk mineralization and possibly the three occurrences, Dollar Princess, Cinderella and Tekwane, are highlighted in the central nickel pattern. The previously discussed Cu highs 1.1 and 5.1 are in the main coincident with the central Ni pattern. Ni highs of 300+ ppm (1.1, 1.2) and 250+ ppm (1.3) are found within the central pattern. The northern nickel high (1.1) is associated with the Selkirk mineralisation. The bulk of the reported anomalous Cu, Ni areas from the massive regional soil geochemical grids over the belt are contained within the central pattern. The Phoenix Ni-Cu mineralisation is found within annotated pattern 2.1, northeast of the central pattern.

The eastern Ni pattern is partly coincident with the previously discussed eastern copper patterns 7.1 and 7.2. The Ni pattern contains two regional highs of 250+ and 300+ ppm (3.1, 3.2) underlain respectively by Lady Mary/Penhalonga Formations and Penhalonga/Selkirk Formations.

Two small Ni highs of 150+ (4.1) and 300+ ppm (5.1) are underlain by fault bounded blocks of Lady Mary Formation containing respectively the more prominent gold mineralisation at Map-Nora and Golden Eagle. The two highs have previously reported coincident Cu, i.e. 4.1 Ni - 4.1 Cu, 5.1 Ni - 3.1 Cu. Likewise in the southeastern corner of the sampled area, where the latter of two spot Ni highs of 200+ ppm (6.1,
7.1) underlain by craton, has a weak coincident Cu response. The former high (6.1) is underlain by Lady Mary Formation.

3.2.4 Lead

Pronounced Pb patterns are outlined by the 150 and 300 ppm isopleths in Figure F5. A further subjective isopleth has been placed at 75 ppm. Seven general annotated Pb patterns of interest are present. These are:

(1) The extensive Pb pattern of 150+ ppm (1.1), the majority of which is centered to the southwest of the Tati belt over deformed orthogneisses of the craton. A smaller Pb enhancement is also present to the north of the main pattern. A discrete high of 300+ ppm Pb (1.2) is present within the larger pattern. Of interest too is the Pb high 250+ ppm (1.3) on northeastern periphery of the pattern which is underlain by faulted amphibolites of the Lady Mary Formation of the Tati belt.

(2) A prominent Pb high is centered over the post-tectonic granite batholith of the Timbale Hills between the Vumba and Tati belts. The highest Pb values of 300+ ppm are found on the faulted northeastern (2.1) and southern (2.2) margins of the batholith.

(3) A smaller prominent 250 to 300+ ppm Pb high (3.1) is present in the extreme northern portion of the area of interest over mainly migmatitic gneiss of the craton.

(4) A pronounced Pb high of 250+ ppm (4.1) is present within the Tati belt and is bounded by two parallel faults and underlain by amphibolites of the Lady Mary Formations. Extensive gold mineralization in quartz veins, as evidenced by the persistent reefs at the Map-Nora, Todd's Creek and Kent prospects is present here. Silver is a consistent, but minor associate of gold in this geological environment.

(5) A spot high of 200+ ppm Pb (5.1) is present over felsic and intermediate intrusive and Penhalonga Formation meta-andesites/rhyolites. One of the larger and more extensive of the Tati gold producers, the Monarch mines are present here.
(6) A 150 to 200+ ppm Pb pattern (6.1) in the south central area of the Tati belt is found over a prominent north-south faulted portion of felsic metavolcanics of the Selkirk Formation. Minor gold mineralization in quartz veins is found at the Dinuku and Penhalonga prospects on the southern periphery of the pattern. The latter prospect was one of the more important silver producers.

(7) A spot 200+ ppm Pb high (7.1) is underlain by Lady Mary and Penhalonga Formation in the southeastern portion of the belt.

No comment can be made on the remaining unannotated highs over the craton.

3.2.5 Zinc

Patterns of interest are outlined by the 500, 1000 and 2000 ppm isopleths in Figure F5. The 500 ppm isopleth generally outlines high background areas reflecting a predominance of mafic rock types e.g. in the Tati belt. The zinc highs in the central and eastern portion of the Tati belt are orientated approximately north-south cutting the grain of the greenstone belt. This feature has been noticed previously with a number of elements and may reflect regional structure. Cu-Ni mineralization is generally present in the 2000+ ppm zinc highs. For example Selkirk and Tekwane are present within the highs annotated 1.1 and 2.1. A number of gold prospects are also present within the highs. In the central portion of the belt a large 2000+ ppm Zn pattern (3.1) is underlain by the Lady Mary, Penhalonga and Selkirk Formations and felsic intrusives. The Bonanza and Mons gold prospects are present in the southern portion of the high. The high here is of exploration interest for possible volcanogenic Cu-Zn sulphides as it is coincident with moderately high Cu values (area 5.1, Cu data) and is underlain by the acid felsic volcanics of the Selkirk Formation. The spot 1000+ ppm high (4.1), further westwards is of interest too and has been highlighted by other elemental data. Structurally disturbed amphibolites and meta-andesite/rhyolites of the Lady Mary and Penhalonga formations are present here. Gold and scheelite mineralisation is recorded at the Golden Eagle prospect. Further northwards a spot 1000 ppm high (5.1) is present over the environs of the Monarch gold mines.
In the northern portion of the sampled area zinc enhancements of 1000+ ppm (6.1, 6.2) are noted over the western and southeastern contacts of the faulted granite batholith of the Timbale Hills. The western enhancement (6.1) is coincident with vanadium and in part copper, lead and yttrium while the latter 6.2, molybdenum, tungsten, lead, tin and bismuth.

Northwards still zinc patterns (7.1, 8.1) are present over the orthogneiss of the craton. These patterns are also coincident with vanadium and copper enhancements.

The southern portion of the Vumba belt (9.1) and northern granite batholith (9.2) have low order Zn enhancements of 500+ ppm.

Two highs of 1000+ ppm (10.1, 10.2) are present within small general Zn enhancements in the craton west and east of the Tati belt. Pb enrichment accompanies the western high (10.1). The area of the eastern high (10.2) is structurally disturbed.

### 3.2.6 Vanadium

Vanadium patterns of interest in Figure F5 are outlined by the 400, 600 and 800 ppm isopleths. As expected the majority of the area of the Tati belt underlain by mafic volcanics is highlighted in the data. The northern Vumba belt is an exception, though there are local highs of 300+ ppm within the sea of low order values. South and east of the Vumba belt are the three most prominent patterns (1.1 to 1.3) over gneiss of the craton. These are in part coincident with weak Cu responses. Patterns 1.3 and 1.2 are underlain in part by the faulted eastern, western and northern portions of the Timbale Hills granite batholith. Vanadium peaks at 1000 ppm within these two patterns. Pattern 1.1 is distinctive in that it is a high in large regional low in the north-eastern portion of the concession.

In the eastern portion of the Tati belt vanadium patterns are orientated in an approximate north-south direction. The regional environs of known Ni-Cu mineralization are also enhanced by 300 to 500+ ppm V values. The most prominent vanadium pattern (2.1) is found over a structurally controlled block of Lady Mary and Penhalonga Formation. Vanadium values...
peak here at 1000 ppm. The area contains a great number of gold prospects, the Map-Nora being the largest. A spot high of 800+ ppm (3.1) is present in the eastern portion of the belt, again in a structurally disturbed area. Its significance is not known.

3.2.7 Bismuth
Some 61.8% of the samples fall below the 5 ppm detection limit for the method. However, pronounced Bi highs and patterns are outlined by the 15 ppm isopleth in Figure F6. A further isopleth has been placed at 7.5 ppm. Patterns of interest are annotated and are as follows:

(1) A large prominent north–south trending Bi pattern straddles both the Tati belt and craton. Two highs of 15 to 30+ ppm (1.1) and 15+ ppm (1.2) are present within the pattern. On the flanks of the northern portion of the larger southern high (1.1) en-echelon fissure vein gold workings at the Bonanza and Mons prospects are present in the Lady Mary and Penhalonga Formations. The highest value of 35 ppm Bi is recorded here. The northern high (1.2) is underlain by felsic and intermediate intrusives. Gold in quartz veins is present on the flanks of the high at the Cherished Hope prospect.

(2) Two patterns (2.1, 2.2) with associated Bi highs of 15 and 25+ ppm respectively are present in the southern most extremity of the area over paragneiss of the Shashe mobile belt.

(3) A small Bi pattern with a distinct Bi high of 25+ ppm (3.1) is present over faulted amphibolites and meta-rhyolites/andesites respectively of the Lady Mary and Penhalonga Formations in the western portion of the Tati belt. A number of gold prospects are present within the high, the most prominent being the structurally controlled disseminated mineralization at the Golden Eagle prospect and quartz vein mineralization within the formations at the New Robin, Mopanipani, Moth and Golden Butterfly prospects.

(4) A pattern (4.1) is present in the Francistown area over felsic and intermediate intrusives and meta-andesites/rhyolites of the Penhalonga Formation. Gold mineralization is present in quartz
MINERAL OCCURRENCES & GEOLOGY
Bi, Mo, Nb, Sn, W & Y
LOAM CONCENTRATE GEOCHEMISTRY

Legend as shown in Fig. F5
veins near intrusive contacts within the 15+ ppm high in the pattern. The Monarch mines, the most extensive of the Tati gold producers, along with the lesser prominent prospects, Mambo and Blue Sky, are present within the high.

(5) A general northerly trending Bi pattern and spot highs are present over the Vumba belt and the eastern periphery of a granite stock. Old gold prospects such as the Somerset, are present on the western periphery of the main pattern (5.1) on the flanks of the 15+ ppm Bi high. A spot high of 10+ ppm (5.2) is present on the western periphery of the pattern.

Little comment can be made on the other patterns. These being; the large 7.5+ ppm Bi pattern (6.1) over orthogneiss of the craton; minor patterns of 7.5 to 10+ ppm over principally amphibolites of the Lady Mary Formation (7.1, 7.2); and the northern margins of the Tati belt and craton (7.1, 8.2); the spot 7.5+ and 10+ ppm Bi responses (9.1, 9.2) on the northern and southern periphery of the Timbale granite. The remaining unannotated responses are present over the craton.

3.2.8 Molybdenum
The majority of the results in Figure F6 are below the 5 ppm detection limit for the analytical method. The seven positive results of 10 and 15 ppm are distributed as follows. A prominent Mo pattern (1.1, 1.2) containing the 15 ppm highs is present on the eastern faulted margin of the granite batholith of the Timbale Hills. Minor spot highs of 10 ppm are present to the northeast of the Tati belt (2.1), and to the southwest of the Timbale Hills (3.1) over migmatite in the craton.

3.2.9 Niobium
The majority of the results (99.2%) are below the 100 ppm detection limit for the method. The few positive results (100 ppm) in Figure F6 are mainly found over the craton in the mid-western portion of the sampled area. Of interest, however is the small annotated pattern 1.1 on the southern margins of the granite of the Timbale Hills.

3.2.10 Tin
Tin patterns outlined by the 25, 50 and 100 ppm isopleths in Figure

...22.
F6 are scattered over the sampled area. However the most prominent patterns are found in the Vumba and Tati belts and have been annotated accordingly.

The pattern over the Vumba belt is the most prominent. It is odd that the strongest pattern of 100+ ppm Sn is present over the greenstones and not the granite in the northern portion of the belt. The 350 ppm high in the annotated pattern 1.1, is coincident with a previously reported Cu high.

A number of patterns are evident over the Tati belt. As with the Cu patterns the tin patterns transect the grain of the belt in a similar north-south trend. The largest pattern occupies much of the eastern portion of the belt. Within this pattern of 25+ ppm Sn, three distinctive highs are present (2.1 to 2.3). The most prominent and largest in areal extent is a high of 50+ ppm (2.1). It contains mineralization with the exception of the Phoenix mineralization to the north. The area is underlain by the Selkirk and Penhalonga Formations and mafic intrusives. Little can be said about the 50 to 100+ ppm second Sn high of importance (2.2), with the exception of the presence of gold prospects (Rainbow, Jim's Luck and Matsiloje) in quartz veins near iron formation within the Penhalonga Formation. A similar situation is found southwards with a small high of 50+ ppm (2.3), underlain by the same unit.

The pattern (3.1) in the central portion of the Tati belt is approximately coincident with previously mentioned Cu pattern 5.1. The northern high of 100+ ppm Sn within the pattern is underlain by Selkirk Formation and felsic to intermediate intrusives. It is also coincident with a previously reported 250 ppm Cu high. The general significance of the high within the pattern is not known. The southern portion of the pattern contains the more significant Bonanza and Mons gold prospects in the Lady Mary Formation.

Westwards from 3.1 a general 25+ ppm Sn pattern and spot highs (4.1, 4.2) are present over an area underlain by faulted Lady Mary and Penhalonga Formations. Extensive gold mineralization is present within the pattern. Of note are the Map-Nora Mines. The southern portion of 4.1 is coincident with a high of 100+ ppm in the Cu data annotated 3.1. The
spot Sn high (4.2) to the southeast over similarly faulted formations contains a scheelite occurrence. It is also coincident with a previously reported high in the Cu data (i.e. Cu area 4.1).

Two highs of 50+ ppm annotated 5.1 and 5.2 are found in part over the margins of granites intruding the western portion of the belt. The larger eastern pattern (5.1) extends over an area containing considerable gold mineralization. Tungsten mineralization is recorded at the Prospect Gold Mine within the larger pattern.

North of Francistown, a 25+ ppm Sn pattern with a southern central 50+ ppm high (6.1) is present over intermediate intrusives and the craton. The pattern is in part coincident with Bi, Mo and with an as yet undisputed W pattern.

Northwards from 6.1 are two annotated enhancements 7.1 and 8.1. The first is present over orthogneiss of the craton while the latter is present over the southern faulted portion of the granite batholith of the Timbale Hills. The enhancements are coincident with previously mentioned prominent Pb and Mo patterns and as yet mentioned spotty W results.

Elsewhere over the sampled area, Sn patterns and spot values are evident over the area of the craton underlain by orthogneiss.

3.2.11 Tungsten
The majority of the results (98.72%) are below the 100 ppm detection limit for the method. (Figure F6). Areas containing known tungsten mineralization in the Tati belt are not expressed in the data. However a prominent 100+ ppm tungsten pattern (1.1) with a western 200 ppm high is present over the northern portion of the Tati belt and craton. It is underlain in part by amphibolites of the Lady Mary Formation, paragneiss and orthogneiss of the craton, and intermediate intrusives. A spot 100+ ppm (2.1) is also present on the southern flanks of the Timbale Hills granite batholith. The remaining 100+ ppm W value (2.2) is found over orthogneiss of the craton.

3.2.12 Yttrium
Three main areas of yttrium enrichment are outlined by the 75, 150
and 300 ppm isopleths in Figure F6. These main patterns are found, principally over the large area of orthogneiss of the craton in the southwestern portion of the sampled area and over the granite batholiths of the Timbale Hills and northern Vumba belt.

Distinctive highs can be seen within each of the three main patterns. The largest area of Y enrichment in the southwest has four distinctive highs. Two highs 1.1, (550+ ppm) and 1.2 (200+ ppm) are underlain by the Tati belt and contain gold mineralization in amphibolites of the Lady Mary Formation. Area 1.2 contains the Bonanza and Mons gold prospects while Area 1.1 is a structurally disturbed area containing the Golden Eagle, Moth, Golden Butterfly and New Robin gold prospects. The 300+ ppm (1.3) and 400+ ppm (1.4) highs over orthogneiss of the craton are inexplicable.

The Y enhancement over the Timbale granite batholith (2.1) is marked by a distinctive 150 to 250+ ppm Y enrichment on the northern faulted periphery of the batholith. Spotty low order values of 75 to 100+ ppm are present over the south central portion of the batholith and its periphery (2.2).

The batholith flanking the northern portion of the Vumba belt has similar low order Y results (3.1) with a spot 150+ ppm Y high on its northeastern periphery. Minor inexplicable low order Y enhancements are present elsewhere over the craton.

3.3 Discussion

Figure F4 summarises the geochemical patterns over the sampled area. Distinctive minor geochemical provinces at the district level are evident in the data. Some of these are related to known metallogenic districts. These geochemical districts are annotated on Figure F4 and are as follows:

(1) Vumba District

A Cu-Sn-Au-Bi district is associated with the Vumba belt. Cu-Sn is central; Au peripheral, but in part coincidental with the northern portion of the Cu-Sn pattern. Bi is in turn part coincidental but peripheral to Au. The significance of the elemental zoning is as yet undetermined. However some Au mineralization is recorded within the area of the Au pattern.
(2) Timbale District
A general central Pb-Y enrichment is present with:
(i) north flanking, semicoincident northeast-southwest trending
spotty Bi-Zn, Bi-Au and V-Zn associations; and
(ii) south flanking but in part semicoincident and more interesting
from the economic view point, Mo-W-Sn-Pb-(Zn-Bi-V) and Nb
associations. The significance of these two subdistricts
is again unknown.

(3) North Francistown District
A Sn-W-Mo-Bi district is present north of Francistown. Sn is central
and coincident with the large W pattern while Mo is coincidental
with both. Bi is peripheral to the Sn-W-(Mo). The southern portion
of the district overlaps the southern adjoining Tati gold province.
Coincidental Au-Bi-Pb-Zn in the southern portion of the district
highlights the area of the Monarch gold mineralization. However,
the significance of the main tungsten district is unknown.

(4) Southwest Cratonic District
A distinctive Pb-Y-Bi-Sn-(Zn) district is found over the craton
southwest of the Tati belt. The Bi-Sn is central and smaller than
the main Pb-Y. Some overlap occurs over the southern portion of
the Western Tati District. The significance of the elemental assoc­
iation is unknown especially the economically interesting Pb-Y-Bi-
Sn-Zn core.

(5) Western Tati District
The Western Tati District is dominantly a Au district within which
are three distinctive subdistricts. These are:
(i) A substantial northern central, Au-Sn-Cu-Bi subdistrict
related(?) to a post tectonic batholith. Tungsten mineral­
ization is recorded in the southern portion of the pattern.
The Sn-Cu-Bi association present over a similar geological
setting west of the main pattern is probably related.

(ii) A central Au-Sn-V-Cu-Ni-Pb subdistrict. Extensive gold
workings are recorded here.
(iii) A southern Au-Bi-Cu-Ni-Zn-Y subdistrict. Extensive gold workings are recorded here.

(6) Central Tati District
The central Tati District is primarily a Cu-Ni district within which are three distinctive subdistricts.

(i) A western copper-nickel subdistrict, with at times coincident and overlapping Sn and Bi-Zn. The central eastern Bi-Cu-Zn-Sn and southern peripheral Bi-Pb-Zn-Sn associations are interesting from the implications of the occurrence of volcanogenic massive sulphide in the greenstones.

(ii) A central copper-nickel subdistrict, within which is a distinctive associated Pb-Zn area overlapping in part a Sn district to the east. Au and Cu-Ni mineralization are present in the area.

(iii) Western tin subdistrict which overlaps (ii) and has internally a distinct northern Au association. Some Au mineralization is recorded in the area.

(7) Eastern Tati District
The Eastern Tati District is again primarily a large copper-nickel district within which are three subdistricts.
These are:

(i) A northern gold-copper-nickel subdistrict. This is in part a reflection of the gold mineralisation in the area such as at Jim's Luck.

(ii) A central tin-copper-nickel subdistrict surrounded to the north and southeast by gold-copper-nickel areas. The relationship of the association to mineralization is unknown.

(iii) A small gold-nickel subdistrict which probably, in part, reflects the frequency of gold mineralization in the area. E.g. the Rainbow gold mines.

...27.
(8) New Zealand District

The New Zealand District is named after the gold mineralization at the New Zealand gold mining centre and albeit is a gold-copper-tin district.

(9) Others

The writer has been primarily concerned with broad scale multi elemental associations over geological environments which may be indicative of a metallogenic province or district. A small copper-nickel cell (9.1) underlain by mafics in the extreme southwestern corner of the grid is therefore probably of interest. The remaining large mono-elemental patterns 9.2 to 9.4 appear to primarily reflect high background situations. For example the large nickel pattern (9.2) reflects the intrusive mafic and ultramafic rocks in the Selkirk Formation rather than the Phoenix Cu-Ni mineralization. The large gold pattern (9.3), over both remnant greenstone belt and craton in the northeast of the grid however may be an exception.

3.4 Conclusions

The writer has outlined at least eight geochemical provinces at the district level which correspond in gross terms to a polymetallic geochemical province which has probably evolved in time through distinctive geological and mineralising events. Au and Cu-Ni geochemical districts discussed have equivalent metallogenic status. The remainder, i.e. the granitoid Sn-W-Mo-Bi and volcanogenic Au-Pb-Zn-Bi associations are geochemical indications of the possibility of hitherto undetected metallogenic events.

With the great advantage of hindsight, the Botswana experiment illustrates the point that, loam concentrates produced by tabling a representative composite of "loam" scrape samples collected on a grid within an 8 km\(^2\) cell, and subjected to multielemental spectrographic analysis, can delineate geochemical district. Follow up investigations within such districts may establish the existence of comparable metallogenic districts. If the exercise had been carried out earlier and integrated with airborne geophysics the Selkirk and Tekwane mineralizations may...28.
have been found sooner. The method however is not a panacea. A regional Ni response is present over the environs of the Phoenix Cu-Ni mineralization but the associated Cu is of a low order and would perhaps indicate a high background situation. A more sensitive analytical method (XRF) coupled with confirmatory mineralogical identification by optical methods and the energy-dispersive, X-ray multichannel micro analyser would also yield more satisfactory results.

4. WESTERN AUSTRALIAN EASTERN GOLDFIELDS PROVINCE EXPERIMENTS

4.1 Introduction

The greatest problem confronting mineral exploration in Australia is the widespread concealment of geology by superficial deposits such as windblown sand, alluvium and laterite coupled with the intense surface leaching under the prevailing conditions of deep oxidation. Indeed, in the intensively explored Kalgoorlie Region in which the orientation studies have been conducted, outcrop would occupy no more than 10 to 20% of the surface area. The majority of the gold and (Ni dominated) base metal discoveries in the greenstones here are confined virtually to outcrop areas. Geological reasons aside, the apparent lack of volcanogenic Cu-Zn sulphide bodies even in outcrop areas in the Yilgarn generally, is probably related to intense surface leaching under conditions of deep oxidation. The Golden Grove discovery 13.5 x 10^6 tonnes of 3.5% Cu, 0.5% Zn is a good example. Thus, it could be assumed that many more deposits remain to be discovered provided effective exploration techniques can be developed to circumvent the above problems.

Cost effectiveness here of the technical methodology is most important. Currently overburden drilling for bedrock sampling is at least 20 and up to 40 times the cost of surface sampling so that this technique is used in small areas as a "follow-up" to test targets defined by geological/geophysical techniques. The use of elements associated with ore, but are immobile in the zone of oxidation in highly leached environments is perhaps one geochemical technique worthy of further investigation. Indeed limited research work by the CSIRO, Smith et al (1979) and industry (Geopeko) Sherrington et al (1979); Mazzuchelli and James, (1966) have shown the applicability of surface ferruginous pea gravels...
which develop over laterite profiles as a guide to various types of mineralisation. The former have concerned themselves with base metal and uranium deposits while the latter with gold. Multi-element research by Smith et al (1979) at Golden Grove has shown that a consistent Bi-Sn anomaly extends over an area of 2 km² around the gossan where as only one sample near the gossan carried anomalous Cu. Zn and Pb were only considered to be high background and of low order respectively. Intermediate Sb and As halos were also noted as the gossan was approached. Gossan fragments containing pathfinder elements are thought to have been dispersed from the mineralization mechanically by sheet wash during a Tertiary weathering period and have subsequently been lithified.

Pea gravels will obviously be a component of a loam sample in areas having a similar "landscape environment". For example, the Tati experiment. In retrospect of particular relevance from the Tati experiment, is the observation that in cells underlain by greenstones Bi-Sn accompanies Cu-Ni, Pb-Zn and monoelemental Cu and Ni anomalism. Some of the anomalism is thought to reflect discovered Cu-Ni mineralization. The association of Sn with or without Bi accompanying the major chalcophile elements was at first considered unusual, but has now been placed in perspective. By using these immobile elements, alone as pathfinders, or preferably as support to the major commodity elements, cells can be selected for detailed exploration which hopefully have a greater potential of containing mineralization. The importance of the multi-elemental approach in regional geochemical work is also once more accentuated. Thus, from the positive and encouraging results to emerge from the Tati loam concentrate geochemical examination, experiments at both local and regional scales were carried out to test in a very preliminary manner, the applicability of the products from regional "loam" surveys to regional geochemical exploration in the Eastern Goldfields area.

Materials to be made available by the peripheral collector would be bulk 4 to 6kg minus 0.42mm "loam" residues for concentrate production, and a normal minus 2mm geochemical loam. There was also a possibility that either some excess "heart" concentrate remaining from field jigging of the -2.00+0.42mm loam size fractions or treated concentrates after laboratory mineralogical examination could also be made available for geochemical purposes. Treated concentrates are concentrates that have...
been subjected to a laboratory acidification-attrition process to remove coatings that obscure mineral grains from microscopic identification. If the already prepared concentrates could be shown to be an effective sample media for regional geochemical surveys a considerable saving in cost could be effected.

Mineralogical orientation work (analogous to geochemical orientation work) had been carried out by the collector to ascertain which size fractions should be examined mineralogically for kimberlitic indicator minerals. This had resulted in the decision to use the \(-2.0+0.42\text{mm}\) fraction for mineralogical examination. The reason for the use of this size fraction was that, the number of grains to examine is considerably less (a laboratory probabilistic sampling problem) and at the greater sampling density for loams any minerals of interest released by weathering would not have moved far from their primary source and have suffered comminution in size. It must be remembered that as defined, "loams" may have a component of colluvial material. Even in flat, featureless arid terrain erosion does take place by the process of sheet and rill wash as exemplified by the previously cited Golden Grove example. Thus secondary dispersion by mechanical means can lead to a considerably enlarged target area. Eg at Golden Grove 2km\(^2\).

4.2 Regional Setting

The areas in which the writer's orientation investigations took place are located within the central part of the Archaean Norseman to Wiluna "greenstone belt" which is a subdivision of the Eastern Goldfields Province in the Yilgarn Block of the Western Australian Shield.

A semi-arid climate prevails in the area. Rainfall is sporadic being in the order of 220-250mm per annum and is spread fairly evenly over the year, with perhaps a slight winter bias. Summer rains are the result of cyclonic activity; whereas in the winter, weak rain-bearing depressions move across the area from the west. Diurnal and seasonal temperature changes are significant being similar to Kalgoorlie which has mean January and July maximum of 34°C and 18°C and minimums of 17°C and 6°C. The high summer temperatures and low rainfall cause the annual evaporation rate to be around 2250mm.
The study areas lie on a gently undulating plateau of low relief, whose average elevation is approximately 300m above sea level. The physiography is characterised by two distinct land surfaces known as the "old" and the "new" plateaux (Jutson 1950), which are the result of a complex history of weathering and stripping since early Mesozoic times. The old plateau was subjected to intense laterisation under a warm humid climate in Tertiary times. With the onset of more arid conditions in late Tertiary or early Quaternary times this surface was partly stripped, to form the new plateau. Geomorphologically, the old plateau is represented by flat topped hills capped with laterite, sand and gravel plains, and confined to headwater divide areas between major drainage basins. The new plateau surface is represented by erosional scarps ("breakaways") and pediments, and playa lakes in wide alluvium choked valleys that were once part of a southeastwards flowing Tertiary river system. The present drainage however is internal. After heavy rains the poorly defined drainage lines flood and sheet into internal basins which are occupied by playa lakes.

Soil types are related to the geomorphological units above. On the Tertiary peneplain and in the transition zone to the recent base of erosion, laterites, gravel and sand plains, solonized brown soils and desert loams can be found.

Vegetation is variable and belies the semi-arid nature of the climate. The vegetation ranges from dense mulga scrub on low hills to open eucalyptus woodlands interspersed with tracts of open blue bush and salt bush.

The Archaean Norseman to Wiluna "greenstone belt" is some 200 km wide and 800 km long. This north-northwest structural trending belt consists of four major lithological associations; a mafic-ultramafic volcanic association, a felsic volcanic - volcanoclastic association, an arenaceous and conglomeritic association and granite intrusion. A stratigraphic sequence has been proposed involving multi-cycling of lithological associations (Williams 1970). Three major mafic to felsic volcanic cycles are recognised. Table F3 contains a classification by volcanic cycle of the stratigraphy and ages for the rock sequences in the general...
<table>
<thead>
<tr>
<th>Era</th>
<th>Formation</th>
<th>Age (m.y.)</th>
<th>Thickness (m)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precesen</td>
<td>Widgiewooltha dyke suite</td>
<td>2420 ± 30</td>
<td></td>
<td>Quartz dolerite, gabbro, norite granophyre</td>
</tr>
<tr>
<td>Mercian</td>
<td>Granite Intrusion</td>
<td>2612 ± 13</td>
<td></td>
<td>Intrusion of granite, pegmatite; metamorphism</td>
</tr>
<tr>
<td></td>
<td>Kalpini Formation</td>
<td></td>
<td>4500</td>
<td>Basic to intermediate extrusive and intrusive rock; ultramafic intrusive rocks, clastic sediments</td>
</tr>
<tr>
<td></td>
<td>Gundockerta</td>
<td>ca. 2615</td>
<td>6000</td>
<td>Fine to medium-grained sediments, partly derived by erosion from:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3000</td>
<td>acid to intermediate extrusive and intrusive rock, minor basic extrusives, pyroclastic rocks;</td>
</tr>
<tr>
<td></td>
<td>Mulgabbie Formation</td>
<td>2660</td>
<td>4000</td>
<td>Basic extrusive and intrusive rocks;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ultramafic intrusives; minor intermediate to acid extrusive and intrusive rocks; Nickel sulphide, gold mineralisation</td>
</tr>
<tr>
<td></td>
<td>Gindalbie Formation</td>
<td>2660</td>
<td>4500</td>
<td>Clastic sequence; fine to medium-grained sediments mainly derived from:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7500</td>
<td>Intermediate to acid extrusives and intrusives, minor basic extrusive rocks, pyroclastics;</td>
</tr>
<tr>
<td></td>
<td>Moreland Formation</td>
<td></td>
<td>5000</td>
<td>Basic extrusive and intrusive rocks, ultramafic extrusives; nickel sulphide mineralisation</td>
</tr>
<tr>
<td></td>
<td>Gneiss</td>
<td>2800</td>
<td></td>
<td>Granitic gneisses</td>
</tr>
</tbody>
</table>

Table F3 - Summary Stratigraphy in the Eastern Goldfields Province area
study area. This table synthesises mapping of the Kurnalpi 1:250 000 sheet (Williams 1970) and also summarises in part earlier work by Turek (1966), Kriewaldt (1967) and Sofoulis (1969). Binns et al (1976) has noted that the regional metamorphic grade in the belt is variable ranging from very low greenschist to high amphibolite facies. Generally however, the orientation areas were subject to low to medium grade regional metamorphism.

The Archaean rocks in the region were the focii of two world-renowned events within the last hundred years, i.e. the gold rush of the 1890's and the nickel boom of the late 1960's. Both Au and Ni mineralisation have a similar spatial relationship being generally associated with the mafic-ultramafic phases of cycle 1 and 2. All the known Ni mineralisation is directly associated with ultramafic rocks, usually serpentinised peridotite or dunite, which may be extrusive, intrusive or metamorphic in origin. The best gold mineralisation occurs in tectonically prepared sites in metamorphosed mafic flows or sills with the gold occurring in silicified carbonated lodes or quartz veins. Gold is also found in iron formation and interflow metasedimentary units. The importance of the volcanogenic stratigraphy itself in the location of some of the Kalgoorlie gold deposits has been mooted by Tomich (1974). However, it is suggested that the majority of the Eastern Goldfields gold deposits were derived from the enclosing volcanogenic sequence, being remobilised and concentrated by later tectonic and metasomatic processes. (Travis et al. (1971). Gold mineralisation at 2400 ± 40 m.y. postdates the Ni mineralisation which is associated with metamorphosed country rock dated at 2655 ± 25 m.y. (Turek 1966). Massive pyrite with small amounts of Cu and Zn sulphides have also been recorded in the felsic phases of the volcanic cycles.

4.3 Local Experimental Work

4.3.1 Introduction

Local experimental work was first carried out over the Black Swan Ni-Cu-Co mineralised body, 43 km northeast of Kalgoorlie in the centre of the Eastern Goldfields Province. The reason for this localised experimental work was to generate data on:-...33.
(1) Metal extractabilities of common acid digestion procedures.

(2) Metal distribution and contrast in various size fractions and depths for both soil and soil heavy mineral concentrates in a mineralized environment. The first media being important for ongoing work in the region.

(3) Mineral constituents and the distribution of elements in the common mineral species of "loam" concentrates through electron probe micro-analysis.

4.3.2 Local Setting

The mineralisation at Black Swan occurs in a poorly exposed, north northwest trending and east dipping body of talc-carbonate rock with minor serpentinite, which is interpreted as a concordant ultramafic intrusive into a thick sequence of acid intermediate meta-volcanic rocks. (Figure 7) The small deposit of low-grade (0.75% Ni) disseminated mineralisation consists of the relatively uncommon primary mineral assemblage millerite-pyrite-chalcopyrite-magnetite with secondary "violarie".

The topography is subdued being part of the old plateau surface, at an average elevation of approximately 300m above sea level.

Outcrop is mainly soil covered. Typical soils over the mineralisation and ultramafic rocks are solonized brown soils (Stace 1962). Surface soils are generally grey to red-brown becoming paler with depth as the carbonate content increases. The soils are alkaline and of a variable thickness ranging from 45cm to greater than 120cm.

4.3.3 Sampling and Analytical Procedure

A soil traverse crossing the known semi-outcrop position of the mineralisation was run along line 60200N from stations 12500E to 13500E on the old imperial grid. (Figure F7) Samples were taken at 100 feet (30m) intervals along the traverse and included material above each of the different major rock types present, viz. volcanic, talc-carbonate and ...
CROSS SECTION AB

LOCAL ORIENTATION
BLACK SWAN - GEOLOGY

Figure F7
Soil

Drying, deaggregating

Sieving 1.68mm#, 0.84#mm
0.42mm#, 0.175#mm

Splitting individual fractions

Split 1
Pulverising and grinding to 0.075mm

Split 2
Heavy mineral separation by TBE. Weights of fractions and separates. Grinding separates to 0.075mm.

Analytical Scheme

(1) Cu, Ni, Co, Cr, Fe, Mn, Pb, Zn
   (a) Hot HCl-HNO₃-HF/AAS
   (b) Hot HC10₄/AAS
   (c) Hot 25% HNO₃/AAS
   (d) Cold 1% HNO₃/AAS
   (e) Cold ammonium citrate hydroxylamine hydrochloride/AAS

(2) Multielemental scan by emission spectrography on size fractions Split 1 and 2 surface scrapes only from background and mineralisation stations.

(3) Mineralogical and probe analysis of heavy minerals.

Figure F8 - Flow Sheet for Sample Analysis
serpentinite. At each site, 2 to 3kg of material was collected as follows: firstly, a typical regional loam surface scrape of material down to 15cm; followed by augering material representative of the depths 15-30cm, 45-60cm and 90-105cm. The last two levels could not always be sampled due to the presence of bedrock. All the samples were air-dried, deaggregated and split. Split 1 was sieved through 1.68mm (12#), 0.84mm (20#), 0.42mm (40#) and 0.175mm (80#) Tyler sieves. The +1.68mm material were discarded. Split 2 was retained for heavy mineral separation. Figure F8 summarises sample preparation and the analytical scheme which is outlined below.

Split one fractions were analysed in part by the writer and a custom laboratory by atomic absorption spectrophotometry (AAS). In particular all size fractions from the four depths at stations 1310 (mineralisation) and 1270 (background) were analysed in duplicate for Cu, Ni, Pb, Zn, Co, Cr, Fe and Mn after various hot and cold leaches to gauge metal extractabilities. Prior to analysis size fractions greater than 0.175mm were first ground in a Tema mill to pass this size fraction.

The following hot digestions were carried out by the custom laboratory on 200 mgm of sample; a concentrated mixed acid digestion HF-HNO$_3$-HCl (5:1:1) herewith called "total", concentrated 70% HCIO$_4$ and 25% HNO$_3$. The latter two attacks were carried out with 4 mls of acid at 180°C for 1 hour and diluted to 20 ml with demetallised water. The former digestion was carried out with 4 mls of acid over 3 hours at 250°C, taken to dryness and the residue taken up in 4 mls of 30% HCl for a further hour and then diluted to 20 ml.

Cold leaches tried by the writer were 1% HNO$_3$, and 0.3M ammonium citrate with 2% W/V hydroxylamine hydrochloride adjusted with ammonium hydroxide to pH 7. The latter digestion, after Ward et al (1963) and herewith designated by the symbols Amc, is essentially the Cu buffer used by the writer in the field analytical work in Section D. These leaches were carried out on 500 mgm of sample and 5 ml of leachate over 8 hours with regular (hourly) shakings. The leachate was topped to 10 ml after the last shaking, allowed to clear and decanted for analysis on a Perkin Elmer 360 AAS. The 360 AAS was operated by following the set operating conditions prevailing at Leicester, and the 360 Perkin Elmer handbook was
<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>COLD LEACH</th>
<th>HOT LEACH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Am. Citrate</td>
<td>1% HNO$_3$</td>
</tr>
<tr>
<td>Fe</td>
<td>14%</td>
<td>22%</td>
</tr>
<tr>
<td>Mn</td>
<td>6%</td>
<td>16%</td>
</tr>
<tr>
<td>Cu</td>
<td>22%</td>
<td>50(22)%</td>
</tr>
<tr>
<td>Pb</td>
<td>M%</td>
<td>M%</td>
</tr>
<tr>
<td>Zn</td>
<td>50(NH)%</td>
<td>50(40)%</td>
</tr>
<tr>
<td>Ni</td>
<td>50%</td>
<td>40(32)%</td>
</tr>
<tr>
<td>Co</td>
<td>21%</td>
<td>18%</td>
</tr>
<tr>
<td>Cr</td>
<td>50(NH)%</td>
<td>M%</td>
</tr>
</tbody>
</table>

Notation: NH = Near meaningless.  M = meaningless.

Table F4 Analytical precision, soil samples.
consulted for optimum operating conditions for the elements being determined. Half of the samples were run in duplicate. Each analytical run, equivalent to a digestion type, contained 48 samples plus a blank of 0.5% \( \text{LaCl}_2 \) in 10% \( \text{HNO}_3 \) in demetallised water.

Typical analytical precision for both hot and cold digestion on replicate analysis using the graphical method of Thompson and Howarth can be seen in Table F4.

As a generalisation from Table F4, analytical precision improves with an increase in the robustness of the attack. Meaningless and near meaningless precision estimates were made for some elements (Cr, Pb) because their presence in the cold leaches were at or near the detection limit of the analytical method.

Split two fractions were weighed and then subjected to heavy mineral separation by the heavy liquid tetra-bromo-ethane (T.B.E.) which has a specific gravity of 2.96. After weighing, the heavy mineral pulps were then sieved through the same four meshes as the split one soil samples. The split two size fractions and depth samples from mineralised and background situations (again respectively, stations 1270 and 1310) were analysed by the same digestive procedures as the soils. The only exception in the analytical method being the larger sample weight (500 mgm) taken by both the custom laboratory and the writer. The concentrates were again ground in a Tema Mill, but to pass 75 microns.

Due to the paucity of sample material at depth and in the fine fractions not all digestions could be effected and analytical control was limited, especially in the case of the cold leaches to 1 in 10 samples. The cold extractable work was again carried out by the writer and was completed during his last visit to Leicester. This work however was plagued with machine problems and moreover due to the lack of nitrous oxide all Cr determinations were carried out with an air-acetylene flame and consequently the results are noisy and suspect.

Analytical precision, again following the method of Thompson and Howarth on replicate analyses was similar to the soils though a little higher. For example the \( \text{HClO}_4 \) attack: Fe 30%, Mn 20%, Cu 8%, Pb 12%, Zn 13%,
Ni 12%, Co 16%, Cr 35%; the mixed acid (HF-HNO₃-HClO₄) attack, Fe 15%, Mn 10%, Cu 8%, Pb 6%, Zn 8%, Ni 5%, Co 12% and Cr 10%. The difference in precision probably in part reflects the contrasting sample type and modes of elemental dispersion, i.e. clastic versus chemical. A noticeable improvement in precision for the concentrates was again noted as the robustness of the attack increased. This probably reflects the near complete breakdown of magnetite and chromite in the samples.

Multi-elemental spectrographic work was carried out on the remaining soil and heavy mineral residues for a surface loam scrape at stations 1310 (mineralisation) and 1270 (background) Elements, with detection limits in ppm bracketed, determined by emission spectrography were, Ag(0.1), As(50), Ba(200), Be(1), Bi(1), Cd(3), Ce(300), Co(5), Cr(20), Cu(1), Ga(1), Ge(1), In(10), La(50), Mo(3), Mn(10), Nb(20), Ni(5), Pb(1), Sb(30), Sc(3), Sn(1), Sr(50), Ta(100), Th(100), Ti(100), V(10), W(50), Yb(1), Zn(10), Zr(10). Analytical precision (maximum) is of the order of ± 45%. See Section 4.4.3.

Mineralogical work was also carried out on the heavy mineral fractions of a soil scrape and a sample at depth from mineralisation (station 1310) and background (station 1270). The primary purpose of the work was to determine the nature of the mineralogy of the concentrates, in particular to see if any products of the oxidation of sulphides were present, and if possible the distribution and concentration of elements in the individual mineral species by X-ray micro-analysis.

4.3.4 Analytical Results

4.3.4.1 Metal Extractabilities of Digestants

Metal extractabilities for various hot and cold digestions on both concentrates and soils were calculated using the "total" emission spectrographic results as a base (100%). These results are set out in Table F5. Both media are from the surface, at background (1270) and mineralised (1310) situation stations.

...37.
<table>
<thead>
<tr>
<th>Element</th>
<th>Hx - &quot;total&quot;</th>
<th>Hx - HClO₄</th>
<th>Hx - 25% HN₂O₃</th>
<th>Cx - 1% HNO₃</th>
<th>Cx - AMC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Soil</td>
<td>% Concentrate</td>
<td>% Soil</td>
<td>% Concentrate</td>
<td>% Soil</td>
</tr>
<tr>
<td>Cu</td>
<td>13-118*</td>
<td>73-80*</td>
<td>160</td>
<td>80-90*</td>
<td>72-100*</td>
</tr>
<tr>
<td>Ni</td>
<td>150-192*</td>
<td>115</td>
<td>130-176*</td>
<td>123-125*</td>
<td>60-160*</td>
</tr>
<tr>
<td>Co</td>
<td>115-125*</td>
<td>103-146</td>
<td>98-114*</td>
<td>117-136</td>
<td>60-104*</td>
</tr>
<tr>
<td>Cr</td>
<td>210-240*</td>
<td>247-413</td>
<td>84-88</td>
<td>233-400</td>
<td>90-113*</td>
</tr>
<tr>
<td>Pb</td>
<td>72-80</td>
<td>75-85</td>
<td>60-84</td>
<td>75-85</td>
<td>33-44</td>
</tr>
<tr>
<td>Zn</td>
<td>72*-120*</td>
<td>120*-130*</td>
<td>90*-116*</td>
<td>138*-158*</td>
<td>47*-62*</td>
</tr>
</tbody>
</table>

Notes:—
Base 100% equivalent emission spectrographic result
113 Surface scrape background -1.68+0.84 mm #
118 Surface scrape mineralisation -1.68+0.84 mm #
Hx Hot extractable; Cx Cold extractable

Table F5 - Metal Extractabilities (%) for Hot and Cold Digestions using Emission Spectrography as a Base 100%
As a generalisation hot "total" and perchloric digestions appear to extract more Cu, Ni and Co from soils than emission spectrography. A marked decrease in metal extractability is shown for the hot 25% nitric acid digestion though a greater extractability is shown for the mineralised situation. The increase in Cu, Ni, Co extractability over mineralisation is however noticeable for all hot extractable digestions and reflects a greater amount of labile Cu, Ni, Co associated with oxidising mineralisation. An interesting feature of the hot nitric acid digestion is the greater extractability of Cr when compared with the perchloric digestion. For the case of Pb, hot acid digestions are less extractable than emission spectrography. The extractability of Pb with hot acid shows the same general trend as the other elements i.e. the "total" attack being the most metal extractive and the nitric acid attack being the least extractive. Of interest is the greater extractability of Pb in the background situation. The trends for Zn are interesting too in that Zn extractability for hot "total" and perchloric acids in the background situation is greater than emission spectrography and are approximately equal.

As the Fe results for the base spectrographic result are greater than 1% little can be said with the exception of the extractability of Fe by perchloric being a little less than that of a "total" digestion and that there is a marked decrease in extractability with nitric acid. The Fe content of soil over mineralisation is also more readily extractable by hot "total" and perchloric digestions than in background situation. Extraction of Mn is of interest in that hot nitric acid is perhaps superior to the "total" and perchloric digestion in Mn extractability.

Metal extractability by the investigated cold leaches is extremely variable with Mn having the greatest metal extractability and Fe, in the case of Amc, the least. With the exception of Co, Mn and Fe metal extractability of cold 1% nitric acid is approximately twice that of the ammonium citrate leach. The extractability of Co is approximately equal for both leaches. Mn is slightly higher in the case of Amc leach and approaches the extraction rates of hot digestions. Fe has a very low extracta-
bility in Amc. This feature of low extractability of Fe and high extractability of Mn would be of use in investigations of coprecipitation effects of base metals on oxides. Peak metal extractability with respect to the elements in background and mineralisation is mixed though Ni consistently peaks in percent extraction for both leaches over mineralisation. The data for Cr and to an extent Pb are meaningless.

(b) Concentrates

Hot "total" and perchloric digestions for Ni, Co, Cr, Fe, Mn and Zn have greater metal extractability than emission spectrography. Cu and Pb are however exceptions. For all elements there is a notable decrease in metal extractability with the hot nitric digestion in terms of both the total and perchloric digestion and emission spectrography. The extractability of Cu, Ni, Co, Zn and Fe is greater for the perchloric than the total digestion while for Pb and Mn the extractabilities of these two digestions are approximately equivalent. As a generalisation only hot acid extractabilities for Cu and Ni are consistently greater in the mineralised situation than the background situation.

Similar remarks pertain as per the soils to metal extractability of cold leaches. However peak metal extractability is observed for Cu, Ni and Co over mineralisation. The data again for Cr and Pb is meaningless.

It is of interest to note that metal extractabilities for both hot and cold digestions are generally less for concentrates than soils. The hot total and perchloric acid extractable Cr and Zn however are exceptions.

4.3.4.2 Metal Distribution and Contrast in Size Fraction and Depth

Samples

4.3.4.2.1 Acid Digestions

Figures F9 to 13 show the elemental responses over mineralisation (station 1310) compared with background (station 1270) for the analytical work carried out on the various hot and cold digestions on the four size fractions and sampling depths for the soil and concentrate media.
(1) Soils (Figures F9 to 13)

Copper

Copper values and contrast rapidly increases with increasing size fractions and depth for all hot extractable digestions. The \(-1.68 + 0.84\text{mm}\) fraction from 45 to 60cm depth has both peak value and optimum contrast. For example; "total" 1140 ppm 20.5x; \(\text{HClO}_4\) 1080 ppm 24.0x; \(\text{HNO}_3\) 400ppm 12.9x. As a generalisation the distribution of Cu values in size fractions from background and mineralised situations are strongly antipathetic.

The trends shown by the cold extractable digestions differ from each other and the hot extractable digestions. For the \(1\%\ \text{HNO}_3\) digestion there is a marked decrease in value with depth and the finer size fraction. However peak value accompanied by optimum contrast (15ppm, 2.1x) is found at 45 to 60cm depth in the mid fine fraction \((-0.42 + 0.175\text{mm})\). The surface and at depth cold nitric extractable Cu results are generally poor in contrast.

Peak values and contrast occur in samples from mid depth (15 to 30cm, 45 to 60cm) and the mid size fraction for the cold Amc digestion. Background station samples with the exception of the \(-0.175\text{mm}\) fraction at all depths, show an antipathetic trend in values to mineralised samples. Surface scrape samples over mineralisation are bimodal in value and contrast with peaks in the coarsest (7 ppm 2.5x) and finest (5 ppm 5.0x) size fractions respectively.

Nickel

Nickel generally peaks with optimum contrast in the coarsest size fraction \((-1.68 + 0.84\text{mm})\) of a surface scrape for all hot acid digestions. However the nitric digestion has a superior contrast. For example "total" 4800 ppm 12.8x; \(\text{HClO}_4\) 4375 ppm 13.5x; \(\text{HNO}_3\) 3750 ppm 26.3x. As a general trend there is an increase in values in the surface scrape and near
surface samples for the coarse size fractions from the mineralised situation and for all size fractions from the background situation. There is however a secondary trend of increasing values and contrast at depth which is accentuated and becomes dominant in the finer fractions. The distribution of Ni values in the background and mineralised situations generally becomes antipathetic in the finer size fractions. The "total" and perchloric acid digestions have a similar order of contrast though for the nitric acid digestion contrast is higher in the coarse and finer size fractions.

A trend of increasing values and contrast to the coarsest size fraction and surface is seen for both cold leaches. Peak value and contrast is found in the surface scrape and -1.68 + 0.84mm size fraction and is superior in the case of the nitric leach. eg 260 ppm, 21.7x cf 100ppm 11.9x. Bimodality can be seen in value and contrast for the midsize fractions and 90 to 105cm depth. It is best seen in the nitric extractable results. The Ni distributions in background and mineralisation situations are also generally sympathetic.

Cobalt values and contrast exhibit similar trends to Cu. For the hot extractable results an increase in values and contrast is noted with depth and increasing coarseness of size fraction. A strong antipathy is noted between background and mineralisation Ni values for all size fraction, i.e. background values decrease with depth while values over mineralisation increase with depth. For the total attack, peak value (210 ppm) and contrast (5.5x) is found in the -1.68 + 0.84mm fraction at 45 to 60 cm depth. Likewise, for the perchloric digestion, though value and contrast is superior (230 ppm, 7.0x). Contrast is improved over the total attack for the nitric digestion and bimodality is noted in the coarsest size fraction. Peak value and contrast occurs in the surface scrape (105 ppm, 4.4x) and at 45 to 60cm depth (97 ppm, 5.1x).

The cold extractable Co results differ somewhat, both among themselves and the hot digestions. The cold nitric leaches for background and mineralised situation have a sympathetic relationship. Values and contrasts are contrary to the hot digestion decreasing with depth though
contrasts improves for all size fractions at 95-105 cm. Geochemical relief however is minimal with some relief at the surface for the coarser size fractions (1.2x) though improved contrast (1.5x) is found at 95 to 105 cm depth for the mid-coarse fraction. The results for the cold Amc leach are mixed. Samples over mineralisation have peak value and contrast in the -1.68 + 0.84 mm size fraction. However they are bimodal peaking in the surface scrape (22 ppm, 5.5x) and at 45 to 60 cm depth (16 ppm, 1.7x). For the mid size fractions (-0.840 + 0.420 mm, -0.420 + 0.175 mm) increasing values are noted with depth with improvement in contrast (1.8x, 1.3x). In the finest fraction the trend of increasing values with depth in the mineralised sample is reversed with Co peaking in the surface scrape with minimal contrast (1.1x).

Chromium

A sharp increase in value and contrast is noted for the hot "total" and perchloric digestions in the coarsest fraction for mid depth samples. For the "total" digestion, a 5.1x contrast accompanies the peak value of 1950 ppm over mineralisation while for the perchloric digestion a 3.0x contrast accompanies the peak value of 1300 ppm from the same sampling depth. For the finer size fractions of these two digestion and all fractions of the hot HNO₃ digestion values increase towards the surface but with accompanying decrease in contrast. Some bimodality can however be seen with the nitric results. Generally the hot HClO₄ extractable Cr results have superior contrasts.

Little can be said about the cold extractable results with the exception of the increase in Cr values and contrast especially in the coarser size fractions of the mid depth samples. In particular for the Amc leach on the -1.68 + 0.84 mm fraction at 15 to 30 cm and 45 to 60 cm depths (3 ppm, 3.0x; 3 ppm, 3.0x) and for the nitric leaches on the surface scrape for the -1.68 + 0.84 mm and 0.84 + 0.42 mm fractions.

Iron

The Fe results follow the trend of the previously discussed Cr results. A sharp increase in value and contrast is noted for the hot "total" and perchloric digestions in the coarsest fraction for the mid depth
samples. For the total digestion a contrast of 2.6x accompanies the peak value of 18.50% over mineralisation at 15 to 30cm depth while for the perchloric attack a contrast of 2.1x accompanies the peak value of 13.7%. A slightly better contrast of 2.2x is found at 45 to 60cm sample depth. For the remaining size fractions for these two digestions and for all size fractions for the hot HNO₃ digestion, values generally increase towards the surface with accompanying erratic increase in contrast, but showing minimal geochemical relief.

The cold extractable results show an increase in values towards the surface accompanied by a general decrease in contrast. The results for the -0.175mm fraction of the nitric leach though is an exception having a 2.5x contrast. Minor though not significant geochemical relief (1.1 to 1.4x) is noted for depth samples in all but the finest fraction for the ammonium citrate digestion. In contrast the mid-size fractions for the nitric leaches show significant geochemical relief, e.g. at 95 to 105cms, -0.84 + 0.42mm 2.2x; -0.420 + 0.175mm, 9.0x.

Manganese

Little can be said about the Mn results. True geochemical relief over mineralisation is only seen in the -1.60 + 0.84mm fraction of the soil scrape where Mn peaks at 1575 ppm with a 2.6x contrast in the total result. Meagre contrast with peak values is noted in the same surface scrape fraction in the perchloric (820ppm, 1.1x) and cold nitric leaches (510 ppm 1.2x). Slightly better contrasts are found in the finer fractions at 95 to 105cm depth for the hot nitric digestion ie -0.420 + 0.175mm (1.6x), -0.175mm (1.3x). Mineralised and background samples are sympathetic in their trend of decreasing values with depth and fine size fraction. Mn appears more readily extractable in Amc than nitric acid leaches.

Lead

Generally little can be said about the hot extractable Pb results due to their general lack of contrast. Lead minerals are not a constituent of the ore. However the coarsest size fraction from the intermediate sampled depth over mineralisation is enigmatic showing both an increase
in value and contrast. The distribution of Pb values with the exception of the coarsest size fraction is sympathetic for both background and mineralised situations.

Due to the erratic nature of the cold extractable results little can be said.

Zinc

Zinc minerals are not a constituent of the ore and as such geochemical relief is virtually absent with the exception of the finer fractions from 95 to 105cm depth for the hot HNO₃ digestion. Hot extractable Zn values from background and mineralised situations are generally sympathetic decreasing markedly with depth and slightly with increasing size fraction. A slight increase in contrast is noted with depth and with the finer size fractions. Similar results are noted with the cold extractable digestions

(2) Concentrates (Figures F14 to 18)

The concentrate data is lacking in information for some of the digestions because of insufficient material being available for analysis. However some broad trends are evident.

Copper

Copper values and contrast rapidly increase with depth and increasing size fraction for all hot extractable digestions. Peak value and contrast are coincidental in the -1.68 + 0.84mm fraction at 45 to 60cm depth eg "total" 3860 ppm (25.7x); HClO₄ 3650ppm (36.5x) and HNO₃ 1250ppm (22.0x). The nitric results for the mineralised samples show similar trends, but an information gap is present due to insufficient material for the majority of the background samples.

With the cold extractable results similar trends as per the hot digestions are indicated, but firm comment is hampered by the unavailability of results in background cases. Increase of values with depth and in the coarser size fractions are again indicated. The cx 1% HNO₃ Cu peaks
at 140 ppm over mineralisation in the $-0.84 + 0.42\text{mm}$ fraction at 45 to 60 cm depth. An indication of adequate contrast is perhaps indicated by the $6.7x$ contrast in the $-1.68 + 0.84\text{mm}$ fraction from the same depth. Likewise the cxAmc results over mineralisation peak at 110 ppm in the same size fraction and depth. Similarly adequate contrast is perhaps indicated by the $17.0x$ contrast from the same depth but the coarsest size fraction. A general sympathy is noted between values over background and mineralised situations but there is an indication of bimodality with the background samples at surface and depth.

Nickel

Nickel values and contrast can be seen to generally increase and peak with depth and increasing size fraction for all hot extractable digestions. As per the Cu results, peak values and contrast are coincidental in the $-1.68 + 0.84\text{ mm}$ fraction at 45 to 60 cm depth, e.g. "total" 7880 ppm (9.9x); HClO$_4$ 7250 ppm (9.9x) while for HNO$_3$ 2600 ppm but no contrast can be indicated because of information gap. The HNO$_3$ results are a little different from the "total" and HClO$_4$ results in that bimodality of peak and contrast is indicated at the surface 1400 ppm (7.5x) and 45 to 60 cm depth 2060 ppm (13.3x) for the $-1.68 + 0.84\text{mm}$ size fraction.

Comments made for Cu apply to the cold extractable Ni results with respect to increasing values with depth and increasing size fraction, e.g. cx 1% HNO$_3$ and Amc have peak values of 1030 and 115 ppm respectively in the $-0.84 + 0.42\text{mm}$ fraction at 45 to 60 cm depth. From the HNO$_3$ and Amc results for the both the finest and coarsest size fraction bimodality can be seen in the surface and 90 to 105 cm depth sample, e.g. the $-1.68 + 0.84\text{mm}$ fraction for the HNO$_3$ leach, at surface 157 ppm, 5.8x contrast, at 90 to 105 cm depth 147 ppm, 1.6x contrast; for the Amc leach 75 ppm, 15.0x contrast, at 90 to 105 cm depth 70 ppm, 1.0x contrast. The $-0.175$ fraction for the HNO$_3$ leach at surface 35 ppm, 7.0x contrast, at 90 to 105 cm depth 90 ppm, 4.2x contrast; for the Amc leach at surface 20 ppm, 4.0x contrast, at 45 to 60 cm depth 20 ppm, no comment can be made on contrast.
Cobalt values and contrast can be seen to generally increase and peak with depth and increasing size fraction for all hot extractable digestions. As per the previously discussed Cu and Ni results peak values and contrast are only near coincidental in either of the coarser size fraction and depth samples, e.g. "total" 680ppm in the -0.84 + 0.42mm fraction at 90 to 105cm depth, no indication of contrast, but it is assumed to be less than the 7.6x from 45 to 60cm depth. Likewise the HClO₄ digestion, 380ppm in the -0.84 + 0.42mm fraction at 90 to 105cm depth, but with a contrast of 4.2x which is less than the 6.6x at 45 to 60cm depth for the same size fraction. Because of missing data in the case of the HNO₃ digestion little can be said. A peak value of 375 ppm can be seen in the mid coarse size fraction at 45 to 60cm depth. Bimodality can be seen in the -1.68 + 0.84mm fraction with values and contrast peaking in both the surface scrape 100 ppm, 4.0x and at 90 to 105cm depth 150 ppm, 3.6x.

Again with the cold extractable results, similar trends as per the hot digestions are indicated, but comment is hampered by unavailability of background results. Peak values over mineralisation are found at 90 to 105cm depth for mid size fractions for both cold leaches ie HNO₃ 200ppm, Amc 107ppm. A general marked decline in values is noticeable at all depths for the -0.175mm fraction samples for both leaches. A similar observation in part holds for the -1.68 + 0.84mm fraction samples. However in the former case for the HNO₃ leach where information on contrast is available it is still high ranging from 4.0 to 6.0x but decreasing with depth. For these two size fractions bimodality is obvious in the surface scrape and at depth and is expressed in the coarsest size fraction results, but is accentuated in the Amc results, e.g. Amc surface scrape 25 ppm, 25.0x; 90 to 105 cm depth 29 ppm, 2.6x; HNO₃ surface scrape 19 ppm, 19.0x; 90 to 105cm depth 21 ppm 2.1x. Excellent contrast is noted in surface cx results from all size fractions over mineralisation. However the Amc results for the two coarser fractions is superior.
Chromium

Chromium values, and contrast where present can be seen to generally increase in value with depth and increasing size fraction. Contrast is adequate in the case of the depth samples for the "total" and hot HClO₄ digestions on the coarser size fractions. The latter digestion is superior in terms of contrast, e.g. at 90 to 105 cm depth for the -1.68 + 0.84 mm fraction "total" Cr 8000 ppm 2.7x contrast; HClO₄ Cr 4200 ppm 6.5x contrast. The nitric digestion results are poor in terms of value and contrast for the same depth and size fraction samples i.e 450 ppm, 0.9x contrast.

Little comment can be made about the cold leaches. There is some repetition of the trend at depth. Contrast where indicated are generally poor especially the -1.68 + 0.84 mm fraction highlighted in the hot digestions. However at 45 to 60 cm, Cr peaks at 19 ppm and 9.5x contrast in the Amc leach. This peak is repeated, but in a diminishing manner in the other size fraction with no indication of contrast.

Iron

Little can be said about the iron results. Geochemical relief is minimal for both the hot and cold digestions and no obvious trend is indicated with respect to digestion type, size fraction and depth.

Manganese

As a generalisation Mn over mineralisation is usually bimodal peaking in the surface scrape and at depth. The values in the scrape sample in turn usually peak in the -1.68 + 0.84 mm fraction with optimum contrast, e.g. "total" 1500 ppm 3.5x; HClO₄ 1000 ppm 2.2x; HNO₃ 740 ppm 3.4x. This is repeated with the cold extractable results, but contrast is far superior especially for the Amc results; e.g. Amc 460 ppm 13.4x, 1% HNO₃ 360 ppm 4.5x. The values at depth in turn appear to peak in the mid size fraction with minimal contrast. However, no firm conclusions can be drawn on the matter because of missing data. An interesting feature is the strong antipathy of values with depth for mineralisation and background situation -1.68 + 0.84 mm fraction samples. This feature is seen in all the digestions with the exception of the hot perchloric.
Lead

Lead minerals are not a constituent of the ore and little of interest was to be expected. Surprisingly the extractability of lead by a HClO₄ digestion is greater than the total digestion (approximately double). Some very minor geochemical relief is noted over mineralisation, but is erratic in its distribution. In the gross sense it is confined to surface scrape and near surface samples in the finer size fractions for the hot digestions. The best observed response is 60 ppm (3.7x) in the -0.175mm fraction of a surface scrape which was subjected to a hot nitric digestion. The results for the Amc extractable Pb results cannot be commented upon as they are mainly below the limit of detection. However with the cx HNO₃ results some response is evident at mid depths in principally the -0.84 + 0.42mm fraction.

Zinc

Zinc minerals per say are not a constituent of the ore mineralogy, but some exsolution of sphalerite is recorded in the constituent pyrite of the ore mineralogy and as such some geochemical relief over mineralisation with respect to background could be expected. This is best illustrated by the HClO₄ digestion results. Bimodality can be seen for the results over mineralisation. Zn peaks in value and contrast in both the surface scrape and 90 to 105cm depth for all size fractions. The depth samples generally are greater in value and contrast than the surface samples. In fact, contrast is such that the twice background optimum threshold is reached and exceeded in the case of the -1.68 + 0.84mm size fraction for the perchloric and "total" digestions respectively (2.0x, 2.1x). Similar observations can be made on bimodality for the cold extractable results. However for both digestions optimum contrast and peak results are seen in the finer fractions at 90 to 105cm depth especially for the -0.175mm fraction, i.e. cx HNO₃ 64 ppm 12.8x; Amc 25 ppm, 8.3x.
4.3.4.2.2 Multi-element spectrographic results

(1) Soils

The results for Ag, As, Ba, Co, Cr, Cu, Ga, Mn, Ni, Pb, Sc, Sn, Sr, Ti, V, Yb, Y and Zn are reported below and can be seen in Figure F19. Be, Bi, Cd, Ce, Ge, In, La, Mo, Nb, Sb, Ta, Th, W and Zr fall below the previously stated detection limits for the analytical method.

Silver

The silver results are erratic and are near or at the 0.1 ppm detection limit. Peak values (0.2 ppm) and contrast 2.0x) fall in the -0.84 + 0.42 and -0.175mm fractions.

Arsenic

The majority of the arsenic results fall below the 50 ppm detection limit with the exception of the coarsest size fraction (+0.840) for background and mineralised situations. A 100 ppm result and contrast of 2.0x defines mineralisation.

Barium

Barium results with the exception of the -1.68 + 0.84mm size fraction from the mineralised situation, peak at 400 ppm. The optimum contrast appears to be present in the finest fraction (2.0+x).

Cobalt

The peak cobalt result (100 ppm) and contrast (2.5x) is found in the coarsest size fraction for the mineralised situation as per the previously described hot acid digestion cases. Co results and contrasts decrease rapidly in the finer size fractions.
Chromium

Peak chromium results (500 ppm) are found in both the coarser size fractions over mineralisation. Optimum contrast (5.0x) is found in the -0.84 + 0.42mm fraction. A decrease in Cr values and contrast is marked in the finer size fractions. Similar results were noted in the previously described hot acid digestion cases.

Copper

The peak copper result (150 ppm) and contrast (3.0x) is found in the coarsest size fraction. A marked decrease in Cu values and contrast is shown in the finer size fractions. Similar results and trends were noted in the previously described hot acid digestion cases.

Gallium

Gallium responses in the size fractions over mineralisation are low. There is a tendency for Ga to increase and peak in the finest and coarsest fractions in the background situation. Contrasts are generally low (≤1.0x) in all size fractions over mineralisation.

Manganese

Manganese results in the case of the fractions from the mineralised situation are bimodal. A large peak of 760 ppm with a contrast of 2.0x is present in the coarsest size fraction while a smaller peak of 300 ppm is present in the finest fraction. However, contrast in the finest fraction is poor (1.0x).

Nickel

Nickel results and contrasts respectively peak at 2500 ppm and 10.0x in the coarsest size fraction. A marked decrease in values and contrast is also noticeable in the finer fractions over mineralisation. Similar results were noted in the hot acid digestion cases.
Lead

Lead responses in the size fractions over mineralisation are uniformly low at 20 ppm and contrasts are poor. Similar results were noted in the hot acid digestion cases.

Scandium

Little can be said about the scandium results, a similar order of values is apparent in the size fractions from both mineralised and background situations.

Tin

Tin results peak at 40 ppm in the coarsest size fraction over mineralisation, but optimum contrast (30x) is found in the -0.84 + 0.42mm fraction. There is a sharp drop in Sn values and contrast in the finest fractions over mineralisation.

Strontium

Strontium results are erratic because of the high detection limit of 50 ppm. However, a positive response of 50 ppm is found in the -0.84 + 0.42 and -0.175mm fractions over mineralisation, but contrasts are poor (<1.0x).

Titanium

Background situation titanium results in all size fractions are greater than the mineralised situation. A poor contrast between background and mineralisation is thus noticeable. Ti results for both situations peak in the mid size fractions.

Vanadium

Vanadium results over mineralisation peak at 150 ppm and are found in the -0.84 + 0.42mm fraction. The best, but still inadequate contrast of 1.5x, is found in the same size fraction.
Ytterbium

Little can be said about the ytterbium results as the results for size fractions from both mineralised and background situations are at or below the detection limit of 1 ppm for the analytical method.

Yttrium

Little can be said about the yttrium results as the results of size fractions from the mineralised situations are at or below the detection limit of 10 ppm for the analytical method. Size fractions from the background situation are uniformly high at 20 ppm.

Zinc

Zinc results are similar to the hot acid digestion cases. Zn levels are comparable in size fractions from both mineralised and background situations. Zn in both cases generally peaks in both the coarsest and finest size fractions. Contrasts are notably low (<1.0x).

(2) Concentrates

The results for As, Co, Cr, Cu, Ga, Ge*, Mn, Nb, Ni, Pb, Sc, Sn, Sr, Ti, V, Yb, Y, Zr and Zn are reported below and can be seen in Figure F20. Ba*, Be, Bi, Cd, Ce, In, La, Mo, Sb, Ta, Th and W fall below the previously stated detection limits for the analytical method. Elements that have been asterisked were present (Ba) and absent (Ge) respectively in the soil data.

Silver

Silver responses in all size fractions for background and mineralised situations are essentially the same. Little can be said about the results with the exception of the trend of increased Ag values in the fine fractions.

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Arsenic

Arsenic is bimodal in its distribution in size fractions of the mineralised situation. It peaks at 500 ppm in the coarsest size fraction with a contrast of 2.5x, and 150 ppm in the finest fraction with a contrast of 3.0x. In the background situation a trend of high As values in the coarser size fractions is also obvious.

Cobalt

The peak cobalt result (150 ppm) and contrast (3.0x) is found in the coarsest size fraction of the mineralised situation. Co values and contrast also decrease markedly in the finer fractions as per the previously described hot acid digestions. Background situation cobalt values in all size fractions are generally the same.

Chromium

Chromium results for both background and mineralised situations generally peak in the coarsest size fraction. However, the coarsest size fraction of the mineralised situation has the peak Cr value of 1500 ppm and a contrast of 2.0x. Similar contrasts, but with accompanying lower values (1000 ppm) are found in the finest fractions. The trend in the hot acid digestion is not as marked as in the spectrographic results.

Copper

Copper values generally peak in the coarsest size fraction for both background and mineralised situations. For the case of the mineralised situation Cu peaks at 300 ppm with a contrast of 2.0x. The remaining size fractions are equal in value and contrast. A similar trend was noted in the hot acid digestion results.

Gallium

Gallium responses over mineralisation in all size fractions are constant at 25 ppm. In contrast Ga results peak in the mid coarse fraction of the background situation. Some geochemical relief is evident between
background and mineralisation in the coarsest size fraction, but contrast is poor reaching only 1.3x.

Germanium

Germanium results are erratic, being either at or below the 1 ppm limit of detection in both mineralised and background situation size fractions. Little can be said about the results.

Manganese

Manganese results in the mineralised situation peak in the coarsest size fraction at a 1000 ppm with an accompanying contrast of 3.3x. The remaining size fractions show a marked decrease in value and contrast. Minor geochemical relief (contrast 1.2 to 1.5x) is present in the mid size fractions.

Niobium

Little can be said about the results as only the -0.175mm fraction results for both background and mineralised situations are at the 20 ppm detection limit for the analytical method.

Nickel

Nickel results for both situations peak in the coarsest size fraction. Peak results for the mineralised situation is 2000 ppm with a 3.3x contrast. A rapid decrease in values and contrast is noted for the finer size fractions. However contrast over mineralisation is still significant ranging from 2.7 to 2.4x. Similar results were noted in the hot acid digestion cases.

Lead

Little can be said about the lead responses in the size fractions over mineralisation and background as a similar order of responses and contrasts were obtained. Similar results were also noted in the hot acid digestion cases.
Tin

The tin results are interesting in that strong antipathetic trends are evident between mineralised and background situations. A trend of relatively high Sn values which peak at 40 ppm in the finest fraction of the background situation suppresses a small peak of 4 ppm in the mineralised situation. However, a peak of 8 ppm is evident in the coarsest size fraction in the mineralised situation in contrast to the below detection value of Sn (1 ppm) for the background situation.

Scandium

Scandium results in the mineralised situation are bimodal. Results peak at 30 ppm with a 3.0x contrast in the coarsest size fraction, while in the finest size fraction Sc peaks at 10 ppm with a poor contrast of 1.3x.

Strontium

Little can be said about the strontium results because the majority are below the detection limit of 50 ppm. The one positive result at the detection limit is found in the coarsest size fraction of the mineralised situation.

Titanium

Titanium results are of interest. There is a general trend of higher results in the finer size fractions with values for both mineralised and background situations peaking in the finest fraction. Peak results for the mineralised finest size fraction situation exceeds the analytical range (ie 10,000+ ppm) and contrast is at least 1.4x. However, the results from the mineralised situation are bimodal. Ti also peaks in the coarsest size fraction at 5000 ppm, with an accompanying 2.0x contrast.
Vanadium

Vanadium results show a peak (400 ppm) in the mineralised situation in the coarsest size fraction. Contrast is poor at 1.3x. In the remaining size fractions the V values for the mineralised situations are the same at 300 ppm. However, a fluctuating background reveals some geochemical relief (i.e. 1.2x contrast) in the -0.84 + 0.42mm and 0.175mm fractions.

Ytterbium

The ytterbium results are interesting in that a distinctive trend of higher results in the coarser size fractions for the mineralised situation is evident over a constant background. Yb peaks at 3 ppm with a 3.0x contrast in the coarsest size fraction.

Yttrium

The yttrium results are distinctive in that a bimodal character is revealed for the size fractions belonging to the mineralised situation while the size fractions of the background situation are constant in value at 10 ppm the detection limit for the analytical method. The Y results peak in the coarsest size fraction at 30 ppm with a 3.0x contrast over background. A further peak is evident in the finer size fractions, i.e. 20 ppm, 2.0x contrast.

Zirconium

Zirconium results are generally flat for all background size fractions at 200 ppm. However some geochemical relief is evident in the mineralised situation, i.e. Zr peaks at 240 ppm, 1.3x contrast and 300 ppm, 1.5x contrast in the coarsest and mid finest size fractions respectively.

4.3.5 Mineralogical Work and Results

4.3.5.1 Mineralogy

The mineralogical samples were collected 18 months after the original sampling because the original concentrates had been pulped "entoto" for...
Figure F21  Portion of the field of view of a concentrate sample showing opaques, a large chlorite, zircon, and iron oxide coated quartz grains. (25X)

Figure F22  Concentrate analytical pulp, showing opaques in a fine groundmass of mineralogical flour. Large opaque 60 microns. (100X)
Figure F23 Composite grains. Talc-chlorite with idiomorphic magnetite. (25X)

Figure F24 Goethite-(limonite-haematite) and magnetite grains. (25X)
Figure F25 Magnetite grain showing classic ilmenite herring-bone exsolution texture, i.e., ilmenite rods (0001) in (111) magnetite cleavage. (50X)

Figure F26 Enlargement of above showing herring-bone ilmenite exsolution in magnetite (111) cleavage. (100X)
Figure F27 Cracked magnetite grain, martised, altered to goethite along cracks. (50X)

Figure F28 Enlargement of above showing grain surface pitting and red-brown limonite. (100X)
analysis. The resampling was conducted after a bushfire had burnt through the area and had nearly obliterated the grid. The grid line was relocated, but the exact position over mineralisation is doubted. Thus the samples retaken from the mineralised situation were considered suspect at the time of collection, even though confidence was placed in correct location of the grid line in the burnt out area. This doubt was subsequently confirmed by chemical analysis of a small split of the soil samples. Nevertheless, concentrates were produced for mineralogical examination from these collected samples, but the concentrates are considered to be only representative of background. To circumvent this "information gap" the analytical pulps of the original concentrates were also briquetted by the writer and examined. Expected maximum size of particulates in the pulps was no greater than 75 microns (Figure F22). This latter mineralogical work proved both tedious and difficult.

The mineralogy of surface and depth concentrates were found to differ little in composition. Opaques dominated. In particular, magnetite and geothite-limonite predominated being approximately equivalent in abundance. Trace chromite, ilmenite and rare pyrolusite comprised the rest of the opaques. Occasional chlorite, serpentine(?), amphibole, zircon and caliche were observed. Limonitic coated quartz grains were common. Composite particles consisting of white-greenish talc-chlorite(?) with idiomorphic magnetite were abundant in the coarser size range (800+ microns) of the grains examined. (Figures F21 to 24).

Some of the magnetite was altered to haematite around grain rims or was martised (111) and altered to goethite along cracks. Occasionally magnetite grains with classic ilmenite herringbone exsolution were observed, i.e. ilmenite rods (0001) in the magnetite (111) cleavage (Figures F25 to 26). Vickers Hardness (VHN) and reflectivity measurements carried out on magnetite and geothite grains confirmed the identity of the species. The measured parameters ranged from 496 to 548 (VHN) and 19.5 to 21.2 (reflectivity) respectively for magnetite and 515 to 830 (VHN) and 16.4 to 18.2 (reflectivity) for goethite. Goethite-(haematite-limonite) ranged from having a "rotted" reddish brown appearance to being banded. (Figures F27 to 28). No relict textures after sulphides could be identified. Ilmenite when present appeared to be undergoing leucoxination. In contrast, the occasional chromite appeared fresh.

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4.3.5.2 Micro-analytical results

It was originally proposed to subject the identified mineral constituents in the four size fractions originating from a surface scrape and at depth in mineralised (1310) and background (1270) situations to micro-analysis with the Cambridge micro-scanner, a four channel X-ray fluorescence micro-analyser. However problems with down channels in the probe and the vacuum coating equipment in the writer's last visit to the geology department negated this work. Nevertheless, through the auspices of Mr George McTurk, access was gained to the newly installed Link System 860 scanning electron microscope and ancillary energy dispersive X-ray fluorescence micro-analyser system in the Medical School.

At the moment qualitative analyses of elements upwards from atomic number 12 (Mg) are possible. There are obvious advantages in using such a system, especially if it is upgraded to a quantitative analytical capacity. These advantages are:

1. Grains can be examined and their three dimensional morphology and coatings reported. (See Figure F29)

2. A continuous and instantaneous elemental spectrum can be obtained for a point source or over a small area and viewed on a CRT output. An estimate of sample bulk composition is thus possible over 1 cm² area if the sample is finely ground.

3. Comparisons can be made between sample spectrums on the CRT, through the facility of floppy disc storage in the micro-processor controller. Currently a photographic record is made of the display on the CRT output by a camera mounted on a stand at a fixed distance from the screen. The facility exist for the addition of an X-Y plotter to record a hard copy of the X-ray spectrum.

A broken two day time period was allowed on the equipment. What first had to be determined was if uncoated material could be examined and qualitatively analysed. The Medical School unfortunately was currently sharing the vacuum coating facility in the geology department. Generally in electron microscopy probe analysis the geological material being examined is

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mounted in an araldite block and coated with carbon or aluminium to prevent charge build up which deflects the electron beam. (Refer Figure F29). Initially, some success was experienced using grain samples mounted in conventional briquettes at low power. However better results were achieved by mounting loose grains on an aluminium stub. The flat of the stub was first sprayed with an aerosol borne glue. This was then dipped into the sample to be analysed, so that the flat was coated with an even layer of grains. The flat of the stub was viewed under a binocular microscope and a sketch made of the grains in the field of view for subsequent referencing in the electron microscope-probe.

Generalisations only, can be made from the limited qualitative probe work. However the following interesting points emerge. Magnetite and goethitic-limonite from background situations appear to have minimal trace element content in contrast to slightly enhanced contents of Ni, Cu, Cr, Zn from the mineralised situations. Refer Figures F30 to 33, for X-ray spectra traces of grains. However spectral scans at random on opaque grains of an indeterminate nature in the analytical pulps from mineralised situations gave consistently anomalous high counts in Ni, Cu, Zn and Pt(?) or Au. Fe was generally less abundant than silica. This is illustrated in Figure F34 where spectra for background and mineralised surface scrape samples for the -0.175mm fraction are displayed. The two samples are also compared in the same figure by use of the microprocessor memory. The pointer is set on the position for Au. The dotted outline is the sample from the mineralised situation. A 1 cm² area was subsequently fluoresced for all background and mineralised pulps and similar contrasting spectral scans were again noted. The question arises, what are or is the grain species causing the geochemical response? Unfortunately this could not be determined. One grain probed had a possible S response (Figure F31a) with associated enhanced Ni and Cu contents pointing to a possible ex sulphide source. Generally the elements noted in the spectrographic scan were discernable in the probe work. However Co, a dominant element of interest could not be easily discerned because of overlap with Fe or Ni lines.
(a) Grains mounted on aluminium stub for probing. (3X)

(b) Close up of grains on above stub. Morphology and coatings on grains are well illustrated. (10X)

(c) Shattered magnetite grains. Horizontal lines on photo due to beam instability because of uncoated briquette. Scale on photo 100 microns.

Figure F29
Figure F30 - Principal X-ray emission spectra of chemical elements. Spectral peaks in Figures 31 to 34 may be referenced against this chart.
(a) Goethitic grain mineralised situation. Peaks 1=Al\textsubscript{K\alpha}, 2=Si\textsubscript{K\alpha}, 3=S\textsubscript{K\alpha} (?), 4=Ca\textsubscript{K\alpha}, 5=Ti\textsubscript{K\alpha}, 6=Cr\textsubscript{K\alpha}, 7=Mn\textsubscript{K\alpha} (?), 8=Fe\textsubscript{K\alpha}, 9=Fe\textsubscript{K\beta}, 10=Ni\textsubscript{K\alpha}, 11=Cu\textsubscript{K\alpha}.

(b) Magnetite mineralised situation showing Cr,Ni enrichment. Peaks 1=Al\textsubscript{K\alpha}, 2=Si\textsubscript{K\alpha}, 3=Ca\textsubscript{K\alpha} (?), 4=Ti\textsubscript{K\alpha}, 5=Cr\textsubscript{K\alpha}, 6=Mn\textsubscript{K\alpha} + Cr\textsubscript{K\beta}, 7=Fe\textsubscript{K\alpha}, 8=Fe\textsubscript{K\beta}, 9=Yb\textsubscript{K\alpha} + Ni\textsubscript{K\alpha}, 10=Cu\textsubscript{K\alpha} + Ni\textsubscript{K\beta}.

(c) Magnetite (?) mineralised situation. Peaks 1=Cu+NiL\textsubscript{α} (?), 2=Al\textsubscript{K\alpha}, 3=Si\textsubscript{K\alpha}, 4=P\textsubscript{K\alpha} + Zr\textsubscript{L\alpha} + Nb\textsubscript{L\alpha}, 5=Fe\textsubscript{K\alpha}, 6=Fe\textsubscript{K\beta}, 7=Ni\textsubscript{K\alpha}, 8=Cu\textsubscript{K\alpha}, 9=Ni\textsubscript{K\beta}.

Figure F31.
(a) Relatively pure goethite grain background situation. Peaks 1=Fe\(_{\text{Kα}}\), 2=Fe\(_{\text{Kβ}}\), very minor Ni & Cu ie 3=Ni\(_{\text{Kα}}\), 4=Cu\(_{\text{Kα}}\).

(b) Chromite (spinel). Peaks 1=Mg\(_{\text{Kα}}\), 2=Al\(_{\text{Kα}}\), 3=Si\(_{\text{Kα}}\), 4=Cr\(_{\text{Kα}}\), 5=Cr\(_{\text{Kβ}}\), 6=Fe\(_{\text{Kα}}\), 7=Fe\(_{\text{Kα}}\).

(c) Comparison of X-ray spectra between magnetite (dotted) and chromite (solid) in background situation. Pointer on K\(_{\text{α}}\) line for Cr, Peaks 1=Ti\(_{\text{Kα}}\), 2=V\(_{\text{Kα}}\), 3=Cr\(_{\text{Kα}}\), 4=Cr\(_{\text{Kβ}}\), 5=Fe\(_{\text{Kα}}\), 6=Fe\(_{\text{Kα}}\), 7=Ni\(_{\text{Kα}}\), 8=Zn\(_{\text{Kα}}\).

Figure F32
(a) Background situation. Magnetite grain-Ti enrichment. Peaks 1=Al$_{K \alpha}$, 2=Si$_{K \alpha}$, 3=P$_{K \alpha}$, 4=Ti$_{K \alpha}$ (pointer), 5=Ti$_{K \alpha}$ + V$_{K \alpha}$, 6=Cr$_{K \alpha}$ (+V$_{K \alpha}$), 7=Fe$_{K \alpha}$, 8=Fe$_{K \beta}$, 9=Ni$_{K \alpha}$, 10=Cu$_{K \alpha}$.

(b) Background situation. Magnetite-Cr enrichment. Peaks 1=Al$_{K \alpha}$, 2=Si$_{K \alpha}$, 3=Cr$_{K \alpha}$, 4=Fe$_{K \alpha}$, 5=Fe$_{K \beta}$.

(c) Background situation. Chromite. Peaks 1=Al$_{K \alpha}$, 2=Si$_{K \alpha}$, 3=Ti$_{K \alpha}$, 4=V$_{K \alpha}$, 5=Cr$_{K \alpha}$, 6=Cr$_{K \beta}$, 7=Fe$_{K \alpha}$, 8=Co$_{K \alpha}$ + Co$_{K \beta}$, 9=Ni$_{K \alpha}$, 10=Ni$_{K \beta}$, 11=Zn$_{K \alpha}$.

Figure F33
Figure 34: Qualitative comparison of X-ray spectra on similar opaque grains of indeterminate nature from mineralised (1310) and background (1270) surface scrapes.
4.3.6 Discussion

As a generalisation the hot "total" and perchloric digestions/AAS method appeared to extract and measure more Cu, Ni, Co, Cr than emission spectrography. Extractability by hot acid digestion was in the order ("total" > perchloric) > 25% nitric. Even though nitric acid was generally less extractive it was superior in extractability in the case of Mn. Metal extractability of the 1% HNO₃ and Amc cold leaches was found to be extremely variable. Base metal extractability is of the order of 5 to 10% though Mn extractability approached that of hot digestions. Selectivity of metal extraction was demonstrated for Fe and Mn, with Fe having a very low extractability in Amc. This feature would be useful in investigations of coprecipitation effects of base metals on Fe-Mn oxides. For both media, Cu, Ni and Co extractabilities by cold and hot digestions increased over mineralisation, reflecting the greater abundance of labile Cu, Ni and Co. However metal extractability by both cold and hot digestions is generally less for concentrates than soils reflecting the nature of the fixation of the metal in the sample media, i.e. strongly bonded elements within the lattice of a mineral species in the case of concentrates versus loosely bonded elements in essentially a chemical salt in the case of soils. As a generalisation it was noted that the more robust the digestion (i.e. the greater the metal extractability) the better the analytical precision.

A general trend was noted in the elemental results for both sample media with respect to size fraction and depth samples. The best Cu, Co, Cr response for hot digestions (optimum contrast and highest values) is found in the coarsest size fraction (-1.68+0.84mm) at a sampling depth of 45 to 60cm. Nickel in soil though, peaks in value and contrast in the coarsest fraction of a soil scrape though a significant subsidiary peak is also found at 45 to 60cm depth. Bimodality of Ni, Co, (Cu) is also seen for the cold digestions in both media. Peak value and optimum contrast is found in the coarsest size fraction of the surface scrape rather than at depth.
The multi-elemental spectrographic scan of the four size fractions of the surface loam and concentrate samples from background and mineralised situations reaffirmed the optimum response of Ni, Cu, Co, Cr, Mn in the -1.68+0.84mm fraction over mineralisation, but with the addition of As, Sn, Sc, Ti, Yb, Y. However, with the exception of As and Sn, these additional elements are responsive only in the concentrates.

The mineralogy of surface and depth concentrates were found to differ little in composition. Opaques dominated, with magnetite and goethite-limonite being approximately equivalent in abundance. Trace ilmenite, chromite and rare pyrolusite were present along with amphibole, zircon, chlorite, serpentine (?) and caliche. Composite particles, idiomorphic magnetite in talc-chlorite, were abundant in the coarser size fractions. No relict textures after sulphides were noted. Limited qualitative probe work confirmed the main elemental responses over mineralisation. In particular the probe work showed that the Ni, Cu, Cr and Zn contents of magnetite and goethite-limonite from mineralisation were enhanced with respect to background. Co could not be discerned because of the overlap with Fe and Ni lines. One grain had a possible S response with associated enhanced Ni, Cu content pointing to an ex-sulphide source. The response in the concentrates over mineralisation however is thought to be derived from an indeterminate opaque mineral species which gave consistent highly anomalous counts in Ni, Cu, Zn and Pt or Au. The opaque mineral could not be identified because of the grain size in the analytical pulps. Similar contrasting spectral scans were also noted between mineralised and background concentrate samples when a 1cm² area of pulp samples on stubs for all size fraction and depth samples were fluoresced.

4.3.7 Conclusion

At Black Swan the -1.68+0.84mm fraction of both soil and soil concentrates from a surface scrape analysed for Cu, Ni, Co, after a hot "total" or perchloric digestion were found to delineate mineralisation, though for superior contrast a sample depth of 45 to 60cm was indicated. Contrast at surface for Cu, Ni and Co could be improved by analysing for these elements after a cold 1% nitric acid leach rather than a hot "total" or perchloric digestion.
When both the soil, and soil concentrate size fractions of surface scrapes from background and mineralised situations were subjected to multi-elemental spectrographic analysis, it was found that the -1.68 +0.84mm concentrates were anomalous in more elements; in particular the elements, Cu, Ni, Co, Cr, As, Sn, Sc, Ti, Mn, Y and Yb. The commodity elements of interest Ni(Cu) were however lower in contrast than the respective -1.68+0.84mm soil samples. Sn a previously noted "immobile" chalcophile pathfinder element was prominent. Au and Pt were also indicated from qualitative probe work. From mineralogical and qualitative probe work it would appear that even though the content of the ore elements in the dominant heavy mineral species, magnetite and goethite-limonite, from mineralised and background situations differ, they are of less importance than the presence of suspected secondary ore heavy mineral species.

Routine soil geochemical exploration work for Cu and Ni in similar landscape areas of residual soil in the Eastern Goldfields is best effected by auger sampling and collecting soil at 45 to 60cm depth. These samples when sieved to -1.68+0.84mm, crushed and ground to 75 microns, and analysed for Cu, Ni, Co, Cr and possibly Zn after a "total" digestion involving a hot nitric-hydrochloric-hydrofluoric acid mixture or the lesser extractive though near equivalent hot perchloric acid digestion, should give an all round superior contrast and sensitivity in outlining areas of mineralisation.

4.4 Regional Loam Grid

4.4.1 Introduction

A 225 km² area to the south of Black Swan, known to contain both minor nickel and gold mineralisation had in the past, been covered by a "loam" grid at a density of one sample per square kilometre. The -1.68+0.84mm jigged concentrates from the exercise were available in storage.
With the results from the local Black Swan study showing that the coarse size fraction in surface concentrates differentiated mineralisation best, the grid area appeared to present an excellent study area to determine if mineralisation is discernable in regional "loam" concentrates of this size fraction which have been subjected to multi-elemental analysis. In particular the area is no longer idealised as at Black Swan as much of the area is covered by a variety of overburden types.

4.4.2 Local Setting

Climatically and vegetationally the area is similar to Black Swan. Topographically the area has a prominent "breakaway" to the south of the east-west access track and the landscape falls away to a low dune fringed playa lake.

The regional loam grid lies within the Yindarlgooda Syncline and essentially contains lithologies of the previously mentioned Archaean volcanic cycle 3, (Kalpini Formation), minor amounts of rocks of volcanic cycle 2 (Gundockerta, Mulgabbie Formations) and granite. Much of the area is obscured by Tertiary laterite and Quaternary to Recent alluvium, colluvium, eluvium and eolian deposits. (Figure F35). Alluvium fringes the sparse drainage and the playa lake in the eastern and southern portions of the area respectively. Eolian deposits are found around the lake margins, while colluvial and eluvial deposits are predominant in the more elevated northern portion of the grid. Tertiary laterite is more prominent in the eastern portion of the grid.

The geology and magnetic field patterns over the area are shown in Figure F35. The magnetics have been taken from the Bureau of Mineral Resources published aeromagnetic maps (Northeast and southeast portions Kurnalpi 1:125 000, BMR pub. 1961). The maps show the results of a broad regional aeromagnetic survey flown at an altitude of 150m on lines 1.5 km apart. The two main aeromagnetic anomalies are known to host minor nickel mineralisation. This data was enlarged to 1:50 000 scale and compliments the geology.

...63.
A small gold production has been reported from the area. (W.A. Mines Dept. Annual Report 1976). Up to 1976, the Western Australian Government Statistician had recorded gold output from the area under the headings of:

- Alluvial 818,24 gm
- Dollied stone 5076,80 gm
- Ore treated 3443,9 tonnes for 63 759 gm Au

The average ore grade of 18,5 gm/tonne is high by modern standards. Gold has been obtained from volcanics in the Gundockerta Formation of Volcanic Cycle 2 and is thought to be derived from both basic and acid igneous activity, with subsequent modification and reconstitution of the mineralisation occurring during later tectonic and metamorphic events (Williams, 1970).

The area was systematically explored for nickel mineralisation during the exploration boom of the late sixties. Narrow zones of both disseminated and massive sulphides were located on the basal ultramafic/sediment contact of an intrusive ultramafic shaded in the geology map of Figure F10. Widths of up to 1.82m of 4.35% Ni and 0.41% Cu have been recorded in the southeastern most ultramafic. (Jones Mining N.L. stock exchange report 1969). The mineralogy encountered was both massive pyrite-violarite-pentlandite-pyrrohotite-chalcopyrite, and disseminated pyrite-millerite.

4.4.3 Sampling and analytical procedure

Two sets of jigged -1.68+0.84mm "heart" concentrates were made available for study purposes. One set of concentrates had been cleaned for mineralogical examination, i.e. subjected to mild acidification and scrubbing in an attrition cell and henceforth will be referred to as "treated" concentrates. The other set of concentrates had not been treated and will be referred to as "raw" concentrates. Both sets of concentrates were derived by taking splits from the same parent jig heart concentrate sample.

As previously mentioned the reason for the collector treating concentrates was to remove coatings of iron oxides from mineral grains. These coatings obscure from microscopic identification kimberlitic indicator minerals.
It would be preferable from the sample collector's point of view, if all the size fraction was first treated and mineralogically examined. If required, the concentrate residues could then be made available for geochemical purposes. However in geochemical prospecting coatings on grains are themselves a media for geochemical prospecting since they absorb ore metals of interest. Coatings have been studied by using mild chemical extractants/AAS analysis, X-ray fluorescence analysis of coatings in situ on samples (Carpenter et al 1978) or by analysing mechanically produced concentrates of coatings (Huff 1971). High contrast anomalies have been reported by the previously cited authors. It was therefore important to compare the patterns between the two concentrate types over the regional grid.

Initially both sets of concentrates were bromoformed, then crushed and ground to 75 microns in a Tema Mill. The known elements of interest in the area; As, Au, Cu and Ni were determined on the "raw" concentrates. Due to the spotty As and Au results only the latter two elements were determined on the "treated" concentrate set. The following analytical methods were used. A 500 mg sample was subjected to the "total" attack, as outlined in the previous section on the Black Swan experimental work followed by taking up the residue in 10% HCl, allowing the solution to clear, then aspirating directly into an air/acetylene flame of an atomic absorption spectrophotometer for copper and nickel determinations. Arsenic determinations were made by the vapour generation (arsine) technique following the method outlined in Section B. Gold determinations were carried out by a modified method after Olson (1965). The method involves an initial 35% hydrochloric acid digestion then an "aqua regia" digestion (35% hydrochloric acid, 70% nitric acid in 2:3 proportions) on a 25gm weight of sample. The gold is extracted from a sample aliquot of digestant by complexing with 4 methyl pentan-2-one and measured by aspirating directly into an air/acetylene flame of an atomic absorption spectrophotometer.

The analytical precision by replicate analyses of duplicate samples, following the simple graphical method of Thompson and Howarth was, Cu 9%, Ni 12%, As 25% and Au 50%. The poor analytical precision for Au can be explained by the majority of the results being at or near the level of detection. However internal and external (Newmont) lab-
F65.

oratory standards run by the laboratory with the samples were within 
+ 10% relative standard deviation of the accepted values.

The "raw" samples were also subsequently scanned by optical emission 
spectrography for the following 17 elements: Ag, Bi, Be, Co, Cr, Cu, 
La, Mn, Mo, Nb, Ni, Pb, Sb, Sn, V, Y, Zn.Replicate analyses were carried 
out on 10% of the samples. Generally the maximum level of precision 
for the technique was + 45%, calculation again being carried out by 
the method of Thompson and Howarth for replicate analyses. (See Table 
F6).

4.4.4 Analytical Results

The geochemical statistics for the "raw" and "treated" concentrate 
elemental data can be seen in Table F7. Both normal and a log base 
10 transformation of the raw data have been used. The "raw" AAS Cu, 
Ni and As results appear to follow a log normal distribution while 
Au is positively skewed and negatively kurtotic. The Au results mainly 
fall below the limit of detection for the analytical method. The ele­
ments in the spectrographic scan of the "raw" concentrates show differing 
distributions. Co, Mn, Ni, Pb, V, Y, Zn appear to follow the log normal 
distribution, while Cr is log normal in kurtosis but highly positively 
skewed; Cu is log normal in skewness but positively kurtotic, and Ag, 
Sn, Mo highly positively skewed and kurtotic. The distribution patterns 
of the latter elements cannot be commented upon, since the majority 
of the values (99%) fall below the detection limit for the analytical 
method. Similarly the Bi, Be, La, Nb and Sb results cannot be commented 
upon as they all fall below the detection limit for the method. The 
"treated" AAS Cu and Ni results are both positively kurtotic and skewed.

Correlation matrices for all elemental data types are presented in 
Table F8. These correlation matrices were again calculated by the non 
parametric Spearman Ranking Method through the facility of the computer 
program NONPAR CORR from the SPSS Library. As a supplement to the accom­
panying test of significance in the output, a histogram of the correl­
ation coefficients have been constructed for the spectrographic data 
to examine natural groupings of elemental pairs. Three groupings of 
elemental pairs are recognised in the spectrographic data set and have
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<tr>
<td>Zn</td>
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Calculation based on 26 samples

** values at or below limit of detection thereby making calculation meaningless.

Table F6 - Spectrographic Scheme For Regional Grid "Loam" Concentrate Samples
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<th>H</th>
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<th>E</th>
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(a) Raw Loam Concentrate - Emission Spectrographic Data

(b) Raw Loam Concentrates - AAS Data

(c) Treated Loam Concentrates - AAS Data

Number of samples = 226

Table F7 Elemental statistics, Regional grid
### Table F8: Elemental correlation matrices, Regional grid.

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- **S** = .001: Strong
- **W** = .001-.002: Moderate
- **M** = .05-.011: Weak

(a) Raw loam concentrate spectrographic data

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(b) Raw loam concentrate - AAS data

(c) Treated loam concentrate - AAS data

**Table F8 Elemental correlation matrices, Regional grid.**
been assigned ratings of strong (0.70+), moderate (0.50-0.69) and weak (0.20-0.34). The elemental associations of economic interest in these groupings appear to originate from the strong and upper portions of the moderate groupings. These associations in particular, Ni-Cu-(Co)-As; As-(Cu-Zn), Cu-Pb and Zn-(Cu-Co) are chalcophile in nature and contrast with probable lithological associations Cr-Ni-Pb-V (mafic-ultramafic lithologies), Pb-Y-As (granitic-pegmatitic lithologies) and the association Mn-Cr-Co-Ni which may indicate scavenging in the secondary environment.

The correlation coefficients between As and Cu (0.704), Cu and Ni (0.650) and possibly As and Ni (0.514), for the "raw" AAS data are similarly significant. In contrast the correlation between Cu and Ni (0.177) for the "treated" AAS data is extremely weak.

Cumulative frequency plots for all elemental data were drawn and isopleths chosen for data contouring from breakpoints or points of inflexion on these plots.

(1) Raw Concentrates - "Total" Digestion/AAS

Copper (Figure F36)

The copper patterns of interest are outlined by the 80 and 150 ppm isopleths. Generally there is a northwest-southeast trend to the copper patterns which follows the grain of the country rock. A large copper pattern is present in the central portion of the grid. Within the large pattern are two highs annotated (a) and (b). The main high (a) is present over both ultramafics and mafics of the Kalpini Formation. Cu peaks at 220 ppm within the high. The small central eastern high (b) is a spot value of 170 ppm falling over eluvium covered sediments(?) of the Kalpini Formation.

In the eastern portion of the grid a large Cu pattern is present over in part laterite covered Kalpini ultramafic and sediment. A high of 180 ppm annotated (c) is present within the pattern.

...67.
E5 REGIONAL GRID
LOAM CONCENTRATE GEOCHEMISTRY
COPPER P.P.M.
RAW CONCENTRATES

POPULATIONS

[Legend with populations]
In the northern portion of the grid a Cu pattern annotated (d) falls over amphibolite of the Mulgabbie formation. Much of the geology is obscured by recent colluvium and Tertiary laterite. A peak Cu value of 255 ppm is recorded within the pattern.

Elsewhere over the grid three spot values of 90, 110 and 120 ppm occur over Kalpini Formation sediments.

Nickel (Figure F37)

Nickel patterns of interest are outlined by the 220 and 650 ppm isopleths. As with Cu the patterns follow the northwest-southeast grain of the country rock. This is most pronounced in the central area of the grid where intrusive ultramafic rocks are present. Within this central high two large patterns (a, b) correspond to areas of ultramafic while the third (c) occurs over eluvium covered sediments(?). Within the larger pattern, (a), northern and southern highs of 2100 and 1400 ppm Ni are present. Similarly within (b) values peak at 1200 and 1300 ppm Ni. At (c) a spot 960 ppm Ni value is present. Both (a) and (b) are coincident with prominent aeromagnetic anomalies in Figure F35.

In the northeast corner of the grid a spot 900 ppm Ni value is present over colluvium covered Kalpini Formation sediments and granite.

Though there is some separation of the Ni and Cu patterns with relation to the ultramafic and mafic rock types, there is an interesting correspondence in Ni and Cu patterns in the central portion of the grid. The southern portion of the two larger eastern and western Ni patterns have coincident Cu. These areas are underlain by mineralised ultramafic in contact with sediments. The small central coincident Cu and Ni anomaly is an enigma. It is underlain by eluvium covered sediments(?). No aeromagnetic response is evident to indicate the presence of an ultramafic intrusive, though this may be a function of the "broad brush" flight line spacing.
LOAM CONCENTRATE GEOCHEMISTRY
NICKEL P.P.M.
RAW CONCENTRATES

E5 REGIONAL GRID

- 1.68 + 0.84 mm H
TOTAL / A.A.B.
Gold (Figure F38)

Gold values are of a low order, peaking at 100 ppb. The majority of the sample results are at or below the detection limit of 10 ppb. The gold values have been arbitrarily contoured to outline areas above the detection limit. The location of known gold mineralisation has also been added to the figure. There is marginal correspondence between the regional gold patterns and reported mineralisations. The anomaly annotated (a) over reported gold mineralisation northwest of Jubilee Tank is an exception. However, the large northwest trending pattern, annotated (b) is of interest as it appears to follow the structural grain of the country and among the units underlying the pattern is the Gundokerta Formation from which a little gold production has been recorded. A prominent east-west trending Au pattern of 100 ppb is present to the north of (b). This is suspect as it may represent "line analytical anomalism."

The extensive pattern in the southeastern portion of the grid (c) is underlain by alluvium covered sediments of the Kalpini Formation. The cause of the pattern is inexplicable.

Arsenic (Figure F39)

Arsenic was included as it has been shown elsewhere in the Eastern Goldfields to be an excellent pathfinder for gold, Mazzuchelli and James (1966, 1980) and in some cases nickel as at Mt Martin where arsenides are present in the mineralisation. McKay pers. comm. As with the previously discussed elements arsenic values over the grid have been contoured from break points taken from the cumulative frequency plot.

Arsenic patterns are more diffuse than the previously discussed copper, nickel and gold patterns. There is however a broad general high in the central area of the grid striking approximately northwest–southeast. The previously commented upon northwest trending gold enhancement in the northern portion of the grid has a corresponding As low, though the gold enhancement in the southeastern portion of the grid has a corresponding As high.
POPULATIONS

- Recorded Au Mineralisation

K I L O M E T R E S

E5 REGIONAL GRID
LOAM CONCENTRATE GEOCHEMISTRY
ARSENIC PPM.
RAW CONCENTRATES

HYDRIIDE GENERATION/A.A.S.
Discrete patterns of interest as outlined by the 65 and 115 ppm isopleths are found dominantly over Kalpini Formation sediments (patterns a, b and c) or mafic extrusives (patterns c, d and e). Peak As values of 193, 154 and 130 ppm are recorded within patterns a, b, c over the former lithology. Correspondence is noted between the As patterns, reported gold occurrences and previously described gold patterns such as:

(i) pattern e which is in part coincident with a previously discussed gold pattern;

(ii) pattern b where gold mineralisation is noted as being coincident;

(iii) a spot 32 ppm As value, annotated d, which shows correspondence to gold mineralisation and geochemistry and

(iv) a spot 70 ppm As, annotated e, which has a corresponding spot 50 ppb Au value.

Correspondence is also noted between As patterns a, c, e and Cu, Ni patterns. This is unexpected as arsenides are not a component of the mineralogy reported from drill intersected mineralisation in the ultramafics.

(2) Raw Concentrates - Multielemental Spectrographic scan

Copper (Figure F40)

Diffuse though similar patterns, as outlined by the 110 and 220 ppm isopleths, are present in the spectrographic copper results when compared with the total digestion/AAS results. The dominant northwest-southeast trend in the central grid area is evident as well as other features previously discussed. Much of the pattern here is underlain by Kalpini Formation mafic extrusives. The peak Cu value of 250 ppm is recorded here and in the spotty Cu pattern over amphibolite of the Mulgabbie Formation in the northwest corner of the grid.
Nickel (Figure F41)

Similar patterns are evident with the spectrographic nickel results when compared with the total digestion/AAS results. The dominant northwest-southeast trending central pattern is still evident though it is not as sharply defined as the AAS results. The peak Ni value of 700 ppm is found over areas underlain by intrusive ultramafic in the eastern and western portions of the central high.

Lead (Figure F42)

The majority of the Pb patterns as outlined by the 40 ppm isopleth are underlain by sediments of the Kalpini Formation. In particular of note, is the general northwest-southeast high in the northern portion of the sampled area. Marked highs of 70 and 80 ppm are present within these patterns.

Zinc (Figure F43)

Break points of interest are 60, 100 and 275 ppm. The latter figure is the anomalous two standard deviation of the top population. Patterns as outlined by the 100 ppm isopleth are present over both mafics and sediments. However, highs outlined by the 275 ppm isopleth are distinctive and present in the central portion of the grid, an area underlain by Kalpini Formation mafic and ultramafic rocks.

Chromium (Figure F44)

Break points of interest of 275, 400, 625 and 825 ppm from the cumulative frequency plots have been plotted. General Cr patterns of note are outlined by the 625+ ppm isopleth and are present over the eastern ultramafic and possible ultramafic hidden under eluvium and alluvium in the central portion of the sampled area. The peak value of 2000 ppm is present over the eastern ultramafic.
POPULATIONS

- 275 = TOP POP + 2SD
- 100 - 274
- 60 - 99
- < 60

E5 REGIONAL GRID
LOAM CONCENTRATE GEOCHEMISTRY
ZINC P.P.M.
RAW CONCENTRATES

EMISSION SPEC
-168 ± 0.34 mm
POPULATIONS

E5 REGIONAL GRID
LOAM CONCENTRATE GEOCHEMISTRY
CHROMIUM P.P.M.
RAW CONCENTRATES

EMISSION SPEC.
-1.68 ± 0.84 mm
Vanadium (Figure F45)

The vanadium results appear to belong to one population. The first and second standard deviation isopleths of 250 and 420 ppm have therefore been arbitrarily contoured. The majority of the patterns are found south of the east–west access track over eluvium and alluvium covered mafics and sediments of the Kalpini formation. The largest pattern of significance is found in the south-central portion of the sampled area. Vanadium values here peak at 800 ppm.

Cobalt (Figure F46)

Three Co patterns of interest are outlined by the 50 ppm isopleth. The largest of the patterns is found over ultramafics, mafics and sediments of the Kalpini Formation in the Jubilee Tank area. The 100 ppm high is related to the central Cu–Ni mineralised ultramafic. The eastern Co pattern is similarly related to mineralised ultramafic. Again a 100 ppm Co high is present within the pattern. The northern Co pattern is underlain by amphibolite, sediments and granites. The peak 100 ppm value in the pattern is associated with the granite.

Manganese (Figure F47)

A large Mn pattern as outlined by the 550 ppm isopleth is present in the central area of the grid over both eluvium covered sediments and mafics. Further distinctive highs as outlined by the 1300 ppm isopleth, are present within the pattern.

Yttrium (Figure F48)

Generally Y patterns (20+ ppm) are present over both sediments, mafics and ultramafics. Spot anomalies (50+ ppm) are present south of Jubilee Tank over Kalpini Formation mafics (50 ppm) suspected eluvium covered Kalpini Formation sediments (70 ppm) and over the eastern intrusive ultramafic (50 ppm).
E5 REGIONAL GRID
LOAM CONCENTRATE GEOCHEMISTRY
VANADIUM P.P.M.
RAW CONCENTRATES
POPULATIONS

- > 1300
- 550 - 1299
- < 550

E5 REGIONAL GRID
LOAM CONCENTRATE GEOCHEMISTRY
MANGANESE P.P.M.
RAW CONCENTRATES

Emission Spec:
-1.68 ± 0.84 mm
Silver (Figure F49)

Little can be said about the silver results with the exception of the 1 and 2 ppm responses over alluvium covered suspected Kalpini Formation sediments in the southern portion of the grid.

Tin (Figure F50)

The few positive tin results are spotty. The most "consistent pattern" is found in the extreme northeast corner of the grid over colluvium. Sn peaks at 100 ppm here. North of Jubilee Tank a "pattern" is found over both eluvium covered Kalpini and Gundokerta Formation sediments. Tin peaks at 10 ppm here. North of Lake Yindarlgooda a spot 30 ppm Sn value is present over Recent fringing alluvium.

Molybdenum (Figure F51)

Likewise with the preceding two elements, little can be said with the exception of the spot 3 ppm values over Kalpini Formation sediments north of the east-west access track.

(3) Treated Concentrates - Total digestion/AAS

Copper (Figure F52)

The copper patterns of interest are outlined by the 90 and 170 ppm isopleths. As with the "raw" concentrates there is a northwest-southeast trending pattern in the central portion of the grid which follows the grain of the country rock. This pattern is distinctive in contrast to the broader "raw" concentrate Cu pattern. The majority of the pattern is present over Kalpini Formation mafics and ultramafics particularly the 425 ppm high annotated (a) in Figure F27. The small central and eastern highs (b, c) seen in the "raw" concentrate data and similarly annotated in the figure are again present. A spot value of 205 ppm (b) falls over eluvium covered sediments (?) of the Kalpini Formation while (c), a spot 235 ppm value, is present over in part laterite covered...73.
ARBITRARY ISOPOLETH

E5 REGIONAL GRID
LOAM CONCENTRATE GEOCHEMISTRY
MOLYBDENUM P.P.M.
RAW CONCENTRATES
Kalpini ultramafic.

In the north western portion of the grid a large pattern annotated (d) again falls over amphibolite of the Mulgabbie Formation which is obscured by recent colluvium and Tertiary laterite. A peak Cu value of 245 ppm is recorded within the pattern.

The pattern annotated (e) falling over Kalpini Formation sediments and Mulgabbie Formation amphibolite in the eastern portion of the grid is more extensive than the similarly annotated 90 ppm high in the "raw" concentrate data.

A startling difference between the "treated" and "raw" concentrate data is the extensive Cu pattern (f) in the northeastern corner of the grid for the treated concentrates. This, copper pattern is present over colluvium obscured geology. The general high of 100 to 270 ppm Cu is in sharp contrast to the respective 10 to 20 ppm and 10 to 30 ppm Cu lows of the "raw" concentrate and spectrophotographic data.

Nickel (Figure F53)

Nickel patterns of interest are outlined by the 250 and 650 ppm isopleths. As with the "raw data", patterns follow the northwest-southeast grain of the country rock. Again, a pronounced enhancement is noticeable in the central area of the grid where intrusive ultramafic rocks are present. Within the enhancement three highs 1700, 1600 and 1100 ppm respectively are similarly present and annotated (a), (b) and (c).

A line of highs trending northwest-southeast accentuates the northwestern portion of the grid. this is in sharp contrast with the "raw" data where this feature is not obvious. The 1900 ppm high annotated (d) in the figure corresponds to a similarly annotated spot high of 100 ppm in the "raw" data. Little can be said about the geology underlying the pattern as it is obscured by colluvium. However, it is of interest to note the pattern fall over a broad magnetic high.

...74.
Though there is again some separation of the Ni and Cu patterns with relation to the ultramafic and mafic rock types and in the colluvium covered northeastern portion of the grid there is still correspondence in Ni and Cu patterns in the central portion of the grid over mineralised ultramafic. The small coincidental enigmatic Cu, Ni anomaly underlain by alluvium covered sediments (?) is also still present.

4.4.5 Discussion and Conclusions

The acid extractable Cu and Ni data sets of the two media were first re-examined in order to determine if smoothing by moving averaging would improve the interpretability of the data. In particular the calculation of standard deviation as well as the mean in the smoothing process of moving cell averaging may supply additional information.

For example, areas which have a high mean and standard deviation or, a low order mean and high standard deviation, are both equally of interest. A moving cell of 2 x 2 km was passed over the map area of both Cu and Ni data sets in north-south runs through the facility of a Fortran program GPLAN. A 50% overlap was employed which meant that each point was included in four adjacent cells (i.e. averaged four times). The resulting smoothed elemental cell data files for the media, i.e. cell centroid co-ordinates, number of samples per cell, arithmetic mean, standard deviation and coefficient of variation, were further treated to simple statistics through SPSS (FREQUENCIES). This enabled cumulative frequency plots for all elemental cell data to be drawn and isopleths chosen for data contouring from break points or points of inflexion on these plots. Subsequent data presentation of the number of samples per cell, cell means and standard deviations was effected through the facility of the line printer using the isopleth subroutine of SYMAP which was described in Section C. Refer Figures F54 (number of samples/cell), F55 (cell mean raw Cu), F56 (cell standard deviation raw Cu), F57 (cell mean raw Ni), F58 (cell standard deviation raw Ni), F59 (cell mean treated Cu), F60 (cell standard deviation treated Cu), F61 (cell mean treated Ni), F62 (cell standard deviation treated Ni).
REGIONAL GRID NUMBER PERCELL

DATA VALUE EXTREMES 8RF
1.00 7.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM 1.00 1.50 3.50 4.50 5.00
MAXIMUM 1.50 3.50 5.00 7.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

SYMBOLS

LEVEL
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Figure F54
REGIONAL GRID CU CELL HFAN RAW DATA

DATA VALUE EXTREMES ARE 10.00 180.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

MAXIMUM 21.00 32.00 50.00 75.00 97.00 115.00 180.00

FRQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL 2

SYMBOLS

FREQ. 16 15 13 9 XLLXX XLLXX XLLXX XLLXX

Figure F55
REGIONAL GRID C U C E L L S T D E V R A W D A T A

DATA VALUE EXTREMES ARE 0.00 109.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM MAXIMUM INCLUDING IN HIGHEST LEVEL ONLY
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

SYMBOLS

FREQUENCY

Figure F56
REGIONAL GRID HI-CELL MEAN RAW DATA

DATA VALUE EXTREMES ARE
10.00 1200.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
MINIMUM 90.00 95.00 96.00 100.00 125.00 250.00 325.00 450.00 800.00 1200.00
MAXIMUM 250.00 250.00 250.00 250.00 250.00 250.00 250.00 250.00 250.00 250.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

SYMBOLS

FREQ. 1 2 3 4 5 6 7 8 9 10 11 12

Figure F57
REGIONAL GRID HI CELL SDEV RAW DATA

DATA VALUE EXTREMES ARE 0.01 1007.00

ABSOLUTE VALUE RANGE APPLYING TO EACHLEVEL

MINIMUM 15.00 52.00 26.00 174.00

MAXIMUM 220.00 340.00 400.00 1027.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

SYMBOLS

Figure F58
REGIONAL GRID CU CELL MEAN TREATED DATA

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

Minimum: 15.00 20.00 67.00 115.00
Maximum: 15.00 235.00

DATA VALUE EXTREME ARE

15.00 235.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL

0 1 2 3 4 km

SCALE ++++++++++++ ++++++++

Figure F59
### Regional Grid Cell Survey Treated Data

**Data Value Extremes Are:**

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>173.00</td>
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</table>

**Absolute Value Range Applying in Each Level**

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<thead>
<tr>
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<th>MAXIMUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00</td>
<td>18.00</td>
</tr>
<tr>
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<td>26.00</td>
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<tr>
<td>15.00</td>
<td>25.00</td>
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</table>

**Frequency Distribution of Data Point Values in Each Level**

<table>
<thead>
<tr>
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<th>FREQ.</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

**Figure F60**
REGIONAL GRID NI CELL STORED TREATED DATA

DATA VALUE EXTREMES ARE 0.00 1049.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

<table>
<thead>
<tr>
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<th>MAXIMUM</th>
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<tr>
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<tr>
<td>2</td>
<td>33.00</td>
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<tr>
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<td>110.00</td>
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</tr>
<tr>
<td>5</td>
<td>825.00</td>
<td>1049.00</td>
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FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

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<td>3</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
</tr>
</tbody>
</table>

Figure F62
From Figure F54 the number of cells containing greater than 1 sample have been plotted. Cells, contain up to 7 samples per cell with the average being 3.7 samples. In the output of the means and standard deviations, cells containing less than two samples have been deleted from the chloropleth outputs by recourse to the package A-OUTLINES in SYMAP, i.e. constructing a barrier at half the distance between centroids of the "offending" cell and the rest of the data in the mapped area.

With recourse to Figures F36 and 37 (raw Cu and Ni respectively) and their equivalent in the smoothed data (Figures F55 and 57) it can be seen that outlined areal high of interest are the same in both raw and smoothed data sets. In particular highs in the smoothed data are also areas of high data variability. A pronounced low is again evidenced in the smoothed Cu and Ni data in the extreme northeastern corner of the grid. Both lows have accompanying low variability. Similarly with recourse to Figures F52 and 53 (treated Cu and Ni respectively) and their equivalent in the smoothed data (Figures F59 and 62) areal highs are similar in extent and have corresponding areas of high data variability. However, in the extreme northeastern corner of the grid a pronounced high is evident in both the moving mean and standard deviation Cu data. Greater variability is also shown in the northern portion of the central northwest trending Cu high. Ni data in the extreme northeastern portion of the grid is low in both mean and standard deviation values though there has again been an increase with respect to the raw smoothed data.

The standard deviation data has been of particular interest in that it clearly differentiates in all Cu and Ni data sets the importance of targets in the central geochemically anomalous northwest trending ridge. This order of importance is the northern, southern and central geochemical anomalies. In contrast to the former, the latter is of particular possible interest in that it is not accompanied by a regional magnetic anomaly, though this may be a function of the line spacing on the original government survey. High standard deviation Cu and Ni patterns are also noted respectively in the northwestern and northeastern portion of the grid. Even though data variability is high here these patterns are mono-elemental in character and would be given a low rating...
for follow up investigations. The difference, principally in Cu for the media data sets, is again evident in the extreme northeastern corner of the grid and is inexplicable.

Three profiles AA', BB', CC' have been drawn across the grid to illustrate and summarise the relationship between the two raw data types, analytical methods, geology and magnetics. (Figures F63 to 65).

In profile AA' (Figure F63) a prominent central magnetic anomaly corresponds to the intrusive ultramafic while the magnetic plateau to probable semi-concealed amphibolites. Good correspondence is found between the geochemistry, geology and magnetics. The position of the mineralisation in the basal portion of the ultramafic is indicated by the prominent Ni, Cu anomaly in both the "raw" and "treated" total data. The spectrographic results are more erratic. The ultramafic is defined by the Ni, Co, Cr results. On the basis of the geochemical data alone, the position of the mineralisation within the ultramafic is doubtful, although the results for Co may be an exception. The area of Tertiary laterite in the profile is highlighted by the Ni results in both data sets and the spectrographic Ni, Cr results of the "raw" data.

In profile BB' (Figure F64) a distinctive broad central magnetic high corresponds to extrusive mafics and intrusive ultramafic while a broad magnetic plateau corresponds to an area of colluvium covered geology, containing amphibolites, and some intrusive granite. Good correspondence is again seen with the geology, magnetics and geochemistry though the prominent double peak in the "raw" data is broader in the "treated" data. The "treated" Cu data is greater in magnitude than the "raw" data and in some respects the converse is true of the Ni results. However there is similarity in elemental patterns in all data. The spectrographic data is again more erratic than the total data. The position of the mineralised basal portion of the ultramafic is prominent in all data sets though it is more diagnostic in the "treated" results. An odd prominent Ni (Co) peak is found in all data types over a granite intrusive in the northern portion of the profile in the middle of the magnetic plateau.
Figure F63 - Summary relationship between data types, analytical methods, geology and magnetics on profile AA', regional loam grid.
Figure F64 - Summary relationship between data types, analytical methods and magnetics on profile BB' regional loam grid
Figure F65 - Summary relationship between data types, analytical methods and magnetics on profile CC', regional loam grid
In profile CC', (Figure F65) a double hump is present in the magnetics over the southern unsampled portion of the profile occupied by the playa lake. Gabbroid rock types are inferred to underlie the lake. The sharp prominent central magnetic anomaly reflects in part concealed ultramafic. At the northern end of the line the flanks of a magnetic anomaly is present over inferred concealed amphibolite. A reasonable correlation is found between geology, geochemistry and magnetics for both sample types and analytical methods. There is a pronounced differentiation between the extrusive mafic and intrusive ultramafic in the Cu and Ni profiles. The ultramafic here is not mineralised. An interesting Cu peak is found in the northern portion of the profile over colluvium covered sediments (?) in all data and analytical types. The "treated" Cu data results are again greater in magnitude than the "raw" Cu data and in some respects the converse is true of the Ni results.

Attention was focused on the enigmatic Cu (Ni) high in the treated concentrate results in the north-eastern corner of the regional grid. As noted previously the Cu low in both the AAS and spectrographic raw concentrate data has become a pronounced high (a twenty fold increase) in the treated concentrate data. In contrast Ni tends to be low in both media data sets even though there has been an increase in values in the treated concentrates. In order to resolve the problem forty four samples covering the enigma were renumbered by the writer and reanalysed by the custom laboratory for Cu and Ni by AAS after a "total" mixed acid attack. If the original pattern is real the pattern and values should be repeated.

The results of the above analytical work are compared with the original work in Figures F66 and 67. Table F9 summarises statistically the results for both data sets and also contains a Spearman rank correlation matrix. As the data sets appeared fairly similar a Kolmogorov-Smirnov test (testing absolute differences between data sets) is included in the table.

The original patterns are reproduced even though the reanalysed Cu and Ni results are generally lower than the original "total" digestion results. However the spot Ni high is far higher than the original "total" result (3200 cf 1900 ppm) and the surrounding results to the east and west are also enhanced (i.e. 170 cf 125 ppm, 245 cf 205 ppm). A very
<table>
<thead>
<tr>
<th>Element</th>
<th>Low</th>
<th>High</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu₁</td>
<td>10</td>
<td>270</td>
<td>79.5</td>
<td>61.8</td>
<td>0.78</td>
</tr>
<tr>
<td>Ni₁</td>
<td>45</td>
<td>1900</td>
<td>216.8</td>
<td>(177.7)</td>
<td>1.33 (0.73)</td>
</tr>
<tr>
<td>Cu₂</td>
<td>6</td>
<td>260</td>
<td>78.7</td>
<td>59.6</td>
<td>0.75</td>
</tr>
<tr>
<td>Ni₂</td>
<td>46</td>
<td>3200</td>
<td>227.6</td>
<td>(151.5)</td>
<td>2.08 (0.82)</td>
</tr>
</tbody>
</table>

"total" attack = Cu₁, Ni₁  
HClO₄ attack = Cu₂, Ni₂  
n = 44(43)

(result) effect of removing Ni outlier high

(a) Statistics

<table>
<thead>
<tr>
<th></th>
<th>Cu₁</th>
<th>Ni₁</th>
<th>Cu₂</th>
<th>Ni₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu₁</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ni₁</td>
<td>0.023 (0.053)</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cu₂</td>
<td>0.969 (0.972)</td>
<td>-0.007 (0.046)</td>
<td>1.000</td>
<td>-</td>
</tr>
<tr>
<td>Ni₂</td>
<td>-0.142 (-0.121)</td>
<td>0.963 (0.960)</td>
<td>-0.146 (-0.104)</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Upper matrix significance levels  
n = 44(43)

(b) Spearman rank correlation matrix

<table>
<thead>
<tr>
<th></th>
<th>Cu</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>Maximum D (absolute)</td>
<td>0.1136 (0.1136); 0.9389* (0.9333)*</td>
</tr>
<tr>
<td>Ni</td>
<td>Maximum D (absolute)</td>
<td>-0.2727 (-0.2791); 0.0758* (0.0702)*</td>
</tr>
</tbody>
</table>

* 2 tailed test - Significance level.  0.05  
n = 44(43)

(c) Kolomogorov-Smirnov Test between original and reanalysed data.

Table F9 - Summary Statistics Original and Reanalysed Samples  
Northeastern Portion of the Regional Grid
COMPARISON BETWEEN THE ORIGINAL AND REANALYSED Cu RESULTS FOR TREATED CONCENTRATES, NORTH-EAST CORNER OF REGIONAL GRID

Fig F.66
COMPARISON BETWEEN THE ORIGINAL AND REANALYSED Ni RESULTS FOR TREATED CONCENTRATES,
NORTH-EAST CORNER OF REGIONAL GRID

Fig. F67
minor enhancement can also be seen in the Cu results for the same samples.

Summary statistics in Table F9 confirms the visual observations. The mean and coefficient of variation of the Cu results are of the same relative order, but are less for the new data than the original data (78.7 cf 79.5; 0.75 cf 0.78). The similarity of the Cu data sets is however, best indicated by the tabulated strong significant Spearman rank correlation (0.969) and the small insignificant (0.1136) K-S test D results. The Ni results are somewhat similar if the effect of the Ni high is eliminated. The mean of the reanalysed results is lower than the original data (151.5 cf 177.7) though from the coefficient of variation there is more variability in the new data set (0.83 cf 0.73). There is also a strong significant correlation between Ni data sets (0.960), but in contrast to the Cu results, the K-S test indicates that the Ni data sets are approaching a significant difference. This fact is not entirely unexpected from the visual observations first made of the data sets. The conclusion reached is that the original patterns are real though there is perhaps a bias in the original and subsequent analytical work on the treated concentrates. No explanation can thus be given for the differences between raw and treated concentrate values in the north eastern portion of the grid.

5. ENRICHMENT INDEXING CONCENTRATE DATA

All the work to date has been conducted on "entoto" concentrates of specific size fractions which are composed of dominantly opaques (magnetite, goethite-limonite), biotite, secondary ore products, and in the very coarse size fractions, composites particles (magnetite-talc-chlorite). No attempt has been made to selectively further enrich the concentrates by magnetic or electromagnetic means and analysing the resulting specific enriched and depleted fractions as in other reported concentrate work. Brundin and Bergstrom (1977), Myer (1979). Generally this work is expensive, i.e. preparation is time consuming and, for a non specific survey a number of extra fractions of the sized concentrate would need to be examined mineralogically and/or analytically.

...79.
Recent reading of the English translation of a Russian text by Beus A A and Grigorian S V - "Geochemical Exploration Methods for Mineral Deposits" (1977), Wilmette, Illinois: Applied Publishing, gives some interesting food for thought with regard to this aspect of heavy mineral work. Beus and Grigorian devote a section (p81-90) to illustrating a method of enhancing anomalies in lithogeochemical studies by the concentration of the heavy mineral fractions from rock samples.

As an example, the distribution of elements accompanying U (Pb, Mo, Cu, Zn) in different size fractions of granite samples from mineralised and background situations were compared. Samples of about 2 kg were weighed, crushed to 1mm and sieved to 5 fractions (-1.0 + 0.6; -0.6 + 0.4; -0.4 + 0.25; -0.25 + 0.1; -0.1mm). The resulting sieved fractions were further weighed and subjected to a heavy media separation. Both the light and heavy fractions were retained, weighed and analysed spectrographically. A selective enrichment of the elements of interest was found in the heavy fractions and was pronounced in the samples collected from the mineralised situation, particularly the samples of the finest size fraction. Refer Table F10. An enrichment index was also calculated for each size fraction sample. The enrichment index is given by the formula

\[
Q = \frac{C \cdot d}{D} \times 100
\]

- \(Q\) = enrichment index
- \(C\) = elemental concentration in %
- \(d\) = weight of the fraction (gm)
- \(D\) = total weight of sample (gm)

A considerable enrichment in values (hence the name) is the result of calculating this parameter. This is illustrated in Table F10. It appears from the table that for this lithogeochemical example the smaller the size fraction, the larger the index. In particular, superior contrast between mineralised and background situations, (Beus' anomaly ratio) is evident when the enrichment index is used as against the raw values. The writer has added the raw value contrasts to Beus and Grigorian's work in Table F10.

...80.
<table>
<thead>
<tr>
<th>Size Group (heavy fraction), mm</th>
<th>General sample from within the halo</th>
<th>General sample from outside the halo</th>
</tr>
</thead>
<tbody>
<tr>
<td>+0.6</td>
<td>19.1</td>
<td>187</td>
</tr>
<tr>
<td>-0.6+0.4</td>
<td>408</td>
<td>187</td>
</tr>
<tr>
<td>-0.4+0.25</td>
<td>320</td>
<td>187</td>
</tr>
<tr>
<td>-0.25+0.1</td>
<td>382</td>
<td>187</td>
</tr>
<tr>
<td>-0.1</td>
<td>125</td>
<td>187</td>
</tr>
<tr>
<td>+0.6</td>
<td>19.1</td>
<td>187</td>
</tr>
<tr>
<td>-0.6+0.4</td>
<td>408</td>
<td>187</td>
</tr>
<tr>
<td>-0.4+0.25</td>
<td>320</td>
<td>187</td>
</tr>
<tr>
<td>-0.25+0.1</td>
<td>382</td>
<td>187</td>
</tr>
<tr>
<td>-0.1</td>
<td>125</td>
<td>187</td>
</tr>
</tbody>
</table>

Note: Sensitivity of the analysis: Pb $1 \times 10^{-8}$%, Mo $1 \times 10^{-11}$%, Cu $1 \times 10^{-10}$%, Zn $1 \times 10^{-2}$%.

(a) Distribution of raw and enrichment indexed elemental values in various size fractions of pulverised granite samples.

(b) Anomaly contrasts; raw versus enrichment indexed elemental values.

<table>
<thead>
<tr>
<th>Indicator element</th>
<th>General sample</th>
<th>Size Group (heavy fraction), mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(bulk) sample</td>
<td>+0.6</td>
</tr>
<tr>
<td>Lead</td>
<td>3.3</td>
<td>25(6)</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>5.0</td>
<td>6(6)</td>
</tr>
<tr>
<td>Copper</td>
<td>5.0</td>
<td>9(9)</td>
</tr>
<tr>
<td>Zinc</td>
<td>1.4</td>
<td>16(3)</td>
</tr>
</tbody>
</table>

Table F10 An example of enrichment indexing lithogeochemical data after Beus and Grigorian (1977).
The question thus arises, "If the enrichment index is calculated for loam heavy mineral concentrates or indeed concentrate geochemical work in general would similar larger higher contrast anomalies emerge?"

Some definitive answer could have emerged from the concentrate work at Black Swan. Unfortunately split two fractions should have been sieved, weighed and then subjected to heavy mineral separation and the product weighed, instead of weighing the split, a heavy mineral separation followed by weighing and sieving the product. This oversight was not intentional, because in the regional work, the collector can supply raw or treated concentrates (or now residues for concentrate production) and the aim of the exercise was to see if concentrates could delineate mineralisation, as per the Tati case study. Thus the individual fraction and heavy mineral product weights were not thought to be needed. Also, from previous experience with stream concentrates, weights are only needed (i.e. the weight of concentrate and the panned weight, either actual or from a fixed volume x arbitrary SG factor, e.g. 5 litres x 2.0 = 10 kg) so that vagaries in the concentration factor in panning between sites can be eliminated and the resulting analytical values at sites can be compared. Generally, a heavy mineral separation by TBE on top of preconcentration by panning, eliminates the panning factor. Nevertheless, an answer to the question on the possible usefulness of the calculation of enrichment indices can be gained from two sources, surprisingly the Black Swan study and a regional drainage programme in Oceania.

The first source, the Black Swan study, is an indication of magnitude only and would have to be validated because certain assumptions were made. Nevertheless it was the impetus of the favourable results that led to a subsequent trial enrichment indexing of concentrate data in a regional drainage programme.

Assumptions had to be made in the Black Swan study and are as follows. All split 1 (raw soil) size fraction analytical pulps for the surface scrape (BS1) and depth (BS4) were weighed and corrected for loss of weight in analyses to obtain a bulk weight. As the sample weight was found to be highly skewed to the coarsest size fractions, (refer Figure F68) in particular the -1.68+0.84 mm fraction which ranges from 45 to 70% of the calculated bulk weight, it was decided to attempt a TBE heavy mineral...
MINERALISED STATION 1310E

BACKGROUND STATION 1270E

SOIL AND HEAVY MINERAL ANALYSIS

Fig. F66
separation on this pulp size fraction, weigh the product and analyse for Cu and Ni. One separation was attempted and abandoned because of sliming and "hanging up" of particulates in the TBE. This effect was due to the fact that the pulps had all been ground to 75 microns for the previous discussed analytical work.

Despite this set-back, it was reasoned that, because the original splitting of the bulk sample collected was carried out on a small splitter, and the volumes of splits 1 and 2 were approximately equal, if both splits had been subjected to heavy mineral separation the yield of heavy mineral would have been approximately the same. Thus, the sieved heavy mineral concentrate of split 2 could be assumed to have been derived from the equivalent split 1 size fractions. Where possible these samples were weighed and corrected for weight loss in the analytical work. However the effect of loss in grinding for both concentrates and soils has not been taken into account. Figure F68 is a theoretical reconstruction of the distribution of heavy mineral weights in the individual size fractions of the bulk samples from surface and depth for stations 1270 (background) and 1310 (mineralisation). As a generalisation both raw size fractions and the heavy mineral fractions are highly skewed to the coarsest size fraction and in a lesser sense the finest size fraction. The heavy mineral yield of the sample from various depths over mineralisation with respect to background appears greater especially at the mid sampled depth.

It was felt that in view of the amount of heavy mineral for the depth and scrape -1.68+0.84mm samples some conclusions may be forthcoming for these samples if they were enrichment indexed. The hot perchloric acid extractable Cu, Ni results of stations 1310 (mineralisation), 1290, 1280, and 1270 (background) were subsequently enrichment indexed. The weights, raw concentrate, enrichment indexed concentrate and soil Cu, Ni results for both the scrape and depth samples from stations 1310, 1290, 1280, 1270 are set out in Table F11 along with comparative bedrock data from rotary air blast drilling. Contrasts at surface and at depth for background and mineralised stations are also set out in the table for study. The tabulated results have also been plotted on semi-logarithmic graph paper. (Figure F69).
### Table F11

<table>
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<th>Depth</th>
<th>Station</th>
<th>W1</th>
<th>W2</th>
<th>W3</th>
<th>Cul</th>
<th>Ni1</th>
<th>Cu2</th>
<th>Ni2</th>
<th>Cul</th>
<th>Ni3</th>
<th>Cu4</th>
<th>Ni4</th>
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</thead>
<tbody>
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<td>1270</td>
<td>418</td>
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<td>850</td>
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<td>53</td>
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<td>624</td>
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<td>1601</td>
<td>223</td>
<td>900</td>
<td>1900</td>
<td>8000</td>
</tr>
<tr>
<td>BS4</td>
<td>1310</td>
<td>688</td>
<td>952</td>
<td>46.6</td>
<td>2400</td>
<td>6800</td>
<td>1625</td>
<td>4605</td>
<td>515</td>
<td>1800</td>
<td>2300</td>
<td>4700</td>
</tr>
</tbody>
</table>

(a) Raw concentrate, enrichment indexed concentrate and soil Cu, Ni data for stations 1270 to 1310.

**Notation:**
- **BS1:** Surface scrape; **BS4** Depth (95-105cm)
- **W1:** -1.68 to 0.84mm (gm); **W2:** Total/wt of sample (gm); **W3:** -1.68+0.84mm concentrate (gm)
- **Cul, Ni1:** Hot HClO₄ extractable Cu, Ni raw concentrate data.
- **Cu₂, Ni₂:** Hot HClO₄ extractable Cu, Ni enrichment indexed concentrate data \( \times 10^{-3} \).
- **Cu₃, Ni₃:** Hot HClO₄ extractable Cu, Ni soil data.
- **Cu₄, Ni₄:** Hot HClO₄ extractable Cu, Ni bedrock data.

(b) Contrasts for data types.

**Notation:**
- **1310 BS1** Contrast at surface between mineralisation and background.
- **1310 BS4** Contrast at depth between mineralisation and background.
- **1270 BS4** Contrast between bedrock sample between mineralisation and background.
- **1270 BS1** Contrast at background station between depth and surface.
- **1310 BS4** Contrast at mineralised station between depth and surface.

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Table F11 Hot extractable HClO₄ Cu, Ni data for raw concentrate, enrichment indexed concentrate, soil and bedrock media, Black Swan.
Figure F69 - Semilogarithmic profile plot comparisons of raw and enrichment indexed concentrate, soil and bedrock Cu and Ni data for stations 1270 to 1310E, line 6020N, Black Swan
From Table F11 a marked increase in elemental contrast is indicated between mineralisation and background for enrichment indexed concentrations over raw concentrates. For example for the scrape situation, Cu from 5.8 to 11.9 (2.0x); Ni from 2.5 to 5.1 (2.0x), and for the depth situation, Cu from 16.0 to 43.9 (2.7x); Ni from 5.4 to 15.4 (2.8x). An increase in contrast between depth and surface for background and mineralised situations is also indicated. For example at the background station, Cu 1.1 to 1.4, Ni 1.5 to 1.9, but more importantly at the mineralised station Cu 2.9 to 5.1, Ni 3.2 to 5.2. It is of interest to note the differing behaviour of contrast between depth and surface for background and mineralised stations for the raw soil sample. The background station contrast for Cu is slightly decreased in contrast with Ni, which shows a marked decrease. At the mineralisation station contrast for Cu shows a pronounced increase while for Ni an even sharper decrease is observed.

The semi-logarithmic plot of the data (Figure F69) has also added information. Generally a decrease in concentration from a source is very close to exponential and results when plotted in a semi-logarithmic system approach a straight line. However "noisy" results must first be smoothed by three point moving averaging to elucidate trends. Such straight line graphical representation of results makes for easier comparison and analysis of data sets. In lithogeochemical studies in the USSR the slope of the line is taken as an indication of elemental contrast, mobility and halo width (Beus et al 1977). Increased slopes indicate less mobility in elements, but high contrast. With the possible exception of the soils, a straight line can be drawn through the elemental data for the media types. The soils are interesting in that two populations are possibly present in both scrape and depth elemental data.

The implications of this in terms of elemental dispersion are as follows:-

At depth Ni and Cu in soil and perhaps in bedrock samples have similar halo widths and contrast, but with Ni having a possible high background shoulder. As the surface is approached Cu becomes lower in contrast than Ni, but the anomaly size of Ni is larger, comprising a dimensionally smaller, but higher contrast anomaly with a high background shoulder. Cu and Ni in concentrates (i.e. both the raw and enrichment indexed data)
appear to generally have larger halos than soils over mineralisation. There perhaps is also a larger halo at surface in the concentrates though with lesser contrast. The mobilities of Cu and Ni in the concentrates are similar because of the probable presence of the elements as a distinct mineral species or within a mineral host. (Refer mineralogical data). In contrast Cu and Ni in the soil is in a chemically more available form where the effects of pH in particular governs mobility from the oxidising sulphide body, e.g. Cu being less mobile at high pH's explaining the enrichment at depth in the caliche rich soil over mineralisation.

The second source on the possible usefulness of the enrichment index comes from a recent granitoid elemental programme over 2400 km² of poorly accessible country in Oceania, Farrell (1980). Both stream sediment and bulk samples for concentrate production were taken in the course of a helicopter borne programme. The -0.60mm size fraction of the bulk samples were sieved out, subjected to a TBE separation and heavy mineral concentrates produced. Weights were recorded at all stages of the proceedings. As the granitoid elements Cu, Mo, Sn, W, Ta, Nb, U, Au were the prime objective of the programme, the concentrates were passed through a Franz Isodynamic Separator. The electro-magnetic separator set at 20° slope and 15° tilt, produced at a final 1,0 ampere current setting a non magnetic fraction for mineralogical scanning and a subsequent multi-elemental analysis by emission spectrography. Concentrate radioactivity and reaction to a UV light were also measured and recorded during the mineralogical scanning for alteration mineralogy, gossan products and the direct species of interest. The nonmagnetic fraction obtained from 0.7 to 1.3A current settings on the Franz has been shown by a number of workers to preferentially accumulate granitoid mineral species of economic interest, Baker (1962), Brundin and Bergstrom (1977). A mean 1.0A setting was decided upon after orientation work in the programme. As an experiment before embarking on the interpretation of the data base, the raw and enrichment indexed spectrographic Sn data for the nonmagnetic fraction were compared for the entire regional survey. The writer found that noise in the raw spectrographic data on enrichment indexing was particularly reduced. High contrast anomalies resulted and dispersion trains were highlighted. Data plotting and subsequent interpretation of the surveyed area was thus carried out on the enrichment indexed elemental data. As all the data had been recorded and...
computerised, calculations were easily carried out on the remaining elements of interest. Figure F70 illustrates in a compare and contrast manner, the effects of enrichment indexing stream concentrate data for a portion of the Sn data over the survey area. Higher contrast anomalies and dispersion trains can be seen to result from enrichment indexing.

6. **SUMMARY DISCUSSION AND CONCLUSIONS**

From the preliminary work to date, loam concentrates appear to be able to delineate geochemical provinces in areas of poor to non existent drainage. In fact, from the interpretation of semiquantitative analytical data of the minus 0.60mm fraction of loam concentrates, which were representative of individual 8km² cell over the 5400 km² Tati district in Botswana, the writer outlined eight geochemical provinces at the district level. These districts correspond in gross terms to a polymetallic geochemical province which has probably evolved in time through distinctive geological and mineralising events. Gold and copper-nickel districts discussed have equivalent metallogenetic status. The remainder with emphasis on the granitoid Sn-W-Mo-Bi and volcanogenic Au-Cu-Pb-Zn-Sn-Bi associations are geochemical indications of possible undetected metallogenetic events.

It was of interest to note from the Tati experiment the occurrence of immobile chalcophile "pathfinder" elements, in particular Bi-Sn with or without the commodity base metals of interest. In such highly leached landscape environments these elements can be used as pathfinders or as further support for rating responses from the major commodity elements.

Experimentation was extended to the Eastern Goldfields Province of Western Australia, an area of minimal drainage and 80 to 90% outcrop concealed by superficial deposits, such as windblown sand, alluvium and laterite coupled with intense surface leaching under the prevailing conditions of deep oxidation. The use of pea gravels, a constituent of the ultra coarse fraction of a loam concentrates (0.80mm to 2mm), has been spasmodically reported here as a media in localised exploration work for base metals [Smith et al 1979] and gold mineralisation. [Mazzucchelli and James 1966, 1980].
Geochemical and mineralogical orientation work on soil concentrates and soils were conducted at the local level, over the Black Swan nickel mineralisation, an ideal situation concealed by shallow residual soil. Metal distribution and contrast was reported in four size fractions (-1.68+0.84mm, -0.84+0.42mm, -0.42+0.175mm and -0.175mm) and depths (surface scrape, 15 to 30cm, 45 to 60cm, 90 to 105cm). Three hot and two cold digestions were employed on both soil and soil heavy mineral concentrates from background and mineralised stations. Surface scapes of the size fractions of both media were also subjected to a multi-elemental spectrographic scan.

The hot "total" and perchloric digestions/AAS method appeared to extract and measure more Cu, Ni, Co, Cr than emission spectrography. Extractability by hot acid digestion was in the order ("total" > perchloric) > 25% nitric. Metal extractability of the 1% HNO₃ and Amc cold leaches was found to be of the order of 5 to 10% for base metals though Mn extractability approached that of hot digestions. Selectivity of metal extraction by cold leaches was demonstrated for Fe and Mn, with Fe having a very low extractability in Amc. This feature would be useful in any investigations of coprecipitation effects of base metals on Fe-Mn oxides. For both media, Cu, Ni and Co extractabilities by cold and hot digestions increased over mineralisation, reflecting the greater abundance of labile Cu, Ni and Co. However, metal extractability by both cold and hot digestions is generally less for concentrates than soils reflecting the nature of the fixation of the metal in the sample media, i.e. strongly bonded elements within the lattice of a mineral species.

A general trend was noted in the elemental results for both sample media with respect to size fraction and depth samples. The best Cu, Ni,Co, Cr response for hot digestions (optimum contrast and highest values) is found in the coarsest size fraction (-1.68+0.84mm) at a sampling depth of 45 to 60cm. However, Ni in soil peaks in value and contrast in the coarsest fraction of a soil scrape, though there is a significant subsidiary peak at 45 to 60cm depth. Peak value and optimum contrast for the cold digestions for both media are found in the coarsest size fraction of the surface scrape rather than at depth.
The multi-elemental spectrographic scan of the four size fractions of the surface loam and concentrate samples from background and mineralised situations reaffirmed the optimum response of Ni, Cu, Co, Cr, Mn in the -1.68+0.84mm fraction over mineralisation, but with the addition of As, Sn, Sc, Ti, Yb, Y. However, with the exception of As and Sn, these additional elements are responsive only in the concentrates.

The mineralogy of surface and depth concentrates were found to differ little in composition. Opaques dominated, with magnetite and goethite-limonite being approximately equivalent in abundance. No relict textures after sulphides were noted. Limited qualitative probe work confirmed the main elemental responses over mineralisation. Ni, Cu, Cr and Zn contents of magnetite and goethite-limonite from mineralisation were enhanced with respect to background. Co could not be discerned because of the overlap with Fe and Ni lines. One grain had a possible S response with associated enhanced Ni, Cu content pointing to an ex-sulphide source. An indeterminate opaque mineral species in the concentrate samples gave consistent highly anomalous counts in Ni, Cu, Zn and either Pt or Au. The opaque mineral could not be identified because of the grain size in the analytical pulps. It is suggested that, even though the content of the ore elements in the dominant heavy mineral species in a concentrate differ in mineralised and background situations, they are of less importance than the presence of secondary or primary ore mineral species.

Work extended to the coarse (-1.68+0.84mm) size fraction of raw and treated concentrates held in storage from a regional 1km² grid over a 225km² area in the Eastern Goldfields. These concentrates were examined to see if known Ni-Cu and Au mineralisations could be discerned on a regional scale. Even though the area is non idealised, as at Black Swan and suffers from a variety of overburden types, a reasonable correspondence was found between the Cu and Ni patterns of the two media and the geology and known mineralisation. Likewise, a fair correspondence was also found between the As and Au results of the raw concentrates and known Au mineralisation. The raw concentrate Cu, Ni data were of a slightly lower order than the treated concentrates and the resulting patterns were not as sharp. However the results are marred by an inexplicable Cu high in the treated concentrates over the northeastern corner...
of the grid. Reanalysis of the treated concentrates, however, substantiated the original pattern. No decision can therefore be made on the true effectiveness of raw versus treated concentrates.

From the multi-elemental spectrographic scan of the raw concentrates other elements, principally Co and Cr were prominent over the mineralised ultramafic. Sn and Bi responses were notably absent.

Moving average smoothing, with calculation of the cell mean and standard deviation, and subsequent spatial representation of these calculated parameters by isopleth mapping, through the facility of SYMAP on the line printer, did improve interpretation. In particular the standard deviation maps allowed the Cu, Ni anomalies in the central grid area to be rated in significance.

Trial enrichment indexing of analytical data of concentrates from soils and streams was attempted. The procedure appears to produce high contrast anomalies and highlights dispersion from mineralised sources. Indexing can be easily accomplished with very little extra effort as generally all multielemental data from regional geochemical programmes is now assembled in a file and processed by computer.
SECTION G

SUMMARY CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

The thesis has discussed various aspects and experimentation in a "macro-regional" geochemical mapping programme on the continental land mass of Australia.

Section A defined and reviewed the objectives and current status of macro-regional geochemical mapping in the world as seen by the writer. It was pointed out that due to the differing fundamental objectives of the two proponents of this work it has become dominantly the domain of the public sector. When such work is carried out by the private sector it is usually under strict company objectives and guidelines. The sampling media employed are principally associated with the hydrosphere and are generally subjected to multi-elemental work. Sample density is variable in nature, but generally the number of samples collected is greater than one per 25/km². The aim of current macro-regional geochemical work at such densities is directed to the detection of as yet identified minor geochemical provinces and associated mineralised belts. However, in such surveys, especially those carried out by the private sector, the density is often biased to the possible reflection of individual ore deposits or ore environments.

Section B outlined broadly the Australian macro-regional geochemical programme as conducted by Australian Anglo American. The project's evolution, aims and objective; sampling and analytical requirements; the simplistic operating and data validation systems were described in depth. The programme is considered to derive great advantage from the extent of data coverage and methods of presentation. Data coverage is available on areas which would not necessarily be prospected in the course of specific base metal or precious metal exploration and the broad data base permits regional and local responses to be placed in the appropriate geological perspective. Consideration and research using the macro-regional data bank and published regional geological,
geophysical and photographic data especially satellite imagery, will suggest areas or regional geological units which may have potential for economic mineralisation and which hitherto have not been specifically indicated.

Much improvement is still needed and is occurring with respect to aspects of sampling, analysis and the processing of data. The usage of various media, size fractions or perhaps the selective enrichment of a media (e.g. the granitoid elements in the non magnetic fraction of stream concentrates; Section F, 5.0) is being applied to specific situations. New generation multi-elemental ICP and XRF equipment is beginning to be used in sample analysis and are becoming especially important in the search for "exotic" elements such as Ta, Nb which in the past suffered from high detection limits in routine multi-elemental emission spectrography. Importantly, the new analytical equipment are micro-processor controlled, enabling final corrected multi-elemental results to be fed directly to floppy disc, paper tape, card or magnetic tape in a user defined format for subsequent data processing. However, this new technology is also contributing to the expanding information explosion. Computer processing of data has to date been by simplistic, batch processing and plotting through "waiting in line at the computer centre". With the exception of the macro-regional data base it has been ad-hoc because of limited allocated resources. However, the growing awareness by management of, an integrated concept to research to find ore bodies, and the provision of specialist technical services to operating divisions, has led to the creation of a research and technical services division (RATS), of which geochemistry, geophysics, photogeology and commodity research are units. In-house computer power has thus become justified due to the increased work load and is especially necessary to handle the information explosion. To this end an in-house computer centre is in the process of evolving. Computing through two PDP 11-34's (one being part of a Landsat processing system) and their ancillary peripherals (interactive terminals, a line printer, plotter, a digitiser and a graphics terminal) will become directly available to the RATS user. Interactive computing, instead of "waiting in line" at the computer centre, will also become the norm.

...3.
As previously stated in Section B, the problem with the accumulation of a vast amount of data in general is that much of it can only be superficially examined before being discarded or if lucky archived. Even the minor amount of data which reaches print often tends to be rapidly demoted in importance. Therefore, the need to conserve and make better use of such expensive and valuable information is obvious. The creation of a workable research data base is thus now of paramount importance to exploration success through integrated multidisciplinary research. This can only really become possible through interactive computing in an "in-house" situation. Thus, the important approaching problems to solve are, the creation, maintenance and administration of a unified geological-geochemical-geophysical research data base from which consistent and correct data can be obtained, and the lesser problem, of the support of a user application library, that will adequately fulfill all the users' needs.

Section C was devoted to a very detailed interpretation of the macro-regional stream sediment and concentrate geochemical data of the Marble Bar 1:250 000 sheet. The aim was to maximise the information content of the data to its limits, through the application of simplistic univariate and a subsequent multivariate technique factor analysis. The flow path of factor analysis was investigated through the proprietary user orientated computer program library of SPSS. Rapid spatial representation of data through line printer mapping was investigated through a proprietary social sciences program SYMAP and GREY after Howarth (1972).

The stream sediment and concentrate elemental data complimented each other. In the macro-regional sense, elements and groupings of elements were noted to be associated with various known mineralised geological environments. These elemental groupings, in effect minor geochemical provinces, were also found outside known mineralised environments over areas underlain by similar favourable and at times unfavourable geology. Such areas both rank equally for detailed investigation for known ore types and hitherto as yet unrecorded styles of mineralisation.
Although time consuming there would appear to be no substitute for detailed univariate elemental interpretations through simplistic population statistics and "living with the data", building up a geochemical synthesis by cross referencing the geochemical data to each other and to geological and mineral occurrence maps. Factor analysis, the multivariate technique in part examined, was a step backwards and here grossly inferior to the univariate interpretation. The failure is thought to be due primarily to the statistical computations not taking into account where a set of values form a pattern in geological space, correlations being biased by value rather than pattern recognition within a geological entity as is done visually. The effects of inter-populations and intra-populations in the main geological entities were possibly also too complex to be separated and any resulting associations were major geological environments which was contrary to the writer's aims. However, the negative aspect of factor analysis should not deter the user, because the more objective PCA SPSS pathway may reveal an elemental association (factor) which, when related to geology by plotting the factor scores, may generate an idea which could lead to an ore deposit.

The SPSS computer program library was found to be extremely user orientated and satisfactorily performs descriptive and inferential statistical analyses economically, while the SYMAP package effectively creates for minimal cost, regional surfaces of any raw data or statistical outputs for pattern recognition and analysis. However, to optimise the SYMAP isopleth mapping procedure for stream samples, recoordination of stream sites to basin centroids by machine digitising may be advisable, if plotting is to be carried at a small scale.

Section D discussed aspects of investigations of local anomalies and regional patterns through a series of case studies. An attempt was made to show through the case studies and subsequent discussion, that although not currently in vogue, under certain conditions, old tried field analytical methods with standardised digestions, can make a valuable contribution from both the technical and personnel aspect to an ongoing integrated exploration programme. An awakening of interest in field analytical techniques in general is noted. Although mainly directed to simplified instrumental methods, e.g. for the elements
Hg, U, F, rather than wet chemical-colorimetric methods, the development of such new techniques and an awareness of the old, should be encouraged by the mining industry, because the exploration geologist must use effectively all methods at his disposal to maximise the probability of exploration success.

Section E followed on from both Sections C and D, and consisted of two experiments in the search for the granitoid commodity elements tin and tantalum in a 100 000 km$^2$ area of the Pilbara, in northwestern Western Australia. The search for exploration targets here was conducted by firstly, an overview of the macro-regional stream concentrate Sn and Nb data integrated with satellite imagery; and secondly, with the aid of EDF, a multivariate pattern recognition technique integrated with the same satellite imagery, in an attempt to give better discrimination to targets defined by the univariate geochemical data. The latter work was consequent to investigations of the applicability of two contrasting discriminant pathways, FLDF and EDF on a difficult semi-quantitative data set, through available proprietary (SPSS inc) and published (Howarth, (1973)) algorithms. The semiquantitative Marble Bar Stream concentrate data from Section C was used as a training-testing set. Detailed knowledge gained from the exhaustive univariate analysis in Section C enabled the formulation of a two group training set over areas of "tin" granite/mineralisation and gneiss/greenstone respectively, and for the writer to gauge the effectiveness of the algorithms' performance in discrimination/classification on the remaining sheet data which constituted the testing set.

The FLDF was shown to be inappropriate to the problem at hand. The EDF algorithm performed well on a small training set with subsequent meaningful classification results, even though the data was semiquantitative in nature. The young "tin" granite phases which have associated Sn and Ta pegmatitic mineralisation were mapped. Location of these phases is a starting point in the search for possible eluvial-alluvial Sn, Ta mineralisation. Other patterns of classified samples belonging to this group, in the older granitic terrain and/or associated with structure, may be indicative of hydrothermal mineralisation with the emphasis on the larger zoned pegmatites. Screening of these patterns...
with the censored Nb data has led to definitive exploration targets for Ta. Field investigations need to be carried out to validate the writers approach to target generation using the macro-regional geochemical data.

Further work is also needed to improve the EDF algorithm's performance, from the point of view of confirmation of discriminatory elements and knowledge of the importance of the elements in the discrimination. To this end, thought should be directed to an interactive approach involving three phases:

(1) The generation of univariate density distributions for the various elements before the multivariate classification phase. Smoothing could be carried out interactively by doubling sigma intervals for each element. A listing of the percentage of samples assigned to each group for the elements could be line printer output. The univariate density distributions of the groups for each element would be shown as line printer plot comparison for the terminal or a steady state classification. The amount of separation of the distributions should be a measure of univariate discrimination.

(2) The quantification of the univariate discrimination by incorporation of the Kolmogorov-Smirnov test.

(3) The final multivariate classification phase, as per the present EDF, using the chosen discriminatory elements. An addition is needed here, the confirmation of the discriminatory elements and the importance of the elements in the discrimination - classification. This probably could be obtained by "working backwards" to obtain the relevant polynomial equations.

With the installation of a Landsat facility some thought should be given to feasibility of pixelling the classification to obtain a result similar to a SYMAP output and using the colour graphics for pattern representation, i.e. using the colour guns for representing the classified groups. If a two group situation exists, a 100% probability of membership to group 1 could be blue, and 100% group 2, yellow.
Mixing of colour would represent intermediate percentage classifications. Overlaying of the macro-regional geochemical data and processed satellite scenes in the Landsat facility should also be considered.

The final section, Section F, investigated in a very preliminary manner the concept of using "loam" (soil) heavy mineral concentrates as a medium for regional geochemical surveys in areas of minimal drainage. Terminology and principles of loam surveys were expounded. The writer first outlined the results of a hindsight examination on a large multi-elemental data set over the 5400 km² area called the Tati Concession in Botswana, which bears geological, geomorphological and climatic similarities to arid tropical northwest Western Australia. Each loam concentrate result here was representative of bulked minus 0.6mm tabled concentrates from a 8 km² cell. The objective of this work was to determine before embarking on experimental work in Australia if; geochemical provinces are discernable in a large regional concentrate data set covering an area of minimal drainage, and subsequently, the relationship of any discernable geochemical provinces to known metallogenic provinces. The objective was met. Eight geochemical provinces at the district level were outlined which correspond in gross terms to a polymetallic geochemical province which probably evolved in time through distinctive geological and mineralising events. Au and Cu-Ni geochemical districts were found to have equivalent metallogenic status. However, the remainder, granitoid Sn-W-Mo-Bi and volcanogenic Au-Pb-Zn-Bi associations, are possibly geochemical indications of hitherto undetected metallogenic events. The observation that, Bi-Sn accompanied Cu-Ni, Pb-Zn and mono-elemental Au and Ni anomalisim, had particular relevance since some of the anomalisim is thought to reflect discovered Cu-Ni anomalisim. The use of such elements which are associated with ore, but are immobile in the zone of oxidation in highly leached environments as in areas of Botswana and Western Australia, is perhaps one geochemical technique worthy of further investigation. The use of immobile elements, alone as pathfinders or preferably as support to the major commodity elements in such landscape environments will be of growing importance. Some success has been reported in localised exploration work in Australia for base metals, gold and uranium using pea gravels, the ultra coarse constituent of loam concentrate, which have been analysed for immobile elements.
Local and regional experimental work was carried out in the Eastern Goldfields Province in Western Australia. Localised experimental work in an idealised landscape environment at Black Swan generated data on; metal extractabilities of common hot and cold digestion procedures for Cu, Ni, Co, Cr, Pb, Zn, Fe and Mn; metal distribution and contrasts for soil and loam (soil) heavy mineral concentrates of various size fractions and from various depth in both mineralised and background environments; and mineral constituents of loam concentrates and their trace element content. The hot "total" and perchloric digestion /AAS method appeared to extract and measure more Cu, Ni, Cr, Co than emission spectrography. Extractabilities by hot acid digestions were generally of the order (total > perchloric) > nitric. Cold leaches (1% HNO₃ and Amc) extracted 5 to 10% of the base metal content of the samples in background circumstances though Mn approached that of the hot digestions. Selectivity of metal extraction was demonstrated for Fe and Mn, with Fe having a very low extractability in Amc. This feature would be useful in any future investigations of co-precipitation effects of base metals on Fe-Mn oxides. Metal extractability by cold and hot digestions was less for concentrates than soils, reflecting the nature of the fixation of the metal in the sample media.

At Black Swan, the -1.68 + 0.84 mm fraction of both soil and soil concentrates from a surface scrape analysed for Cu, Ni, Co, after a hot "total" or perchloric digestion, delineated mineralisation. However, for general soil geochemical work where a superior contrast is required, a 45 to 60cm sampling depth is indicated. However, contrast at surface can also be improved by analysing for these elements after a cold 1% nitric acid leach. Multi-elemental spectrographic work on the respective background and mineralised situation surface samples also confirmed the observations made on the commodity elements of interest for the -1.68+0.84mm fraction. However, other elements notably As, Sn, Sc, Cr, Ti, Mn, Y and Yb were prominent over mineralisation, especially the first two. Au and Pt were also indicated from the qualitative probe work. Immobile elements are again seen to be prevalent especially those associated with general hydrothermal mineralisation.
Although the mineralogy of surface and depth concentrates were found to differ little in composition in background and mineralised situations, the Ni, Cu, Cr, Zn contents of magnetite and goethite-limonite from mineralisation were enhanced with respect to background. Co could not be discerned because of spectral overlap with Fe and Ni lines. However, an indeterminate secondary ore (?) heavy mineral species in the pulps appeared to be of far greater importance and gave consistent highly anomalous Ni, Cu, Zn, Au and Pt counts. It is thus suggested that even though the content of the ore elements in the dominant heavy mineral species in concentrates differ in mineralised and background situations, they are of less importance than the presence of the secondary or primary ore heavy mineral species. In view of the nature of the heavy mineral sample studied (analytical pulps) over mineralisation, it would be worthwhile to relocate the grid station over mineralisation and repeat the mineralogical work to identify the secondary ore species; and with a quantitative probe, determine the trace element contents of species present. The Link system, if readily available and qualitative, would prove invaluable in routine examination of grains in concentrate geochemical work, especially as simple mounting of grains (hand picked if required) can be effected on an aluminium stub. Coating of the grain mount by carbon or aluminium to minimise charge build up and beam deflection, appears to be unnecessary.

Work extended to a 225 km² regional grid where both raw and acidified-attritioned ("treated") -1.68+0.84 mm concentrates were examined to see if known Ni-Cu and Au mineralisations could be discerned on a regional scale. Even though the area is non idealised and suffers from a variety of overburden types, a reasonable correspondence was found between Cu and Ni patterns of the two media and the geology and known Ni mineralisation. Likewise, a fair correspondence was also found between the As and Au results of the raw concentrates and known Au mineralisation. The raw concentrate Cu, Ni data were of a slightly lower order than the treated concentrates and the results were not as sharp. No decision could, however, be made on the true effectiveness of raw versus treated concentrates because the results were marred by an inexplicable Cu high in the treated concentrates over the northeastern portion of the grid which was substantiated by re-analysis. It probably would have been instructive to take the raw concentrates and gradually "strip off the...

...10.
grain coatings" by selective attacks and analyse the leachates, then finally subject the "clean" grains (now equivalent to the treated concentrates) to a "total" attack analysis after grinding to 70 microns. This approach would probably have helped to make a decision on the effectiveness of the available concentrate media. Selective enrichment/-depletion of certain heavy mineral species by electromagnetic means and the study of the relevant enriched or depleted concentrate products has not been attempted here though this approach has been found to be extremely useful in specific concentrate surveys (refer Section F 5.0, Enrichment indexing concentrate data) and would be a fruitful avenue of research in further loam concentrate work.

Concentrate data is inherently noisy, but it was shown that moving average smoothing with calculation of the cell mean and standard deviation and subsequent spatial representation of the calculated parameters by greyscale isopleth mapping did improve interpretation. Trial enrichment indexing of concentrate data also suppresses noise and appears to produce high contrast anomalies and highlights dispersion from mineralised sources. Further work validating the applicability of enrichment indexing concentrate data is, however, still needed.

Finally, the writer in conclusion of this thesis, would again like to stress that exploration is a multi-discipline team effort and that for a successful outcome the geologist must become an explorationist, i.e. be willing to be part of a team and learn to integrate and assimilate data from all available sources on a target and to use all exploration tools at his disposal to increase the probability of success.
APPENDIX I

Contributions to journals and symposia
in the course of the thesis

Pinnacles Cu-Pb-Zn prospect, Dundas Trough, Tasmania (B L Farrell and D B Orr) page 281-283.

Landgon Ag-Pb-Zn prospect, South Coastal Structural High, Queensland (B L Farrell) page 338-342.


Prospecting in areas of glacial overburden in western Tasmania, (B L Farrell and D B Orr).

PROSPECTING IN AREAS OF GLACIAL OVERBURDEN IN WESTERN TASMANIA

By

B. L. FARRELL* AND D. B. ORR*

ABSTRACT

This is a case history of prospecting carried out by Comstaff Pty. Ltd. over the Pinnacles Area, part 4 of Exploration Licence 5/63, 9 km north of Rosebery in Western Tasmania. Evidence is presented to show that A° soil sampling is a viable prospecting method for outlining polymetallic sulphide occurrences in areas where leached organic/glacial soils are common. Diamond drilling of low threshold anomalies has intersected base metal mineralisation.

INTRODUCTION

Comstaff Pty. Ltd. Exploration Licence 5/63 part 4, covers an area of 363 km² and gives a representative cross section of the Mt. Read Volcanics and abutting sediments to the west (Fig. 1). The area under discussion is limited to 2 km² at the Pinnacles, and is located 9 km north of the major polymetallic deposit at Rosebery. This is a case history of exploration in an area where problems of transported overburden, together with an inhospitable climate, relief and vegetation and lack of access, deters the most ardent explorer of base metals.

GEOLOGY

Due to Pleistocene glacial moraine and thick vegetation, outcrops are minimal and are generally confined to creeks or access tracks. Geological conclusions reached are therefore somewhat interpolative.

The regional geology is well covered by Williams et al. (1975) and no further description is required.

The following geological picture of the Pinnacles prospect has been collated from geological examination of costeans, access tracks and diamond drill core.

Lithologies underlying the prospect can be broadly divided into an eastern volcanic sequence (Mt. Read Volcanics) and a western sedimentary sequence (Dundas Group) (Fig. 2).

From the Pinnacles north to Mt. Pearse, mapping indicates a major

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Fig. 1 - Location Plan, EL5/63, Part 4.
Fig. 2 - Pinnacles Grid - Geology.

The contact with the sediments to the west is conformable and a thick shale unit within the Mt. Read Volcanics merges with these sediments on the west side of the Que Syncline (Fig. 3).

MINERALISATION

Massive base metal sulphides were exposed in four localities on surface as indicated in Fig. 2 at points A, B, C, and D. Mineralisation consists of fine grained sphalerite with variable amounts of galena, chalcopyrite, pyrite and barite. Grades at surface range from 0.12% to 1.18% Cu, 4% to 15% Pb, 4% to 29% Zn, 40 to 240 gm per tonne Ag and 8 to 40 gm per tonne Au. The mineralisation at the south trench (A) on line 22S, averaged 8% Zn; 3.7% Pb; 0.67% Cu over 7.6m. This formed the basis for an orientation survey of the base metal content in the soils.

CLIMATE, PHYSIOGRAPHY

VEGETATION, SOILS

The licence area has a cool, wet, temperate climate with rainfall in

excess of 300 cm per annum, and mean January and July temperatures of 12°C and 4°C respectively.

Topography over the licence area is characterised by steep ridges and deeply incised valleys, except where modified by Pleistocene glaciation. Altitudes range from near sea level to 900 m. Valleys, infilled by glacial debris, are often swampy. Although the average rainfall is high, the smaller creeks tend to dry up if precipitation is not sustained.

Vegetation on the lease varies in response to the rapidly changing conditions of aspect, relief and soil type. Fig. 4 illustrates a typical vegetational section across the lease.

The pedological environment at the Pinnacles prospect is characterised by highly leached acidic organic soils (pH 3.4 to 4.8), developed either on glacial overburden (Fig. 5) or directly on bedrock (Fig. 6).

---

**EXPLORATION TECHNIQUES**

**STREAM SEDIMENT GEOCHEMISTRY**

The lease area was stream sampled at a density of eight samples per km² during a regional mapping programme. Active stream sediment samples taken were dried and sieved to -80# before being despatched to the laboratory for Cu, Pb, Zn analyses. The elements were determined by atomic absorption spectrophotometry (A.A.S.) after a hot HClO₄ digestion. Figure 7 shows the Cu, Pb and Zn content of stream sediments over the Pinnacles area. Peak values for Cu, Pb and Zn were 170 ppm, 5300 ppm and 980 ppm respectively reflecting mineralisation at Thomas’ Tunnel (occurrence D).

**SOIL GEOCHEMISTRY**

Follow up of anomalous geochemistry by detailed bank/stream sampling and conventional soil geochemistry generally outlines anomalous areas. However, the latter technique has not been a completely reliable aid to prospecting in areas underlain by highly leached glacial soils.

Elsewhere in the world, in areas of transported glacial overburden, drilling is normally carried out to sample basal till or bedrock. In this way, geological and geochemical maps can be produced and an orebody located by the detection of either a primary or secondary dispersion halo. However, on the Comstaff licences, these methods are not possible due to the problem of access which is governed by the luxuriant vegetation and relief.

---

Fig. 4 - Landscape profile across EL 5/63

<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (cm)</th>
<th>LOG</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>5</td>
<td></td>
<td>Dark black decaying organic matter</td>
</tr>
<tr>
<td>A1</td>
<td>10</td>
<td></td>
<td>Dark block high organic content pH 3.5</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td>Greyblock fairly high organic content, some bleeding up to pea size rock fragments</td>
</tr>
<tr>
<td>A2</td>
<td>35</td>
<td></td>
<td>White bleached zone with bleached rock fragments. Fragments up to 2 cms. in size. At depth pink brown in colour and more clay present, pH 3.5 to 4.5</td>
</tr>
<tr>
<td>B1</td>
<td>65</td>
<td></td>
<td>At base red brown with thin iron pan development</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td></td>
<td>Glacial till with reddish streaking and banding of iron oxides</td>
</tr>
<tr>
<td>B2</td>
<td>110</td>
<td></td>
<td>Glacial Till</td>
</tr>
<tr>
<td></td>
<td>115</td>
<td></td>
<td>Unweathered rock</td>
</tr>
</tbody>
</table>

Fig. 5 - Type A organic soil developed on glacial overburden.
Figure 6 - Type B organic soil developed on bedrock.

Figure 8 illustrates the behaviour of Cu, Pb, Zn and F in various horizons of an analogous soil to type A (Fig. 5). The profile is developed on transported glacial overburden of 3 to 6 m in depth overlying mineralised limestone (Farrell, 1972). In this example groundwater and the heath type of vegetation did not provide a reasonable mechanism to cause the observed secondary dispersion pattern. The main points to note are:

1. The high metal content in the A° to A² horizons.
2. The A³ horizon has been leached of metals.
3. The small accumulation of metals in the basal portion of the B horizon.
4. The general static metal distribution in that portion of the sampled C horizon.
ORIENTATION SURVEY

An orientation survey was carried out close to mineralisation exposed in an old trench on line 22S (mineral occurrence A in Fig. 2). Samples were collected every 3 cm to bedrock, sieved to -80 mesh and analysed for Cu, Pb, Zn, Hg and Ba. Cu, Pb, Zn, Ba were determined by A.A.S. while Hg was determined by the dry absorption technique. With the exception of Ba both methods followed a hot HNO₃ - HClO₄ digestion. Ba determinations were carried out after a triacid (HNO₃ - HClO₄ - H₃PO₄) digestion. Eh, pH and conductivity measurements were also carried out on slurries of the -80# material.

Figure 9 summarises the response of the various parameters measured in the contrasting A° and C horizons.

The behaviour of metals in the A° and C horizons over mineralisation obviously differs. Table 1 outlines contrasts obtained over mineralisation with respect to background for the two horizons.

Fig. 9 - Orientation survey Line 22 South.
Metallic ions released during weathering of the sulphides are transported to the surface organic horizons via an interaction of mechanisms such as the biogeochemical cycle, fluctuating groundwater or perhaps by ionic diffusion under the influence of electro-potentials (Govett, 1973). Organo-metallic compounds formed by chelation in the A° horizon appear to resist solution and downward leaching by the humic acids, thereby giving rise to an anomaly. The differing behaviour of Ba, and to a lesser extent Hg, is perhaps consistent with their more electropositive character. The spot Pb anomaly on the C horizon is probably due to the formation of Pb SO₄ under the extreme acid conditions.

This initial orientation survey led to further trial sampling of the A° horizon at 20 m intervals on two lines across the prospect, and revealed excellent surface correlation of anomalous geochemistry (4700 ppm Cu, 6000 ppm Pb, 4.7% Zn) with known mineralisation exposed at Thomas' Tunnel (D in Fig. 2).

The analytical data was processed by an inhouse computer programme VSTAT. A univariate population analysis was then carried out on the processed data by the use of cumulative probability plots. Table 2 summarises the geochemical statistics.

The results are shown plotted in Figs. 10 to 14. Background values for Cu, Pb, Zn, Ba and Hg were established at 5 ppm, 18 ppm, 24 ppm, 225 ppm and 95 ppb respectively. Although not continuous there are well defined base metal anomalies. These in part reflect known mineralisation at points A and D (Thomas' Tunnel). The unexplained anomalies can be grouped into three convenient zones.

Table 1

<table>
<thead>
<tr>
<th>Element</th>
<th>A°</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>15</td>
<td>1-2</td>
</tr>
<tr>
<td>Pb</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>Zn</td>
<td>100</td>
<td>1-2</td>
</tr>
<tr>
<td>Ba</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>Hg</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>RANGE Low</th>
<th>High</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
<th>THRESHOLDS FOR COMMUNITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu(ppm)</td>
<td>0</td>
<td>6,000</td>
<td>11.1</td>
<td>194.4</td>
<td>5,15,60</td>
</tr>
<tr>
<td>Pb(ppm)</td>
<td>4</td>
<td>10,000</td>
<td>45.3</td>
<td>339.6</td>
<td>18,52,200</td>
</tr>
<tr>
<td>Zn(ppm)</td>
<td>2</td>
<td>10,000</td>
<td>36.7</td>
<td>329.4</td>
<td>24,50,215</td>
</tr>
<tr>
<td>Ba(ppm)</td>
<td>0</td>
<td>3,500</td>
<td>170.2</td>
<td>172.3</td>
<td>225,590</td>
</tr>
<tr>
<td>Hg(ppb)</td>
<td>0</td>
<td>10,000</td>
<td>83.6</td>
<td>360.3</td>
<td>95,185,295</td>
</tr>
</tbody>
</table>
Fig. 10 - Pinnacles Grid - Copper content in A°.

Fig. 11 - Pinnacles Grid - Lead content in A°.

those associated with the western access road (16S, 18S), eastern access road (14S, 17S) and the eastern grid boundary (19S, 21S). A costeaming programme was planned to investigate the cause of these remaining anomalies.

**Western access road**

The 16S costean west of Thomas' Tunnel (D) exposed a 1 m wide zone of fine grained massive sphalerite within acid volcanics at (C). The 18S costean was excavated to test the discontinuous nature of the anomalies in this general zone. It exposed black shales and boulders of massive fine grained sphalerite overlain by varved clays at point (B). The source of the boulders is unknown.

**Eastern access road**

Costeans across the eastern access road anomalies (14S and 17S) exposed a five metre wide band of highly weathered ferruginous volcanics. This horizon has not been examined in depth although hand held auger drilling into the weathered material showed an increase in metal content with depth. The following assay results show this trend. Cu 4 - 250 ppm; Pb 24 - 4000 ppm; Zn 38 - 900 ppm.

**Eastern Boundary**

The eastern boundary anomalies costeaning (19S and 21S) exposed chloritic dacite with high background values.

The geochemical data was also subjected to an R-mode factor analysis (BMDO3M programme). The primary aim of the exercise was to see if there was an overall simple interpretable factor that may reflect or indicate mineralisation. Table 3 summarises the salient points from the R-mode factor analysis. Factor 1, a Cu, Pb, Zn, Hg (Ba) association dominates the matrix, accounting for 84.8% of the cumulative variance. The plot of Factor 1 scores (Fig. 15) summarises the individual elemental plots and confirms the anomalies discussed previously.

**GEOPHYSICS**

A gradient array I.P. survey was completed over the Pinnacles prospect prior to the orientation soil survey.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>R-mode factor analytical data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eigen values</strong></td>
<td>4.241 0.53169 0.15969 0.05049 0.0169</td>
</tr>
<tr>
<td>Cumulative proportion of variance</td>
<td>84.82 95.45 98.65 99.66 99.9</td>
</tr>
<tr>
<td><strong>R-mode varimax rotated factor matrix</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Element</strong></td>
<td><strong>Factor 1</strong></td>
</tr>
<tr>
<td>Cu</td>
<td>0.98572*</td>
</tr>
<tr>
<td>Pb</td>
<td>0.96606*</td>
</tr>
<tr>
<td>Zn</td>
<td>0.98387*</td>
</tr>
<tr>
<td>Ba</td>
<td>0.55166</td>
</tr>
<tr>
<td>Hg</td>
<td>0.92198*</td>
</tr>
</tbody>
</table>

Traverses were made on alternate lines and readings taken every 20m.

From the resistivity measurements a broad zone of low resistivity readings occurs along the western part of the grid, northwards from 22S (Fig. 16). This is equated with the sediments of the Dundas Group west of the Mt. Read Volcanics. A second zone in the middle of the grid may represent an intra-volcanic shale band at depth. Other low resistivity readings may represent bands of sericite schist. A zone of high resistivity at the south west corner of the grid may represent acid volcanics in the core of the Que Syncline.

The highest percentage frequency effect occurs in the south west of the grid, associated with this high resistivity (Fig. 17).

**DIAMOND DRILLING**

Seven boreholes were drilled at the Pinnacles Prospect. Three of these were drilled prior to the geochemical survey to test geophysical targets which apparently were related to known mineralisation at Thomas' Tunnel (mineral occurrence D) and the South Trench (mineral occurrence A).

Pervasive low grade mineralisation (+1% Zn) within black shales was intersected in borehole CP9. The other two boreholes did not intersect significant mineralisation.

The remaining four boreholes were planned to examine the geochemical anomalies west of Thomas' Tunnel. Pervasive low grade mineralisation (+1% Zn) was again intersected in sediments in each of these boreholes.

This mineralisation may represent the source of the remnants of the roots of the observed high grade mineralisation in the axial plane of the Que Syncline.

**CONCLUSIONS**

The base metal content of the A horizon of the highly acidic organic soils overlying Mt. Read Volcanics or glacial moraine, within EL 5/63 part 4, appears to adequately reflect mineralisation or alteration in the underlying rocks. This occurs even when ground waters have removed base metals from a leached zone immediately below the humic soils.

Mechanisms or perhaps an interaction of these mechanisms have been previously cited to explain the above results. These are through the biogeochemical cycle (Hawkes and Webb, 1962), via fluctuating groundwater or through an electrochemical mechanism of dispersion (Govett, 1973; Bolviken and Logn, 1974).

Secondary dispersion via the first two mechanisms does take place on the licence. However observation made in costeans and along access tracks, especially where morainic material is up to 15 m thick and above the water table, reveal that the various types of vegetation have a shallow lateral root system which does not appear to penetrate the leached zone and underlying rock. Therefore from this observation...
coupled with a seemingly classic Eh, pH
and conductivity response in the orienta-
tion survey (Fig. 9) and experience else-
where (Fig. 8) the electrochemical mech-
amism may play a significant role in the
observed secondary dispersion pattern of
the base metals.

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The management of Australian Anglo
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CONCEPTUAL MODELS IN EXPLORATION GEOCHEMISTRY

Australia

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(Received November 22, 1979)

ABSTRACT


This is the fourth in a series of “Conceptual Models” volumes reviewing geochemical exploration practice in different areas of the world. This volume provides an overview of geochemical exploration for base and precious metals in Australia. The subaerial weathering history of most of the continent probably dates from the Permian including, broadly, an early period of widespread lateritization followed by a late trend to aridity. This gave rise to the formation of a deep weathering profile which may subsequently have been partially or wholly eroded. It differs markedly, therefore, from the terrains described in previous volumes in the series. Consequently, emphasis has been placed throughout on the long weathering history, and the influence it has had on element dispersion and on the surface expression of mineralization in a wide range of sample media — ironstones, gossans, weathered bedrock, soils, transported overburden, stream sediments, waters, plants and atmospheres. The nature, use and geochemical characteristics, including multi-element data where possible, are described for each of these sample media.

A set of eight idealized models has been derived using data from fifty-two case histories and previously published literature. The models are based on generalized landform settings, classified hierarchically according to:
   (1) degree of preservation of the deep weathering profile, i.e. complete, partly stripped or absent;
   (2) relief, i.e. low, moderate or high.
A further model describes the landform situation within which calcrete uranium deposits are formed.

The case histories present, for the most part, previously unpublished data and include examples not only of successful exploration but also situations where surface anomalies are spurious.
The construction of the Idealized Models (Section D) and the compilation of the Case Histories (Section E) was the responsibility of the following:

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C.R.M. BUTT and R.E. SMITH
(Editors)
Location. The Langdon Prospect is located 50 km west-northwest of Bundaberg, Qld. at latitude 24°48'S, longitude 151°52'E.

Physical features. The prospect is situated in dissected hilly country 200–250 m above sea level. Drainage is controlled by regional NNW-trending faults and jointing to give a rectilinear pattern. The main geochemical anomaly investigated on the prospect lies on a topographic high locally called “The Pinnacle”. The depth of weathering is about 15 m. The area is classified as having solodic soils. However, extensive scree and soil creep have been generated by the steep slopes and complicate the pedology. Uncleared areas are vegetated by rain forest. The climate is characteristically sub-tropical with distinctive summer cyclonic rainfall. Mean maximum and minimum monthly temperatures are 29° and 21°C in January and 21° and 9°C in July. Rainfall averages 1200 mm p.a.

Geological setting. The Langdon Prospect lies in the pre-Permian Curtis Island Group. This is a N-striking, E-dipping and E-facing sequence of probable marine, shallow water sedimentary rocks containing thin discontinuous to massive rhyolite-quartz trachyte flows and coarse agglomerates (Fig. 109). It has a central lens of mineralized rhyolite, 350 m X 1000 m in outcrop, which forms The Pinnacle. The prominent oval-shaped photo-expression of The Pinnacle and associated intersecting lineaments gives it a plug-like appearance but mapping suggests the central rhyolite body is a normal sequence of volcanic flows and tuffaceous units which have been hydrothermally altered and mineralized.

Mineralization. Low grade Ag-Pb-Zn mineralization, peaking at 42 ppm Ag, 2% Pb and 3% Zn, is present in the rhyolite body. It consists of Fe-rich sphalerite, marcasite-pyrite aggregates after pyrrhotite, subordinate galena and arsenopyrite, with traces of chalcopyrite and tetrahedrite-tennantite. The total sulphide content attains 5–7% in places. The mineralization occurs as: (a) random disseminations in sericitized-silicified volcanic units; (b) discontinuous veins, with carbonate interspersed with sericite-quartz or, rarely, intersecting sericite veins; (c) selective replacement, with carbonate, of feldspar phenocrysts and feldspar crystal fragments.

Weathered bedrock. The mineralization has a subtle expression, appearing as: (a) dispersed clots of dark red-brown limonite and jarosite replacing pyrite in euhedral pseudomorphs or irregular aggregates, giving the rhyolite a rusty speckled appearance; (b) multiple intersecting fractures containing coatings of a dark reddish-brown limonite. The fractures are of variable thickness none of which appears dominant in either intensity or frequency.

From drilling, a very significant increase in Zn accompanied by a somewhat erratic increase in Ag, Cu and Pb occurs below the oxidized zone at 11–18 m. A minor supergene zone of over 1 m is apparent here in some drill holes.
Soils. Soils were sampled over a 2.8 km² area on a 50 m X 150 m grid locally infilled to 50 m X 50 m. The minus 840-µm fraction from the C horizon at 1 m depth was ground to 175 µm and analyzed for Ag, Cu, Pb and Zn after HClO₄ digestion. A Ag-Pb anomaly, 250 m X 600 m, is outlined by the 10 ppm Ag and 2000 ppm Pb isopleths over the rhyolite body (Fig. 110). Peripheral to this pattern, and at a lower elevation, Zn anomalies

Fig. 109. Outcrop geology and distributions of Ag, Pb and Zn shown by stream sediment sampling, Langdon, Queensland.
Fig. 110. Distribution of Ag, Cu, Pb and Zn shown by minus 840-μm fraction of soil C horizon, Langdon.

Fig. 111. Multi-element geochemistry of minus 840-μm fraction of soil C horizon, line 5000N, Langdon.
are outlined by the 1000 ppm isopleth. The Cu distribution differs, being coincident both with the anomalous Ag-Pb and the western anomalous Zn patterns. These patterns, which are reflected in the stream sediment data (see below), illustrate the greater mobility of Zn and, in part, Cu in comparison with Ag and Pb. The Zn distribution partly reflects wallrock enrichment, but the downslope situation of the Zn anomaly suggests it also to be partly hydromorphic in origin.

A multi-element spectrographic scan for Au, Ni, Co, Cd, Bi, Fe, Mn, Ag, Sb, Ba, Cu, Pb and Zn on three lines of soil samples over the central rhyolite body again suggests significant geochemical zoning in the secondary environment. This is shown by results for line 5000N (Fig. 111) where the central Pb-Ag-As-Au-Cu anomaly is flanked by a Zn-Cd anomaly. Manganese occurs with Zn-Cu on the western side and Ba-Ni-Co maxima occur east of the eastern Zn anomaly. Drilling indicates an excellent correlation between minor elements in soil and fresh rock beneath the central anomaly.

**Stream sediments.** The prospect was discovered by a detailed stream sediment survey in which active sediments were sampled at 250 m intervals. The

| TABLE LIV . Summary table, Langdon Prospect, Queensland |
|----------------|----------------|----------------|----------------|----------------|
|                | Ag  | Cu  | Pb  | Zn  | Mn  | As  |
| PRIMARY MINERALIZATION |     |     |     |     |     |     |
| Disseminated (mean grade) | 7   | 40  | 1400| 7500|     |     |
| Range           | to 40| to 100| to 2%| to 3%| 0.2-1%| 400-800|
| SUPergene MINERALIZATION |     |     |     |     |     |     |
| Disseminated    | 35  | 580 | 3500| 75000|     |     |
| GOSSANS         | 1-31| 10-50|1150-6000| 60-800|     |     |
| WEATHERED BEDROCK |     |     |     |     |     |     |
| Mean            | 7   | 39  | 2440| 219 |     |     |
| SOILS (C 'HORIZON') |     |     |     |     |     |     |
| Mean Background | 5   | 25  | 500 | 250 | 7200| 710 |
| Threshold       | 10  | 50  | 2000| 1000|     |     |
| Peak            | 17  | 100 | 7000| 6000| 1%  | 4100|
| STREAM SEDIMENTS |     |     |     |     |     |     |
| Background      | 2.5 | 500 | 500 |     |     |     |
| Threshold       | 10  | 1500| 1000|     |     |     |
| Peak            | 47  | 7750| 3700|     |     |     |
| Au(ppb)         | Ba  | Bi  | Cd  | Co  | Ni  | Sb  |
| (Continued)     |     |     |     |     |     |     |
| PRIMARY MINERALIZATION | 545 | 3-20| 50-100| <5-20| <5-20| 30-70|
| Disseminated (Range) |     |     |     |     |     |     |
| SOILS (C 'HORIZON') |     |     |     |     |     |     |
| Mean Background | ?100| ?   | ?   | ?   | <5-15| <5-30|
| Peak            | 730 | 800 | 20  | 3   | <5-15| 710  |

Data in ppm unless marked otherwise.
natural minus 175-μm fraction was analyzed for Ag, Cu, Pb and Zn by HNO₃/HClO₄ digestion and AAS (Fig. 109). There are strong coincidental anomalies outlined by the 10 ppm Ag and 2000 ppm Pb isopleths over the central rhyolite body. Zinc is low over the rhyolite, with patterns of >1000 ppm Zn occurring peripherally to it.

Langdon exemplifies landform situation F.

50. CHEDDA CLIFFS Pb-Zn-Cu MINERALIZATION, LENNARD SHELF, W.A.

R.J. Fletcher (Carpentaria Exploration Company Pty. Ltd.)

Location. Chedda Cliffs is approximately 100 km east of Derby at latitude 17°12'S, longitude 124°37'E.

Physical features. Topography is subdued, with limestones forming a karst plateau approximately 100 m above the surrounding black soil plains. The limestone has better than 95% outcrop and soil development is restricted to minor amounts of insoluble residues which accumulate in hollows and in the bottoms of clints and grikes. This residual soil supports a luxuriant growth of spinifex but trees are rare and usually restricted to fault zones. The black soil plains are well grassed and treeless. Streams are poorly developed and choked with calcareous tufa. They mostly flow underground within the plateau and emerge as springs at the edge of the limestone, where they have deposited a layer of calcrete on top of the black soil. The area has a tropical climate with hot wet summers and warm dry winters.

Geological setting. The mineralization occurs in Devonian limestones which form part of a fringing reef complex (Fig. 112). The reef structure is well preserved with lagoonal back reef, wave resistant reef, fore-reef talus slope and inter-reef facies clearly recognizable. Reef development was influenced by contemporaneous fault movements.

Mineralization. The Pb-Zn-Cu mineralization is of the Mississippi Valley type in dolomitized limestone and is localized at the intersection of weakly mineralized faults with a palaeokarst horizon formed on top of the reef complex (Fig. 113). Galena, marcasite, pyrite, sphalerite and chalcopyrite occur as irregular masses and disseminations in a matrix of soft, black, organic rich mud, which fills caves and caverns along the palaeokarst horizon. Grades of up to 8.6% Pb and 4.0% Zn over widths of 2—10 m were obtained by drilling but the indicated reserves are only a few thousand tonnes. This lens of massive mineralization is surrounded by a broad halo of weakly disseminated mineralization along joints and fractures in dolomitized limestone.

Gossans. The mineralization outcrops as a small gossan, approximately 20 m X 30 m in extent, composed of cellular limonite (after pyrite and marcasite), cerussite, hydrozincite and malachite. Oxidation extends to a depth of 15 m but residual cores of galena are found in some of the gossan boulders at the surface. The gossan is strongly anomalous in Cu, Pb, Zn, Ag,
Location. The Pinnacles Prospect is 75 km south of Burnie, Tasmania, at latitude 41°40'S, longitude 145°30'E.

Physical features. The prospect is situated on the lower slopes of a deeply incised valley which has been modified by Pleistocene glaciation. The surrounding ridges rise to 900 m above sea level. The area is characterized by the development of highly leached, acid (pH 3.4–4.8), organic soils on glacial moraine, colluvium or bedrock. Vegetation varies in response to changing conditions of aspect, relief and soil type. Button Grass swamps are found on glacial moraine in the valley floor. Scrub and rain forest are present on the valley slopes. A cool wet temperate climate prevails. The annual rainfall of 2300 mm falls mainly in the winter months. Mean daily maximum and minimum temperatures range from 7° and 1°C in July to 18° and 7°C in January.

Geological setting. The prospect is underlain by Cambrian rocks, which can be broadly divided into an eastern volcanic sequence (Mt. Read Volcanics) thrust over a western sedimentary sequence (Dundas Group) (Fig. 77). Subsequent deformation has produced isoclinal folding and overturning with dips of approximately 70° to the east. Much of the geology on the valley floor and hillside is obscured by Pleistocene fluvio-glacial deposits and Recent colluvium, respectively.

Mineralization. Drilling has indicated a zone containing more than 3% Zn over a strike length of 600 m, associated with the contact of acid volcanics and an interbedded black shale horizon. Massive base metal sulphides up to 7 m wide are exposed in excavations D (Fig. 77) and access tracks. Mineralization consists of fine grained sphalerite, with variable amounts of galena, chalcopyrite, pyrite and barite. Grades in fresh sulphides at surface range from 0.12% to 1.18% Cu, 4% to 15% Pb, 4% to 29% Zn, 40 to 240 g/t Ag and 8 to 40 g/t Au. Sericitization and silicification accompany the mineralization.

Gossans. Gossan development is minimal as fresh sulphides occur at or near the surface.

Leached colluvial soils. In an orientation traverse, the minus 175-μm fraction of samples from the soil profile (Ao to C horizons) were analyzed by AAS for Cu, Pb and Zn (HNO₃/HClO₄ digestion) and Ba (HNO₃/HClO₄/H₃PO₄ digestion). Mercury was determined by flameless AAS following acid digestion and reduction of hydride to metallic mercury. The results (Fig. 78) illustrate contrasting behaviour in the Ao and C soil horizons, with Cu, Pb and Zn being concentrated in the Ao horizon, presumably being complexed as organo-metallic compounds and thereby resisting solution and downward leaching. The behaviour of Ba and Hg differs. Subsequently, the Ao horizon over the whole prospect was sampled on a 20 m X 100 m grid.
Fig. 77. Geology and soil geochemistry, Pinnacles Prospect, Tas., illustrating the distribution of Cu, Pb, Zn and Hg shown by sampling the Ao soil horizon, and a plot of Factor 1 from R-mode factor analysis on soils data.
Discontinuous, but well-defined, base metal anomalies occur in three groups which subsequent costeasting and drilling showed to reflect, in part, mineralization. Background and threshold levels are shown on Table XXXVI. R-mode factor analysis showed that a Cu-Pb-Zn-Hg factor was dominant, accounting for 85% of the cumulative variance. A plot of scores for this factor summarized the individual element plots and confirms the three zones of interest (Fig. 77). In many parts of the area, leaching is severe and extends into bedrock. Attempts to sample the B (or C) horizons in such cases have produced variable and uninterpretable results. The Ao horizon, however, appears to be a constant sampling medium with excellent element response and contrast.

Stream sediments. Active stream sediments were collected at a density of 8 samples/km² and the minus 175-μm fraction analyzed for Cu, Pb and Zn by HClO₄ digestion and AAS. The zone of interest was outlined, though the response may be due in part to contamination. Threshold data are tabulated on Table XXXVI.

Pinnacles exemplifies model I3.
TABLE XXXVI. Summary table, Pinnacles Cu-Pb-Zn prospect

<table>
<thead>
<tr>
<th></th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
<th>Ag (g/t)</th>
<th>Au (g/t)</th>
<th>Hg (ppb)</th>
<th>Ba</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRIMARY MINERALIZATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Massive</td>
<td>0.12-1.18%</td>
<td>4-15%</td>
<td>4-29%</td>
<td>40-240</td>
<td>8-40</td>
<td>100-8000</td>
<td>0.1-10%</td>
</tr>
<tr>
<td>SOILS (Ao Horizon)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean background</td>
<td>5</td>
<td>18</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td>95</td>
</tr>
<tr>
<td>Range</td>
<td>0-6000</td>
<td>4-10000</td>
<td>2-10000</td>
<td></td>
<td>185</td>
<td>590</td>
<td>225</td>
</tr>
<tr>
<td>STREAM SEDIMENTS (minus 175μm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threshold</td>
<td>6</td>
<td>75</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>2-8</td>
<td>14-134</td>
<td>14-120</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data in ppm unless marked otherwise.

32. QUE RIVER Zn-Pb DEPOSIT, DUNDAS TROUGH, TAS.
E.H. Skey and C.H. Young (Aberfoyle Exploration Pty. Ltd.)

Location. The Que River Zn-Pb deposit is located 25 km northeast of Rosebery, northwestern Tasmania, latitude 41°36'S, longitude 145°21'E.

Physical features. The deposit is at an altitude of 700 m in a low saddle near the edge of a gently west sloping plateau, at the watershed between the Southwell and Que Rivers.Locally, silicified footwall volcanics form a small hill (720 m) on the eastern side of the swampy ground overlying the less resistant massive sulphide horizons.

Quaternary glaciation appears to have removed most oxidized and supergene mineralization, and primary sulphides extend to near surface. Over mineralized volcanics, the soil profile consists of an A horizon of black to dark brown humus, 5-45 cm thick, overlying 0.5-3 m of ironstained or partly gossanous grey clays, underlain by ironstained grey saprolitic pyroclastics to 10 m or more. Over silicified rocks, fresh sulphides occur just below the humus layer. Over barren dacite and andesites, sands or clays underlie the humus, to a depth of 20 m.

The climate is cool with occasional snow falls and rainfall is about 2500 mm p.a. The water table is at approximately 10 m. Vegetation is dense rainforest characterized by myrtle (Nothofagus cunninghamii) and includes tree ferns (Alsophylla australis) in the understorey. Dense horizontal scrub (Anodopetalum biglandulosum) is commonly developed over the more swampy ground. Outcrop is generally less than 1% resulting from a cover of forest-derived humus about 1 m thick.
APPENDIX II

Skewness and kurtosis
Skewness \( A = \frac{M_3}{S^3} \) where \( M_3 \) = Third moment  
\( S \) = Standard deviation  

and \( \sum_{i=1}^{N} \frac{(X_i - \bar{X})^3}{N} \)

For a normal distribution curve \( A = 0 \)

Kurtosis \( E = \frac{M_4}{S^4} - 3 \) where \( M_4 \) = Fourth moment  
\( S \) = Standard deviation  

and \( \sum_{i=1}^{N} \frac{(X_i - \bar{X})^4}{N} \)

For a normal distribution curve \( E = 0 \) because the ratio is equal to \( 3 \).

To determine the conformity of a given distribution to the normal law, obtain estimates of \( A \) and \( E \). In view of the possible error involved in such estimates which depend primarily on the number of samples it should be determined whether deviations from zero for \( A \) and \( E \) are of a chance nature or are significant. The deviation of these calculated parameters in the case of a normal distribution must not exceed their tripled standard deviation.

i.e. \( \frac{A}{S_A} \leq 3 \quad \frac{E}{S_E} \leq 3 \quad (1) \)

where \( S_A = (6/N)^{1/2} \); \( S_E = 2(6/N)^{1/2} \)

If the conditions in equation (1) are satisfied Skewness and Kurtosis are in insignificant and the distribution obeys the normal law.

Similarly to check the conformity of a distribution to a log normal law \( A \) and \( E \) are calculated by taking the log of the elemental values.
APPENDIX III

Field analytical methods for Cu, Ni, Zn and THM
1. THE DETERMINATION OF "TOTAL" COPPER, NICKEL AND ZINC

1.1 Digestion

1. Fill the 250 mgm measuring scoop with -0.175 mm material. Compact and level the sediment in the scoop. Place sediment in open test tube (16 x 150 mm) with the aid of the small glass funnel provided.

2. Add 2 ml of 25% HNO3 to the tube. Place tube in the metal digestion block. Place digestion block on the primus stove. Regulate the temperature so that the acid bubbles gently in the tubes for 1 hour. Spitting of the acid must be avoided.

3. Dilute to 10 ml with demetallized water (i.e. top up to the 10 ml mark on test tube), mix and allow to settle for 1 hour.

1.2 Analysis

Copper

1. Transfer 2 ml of the clear solution to a screw cap tube (16 x 150 mm) add 5 ml of the copper buffer solution, followed by 1 ml of biquinoline solution.

2. Replace the screw cap and shake the tube and contents vigorously for about 2 minutes.

3. Allow the phases to separate and compare the colour of the organic phase with the colour of standards prepared as described below.

4. If a colour develops in the organic phase that is outside the range of the standards, take a smaller aliquot of the digestion solution (1.0 ml) at stage 1. and repeat the steps described above.

...2.
Nickel

1. Stages 1. to 4. are repeated using a new clean screw-cap tube, but in stage 1., 5 ml of nickel buffer solution is added to the 2ml of clear digestion solution followed by 1ml of furildioxime.

Zinc

1. Stages 1. to 4. are repeated using a new clean tube with a cork, but in stage 1., 5ml of zinc buffer solution is added to the 2 ml of clear digestion solution followed by 5 ml of .001% dithizone.

1.3 Calculation of Copper, Nickel and Zinc Concentrations

This is calculated from:

\[
\text{Concentration (ppm)} = \frac{\text{volume of sample solution (ml)}}{\text{weight of sample (gm)}} \times \frac{\text{ugm of matching standard}}{\text{ml of digestion solution taken}}
\]

1.4 Copper, Nickel and Zinc Standards

While the digestion is proceeding standards should be made up.

Copper Standards

1. To 10 screw-top tubes (16 x 150mm) add respectively, 0, 0.25, 0.5, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.50 ml of the standard copper solution. (Containing 4 ugm Cu/ml).

2. Add copper buffer solution to the tubes to the 10 ml mark.

3. Add 2 ml of biquinoline solution to each tube and shake vigorously for 2 minutes. A rack of 10 copper standards (0, 1 ugm, 2 ugm, 3 ugm, 4 ugm, 5 ugm, 6 ugm, 7 ugm, 8 ugm, 10 ugm) has been produced.
3.

**Nickel Standards**

1. To 10 screw-cap tubes add respectively 0, 0.25, 0.5, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.50 ml of the standard nickel solution. (Containing 4 ugm Ni/ml).

2. Add nickel buffer solution to the tubes to the 10 ml mark.

3. Add 1 ml of furilidioxime solution to each tube and shake vigorously for 2 minutes. A rack of 10 nickel standards of the same concentration as Cu has been produced.

**Zinc Standards**

1. To 10 cork capped tubes (16 x 150mm) add respectively 0, 0.25, 0.5, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.50 ml of standard zinc solution. (Containing 4 ugm Zn/ml).

2. Add zinc buffer solution to the tubes to the 7 ml mark.

3. Add 5 ml of .001% dithizone solution to each tube, cork and shake vigorously for 2 minutes. A rack of 10 zinc standards has been produced.

2. **DETERMINATION OF COLD EXTRACTABLE COPPER, NICKEL AND ZINC**

2.1 **Elemental Determinations**

A. **Cold Extractable Copper**

1. Fill the 250 mgm measuring scoop with the desired sample material. (Usually -0.175 mm sample material). Compact and level the material in the scoop. Place sample material into a screw cap test tube (16 x 150 mm).

2. Add 2 ml of 2.5% HNO₃ to the tube and swirl for 10 seconds.

3. Top up to 5 ml with copper buffer solution.
4. Add 1 ml of biquinoline solution.

5. Cap tube and shake vigorously for 1 minute.

6. Allow the phases to separate and compare the pink colour with a standard copper series.

7. Calculate \( cx \text{ Cu ppm} \):

\[
 cx \text{ Cu ppm} = \frac{\text{ugm of matching standard}}{\text{weight of sample (gm)}} \times \frac{\text{volume of sample solution (m/g)}}{\text{aliquot (ml)}} 
\]

\[
 = \frac{\text{ugm of matching standard}}{.250} \times \frac{5}{5} 
\]

\[ cx \text{ Cu ppm} = \text{ugm of matching standard} \times 4 \]

Analytical Range = 0.8 - 40 ppm.

8. If any samples are offscale repeat processes 1. to 3. then take 2 mls of the solution and add to a new tube. Continue steps 3. to 6. Calculate \( cx \text{ Cu ppm} \) by the above formula.

\[ cx \text{ Cu ppm} = \text{ugm of matching standard} \times 20 \]

Analytical range is now increased to 200 ppm.

B. Cold Extractable Nickel

1. Stages 1. to 8. above are repeated using a new clean screw-cap tube but in stage 3. nickel buffer solution is added, in stage 4., 1 ml of \( \varphi \) furildioxime solution is added.

2. Calculate \( cx \text{ Ni ppm} \) as above 7. to 8.

Analytical range 0.8 - 40 ppm, but can be increased to 200 ppm.

C. Cold Extractable Zinc

1. Fill the 250 mgm scoop with -0.175mm sample material. Compact and
level the material in the scoop, then place sample into a test tube (16 x 150mm).

2. Add 5 ml of zinc buffer solution.

3. Add 2 ml of .001% dithizone solution.

4. Cork the tube, shake vigorously for 1 minute then allow the dithizone layer to separate.

5. The upper layer will be developed between green and red. The test is over if the dithizone is green, blue green, blue grey. These 3 colours should be recorded as 0 g, 1 g, 2 g. For the sample weight taken it is equivalent to 0 ppm, 1.6 ppm, 3.2 ppm.

6. If the colour is purple, red, pink, proceed as follows:
   Add measured amounts of dithizone. Mix gently but do not shake for a minute. Observe the colour, if not blue-grey (2 ugm) add further measured amount of dithizone until this colour is obtained. Record the total volume of dithizone.

7. In the field it is sufficient to record and map the dithizone solution added above 2 ml as the amount of zinc reacting. Analytical range 2 to 20 ml.

   If ppm are required:

   \[
   \text{Zn} \text{(ppm)} = \frac{\text{ugm for Zn (2 ugm for blue)}}{\text{weight of sample (gm)}} \times \frac{\text{number of ml dithizone added}}{\text{number of ml used in standard}}
   \]

   \[
   = 8 \times \frac{\text{number of ml of dithizone added}}{\text{number of ml of dithizone added}}
   \]

   \[
   = 1.6 \times \frac{\text{number of ml of dithizone added}}{5}
   \]

   Analytical range 1.6 – 32 ppm.

8. If the zinc content is offscale repeat steps 1. to 4. but delete 3.

...6.
6.

Take 1 ml when the solution clears, add to a clean test tube, top to 5 ml mark with buffer repeat steps 3. to 6. If mapping in ml of dithizone, new value = 20+5V.

or \( cx \text{ Zn ppm} = \frac{8 \times \text{number of ml of dithizone added}}{1} = 8 \times \text{number of ml of dithizone added} \)

Analytical range 1.6 – 160 ppm.

2.2 Standards

1. Cold Extractable Copper and Nickel

Prepared as outlined in the hot extractable section but 0.2 ugm, 0.4 ugm, .6 ugm, .8 ugm, 1.0 ugm, 2.0 ugm, 3.0 ugm, 4.0 ugm, 5.0 ugm standards are prepared by adding 0.05, 0.10, 0.15, 0.20, 0.25, 0.50, 0.75, 1.0 ml of the 4 ugm/ml Cu standard.

2.3 Reagents

Copper

1. Biquinoline reagent solution, 0.02 percent: Add 0.2 g 2,2' - biquinoline to 900 ml of isoamyl alcohol in a beaker. Warm on a steam bath in a well-ventilated area away from an open flame until the biquinoline is dissolved. Allow the solution to cool, and dilute to 1 litre with isoamyl alcohol. The solution should be colorless; if it is yellow, the reagent is impure and should not be used.

2. Buffer solution: Dissolve 400 gm sodium acetate \((\text{NaC}_2\text{H}_3\text{O}_2 \cdot 3\text{H}_2\text{O})\), 100 gm sodium tartrate \((\text{Na}_2\text{C}_4\text{H}_6\text{O}_6 \cdot 2\text{H}_2\text{O})\), and 20 gm hydroxylamine hydrochloride \((\text{NH}_2\text{OH.HCl})\) in 1 litre of metal free water. If necessary adjust the pH of the solution with HCl or NaOH solutions to between 6 and 7, using pH test paper. To check for copper contamination place 10 ml of buffer in a test tube, add 1 ml biquinoline reagent, cap, and shake for 2 min. Absence of a pink coloration in the organic layer indicates that the solution is satisfactory for use. If contaminated, the buffer will need to be scrubbed.

...7.
3. Standard copper solution (100 ug copper per ml): Dissolve 0.2 gm copper sulphate (CuSO\(_4\).5H\(_2\)O) in 500 ml 0.1M HNO\(_3\). Standard Cu solution required is 4 ugm/ml. Transfer 4 ml of standard Cu solution to a 100 ml volumetric flask and dilute to volume with 0.1M HNO\(_3\). Check solution by AAS (4ugm/ml = 4 ppm).

4. 25% Nitric Acid: Add 250 ml concentrated HNO\(_3\) to 750 ml of metal free water.

Nickel

1. \(\alpha\)-furildioxime solution (0.2%): Dissolve 0.2 gm \(\alpha\)-furildioxime in 15 ml of absolute ethyl alcohol, mix and dilute with benzene to 100 ml.

2. Nickel Buffer Solution: Dissolve 60 gm ammonium nitrate in 200 ml of metal free water; add concentrated NH\(_4\)OH (SG 0.88) until the pH is approximately 9.5, then dilute to 1 litre with metal free water.

3. Standard nickel solution (100 gm/ml): Dissolve .1 gm of nickel power in 20 ml of 25% nitric acid and dilute to 1 litre with metal free water. Working standard (4 gm/ml) is made by transferring 4 ml of standard nickel solution to 100 ml volumetric flask and diluting to volume with metal free water.

Zinc

1. Stock dithizone - chloroform solution (.1% W/V): Weigh 0.1 gm of dithizone using paper or aluminium foil, transfer to a 100 ml stoppered, graduated cylinder. Add chloroform to the 100 ml mark and shake vigorously for at least 5 minutes. Put aside 25 ml of the .1% W/V stock solution for scrubbing the Zn buffer solutions. Place the remaining 75 ml of stock solution in a thermos flask to exclude light.
2. Zinc buffer solution: Separate solutions of sodium thiosulphate and sodium acetate are made and scrubbed of heavy metals before mixing. Dissolve 125 gm sodium thiosulphate (Na$_2$SO$_3$•5H$_2$O) in 400 ml metal free water in a large separatory funnel. Dissolve 300 gm sodium acetate (Na$_2$C$_2$H$_3$O$_2$•3H$_2$O) in 400 ml of metal free water, then add 60 ml of glacial acetic acid.

The individual solutions must now be scrubbed by extraction in a separating funnel with .01% dithizone-chloroform solution** in one or more 50 ml portions as follows to remove heavy metals. After the dithizone addition, the funnel is shaken and the chloroform layer allowed to settle.

If this layer shows any colour except the characteristic clear green of dithizone, heavy metals are present and are reacting with the dithizone to form coloured dithizonates. In that case, the layer should be drained away and another 50 ml portion of .01% dithizone added. When the layer is green and remains green, the excess dithizone must be removed from the scrubbed solution by extracting with successive 50 ml portions of chloroform. The process is the same as that described above, except that now the portions are added, shaken, then discarded until the layer is colourless.

The buffer solution for use is now made by combining the scribbled solutions and diluting to 2 litres with metal free water. The pH must be between 4 and 5.

**NB The 0.1% dithizone-chloroform solution is made from the 25 ml of the .1% W/V stock solution put aside in section 1, made up to 250 ml with chloroform. If extra working solution is needed a further 25 ml of stock solution should be taken from the thermos flask and treated.

1. Cold Extractable Copper, Nickel and Zinc

The reagents and standards are prepared as outlined by the hot extractable method section.
3. FIELD METHOD FOR COLD EXTRACTABLE "TOTAL HEAVY METALS"

1. Fill the 250 mgm measuring scoop with the finest soil or stream sediment material. Place in a 25 ml glass stoppered or corked graduated cylinder.

2. Add 5 ml of buffer solution.

3. Add 2 ml of .001% dithizone solution.

4. Shake and swirl for 10 seconds.

5. If the top layer is green, blue green, blue grey, the analysis is complete and record as 0, 1, 2 mls respectively.

6. If the colour is purple, red, pink, proceed by adding further measured amounts of dithizone. Mix gently for 30 seconds. Proceed with additions and mixing until blue grey is obtained, record the final total volume of dithizone at this point.

7. The total dithizone volumes are an index of the heavy metal content and can be mapped as such. If the sample requires more than 20 mls record as 20+. By comparing the colours of excesses of 20 as 20+, 20++, 20+++, some quantitative idea can be gauged of nearness to metal source, until a cut off can be determined.

Dithizone Solutions

1. Dithizone solutions as for cx and total Zn analyses.

Buffer Solutions

1. Dissolve 50 gm of ammonium citrate and 8 gm of hydroxylamine hydrochloride in a beaker containing 600 ml of metal free water. Add NH₄OH until the pH is 8.5 and test with pH paper.

2. Scrub the buffer as per instructions for total Zn buffer.

3. Dilute to 1 litre with metal free water.
4. **SUGGESTED USAGE OF FIELD KIT**

The field kit should be used in two stages.

4.1 **Stage 1 — Reconnaissance**

This stage is where perhaps 10 to 20 samples are collected in a small area and analysed in a batch to determine which is the anomalous creek. Analysis can be of Cu, Zn, THM or "total" Cu, Ni, Zn.

**Points to note**

1. Every 10th sample is a duplicate. Add a blank in the batch.

2. After reading arrange highs and re-read and record these results in brackets.

3. There is no real need to calculate ppm for Zn or total heavy metal. One can just plot mls of dithizone.

4. If samples are a long way offscale it may be desirable in some cases to bring them back into range.

   i.e. This is done by carrying out the digestion adding buffer: then taking a small aliquot adding it to another tube, with buffer and organic reagent. Use the formula to calculate the concentration.

5. Digestion and reading tubes are colour coded, i.e. digestion tubes are red with or without corks; reading tubes are blue tubes with perspex tops.

4.2 **Stage 1 — "Onstream" Follow-up**

Corked graduated test tubes, one for Cu and Zn are used or corked measuring cylinders. One or the other or perhaps both may be used.

**Equipment**

1. 2 or 3 graduated test-tubes or measuring cylinders and cork.
2. Zn or THM buffer.

3. Dithizone


5. 2.5% HNO₃.


Map the anomaly up the creek until a cutoff is obtained. A search is then conducted on either bank.

Whatever stage follow up is being carried out results must be recorded on the appropriate forms.
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