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GEOLOGICAL SETTING OF COPPER MINERALIZATION IN THE MT. FITTON SOUTH AREA OF THE MT. PAINTER PROVINCE

IAN BUCKHORN, 1973

GEOLOGICAL SETTING OF COPPER MINERALIZATION
IN THE MT. FITTON SOUTH AREA
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by

Ian Buckhorn

This thesis is submitted as partial fulfilment of the course requirements of the Honours Degree of Bachelor of Science in Geology at the University of Adelaide, 1973.

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ABSTRACT

The geological setting of copper mineralization occurring within the Mt. Fitton South area has been examined. The major control on mineralization is the unconformable contact between Carpentarian granites and Adelaidean cover sediments. This contact appears to have controlled the migration of the ore bearing solutions. Ore deposition has been localized in Lower Palaeozoic shear and fault zones which occur at the basement-cover contact. The degree of structural control on mineralization was sufficient to warrant a detailed study of the structural environment of the project area.

Chapter 1

INTRODUCTION

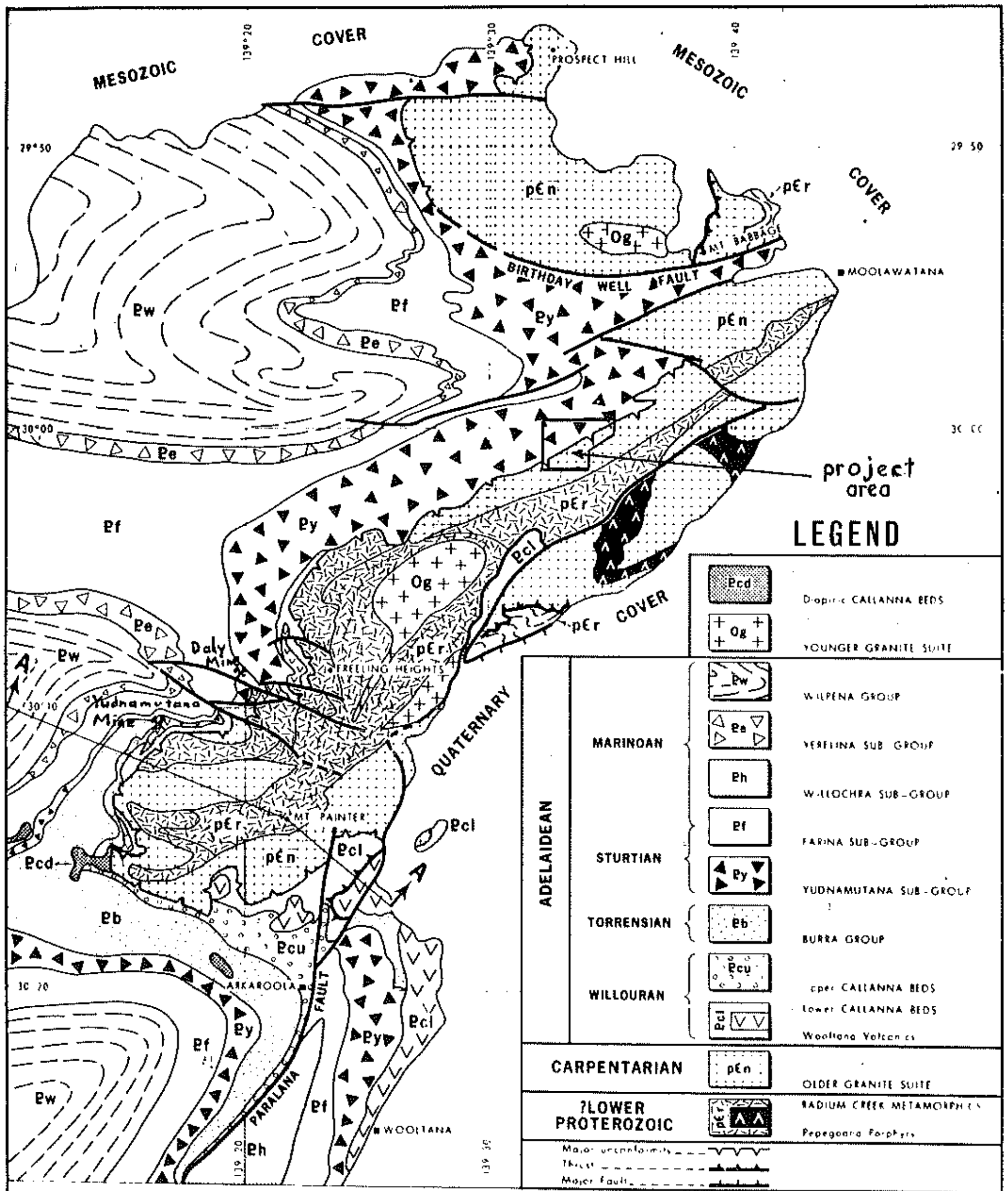
The aim of this thesis is to elucidate the control of the geological environment on copper mineralization which occurs within the Mt. Fitton South area of the north west Mt. Painter Province. The approach to the problem has been through an integrated study of the geological setting from the initial deposition of near shore glacio-marine sediments through to the final phases of the deformation which affected these sediments. By obtaining a good understanding of the geological environment, it is hoped that the interrelation between geological setting and mineralization can be assessed.

The thesis is based on field work carried out within the Mt. Fitton South area during May and June of 1973. The generalized geology (see Fig.1.1) consists of Sturtian age Yudnamutana Sub-group sediments unconformably overlying Carpentarian age granitic basement. Structurally, the project area was subject to a major period of deformation in the Lower Palaeozoic, which gave rise to the present system of folds and faults.

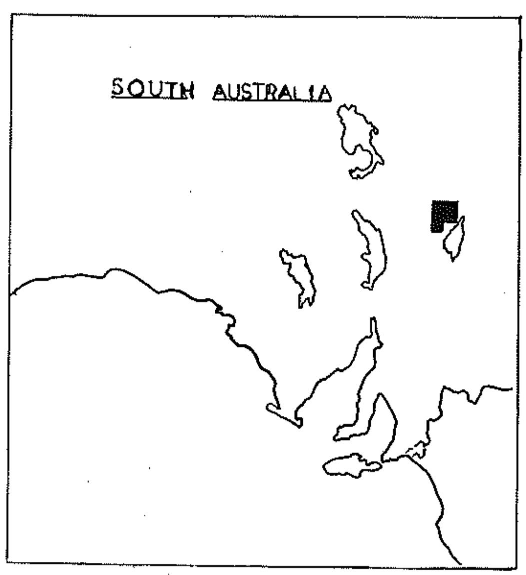
Recent uplift within the area has resulted in a rugged basement topography, with steep drainage gradients, actively degrading streams and high level fluviatile deposits. The Yudnamutana Sub-group cover sediments form a more subdued relief. Outcrop, though usually well exposed, is moderately weathered, particularly within the cover succession. To the north of Hamilton Creek, outcrop is very poor, this mainly being due to coverage by alluvium from Hamilton Creek, which is the major drainage component of the area.

During the course of this study, 250 A.A.S. analyses were performed, each for five elements. To aid in the interpretation of geochemical data, computer analysis was used with varying degrees of success. For structural, metamorphic and sedimentological interpretation, 31 thin sections were prepared. These thin section descriptions were supplemented by hand specimen descriptions, which were particularly necessary in the sedimentological work.

FIGURE 1.1



after Parkin, 1969



GENERALIZED GEOLOGY

and

LOCALITY MAP

Chapter 2

BASEMENT GRANITES

The basement within the Mt. Painter Province consists predominantly of massive and foliated granites of a magmatic origin, which have been defined by Coats and Blissett (1971) as the "Older Granite Suite".

Within the project area, the dominant granite types are the Mt. Neill Granite Porphyry and the Terrapinna Granite, with variants of these two also being present. Aplite dykes occur as later stage intrusives within these granites. The contact between the two major granite types is always gradational, while dyke contacts are very sharp.

2.1 Mt. Neill Granite Porphyry

The Mt. Neill Granite Porphyry is a massive, coarse grained, porphyritic granite containing similar percentages of pink ovoidal microcline phenocrysts and clear, rounded quartz phenocrysts. The groundmass consists of a fine to medium grained mosaic of potash feldspar, quartz and aggregates of biotite and sericite. Within the project area, the Mt. Neill Granite often contains late fractionated quartz-tourmaline nodules.

2.2 Aplites

Aplites occur as light yellow, fine grained quartz-feldspar rocks having a distinctive granular texture. The composition of aplite dykes is quite variable, and ranges from a very quartzose "sugary" textured rock containing quartz-tourmaline nodules through to a fine grained granitic rock containing phenocrysts of rounded 1 cm. quartz (these quartz phenocrysts are similar to those occurring in the Mt. Neill Granite Porphyry). At the contact between the Terrapinna and Mt. Neill Granites, the granitic variant of the aplites may occur as a microgranite of very similar appearance to the Mt. Neill Granite.

2.3 Transitional Terrapinna Granite

For field mapping purposes, the granite occurring in the gradational zone between the Mt. Neill and Terrapinna Granites was defined by the writer as the Transitional Terrapinna Granite. Unlike the true Terrapinna Granite, this Transitional Granite has no "Rapakivi"-type weathering (see page 44, Coats and Blissett, 1971), and also differs from the Terrapinna Granite by its more even grained texture and lesser phenocryst development.

In outcrop appearance, the Transitional Granite is quite similar to the Terrapinna Granite, especially with respect to its development of microcline ovoids. However, the Transitional Granite's base metal geochemistry, particularly for Zn and Mn (see appendix 5.1), verifies its transitional nature, with perhaps the closer base metal affinity being towards the Mt. Neill Granite. The composition of the Transitional Terrapinna Granite is quite variable, with phenocrysts of ovoidal microcline and rounded quartz variously occurring in groundmasses consisting of second generation pink feldspar, quartz, biotite and sericite.

2.4 Terrapinna Granite

Within the project area, the Terrapinna Granite occurs as a massive coarse grained porphyritic rock containing up to 70% megacrysts of ovoidal perthitic microcline and anhedral quartz. The medium grained groundmass consists mainly of quartz, potash feldspar (second generation of crystallization) and biotite (usually less than 10%). The microcline ovoids, which constitute up to 55% of the granite, weather out in the characteristic way known as "Rapakivi" weathering. In the field, the Terrapinna Granite is distinguished from the Mt. Neill Granite by its Rapakivi weathering, the size and predominance of its microcline ovoids and its slightly lower quartz and biotite content.

<u>PLATE 1</u>

A. Contact between the "Rapakivi weathering" Terrapinna Granite (right of photo) and a dyke consisting of Transitional Terrapinna Granite (left of photo).

B. Contact between an aplite dyke and Terrapinna Granite.

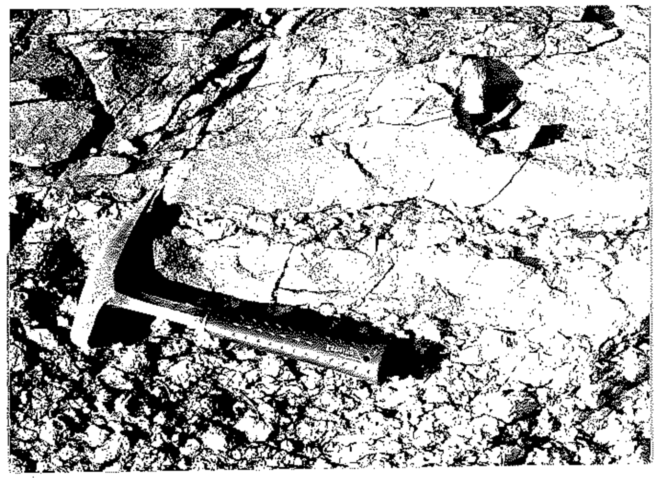
C. Low angle, strongly sheared Terrapinna Granite.

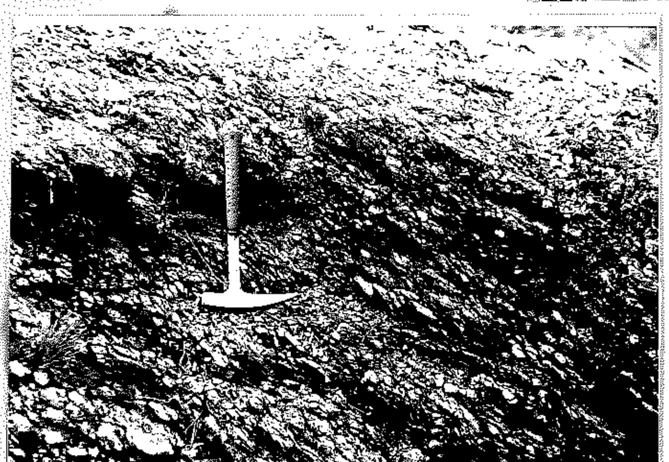
D. Strained microcline ovoids within sheared Terrapinna Granite.

PLATE I

A

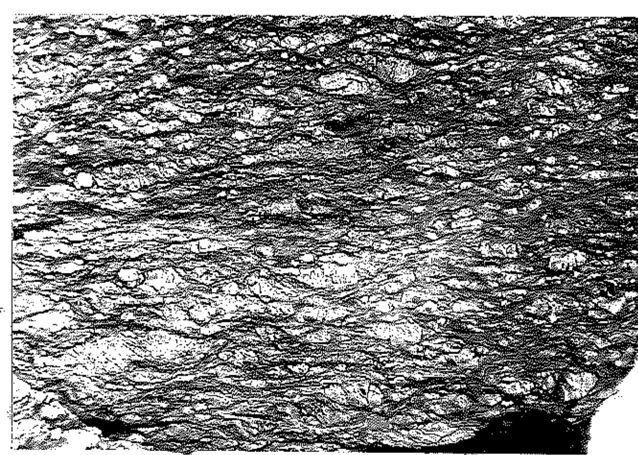
B





C

D



Relative ages of the Granites

Within the mapped area, field relations suggest the Terrapinna Granite to be the earliest to crystallize. Both the Transitional Terrapinna Granite and the aplites occur as sharp contact dykes within the Terrapinna Granite (see plate 1). The aplite phases, as well as the Mt. Neill Granite, represent later stages of magmatism. Aplitic xenoliths, sometimes veined by stringers of granite, are very common within the Mt. Neill Granite. However, aplite dykes also occur within the Mt. Neill Granite, so there is some degree of comagmatism between the two.

Chapter 3

COVER STRATIGRAPHY

Within the project area, the cover succession consists of the lower formations of the Yudnamutana Subgroup, these being the Fitton and Bolla Bollana Formations. The Yudnamutana Subgroup is correlated with Sturtian glacials, with the Bolla Bollana Formation in particular being of demonstrable glaciogene origin. The Fitton Formation succession is dominantly pebbly to cobbly scapolitic meta-siltstones, with fine grained orthoquartzite and amphibolite interbeds. From detailed mapping east of Mt. Shanahan, it is possible to sub-divide the Fitton Formation into six units, these being in descending order :-

UNIT 6 Fine grained orthoquartzites, poor to moderately well bedded, alternating with meta-siltstones and shales. Thin pebbly quartzite and pebbly to cobbly meta-siltstone interbeds are common; thickness ranges from 300 metres in the east to 370 metres in the west.

UNIT 5 Scapolitic meta-siltstones, poor to moderately well laminated and fine bedded, orthoquartzite and pebbly meta-siltstone interbeds; 230 - 360 metres+.

UNIT 4 Massive diamictites; 400 - 500 metres+.

UNIT 3 Scapolitic meta-siltstones with amphibolite interbeds, moderately well laminated and thinly bedded; 220 - 370 metres+.

SUB UNIT 3a - Arkosic conglomerate; 5 - 20 metres+.

UNIT 2 Black matrix diamictite; 40 - 100 metres.

UNIT 1 Basal granite tillite; 80 - 260 metres+.

+ the first value represents a typical thickness in the east, and the second value a typical thickness in the western Mt. Shanahan area.

The cover stratigraphy and environmental interpretations are fully discussed in Appendix 3.1. Thin section descriptions of cover unit rock types have been incorporated within the descriptive stratigraphy part of Appendix 3.1.

From the appendix, it can be seen that the most significant features of the cover succession are :-

1. Thin quartzites, which occur frequently throughout the Fitton Formation, are laterally continuous, and so indicate subaqueous deposition.

2. Deposition conditions were essentially shallow marine, as is evidenced by the forms of current bedding (see Appendix 3.1, with particular reference to the flaser bedding of Units 5 and 6). Intraformational conglomerates are common within the silts and interbedded shale-quartzites, so that shallow high energy conditions can be inferred. Under these conditions of current activity, some reworking of the massive diamictites has occurred.

3. The shallow marine sequence has had sub-glacial deposition intermittently superimposed on it. Massive, poorly sorted deposits are probably related to grounded shelf ice deposition. Possible ice rafted drop stones occur within the shallow marine siltstones of Units 5 and 6. The Bolla Bollana Formation has a strong glacial character.

The fact that the cover sediments are near shore marine may be of significance to ore models proposed for the Mt. Fitton South area. It is a well documented fact that sedimentary copper accumulations are favoured by near shore environments (Stanton, 1972). The Kupferschiefer (Dunham, 1964), White Pine (Brown, 1971; White 1971) and Katangan (Garlick et al, 1972) stratiform copper deposits all occur in near shore marine sediments. The sedimentary environment of the Katangan Copperbelt deposits in particular is analogous to that occurring for the Fitton and lower Bolla Bollana Formations. In both areas, Precambrian granites constitute the basement, and pyritic argillites and carbonaceous shales (see Appendix 3.1, Bolla Bollana Formation) occur in the overlying sediments. The near shore deposition possibly facillitates the introduction of erosionally derived copper into the sedimentary environment (Garlick, 1961).

Chapter 4

STRUCTURE

In any study concerned with the genesis of an ore deposit, it is essential to understand the nature and the timing of all phases of the structural deformation. The emphasis of this present Chapter is essentially on the structural environment of the Mt. Fitton South area, so that no particular reference is made to mineralization. Relations between structure and mineralization will be fully discussed in Chapters 5 and 6.

A simplified geological map (Fig. 4.1) is included as a reference for this Chapter.

4.1 FOLDING, FOLIATION AND CLEAVAGE DEVELOPMENT

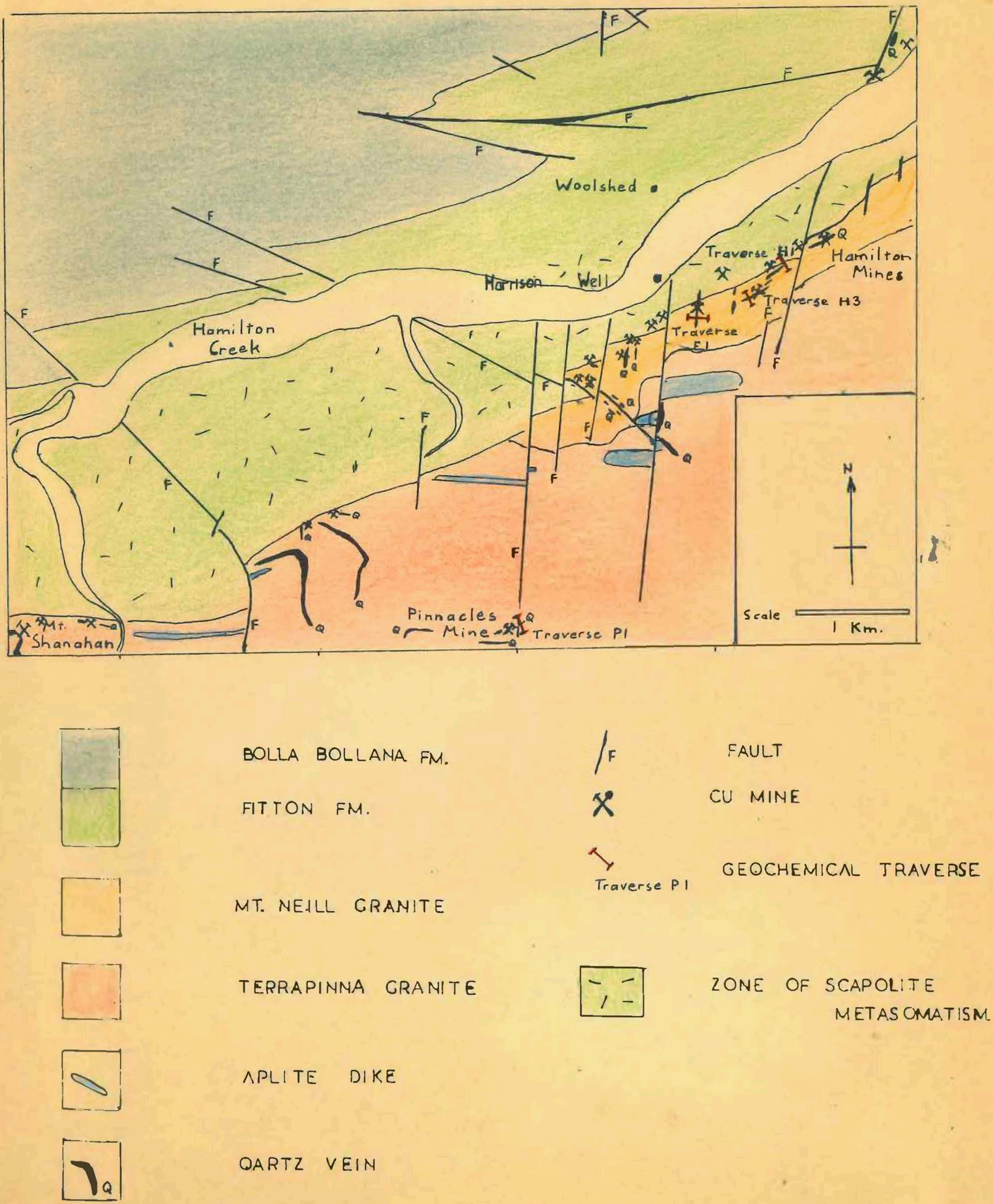
Basement Foliation

A foliation of variable intensity has formed in the basement granites (see plate 1). The foliation is due to the schistose development of biotite and minor retrograde sericite. Ovoid shaped megacrysts of microcline within the foliated granites are rotated parallel to the schistosity.

In general, the degree of foliation development is quite variable, and seemingly without any definite pattern, so that outcrops of massive Terrapinna Granite often occur within zones of moderately foliated granite. The foliation is also variable within individual outcrops, and is often difficult to measure, so that a diffuse spread of stereographic plots is obtained (see Fig. 4.2d).

FIGURE 4·1

SIMPLIFIED GEOLOGICAL MAP



f. Poles to Basement Mylonitic Shearing

65 readings; contours: 6-4-2-0%

Maxima 1 is due to readings obtained in the Hamilton Mines area.

Maxima 2 is due to readings in a shear zone occurring approximately 800 metres east of Mt. Shanahan (see Fig. 4.1).

The dashed great circle represents the basement foliation (S_1), points represent crenulations measured within the shear zone. These crenulations are an expression of the basement foliation.

Maxima 3 is due to readings in shear zones resulting from a basement fault 2 km. east of Mt. Shanahan (see Fig. 4.1). Quartz veining is associated with the shearing.

There is a high degree of overlap between Maxima 3 and the Set II orientation of Figure 4.2e.

Explanation to Figure 4.2

a. Poles to cover bedding

49 readings; contours: 20-15-10-5-0% per 1% area
Plunge of structure = 30° towards 259°.
Dashed great circle represents cover cleavage (S_1),
points represent measured intersection of bedding and cleavage.

b. Poles to Joints

203 readings; contours: 10-8-4-2-1-0%
Dominant joint orientation = 80° towards 077°,
complementary maxima at 72° towards 284°.

c. Poles to Cover Cleavage

54 readings; contours: 30-20-10-5-0%
Average cover cleavage orientation = 79° towards 177°.

d. Poles to Basement Foliation

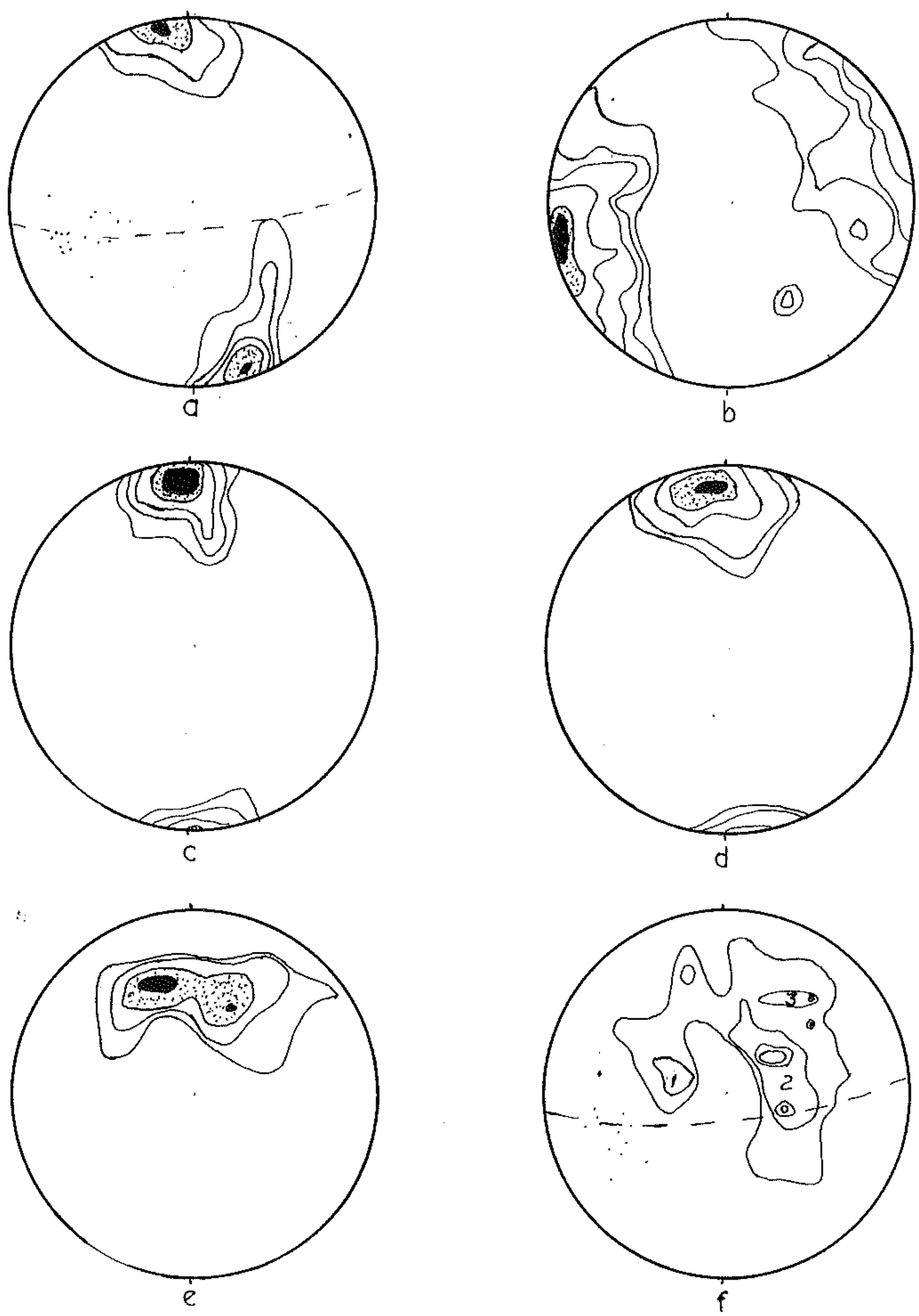
113 readings; contours: 30-20-10-5-0%
Average basement foliation orientation = 78° towards 176°.

e. Poles to Basement Mylonitic Shearing within the Terrapinna Granite

27 readings; contours: 15-10-5-0%
Two diffuse maxima,

Set I = 55° towards 155°
Set II = 48° towards 210°.

Figure 4·2



There is little evidence to suggest any folding of the basement granites. Foliation within the Terrapinna Granite variably dips between 60° and 90° towards the south, with the lower angle dips possibly outlining the hinge zone of a basement anticlinal structure. However, the stereographic plots of foliation within the basement granites show no evidence of the two deformations which would have to be inferred if the foliation had defined an anticlinal structure. In contrast, basement sediments such as the pelitic Brindana Schists and the sericitic Freeling Heights Quartzite, which outcrop south of the project area, have well developed crenulation cleavages which clearly indicate the presence of at least two deformations within the Mt. Painter Complex (this is further discussed in Young, 1973).

Cover Folding

Regionally, the cover succession represents the southern limb of a west plunging syncline. The succession is strongly folded, as is evidenced by the vertical to overturned bedding dips. Cleavage-bedding intersections, which show the cleavage to be dipping less steeply than bedding, generally indicate that the synclinal structure is overturned approximately 20° towards the north (assuming the cleavage is not fanning).

The plunge of the structure is approximately 30° towards 259° (see Fig. 4.2a). No parasitic folds outcropped well enough to allow the actual measurement of minor fold axis plunges. Without exception, the few minor folds had "S" vergences.

Cleavage Within the Cover

Cleavage development within the cover meta-siltstones is quite variable, since it ranges from a complete absence within massive pebbly meta-siltstones through to good development within the very fine grain sediments such as the Unit 1 phyllites and Unit 6 shales.

Within the basal phyllites, the cleavage orientation is seen to vary with the competency of the affected beds, being almost vertical within phyllitic interbeds and being refracted to a low angle fracture cleavage within massive quartzites. "Varve-like" laminations within the phyllite are often displaced in a way similar to "pack of cards" shearing.

The microfabric within the massive, uncleaved meta-siltstones typically consists of granoblastic biotite and quartz showing neither crystallographic nor dimensional preferred orientation. Within the strongly cleaved, fissile shales of Unit 6 and the Bolla Bollana Formation, biotite and pyrite develop lineations parallel to cleavage, and "pressure shadows" of biotite develop on quartz grain boundaries. However, for the most part, the Fitton Formation has nothing more than a parting cleavage parallel to bedding. Nowhere was the stress associated with cover deformation intense enough to have caused phenomena such as strain elongation of quartz clasts.

Relation between Basement and Cover Structures

From the stereographic plots, it can be seen that the basement foliation (Fig. 4.2d) is essentially parallel to the cover cleavage (Fig 4.2c). This indicates that the retrograde metamorphism of the basement can be attributed to the Lower Palaeozoic deformation which caused the cover metamorphism and cleavage development. The absence of a pervasive, well developed foliation within the basement and cover indicates the deformation probably occurred under weak stress conditions, so that massive rock types such as the Terrapinna Granite and massive pebbly siltstones are able to show non-stressed fabrics.

It is interesting to note that granite clasts within the cover sediments are always massive and non-foliated, so reflecting a differing response of the basement and cover to the deformation. This is particularly evident in the Harrison Well area. Here, the basement Mt. Neill Granite has been strongly foliated by the Lower Palaeozoic deformation, yet Mt. Neill Granite boulders occurring in the basal tillite are completely devoid of foliation.

4.2 FAULTING

The faulting is associated with the later phases of the deformation which folded the Adelaidean cover succession. The basement and cover have reacted to the faulting as a single unit, so that for all classes of faults, displacement within the basement granites (as shown by offset aplite dykes) is equal to that occurring within the cover. However, the outcrop expression of faults varies considerably between basement and cover.

In the basement, faults are often characterized by wide zones (typically between 3 and 30 metres width) of pervasive quartz veining and silicification, with strong shearing (often mylonitic) and jointing commonly being well developed within these zones. However, in some cases, the actual presence of a fault is only evident from the displacement of the basement-cover contact. Within the Terrapinna Granite, fault zones typically occur as discrete lineations of haematized, dark granite, which is often schistose and brecciated. Within the cover, faults similarly occur as brecciated, haematized zones, with dislocation being confined to sharp, well defined fault zones, these often being less than 50 cm. wide. This is in complete contrast to the previously mentioned fault development within the more rigid and massive basement granites.

The most distinctive feature related to faulting is the strong association of quartz veining with basement faults. Within the cover, there is a very noticeable absence of quartz veining, with the only significant cover quartz blows occurring close to fault zones at the base of the Fitton Formation.

Two orientations of fault development were present during the Lower Palaeozoic deformation, these being :-

1. faults typically trending between 220° and 320° ("east-west" trending), which when located within the basement, occur as mylonitic shear zones.

2. Faults typically trending between 320° and 010° ("north-south" trending), which most often occur as 360° trending strike-slip faults that sinistrally offset the basement-cover contact.

The mylonitic shear zones and their associated cover faults occurred during the earlier phases of fault development, and may be offset by the later strike-slip faults.

1 (a) Mylonitic Basement Shear Zones

Within the basement granites, zones of very intense shearing occur as sharp discordancies cutting the basement S_1 foliation, which is often evidenced in these shear zones as a crenulation. Quartz veining usually occurs parallel to the shearing, with quartz "fragments" generally being incorporated into the sheared granite.

Within individual outcrops, the shearing is quite variable, so that the stereographic plots of the poles to shearing are diffusely spread (see Fig. 4.2e, f). Despite this variability, it is apparent that two conjugate shear distributions are present, these being 55° towards 155° (Set I) and 48° towards 210° (Set II). Although quite interpretative, the bisectrix of these postulated conjugate shears corresponds to the orientation of S_1 (basement foliation, cover cleavage). There is no evidence to suggest that the mylonitic shear zones are in any way an expression of a possible shearing development about the basement-cover contact. Field evidence strongly suggests these shear zones represent basement faulting at a reasonably ductile phase of the deformation. The Set II shears have the same trend (viz. 300°) as the "east-west" cover faults. In fact, one such "east-west" fault can be traced from the cover into the basement, where it is associated with strong quartz veining and mylonitic shearing (see Fig. 4.1). In contrast, in the Mt. Shanahan area, a strongly sheared zone occurs at the basement-cover contact. There is no faulting of the cover adjacent to this shear zone, but the basal cover phyllite is crenulated in the same orientation as crenulations within the shear zone.

Thin section descriptions and photomicrographs of the mylonitic basement granites are provided in Appendix 4.1.

1 (b). <u>Cover Faults Trending Between 270° and 320° ("east-west" trending)</u>

These faults form a conjugate system with the mylonitic basement shear zones. Faulting is generally evidenced by sharp zones of intense jointing and brecciation, with shearing occasionally developed parallel to the fault zone.

In the "east-west" fault zone north of Hamilton Creek (see Fig. 4.1), fault dislocation appears to have been preceded by the development of tight folds (apparent as folded quartzites adjacent to the fault zone), the limbs of which have been sheared out into a fault melange. The association of these "east-west" trending faults with fold development (assuming the folds are not due to fault drag) indicates that the fault deformation occurred under reasonably ductile conditions. The deformation, which is more intense than that occurring for the later strike-slip faults, is possibly due to a dilational stress (σ_3) approximately trending towards 270°.

2. Strike-Slip Faults

This class of faults is characterized by a conjugate system of sharp dislocations. The conjugate fault development appears to be symmetrical about the trend of the basement-cover contact rather than the 270° trend which was associated with the earlier "east-west" trending faults. The fault zone traces are very linear, regardless of topography, which indicates the faults are steeply inclined to vertically dipping. Evidence from haematized slickensides in fault zones indicates only minor vertical throw on the faults. This can also be inferred from the fact that inclined basement dykes are displaced equal distances to vertically dipping cover sediments. Horizontal fault displacements range from 10's of centimetres up to 200 metres.

4.3 JOINTING

The dominant joint orientation is 85° towards 070°, though wide variations are present (see Fig. 4.2b). A minor conjugate joint set is present which dips 75° towards 280°. Where conjugate joints occur, their bisectrix is a steep to vertically dipping plane, generally trending towards 350°. This indicates a relation between jointing and the "north-south" trending strike-slip faults.

Three classes of joint development are present, these being :-

(1) first order shear joints which are parallel to the strike-slip faults, and therefore parallel to the axis of maximum compressive stress (De Sitter, 1964). When developed within the basement near faults, these joints are sometimes associated with quartz veining and haematized slickensides.

(2) second order joints due to secondary stresses induced along the strike-slip faults (Hills, 1963). These joints are inclined at between 10° and 40° to "north-south" faults.

(3) tension joints, which occur as milky white quartz filled fractures, mainly within the cover orthoquartzites. These joints, which trend approximately north-south, are perpendicular to the direction of maximum extension.

Joint development within the basement and the cover is essentially identical. However, there is one joint orientation which is restricted to the basement aplite dykes alone, this being a strong joint set parallel to the general east-west trend of the dykes.

FAULTING - SUMMARY AND CONCLUSIONS

The fault classification adopted here may be somewhat idealized, since obvious cases exist where faults cannot be placed into either of the major categories. For instance, in the Hamilton Mines area, "north-south" strike-slip faults occur which have all the mylonitic characteristics of the earlier "east-west" phase of faulting. However, the classification does recognize the existence of two distinct environments of faulting, both of which are relevant to the synthesis of a simplified principal stress system for the project area. The maximum principal stress (σ_1) was orientated approximately north-south, and was responsible for compressive features such as the cover cleavage and basement foliation, and later in the deformation, gave rise to the strike-slip faults. σ_2 was orientated vertically, while σ_3 trended towards 270° and was possibly responsible for the dilational cover "east-west" faults and the basement mylonitic shear zones.

4.4 BASEMENT-COVER CONTACT RELATIONS

The basement-cover contact dips either vertically or is overturned, though it is usually obscured by slope talus deposits.

No trends related to the proximity of the basement-cover contact could be recognized in the development of the basement foliation (or shearing). In general though, the Mt. Neill Granite occurring at the contact in the Hamilton Mines area is moderately to strongly sheared, whereas the Terrapinna Granite to the west may variably be massive, weak to moderately sheared or strongly sheared, these variations being without any apparent control.

Within the cover, the strongest cleavage development occurs within phyllites at the contact, though this may be a function of the phyllites very fine grain size and argillaceous nature. There is also a noticeable trend for the cleavage to have shallower dips at or near the contact, which is evidenced as a secondary maxima of 52° towards 188° in the stereographic plots of the cover cleavage (see Fig. 4.2c).

The contact is most likely a simple unconformity, as is illustrated at the Mt. Shanahan Mine, where a basement quartz vein projects into the overlying basal phyllite as a 50 cm. palaeorelief. Such features would not be preserved if the contact was sheared or faulted. There is no evidence such as strain elongation of tillite pebbles or mylonitic shearing of the adjacent basement which could suggest any intense deformation at the contact.

The basement-cover contact is folded with the same pattern as that occurring in the cover succession. This suggests that the basement and cover were folded as a single unit, so that the contact was not a structural discordancy during the folding phase of the deformation. However, the possible relation between conjugate strike-slip faults and the trend of the contact could suggest that the contact influenced the later, more brittle phases of the Lower Palaeozoic deformation.

Chapter 5

THE BASE METAL GEOCHEMISTRY OF THE BASEMENT AND COVER

The primary dispersion of base metals within an environment can be studied using rock geochemistry to outline zones of metal enrichment. If specific lithology types can be shown to have anomalously high background metal values, then their behaviour, as controlled by the geological environment, will have a significant influence on any proposed ore model.

Any metal enriched lithology types will represent possible sources of mineralization, since the mobilization of their elements by processes such as lateral secretion constitutes a potential ore forming process. Apart from indicating potential metal sources, the presence of anomalous metal values can indicate zones of epigenetic dispersion. As an example, if a fault zone was consistently associated with high metal values, it would be reasonable to assume that the fault was permeable to the metal bearing solutions, and so controlled the localization of mineralization.

During the course of field work, approximately 300 rock chip samples were taken throughout the basement and cover. From these samples, a representative distribution of lithology types was analysed by Atomic Absorption Spectrophotometry, with the aim being to establish whether any particular basement granites, cover meta-sediments or structural environments are significantly enriched in base metals.

5.1 BASE METAL GEOCHEMISTRY OF BASEMENT GRANITES

Mt. Neill Granite Porphyry

The majority of copper mines within the project area occur within this granite. However, the Mt. Neill Granite is not significantly enriched in base metals, with background copper values in non-mineralized zones ranging from 10 to 50 p.p.m. (see Appendix 5.1, Tables 1 and 2). If the magma from which the Mt. Neill Granite crystallized had contained copper in excess of that able to be accommodated in silicate lattices, then late fractionated quartz-tourmaline aggregates within the granite would possibly be expected to contain residual phase concentrations of base metal ions. However, no such enrichment occurs.

Terrapinna Granite

One of the larger copper mines of the area, the Pinnacles Mine, is located within Terrapinna Granite. However, this granite cannot be considered as being copper enriched, since background copper in non mineralized areas ranges from 5 p.p.m. to 50 p.p.m. (see Appendix 5.1, Table 6).

North Flinders Mines N.L. have conducted a soil (weathered bedrock) sampling survey on Terrapinna Granite in the mineralized Pinnacles area. Background copper values are very high in this area (see Appendix 5.2), with values away from shear and breccia zones averaging between 20 p.p.m. and 100 p.p.m. Cu. A stream sediment survey by Anaconda (Aust.) Inc. (Mineral Locations Map, Coats and Blissett, 1971), has outlined the Terrapinna Granite as an area of anomalously high copper (from the probability plot of N.F.M.'s data, the 95 percentile of the log normal metal distribution is 170 p.p.m. Cu, which is at variance with the 40 p.p.m. Cu anomaly level used by Anaconda). Within the anomalous area, minor malachite occurs in zones of strongly sheared Terrapinna Granite, especially in the vicinity of the Pinnacles Mine.

Other Basement Acid Intrusives

Variants of the Terrapinna Granite and aplite dykes show no significant base metal enrichment, and cannot be considered as sources of the mineralization (see Appendix 5.1, Tables 3, 4 and 5).

5.2 BASE METAL GEOCHEMISTRY OF THE COVER

Disseminated pyrite is a ubiquitous feature of the cover succession, initially occurring as traces within Unit 3 and increasing to up to 10% within the massive pebbly mudstones of the Bolla Bollana Formation. The pyrite occurs in three distinct associations, these being :-

(1) Disseminated recrystallized pyrite occurring within massive, pebbly siltstones -

base metal values within these meta-siltstones are not anomalous, with copper being less than 60 p.p.m. (see Appendix 5.1, Table 8).

(2) Disseminated pyrite within recrystallized orthoquartzites -

though generally showing recrystallized idiomorphic textures, the occurrence of minor rounded pyrite grains may indicate a detrital origin.

(3) Pyritic bands within laminated, black carbonaceous shales -

this association occurs only in the Bolla Bollana Formation. The sulphides are concentrated in biotite rich laminae, and represent syngenetic sulphide accumulations in an anoxic environment. These pyritic shales show no base metal enrichment.

SOURCE OF BASE METALS - SUMMARY

Although minor isolated shows of copper mineralization occur within the basement granites, and sedimentary sulphides occur within the cover succession, both the basement and the cover may be considered to have no lithology types containing significant base metal enrichment. Base Metal values generally conform to accepted background values (see Appendix 5.3), although the Terrapinna Granite, with copper values in the Pinnacles area consistently over 50 p.p.m., shows some degree of copper enrichment. However, the general absence of copper enriched source rocks is not too critical, since the total reserves of copper ore within area under study are very low. Simple arithmetic calculations (see Appendix 5.4) indicate that mobilization of 10 p.p.m. Cu from either the basement or cover could more than account for the total mineralization of the area.

5.3 INFLUENCE OF STRUCTURAL ENVIRONMENTS ON THE BASE METAL DISTRIBUTION

Basement Mylonitic Shear Zones

Generally, though exceptions do exist, these intensely deformed shear zones lack haematization which could be indicative of the migration of ore bearing solutions. However, basement shear zones, especially within the Pinnacles Mine area, commonly have anomalous copper values, these being between 0.02% and 0.4%.

Basement Breccia Zones

These correspond to the strike slip faults discussed in Chapter 4.2. The breccia zones occur as linear zones of dark haematized Terrapinna Granite, in which quartz and feldspar megacrysts (often brecciated) occur within a haematized chloritic matrix. Geochemically, these zones are of interest, since copper ranges from normal background through to 0.6% (see Appendix 5.1, Table 7). This copper enrichment indicates that these zones have influenced the epigenetic dispersion and the localization of copper bearing solutions.

Breccia Zones within the Cover

These occur as a conjugate set of linear zones extending for up to 1,200 metres into the Fitton and Bolla Bollana Formations. These breccia zones are of particular interest in that they would be suitable low pressure zones for the migration of any metamorphic or meteoric solutions derived from within the cover. If such solutions were ever active within the pyritic cover sediments, then they would represent potential ore forming solutions.

Analysis of haematized cover breccia zones shows them to be not greatly enriched in Cu. However, a sequence of samples taken in a breccia zone within 150 metres of the basement-cover contact had copper values between 126 and 1200 p.p.m. Other anomalous copper values of 296 p.p.m. and 397 p.p.m. occur in gossanous outcrops associated with haematized breccia zones within Units 4 and 5 of the Fitton Formation. Anomalous Zn, Pb and Mn values consistently occur within these zones (see Appendix 5.1, Table 9).

Typically, the breccia zones are silicified and haematized, having a similar outcrop appearance to breccia zones known to be associated with mineralization. This silica and iron alteration may be due to the effects of solutions which were associated with the ore forming processes. It is interesting to note that the greatest breccia zone development occurs in the Fitton Formation directly adjacent the well mineralized Hamilton Mines area.

Chapter 6

MINERALIZATION

In the area under study, the copper mineralization occurs as small, high grade vein deposits which have undergone supergene oxidation, so that the veins are now predominantly malachite, with minor azurite, chalcocite and secondary sulphides such as digenite. Apart from pyrite within associated quartz veins, primary sulphides are totally absent.

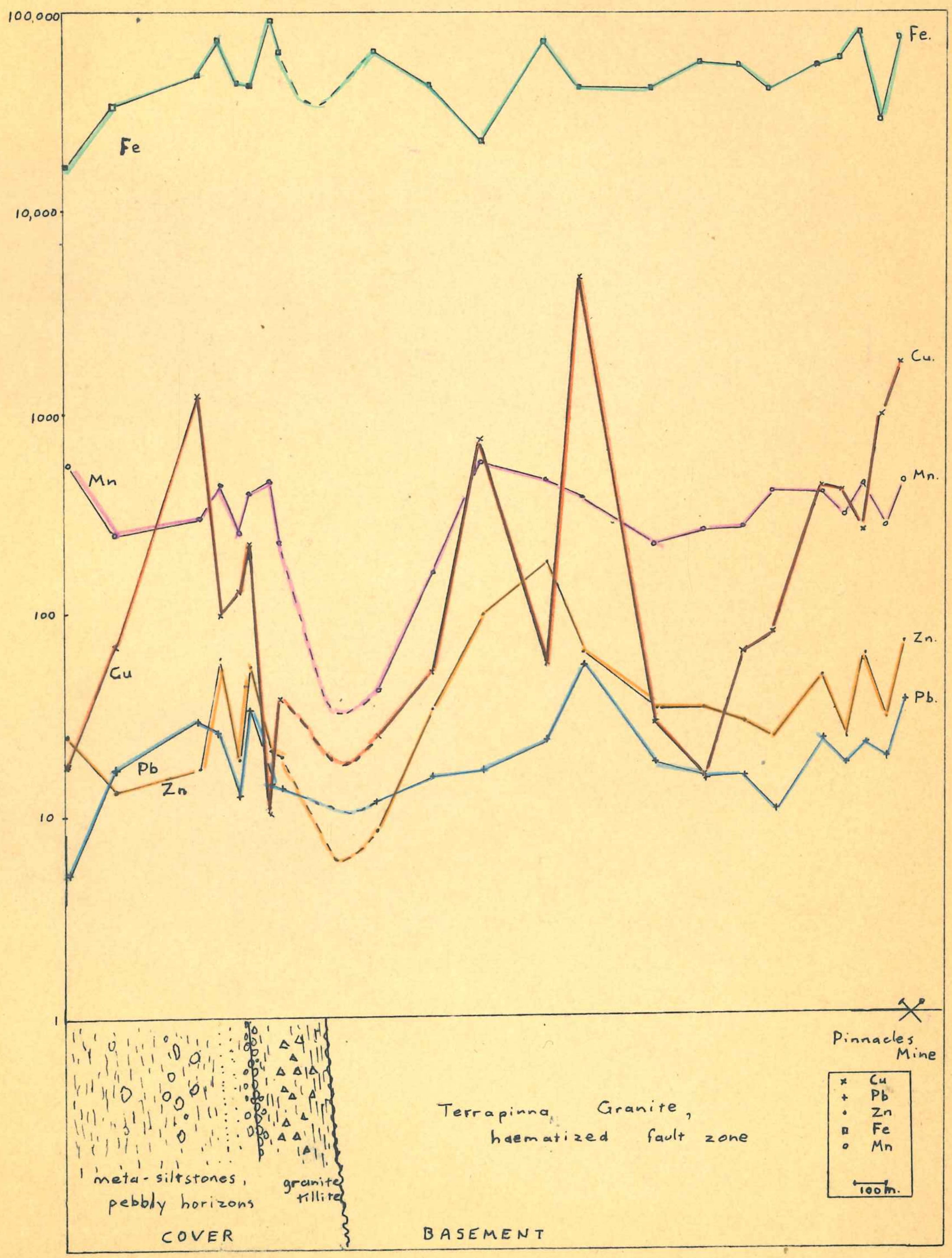
Beginning in the 1860's, the region was extensively prospected, so that wherever any copper mineralization occurs in outcrop, the show is invariably pitted. The presence of all noteworthy mineralization was recorded during field mapping, and favourable environments of ore localization were recognized. From the distribution of mineralized zones (see Fig. 4.1), it appears that the major controls on the ore forming processes are the basement-cover contact and structures associated with the Lower Palaeozoic deformation.

6.1 BASEMENT-COVER CONTACT CONTROL ON MINERALIZATION

Within the project area, mineralization tends to be localized in the basement granites, usually within 200 metres of the cover contact. Exceptions to this situation include three minor copper shows east of Harrison Well within the basal granite tillite, and the Pinnacles Mine, which occurs within basement Terrapinna Granite 1,000 metres from the contact. However, the Pinnacles Mine is associated with the basement-cover contact through a zone of faulting which extends through to the cover. From the Mount Painter Province Mineral Location Plan in Coats and Blissett (1971), it is readily apparent that throughout the Mt. Painter Province, the copper mineralization tends to be spatially related to the basement-cover contact. Significant copper occurrences near this contact include the Hamilton, Mt. Fitton (South) and Mt. Shanahan Mines, which occur within basement granites; and the Daly,

Figure 6·1

Geochemical profile along Pinnacles fault zone, metal distribution about basement-cover contact.



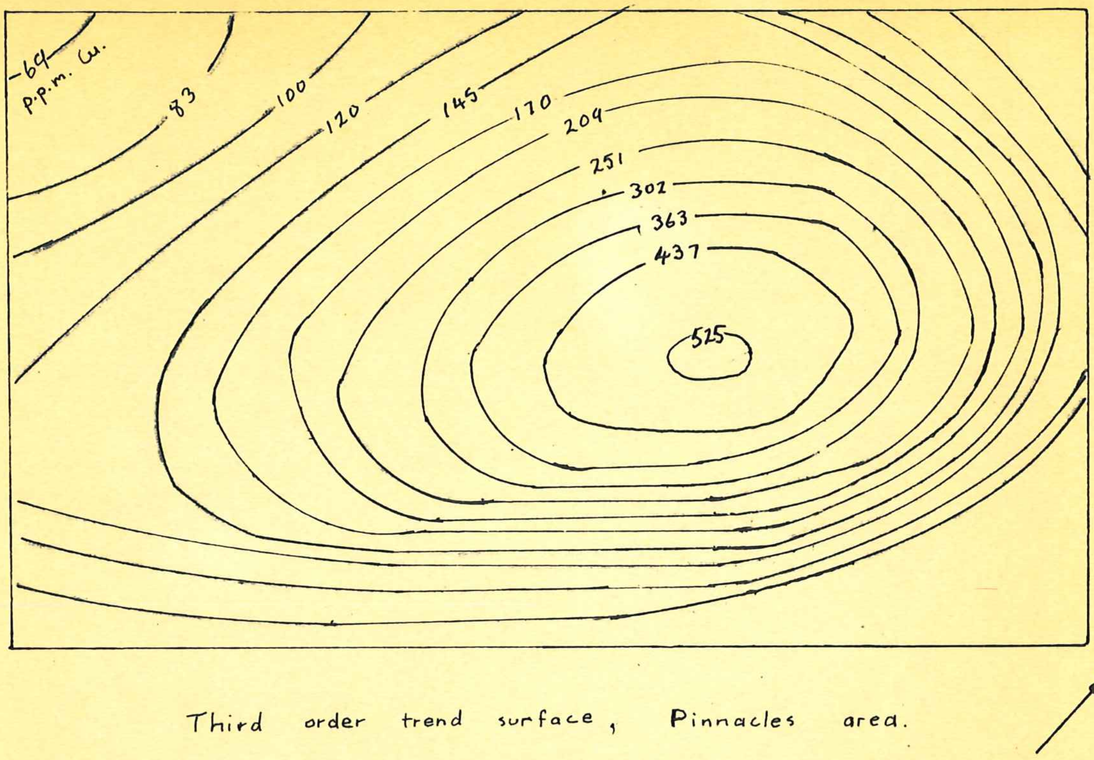
Yudnamutana and Wheal Austin Mines, which occur within cover Callana Beds (see Fig. 1.1, locality map).

Within the mapped area, North Flinders Mines N.L. has conducted a stream sediment sampling survey of the Fitton Formation meta-sediments. The contoured geochemical data clearly shows a trend parallel to the basement-cover contact, with metal values increasing towards this contact. The sampling was carried out on second and third order ephemeral streams which flow south and east into Hamilton Creek. Copper mineralization (the Hamilton Mines) only outcrops in the basement granites on the southern bank of Hamilton Creek (see Fig. 4.1), so that the trend of increasing copper towards the contact cannot be due to the clastic dispersion of copper minerals from the Hamilton Mines. The stream sediment geochemistry probably reflects the primary epigenetic dispersion of copper through the cover, and is not influenced by clastic dispersion in the secondary environment.

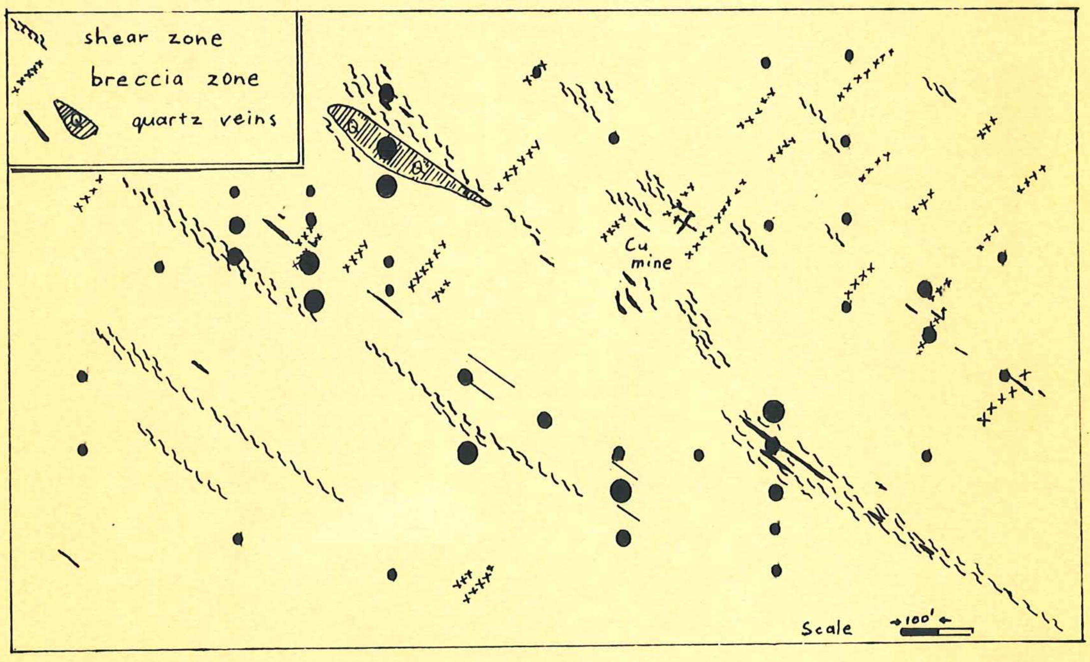
The role of the basement-cover contact was investigated by rock chip sampling along the 1,200 metre length of a fault zone which can be traced from the basement Pinnacles Mine through to the basement-cover contact, and into the cover. The base metal profile along this breccia zone (Fig. 6.1) shows there is a minimum in copper at the contact. Moving from the contact towards the basement, copper increases in two broad cycles to a peak at the Pinnacles Mine. There is also an initial increase in copper towards the cover, but this copper enrichment of the breccia zone ceases further into the Fitton Formation.

If the copper bearing solutions had been derived from either the basement or cover, and had migrated towards the contact, it would be difficult to explain the observed symmetry in the metal distribution about the contact. This symmetry could suggest that the ore bearing solutions emanated from the contact. During the Lower Palaeozoic deformation, this unconformable contact between the massive basement granites and the pebbly phyllites of the basal cover unit may have been a structural environment favourable for solution migration.

Figure 6.2



Third order trend surface, Pinnacles area.



Residual log metal values,

residual log ≤ -.10

residual log ≤ -.15

residual log ≤ -.20

increasing local anomaly intensity.

However, there is no actual field evidence to suggest the basement-cover contact acted as a permeable zone to the ore bearing solutions.

The role of the basement-cover contact in solution migration will be further discussed in Chapter 7 with respect to its influence on the scapolite metasomatism of the lower units of the Fitton Formation.

6.2 STRUCTURAL CONTROL ON MINERALIZATION

Three distinctive environments of mineralization are present, all of which are directly related to structures developed during the Lower Palaeozoic deformation. These structural environments have been discussed in Chapter 4, and are as follows :-

Group A : Mylonitic basement shear zones and associated quartz veins
Group B : Strike-slip fault zones
Group C : Foliation and Joint Planes.

EXAMPLE OF THE STRUCTURAL CONTROL ON MINERALIZATION - PINNACLES MINE AREA

Relations between structure and mineralization are well illustrated in the Pinnacles area. Four significant copper prospects corresponding to mineralization environments A and B are found in association with shear and fault zones. As mentioned in Chapter 5, North Flinders Mines N.L. have soil sampled the area, so that the effect of the shear and breccia zones on the copper distribution can be quantitatively evaluated.

Hand contoured geochemical maps+ indicate a possible trend in copper anomalies parallel to shear and breccia zones. In order to fully interpret the data, it was necessary to separate the local and regional components of the copper distribution, which was done using trend surface analysis. High residual values (which are the differences between the actual data value and the copper value calculated from the cubic trend surface) were then plotted to outline the trend of high local copper values. Two very distinct trends are apparent, one being parallel to the shear zones and the other parallel to the haematized breccia zones (see Fig. 6.2). This indicates a structural influence on the copper distribution, and so supports ore localization being structurally controlled.

+ geochemical data was provided by North Flinders Mines

Specific examples of mineralization from each of the three structural environments will now be discussed using the following format :-

1. Host rock type of the mineralized vein
2. Structural data.
3. Structures developed at the vein contact.
4. Alteration effects related to the vein.
5. Statistical data and its interpretation (see Appendix 6.1).
6. Interpretation of the geochemical traverse.

Group A : Mylonitic basement shear zone associated with quartz veining

Traverse F1 See Fig. 4.1

The type example of this mineralization environment is the Pinnacles Mine. The mine produced no more than 40 tons of ore, with the average Cu grade being less than 20%. Four shafts were sunk on the footwall side of the ore lode, which consists mainly of malachite, azurite and chalcocite associated with a quartz vein.

1. The host rock type is moderately sheared Terrapinna Granite, with the actual ore lode being associated with dark, haematized granite.

2. Structural data

The ore zone is associated with a strongly sheared (mylonitic) zone dipping 45^{o} towards 135^{o}. This type of shear zone, which conforms to a Set I shear orientation (see Fig. 4.2e), is characteristic of Group A mineralization. Away from the ore zone, the Terrapinna Granite is moderately "sheared" 70^{o} towards 180^{o}, which is the general regional trend of the basement foliation.

3. Structures at the vein contact

The footwall vein contact is transitional from strongly sheared granite into the zone of very intense shearing associated with the ore. The hanging wall contact is marked by a sharp shear discordancy between the ore zone a less sheared, silicified granite.

4. Alteration effects

The granite adjacent to the ore zone is extensively haematized and silicified, with goethite and stringers of quartz vein increasing towards the ore vein.

5. Statistical data

Correlation Coefficients

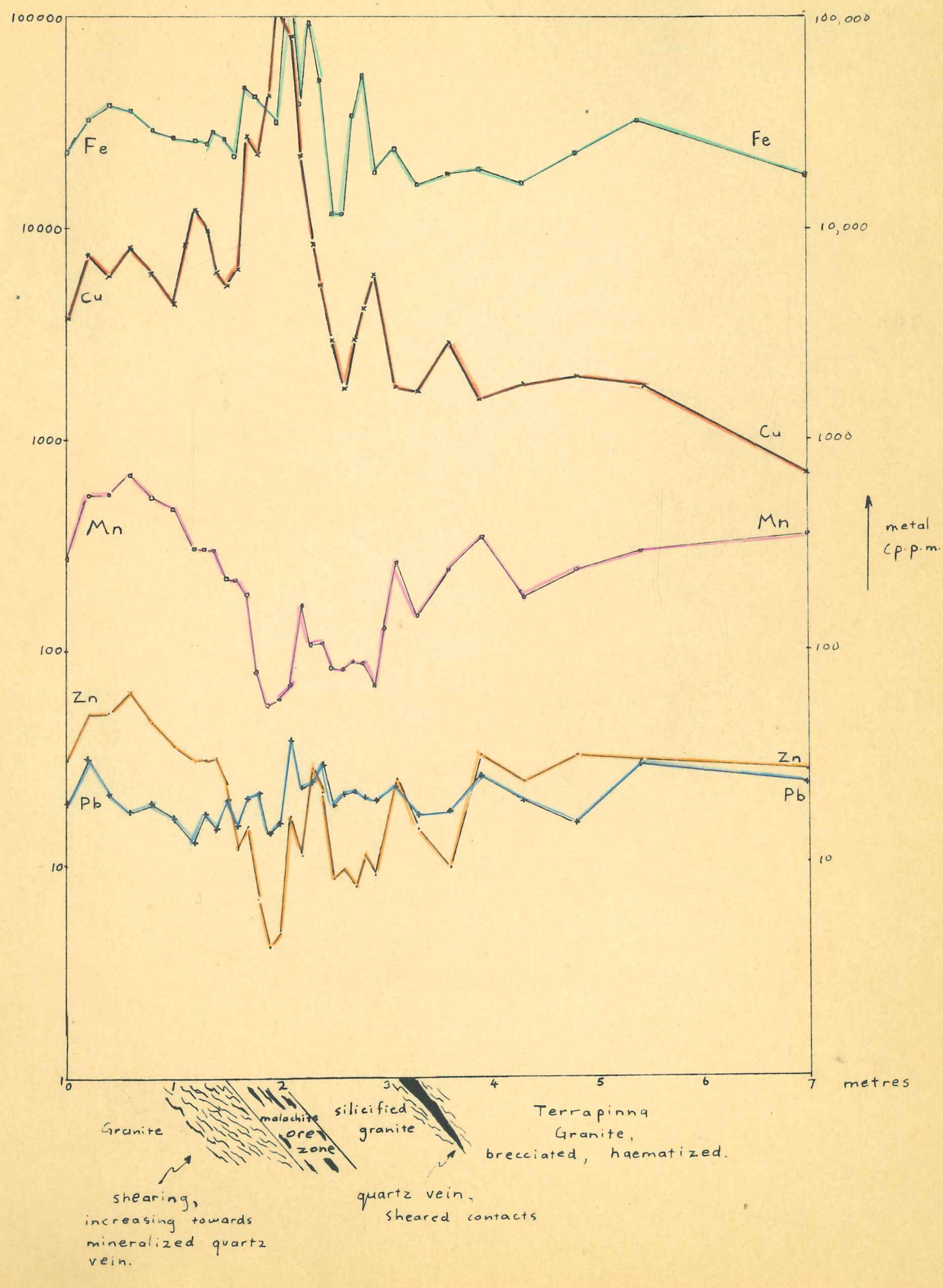
Cu	1				
Pb	-0.060	1			
Zn	-0.336+	0.206	1		
Fe	0.616+	0.435+	0.054	1	
Mn	-0.362+	-0.019	0.868+	-0.183	1
	Cu	Pb	Zn	Fe	Mn

+ denotes significant correlation at the 95% level.

The correlation coefficients show the presence of two distinct metal associations, these being an Fe - Cu association related to ore bearing solutions, and a Zn-Mn-(Pb) association characteristic of the Terrapinna Granite host rock.

Figure 6·3

Traverse P1



The statistical independence of Cu from the Pb-Zn-Mn distribution of the Terrapinna Granite (as shown by the negative correlation coefficients) tends to negate a base metal origin by lateral secretion of metals from the granite adjacent the ore zone. In unmineralized areas, the Terrapinna Granite has a statistical tendency for Cu to positively correlate with Pb, Zn, Mn and Fe (see Appendix 6.2), though only at low significance levels. This contrast of correlation coefficients from mineralized and unmineralized environments clearly indicates the copper mineralization is unrelated to the host rock, and so must be an epigenetic addition to the host Terrapinna Granite.

Probability Distribution　　　　see Fig. 6.6

The probability distributions of the elements indicate :-

(1) 75% of the Cu distribution is associated with a mineralization population.

(2) Zn and Mn have very similar distributions, as well as being highly correlated.

(3) basically, Pb and Fe both have unimodal distributions, though poorly represented upper populations do occur. However, it would have seemed logical to expect Fe to have a significant upper population associated with the mineralization, though the observed unimodal Fe distribution is not surprising in view of the Fe correlation with unimodal Pb.

6. <u>Geochemical Traverse</u>　　　　see Fig. 6.3

From the geochemical profile, it can be seen that Cu exceeds background values by a factor of about 100 for all of the traverse, so indicating lateral secretion from the sheared ore zone granites was not the base metal source. Along the traverse, Zn and Mn values are similar to background Terrapinna Granite values, but show a marked depletion within the ore zone. Although this feature is most likely due to Mn and Zn being depleted in the ore solutions, secondary weathering effects cannot be discounted.

Away from the ore zone, Pb and Fe values are close to or slightly higher than background, with a weak Pb and very strong Fe peak occurring over the mineralized vein.

GROUP A : BASEMENT ZONE OF STRONG SHEARING

Traverse H1 see Fig. 4.1

This traverse is representative of the mineralization in the Hamilton Mines area. The ore vein occurs almost on the basement-cover contact, and is also adjacent to a strike-slip fault zone.

1. The host rock type is weathered and jointed Mt. Neill Granite.

2. Structural data

   The mineralized vein dips 68° towards 158° (approximately a Set I shear orientation, see Fig. 4.2e). Shearing within the host granite is moderate, being approximately 70° towards 170°.

3. Structures at the vein contact

   The footwall vein contact with the host granite is strongly sheared and brecciated, whereas the hanging wall contact is sharp and essentially unsheared.

4. Alteration effects

   Extensive haematite (goethite) alteration has developed in association with the mineralization, especially at the vein margin.

5. Statistical data

Correlation Coefficients

Cu	1				
Pb	0.875+	1			
Zn	0.844+	0.815+	1		
Fe	0.862+	0.793+	0.715+	1	
Mn	0.689+	0.754+	0.782+	0.616+	1
	Cu	Pb	Zn	Fe	Mn

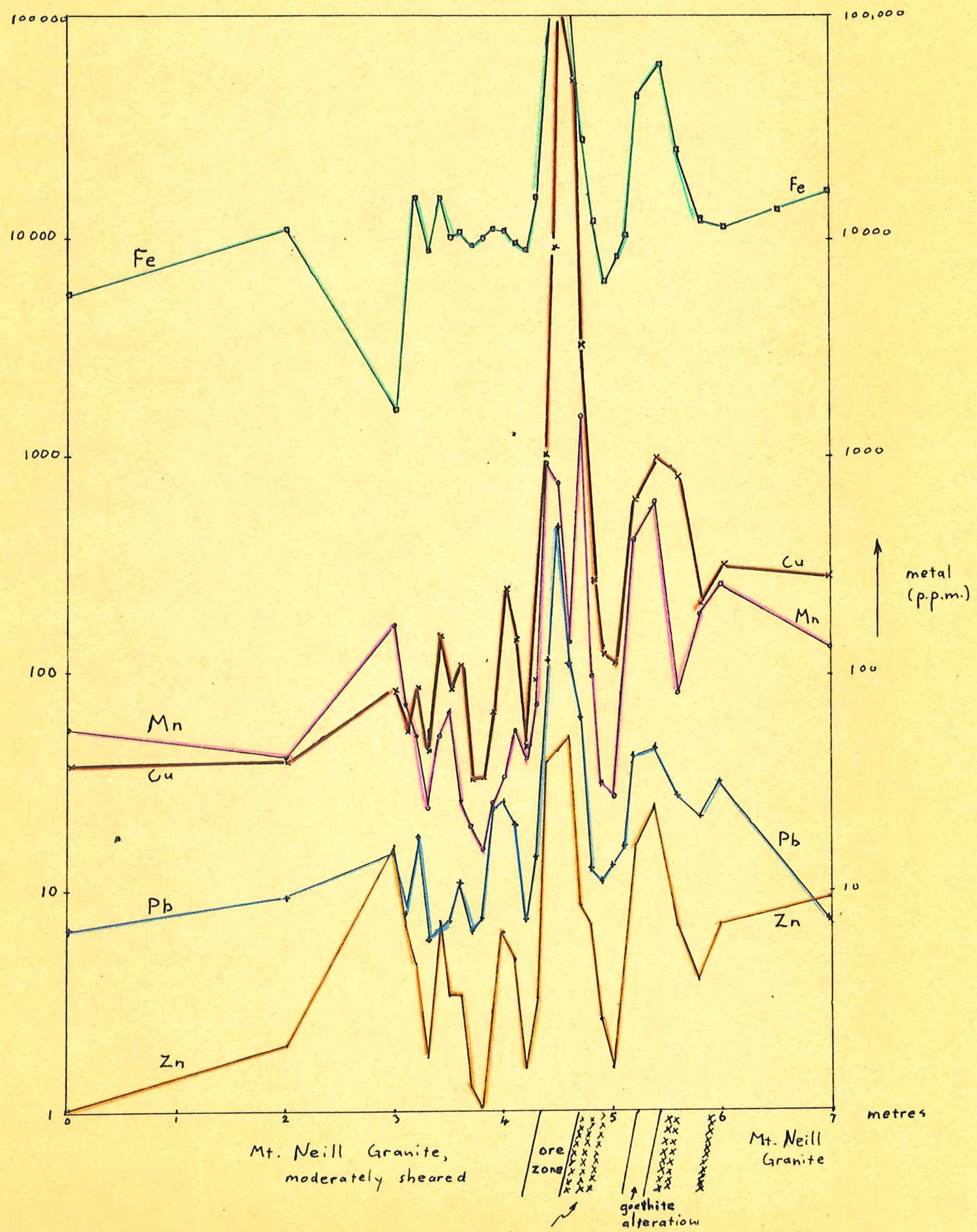
+ denotes significant positive correlation at the 95% level.

These coefficients indicate a very strong positive correlation between Pb, Zn, Fe and Mn, which is also a very distinctive correlation characteristic of malachite ore samples taken throughout the project area (see Appendix 6.2). Somewhat similar correlation characteristics are also found for unmineralized basement granites. In Traverse H1, the observed positive correlation of Pb, Zn, and Mn with Cu is most uncommon and quite difficult to account for. Generally for vein traverses, there is a negative correlation of Cu with Pb, Zn and Mn, so that Cu can usually be interpreted as an epigenetic addition to the host rock Pb-Zn-Mn distribution. In traverse H1 though, the excellent correlation between Cu and the other base metals which constituted the mineralizing solutions could suggest that the ore solutions as sampled at H1 are essentially undifferentiated. There had possibly been insufficient solution migration through reactive host rocks to modify the geochemistry of the ore solutions.

In calculating correlation coefficients, metal contributions from the host granite and the mineralized vein are superimposed. For traverse H1, the base metal characteristics of the granite and the mineralization are similar enough to result in highly positive correlation coefficients. This may possibly imply

Figure 6.4

Traverse H 1



a genetic relation between mineralization and basement granites. Alternatively, base metals within the granite may have been remobilized during the emplacement of the mineralized vein, so that a more uniform redistribution of base metals resulted.

Probability Distribution see Fig. 6.6

All elements show some influence of an upper mineralized population. The inflexion point of the distribution for all elements occurs between 60% and 80% cumulative frequency. This indicates all elements were present to some degree within the ore solutions.

6. Geochemical Traverse

The size and width of the Cu peak indicates that the mineralization could not have been derived by lateral secretion from the adjacent granite. The ratios of Cu:Pb, Cu:Zn, Cu:Fe and Cu:Zn are generally very constant along the traverse, even at the very cupriferous vein margins. However, over a 20 cm. distance corresponding to the maximum malachite concentration, these ratios all show a very sharp increase to at least 100 times their normal value.

It is interesting to note that the wall rock anomaly associated with the mineralized vein conforms to the logarithmic dispersion proposed in text books such as Hawkes and Webb, 1962.

A further example of Group A mineralization in the Hamilton Mines area is discussed in Appendix 6.3

GROUP B : STRIKE-SLIP FAULT ZONE

Traverse F1 see Fig. 4.1

This traverse is representative of the "north-south" trending quartz-malachite veins and zones of silicified granite which occur extensively in the area of the Hamilton and Mt. Fitton (South) Mines. Within this area, mineralization has a definite spatial association with strike-slip fault zones (see Fig. 4.1). Tailing samples from mine shafts often include haematized, slickensided ore specimens, which tends to confirm this fault association. Mineralization also occurs in narrow zones of very strong shearing which are associated with the quartz veining. These zones trend between 360° and 030°, and are generally parallel to the trend of the strike-slip faults. Malachite is often associated with the strongly sheared granite of these zones.

Copper mineralization occurs as a primary association within quartz veins, and as mineralization localized within quartz vein joint planes. Minor primary sulphides are also associated with the quartz veins.

1. The host rock type of the F1 mineralized vein is weathered and jointed Mt. Neill Granite. The vein can be traced into the basal granite tillite.

2. Structural data

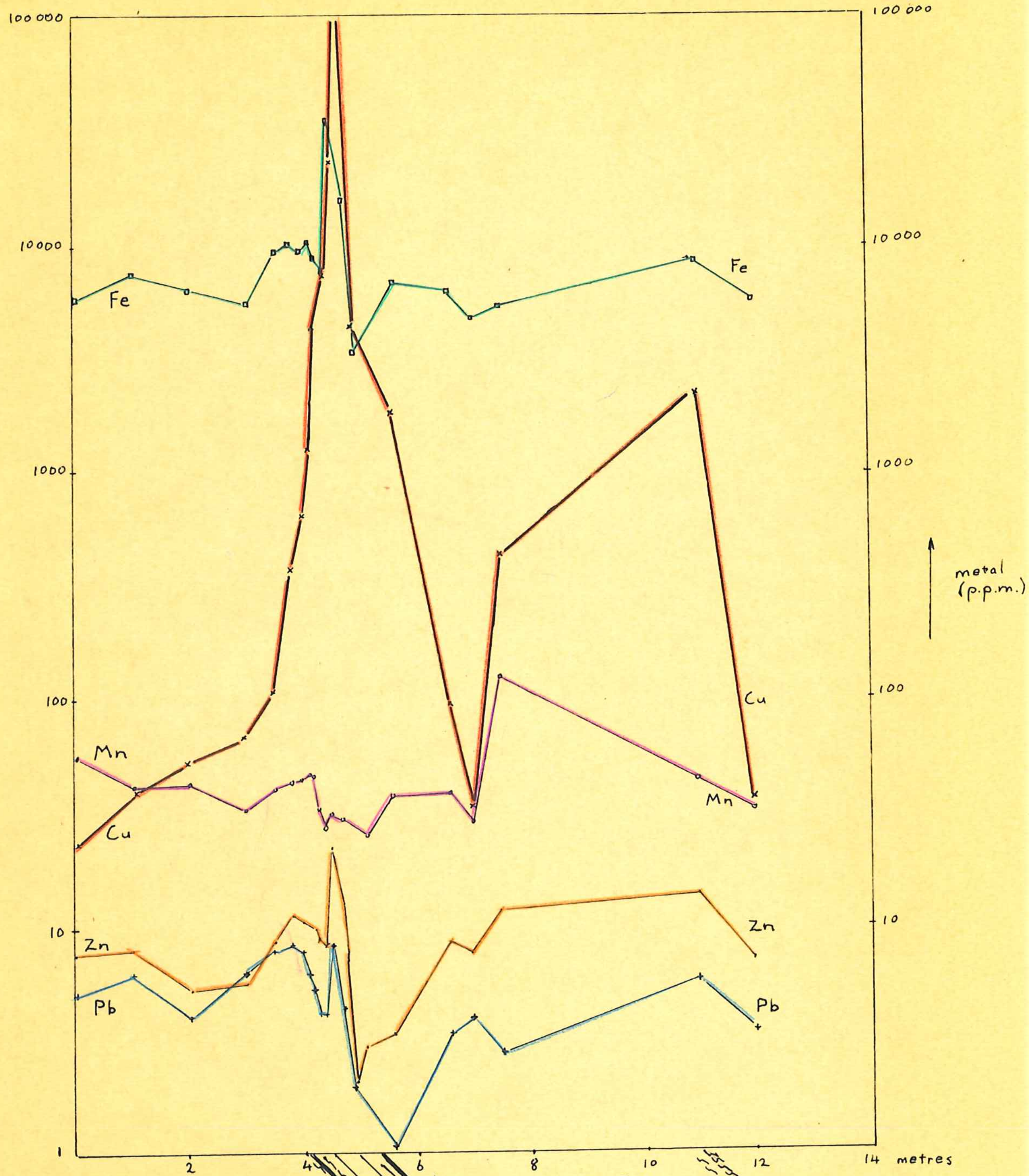
The quartz-malachite vein at the traverse site dips 46° towards 100°, although elsewhere along the quartz vein, dips of 35° towards 120° were recorded on the mylonitic sheared granite adjacent the quartz vein. The host granite is moderately to strongly sheared 70° towards 163°.

3. Structures at the vein contact

The contact granite is very strongly sheared (mylonitic), with stringers of quartz vein being incorporated within the shear planes.

Figure 6·5

Traverse F 1



4. Alteration effects

The host granite is strongly silicified, with the hanging wall contact also being kaolinized.

5. Statistical data

Correlation Coefficients

Cu	1				
Pb	-0.049	1			
Zn	0.243	0.740^{+}	1		
Fe	0.498^{+}	0.459^{+}	0.691^{+}	1	
Mn	-0.305	0.209	0.427^{+}	0.008	1
	Cu	Pb	Zn	Fe	Mn

$^{+}$ denotes significant correlation at the 95% level.

The correlation between Pb, Zn and Mn is probably a feature of the Mt. Neill Granite metal distribution (see Appendix 6.2). Significant correlation between Fe and Cu is due to these elements being the major components of the ore solution (Lepeltier, 1969, has noted that elements constituting mineralization often show good correlation).

Probability Distribution see Fig. 6.6

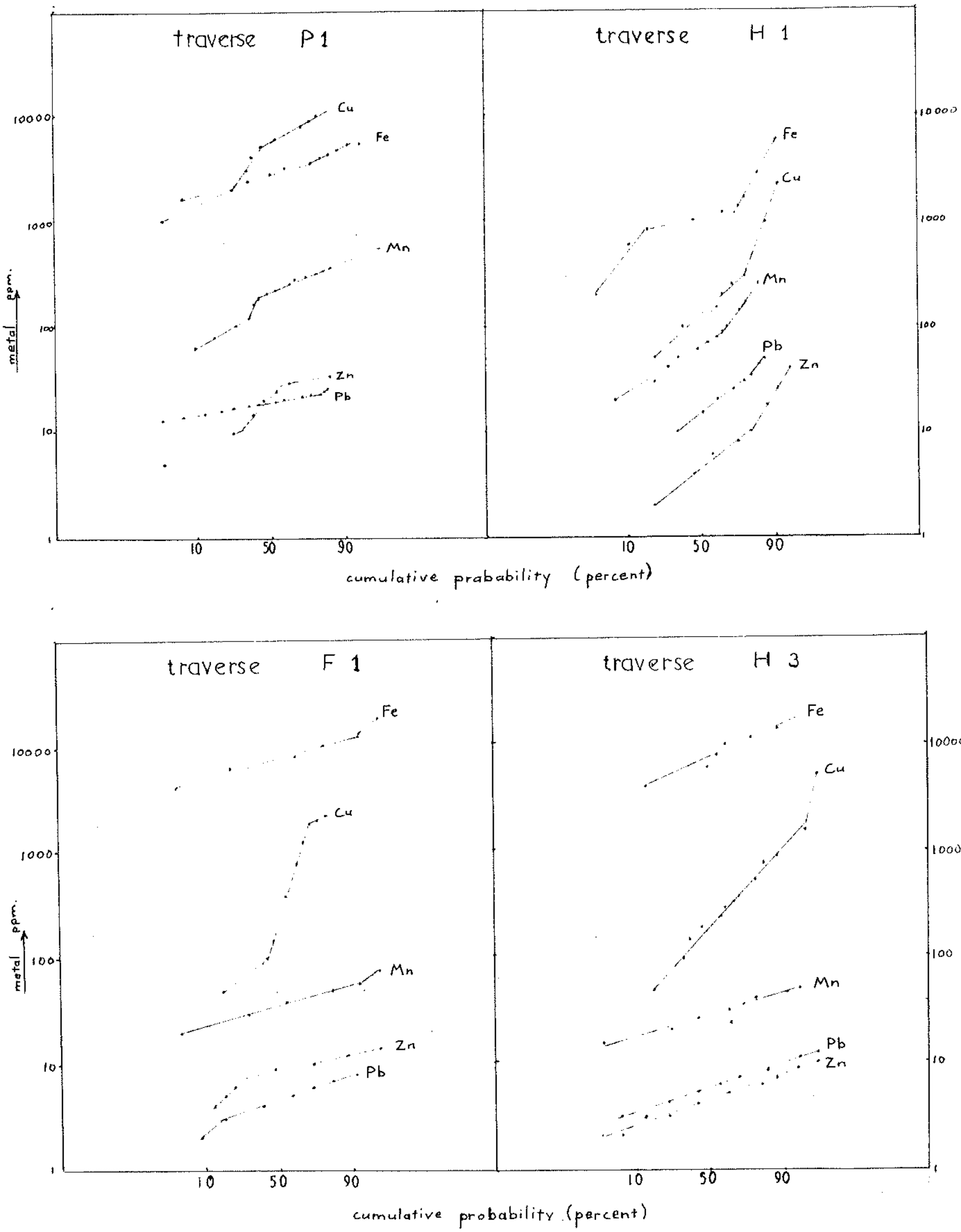
Pb, Zn, Fe and Mn have unimodal distributions characteristic of the host granite. The Cu distribution contains a mineralized upper population (this may also be the case for Fe).

6. Geochemical Traverse

The Cu and Fe profiles clearly show the mineralization was not derived by lateral secretion from the adjacent granite. Pb, Zn and Mn show depletion in the altered margin adjacent the mineralization.

Figure 6·6

Cumulative Frequency Distributions



GROUP B : MINERALIZATION WITHIN THE COVER

On the northern bank of Hamilton Creek, copper mineralization occurs in quartz veins within the basal granite tillite. The quartz veining (and hence mineralization) is related to strike-slip faulting.

Minor malachite shows and gossans elsewhere in the cover are also associated with the strike-slip fault zones.

GROUP C : <u>MINERALIZATION WITHIN FOLIATION AND JOINT PLANES</u>

This association is of minor significance, since the mineralization is usually of a very low grade (less than 0.2% Cu). However, in the Hamilton Mines area in particular, this type of mineralization is frequently pitted.

Group C mineralization is commonly localized in granites near the cover contact, and is often adjacent to strike-slip faults, though exceptions to this are quite common. Mineralization of the Group C type is most common in the Hamilton Mines area, and is also often associated with breccia zones in the Pinnacles Mine area. In most cases, Groups A and B mineralization have associated malachite of the Group C environment.

Chapter 7

THE RELATION OF METAMORPHISM AND METASOMATISM TO ORE GENESIS

In Chapter 5, possible sources of the mineralization were considered. Discussion was limited to an appraisal of the base metal geochemistry of specific lithology types occurring within the project area. In this present Chapter, sources of mineralization are examined on a more regional scale, and metamorphic and metasomatic effects on ore genesis are considered.

7.1 METAMORPHISM

The cover succession has been regionally metamorphosed to between greenschist and albite-epidote-amphibolite facies. Pelitic sediments of the Fitton Formation (see Appendix 3.1) were metamorphosed to granoblastic assemblages of quartz and biotite, with varying amounts of chlorite, calcite, clinozoisite and muscovite. The metamorphic environment was essentially free of directed stress, so that "hornfelsic" textures are predominant.

7.2 METASOMATISM

In the west of the project area, the lower five units of the Fitton Formation have been extensively scapolitized, though towards the east, this scapolitization progressively decreases with distance from the basement-cover contact. The amphibolites of Units 2 and 3 (see Appendix 3.1) may also be of a metasomatic origin, having formed at the same time as the scapolite metasomatism of the lower Fitton Formation. Despite the fact that calcareous interbeds occur in Units 5 and 6, no amphibolites were recognized in sediments further than Unit 4 from the basement contact.

It appears that scapolite (and amphibolite?) metasomatism is spatially related to the basement-cover unconformity. Within the Fitton Formation, the metasomatic "aureole" adjacent the unconformity is best developed near the Mudnawatana Granite (Fig. 51, Coats and Blissett, 1971). The scapolitization progressively decreases towards the east, with the most easterly scapolite occurrence being near the Hamilton Mines area (this also approximately corresponds to the most easterly occurrence of basement-cover contact mineralization).

7.3 THE ORIGIN OF THE ORE BEARING FLUIDS

1. Solution migration within the Fitton Formation

Pervasive solution migration has occurred within the cover sediments. This is evidenced by :-

(1) scapolite (and amphibolite) metasomatism (Chapter 7.1, 7.2)

(2) silicification and haematization of all breccia zones (Chapter 5.3)

(3) feldspathization occurring in association with arkosic conglomerates (Appendix 3.1, Unit 2)

- In the Mt. Shanhan area, siltstones in a 50 cm. zone adjacent an arkosic conglomerate have been feldspathized and silicified. Minor malachite is associated with the altered zone.

These solution effects almost certainly have a genetic relation to the ore forming processes.

2. Origin of the solutions, and possible sources of the mineralization

Two possibilities may be considered, these being :-

a. metasomatic fluids associated with the Ordovician Mudnawatana Granite.

b. metamorphic fluids associated with the Lower Palaeozoic regional metamorphism.

2a. Magmatic Fluids

From studies mainly in the Daly - Yudnamutana area, Coats and Blissett (1971) concluded that the Mt. Painter mineralization is associated with pneumatolytic and hydrothermal activity related to the Ordovician Mudnawatana Granite.

In the southern part of the Mt. Painter Block, late stage magmatic activity is evidenced by the presence of sodic granites, albitites, aplites and pegmatites. Within the cover Callanna Beds, hydrothermal activity is shown by the presence of widespread quartz (and tourmaline) veining. Metasomatic chalcopyrite, pyrite, magnetite and micaceous haematite are also present. Primary metallic minerals within the area are said to be derived from the Mudnawatana Granite (Coats and Blissett, 1971).

Within the Mt. Fitton South area, there is no evidence of Ordovician late stage magmatic activity, although a minor quartz-tourmaline vein was recorded. However, metasomatic activity, as evidenced by the scapolitization, was active within the area. A process could be visualized whereby an advanced front of granite-derived metasomatic fluids migrated along the basement-cover unconformity. Mineralizers within such fluids may have included sodium and chlorine, which would account for the scapolite metasomatism. It is of interest that Wooltana Volcanics may occur at depth on the basement-cover unconformity. These volcanics may show copper enrichment (see Table 14, Coats and Blissett, 1971), so that metasomatic fluids passing through them would constitute potential ore forming solutions.

2b. Metamorphic Fluids

Solution movement may have been a result of regional metamorphism, with base metals and silica being mobilized and concentrated by metamorphic fluids.

Metamorphism within the basement granites

Within the basement, there occurs extensive quartz veining, which is probably associated with the retrograde metamorphism within the basement. D. Young (1973) has found the quartz veining in the area east of the writer's project area to be essentially parallel to the retrograde foliation.

During changes in metamorphic grade, metals may be released from unstable phases (De Vore, 1955). Such metals may then be concentrated in volatile fluid phases, and localized in suitable structures. Such an origin could be postulated for the minor copper showings which occur throughout the Mt. Painter basement, especially within retrograded Brindana Schists.

Metamorphism within the cover

During regional metamorphism, meteoric and connate waters may become activated (Gray, 1959; Sullivan, 1954) so that sulphide transport can occur within the resulting aqueous phases (Marmo, 1960).

Throughout Units 3, 4 and 5, massive non scapolitic pyritic (probably syn-diagenetic) siltstones occur as irregular lenses within cleaved, scapolitic shaly silts. The scapolite metasomatism (and cleavage development) may have mobilized sulphides and metals from the sediments. "Ore-type" solutions were probably active throughout the Fitton and Bolla Bollana Formations, since cover breccia zones are generally haematized and silicified.

The origin of the ore bearing fluids cannot be stated with any certainty. Metamorphic mobilization is definitely viable for the Mt. Fitton South area. However, Coats and Blissett (1971) provide good evidence to show that the Daly - Yudnamutana mineralization is associated with magmatic activity (these authors make no mention of any specific influence of the basement-cover contact on solution migration).

Perhaps the source of the mineralization could be solved by geochemically identifying sulphides from various environments. As an example, the S:Se ratios of the contact mineralization could be compared with S:Se ratios from cover sedimentary sulphides, basement copper shows, and Ordovician pegmatite sulphides. Such a method would only work if Se and S fractionation had not occurred.

Chapter 8

SUMMARY AND CONCLUSIONS

This study has examined the influence of the geological setting on mineralization occurring in the Mt. Fitton South area. Three major controls on mineralization were recognized. In decreasing order of importance, these controls are as follows :-

1. The basement-cover contact

   Mineralization is spatially associated with the basement-cover unconformity. Migration of the ore bearing solutions, as well as the scapolite metasomatizing solutions, was probably controlled by the unconformity.

2. Structures associated with the Lower Palaeozoic deformation

   The mineralization and associated quartz veining were introduced during the Lower Palaeozoic faulting and shearing. The structural environment during ore localization was one of high stress and temperature, as is evidenced by the granite occurring at a quartz vein contact often being incorporated into the vein, thus resulting in a hybrid quartz vein-granite rock.

3. Localization with basement granites

   Quartz veining and mineralization tend to be restricted to the basement. It appears that the granites respond to fault deformation in such a way as to make them favourable environments for ore localization. Alternatively, the association of mineralization with the basement may indicate that the ore bearing solutions were generated during the metamorphism of the basement granites. Although quartz veining occurs throughout the entire basement, the veins are generally only mineralized when within 200 metres of the basement-cover contact (with a notable exception being the Pinnacles mine).

Nature of the mineralizating solutions

The ore bearing solutions consisted mainly of Cu, Fe and silica, with minor Zn. In general, these solutions were depleted in Pb and Mn.

The geochemical profile along the Pinnacles breccia zone (see Fig. 6.1) suggests that the mineralizing solutions were introduced as a series of "pulses" which were of variable base metal composition. Statistical data confirms the variable nature of the ore solutions.

Mt. Painter Copper Mineralization

The style of copper mineralization within the Mt. Painter Province is quite unique. A literature search revealed examples of the Pinnacles-type mineralization (Kazansky, 1972), but no close analogies could be found to the situation where an unconformity controlled mineralization in the manner postulated for the Mt. Fitton South area.

ACKNOWLEDGEMENTS

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Appendix I

The following Apendices represent those cited in the main text of the Thesis. Apart from Appendix 4.1 (and to a lesser degree, Appendix 3.1), all Appendices are related to aspects of mineralization.

Appendix 3.1

This appendix presents the evidence to substantiate the environmental interpretation given in Chapter 3. Each unit has been separately described, and an environmental interpretation made on the basis of these lithological descriptions. Provenance and palaeocurrent directions are also discussed.

Appendix 3.1 is relevant to sections of Chapter 7 in which metamorphism and metasomatism are discussed.

UNIT ONE

The base of this unit is characterized by a grey green phyllite (usually pebbly), which passes gradationally into either a pebbly, schistose-matrix conglomerate, or into a massive granite diamictite. Within the diamictite, there variously occur interbeds of fine to coarse grained quartzites, thin epidote bearing quartzites, meta-siltstones, finely laminated phyllites and well bedded gritty sandstones which may show graded bedding. Boulders within the diamictite are typically white, medium to coarse grained, microcline granites. Maximum megaclast size is 3 metres, with the median size being between 10 and 50 cm. Within the basal 10 metres of the diamictite, the megaclast lithology shows a good correlation with the lithology of the adjacent, underlying basement. With increasing distance from the basal unconformity, more exotic megaclasts become predominant, and boulders derived from local Terrapinna Granite source areas rarely occur.

Where the granite diamictite occurs in palaeo basement depressions, for example east of Mt. Shanahan, there is an increase in the size and number of boulders.

Interpretation

The presence of exotic granite boulders up to 3 metres and the occurrence of unsupported megaclasts suspended in a fine grain structureless matrix could indicate either sub-glacial deposition (Harland et al, 1966) or deposition from a near shore subaqueous mudflow (Dott, 1963).

PLATE A1

Unit 1 Granite Tillite

A. Boulder of massive, unfoliated Terrapinna Granite within a structureless phyllite matrix.

B. Typical outcrop of the Granite Tillite showing alternating layers of massive and pebbly phyllite. Minor varved phyllites may be seen adjacent the granite boulder in the centre of the photo.

C. Typical occurrence of a granite boulder within a phyllite matrix. The phyllite cleavage has been deflected around the boulder.

D. Varved and pebbly phyllites occurring in a 60 metre phyllite lens within the massive Granite Tillite. Possibly dropstones occur within these phyllites.

PLATE A1

A

B

C

D

In support of a glacio-marine or glacio-lacustrine environment is the presence of interbeds ranging from graded bedded coarse sands to finely laminated "varve-like" phyllites which contain pebbly and cobbly horizons, and possible dropstones (see plate A1).

The basal 10 metres, with its very localized clast provenance, may represent terrestrial glaciation, though there is an absence of striated and faceted flatiron boulders. Environments such as a talus scree deposits can be discounted by the degree of megaclast rounding, while sub-aerial landslide and solifluction deposits would not be expected to have interbedded sub-aqueously deposited phyllites and quartzites.

The unit may be a shoreline conglomerate, having resulted from a marine transgression and onlap towards the south west (G. Mortimer, pers. comm.). However, there is an absence of current reworking within the massive granite diamictite, and deposition of the massive horizons by aqueous flow seems unlikely.

UNIT TWO

This unit is a massive, indurated, black matrix diamictite, with a thickness varying between 40 and 100 metres.

The basal 10-15 metres of the unit is a non pebbly dark shale in which occurs the first development of scapolite and actinolite within the Fitton Formation. In contrast to the underlying granite tillite, the black matrix diamictite is completely structureless, and without any laminated interbeds.

The dominant granite megaclasts are of Mt. Neill granite porphyry and a white granite similar to that occurring within the granite tillite. Minor Terrapinna Granite boulders up to 1 metre are also present. The megaclasts are sub-angular to sub-rounded, and show no faceting or striations. The diamictite matrix is a dark, quartz-biotite meta-siltstone, which differs from the granite tillite matrix by its non-schistose nature.

The top of Unit 2 is a distinctive white feldspathized arkosic conglomerate, with minor (less than 5%) black amphibolite clasts. This bed is laterally continuous for 8,000 metres.

Interpretation

The angularity and freshness of granules within the matrix could support glacial deposition from grounded shelf ice (Reading and Walker, 1966). In limited outcrops, megaclasts occur as boulder trains and nests of boulders. Pebbles of feldspar and quartz, and granite megaclasts, are completely separated by a fine matrix, so that no current reworking has occurred, and current transport of the clasts was not operative.

Transport by mass movement, such as a sub-aqueous mudflow, could also be considered. However, the diamictite shows intertonguing relations with Unit 3 siltstones which contain possible dropstones, so a glacial origin is favoured.

UNIT THREE

This unit consists of quartz-biotite meta-siltstones in which scapolite and actinolite are well developed, especially in the upper beds of the unit. Fine grained recrystallized orthoquartzites and actinolite and epidote bearing quartzites are also common. Interbedded within the meta-siltstones are sedimentary amphibolites containing coarse grained decussate actinolite and tremolite in a recrystallized carbonate matrix. Within Unit 3, there occurs an arkosic conglomerate which has been designated a sub-unit. A distinctive feature of Unit 3 is the presence of well developed laminations and thin bedding. Gritty laminae and pebbly horizons commonly occur within the laminated silts. However, only minor clasts which could be interpreted as dropstones were found within the laminated beds.

PLATE A2

A. Typical outcrop of the Unit 4 diamictites. Clasts are predominantly subrounded quartzites. The diamictites usually occur as irregular lenses within poorly outcropping, cleaved meta-siltstones.

B. Massive diamictite of Unit 4 showing characteristic sub-alignment of the clast long axes.

C. Thin interbed of current reworked pebbly siltstone within Unit 5. Note the graded bedding.

D. Dropstone within the laminated silts of Unit 3. These dropstones, though quite rare, show the glaciogene influences within the Fitton Formation.

PLATE A2

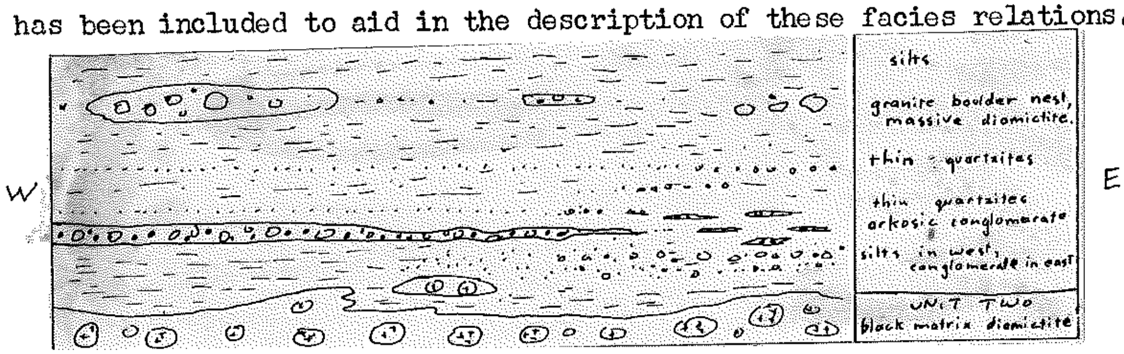
A

B

C

D

Interesting facies changes occur within this unit, so a schematic section has been included to aid in the description of these facies relations.



The sediments in the lower half of the unit show an increase in grain size along strike towards the east. In the west of the project area, laminated meta-siltstones occur at the base of Unit 3. At a locality midway between Mt. Shanahan and Harrison Well, these silts intertongue with lenses of a diamictite very similar to the Unit 2 black matrix diamictite. Possible dropstones occur, but are always associated with pebbly beds (see plate A1). The silts grade laterally into a yellow, medium grained argillaceous sandstone, which becomes increasingly pebbly towards the east, ultimately resembling the arkosic conglomerate sub-unit with respect to clast size and lithology.

This arkosic conglomerate is a very distinctive horizon, which ranges in thickness from 20 metres in the west to 5 metres in the east. In better outcrop, the conglomerate is seen to have a gradational contact with an underlying quartzite, the transition being via a pebbly quartzite. The conglomerate contains abundant well rounded quartzite boulders, as well as silicified dark shale clasts and the granite boulders characteristic of the lower two units. It differs significantly from the lower diamictites by its lack of a fine grain matrix.

Towards the top of Unit 3, laminated and well bedded siltstones are less prominent, and massive pebbly lenses occur. Amphibolites in these upper beds tend to be more massive and less well bedded than those below the arkosic conglomerate. Amphibolitized intraformational conglomerates first occur within the Fitton Formation in these upper pebbly horizons.

In one locality near Harrison Well, a nest of granite boulders, including one of 4 metres diameter, occurs 20 metres above the arkosic conglomerate at a stratigraphic position which elsewhere corresponds to lenses of massive pebbly siltstone. These upper pebbly horizons of Unit 3 typically contain between 5% and 15% sub-rounded quartzite clasts of 1 cm. to 3 cm. diameter.

Interpretation

The laminated and thin bedded siltstones characteristic of Unit 3 represent deposition in a low energy environment. There is a lack of current bedding, so that the parallel stratification represents plane bedding of a low flow regime. Conglomerate interbeds within the laminated silts indicate intermittent influxes of higher energy deposition. These pebbly horizons are laterally continuous, thus indicating marine deposition rather than fluviatile. Similar lateral continuity exists for the fine grain orthoquartzites, though lensing and intertonguing does occur, especially towards the east. In the Harrison Well area, the quartzites become pebbly, with minor cross beds and scour and fill structures, thus indicating shallower, higher energy deposition towards the east of the project area. The arkosic conglomerate and pebbly quartzites are probably shoreline or nearshore conglomerates.

The diamictites occurring in the upper part of the unit may represent sub-aqueous mudflows, initially into a shallow marine environment. Alternatively, the isolated granite megaclasts and quartzite clasts may have been deposited by ice rafting (either from shore ice or from grounded shelf ice).

Within Unit 3 there is a predominance of rounded quartzite clasts. This indicates a different provenance to that present during the deposition of the underlying granite diamictites.

UNIT FOUR

The base of Unit 4 is defined by a massive cobble and boulder horizon which directly overlies an orthoquartzite marker bed of the type common to Unit 3.

The distinctive rock type within the unit is a massive diamictite typically containing between 5% and 20% cobbles and boulders in a pebbly quartz-biotite meta-siltstone matrix. Meta-quartzites are the predominant clast type, with white granite, vein quartz and meta-siltstone clasts also occurring. Morphologically, the clasts are sub-angular to rounded, lack any striations or faceting and are generally less than 10 cm. diameter, though granite megaclasts up to 1 metre do occur. Pebbles and boulders tend to lie flat in the plane parallel to bedding, with their long axes approximately horizontally aligned in an east-west trending plane. This feature is not structurally caused, since the diamictites have not been strongly stressed, as is shown by the decussate alignment of matrix biotite.

In contrast to Unit 3, the meta-siltstones of Unit 4 are poorly bedded, with only minor laminated interbeds. Orthoquartzites, which are very common and laterally continuous in Unit 3, occur in Unit 4 as minor lensing beds of strike length less than 800 metres.

The distribution of cobbles and boulders is very patchy and irregular, with massive boulder beds repetitively occurring as irregular lenses within scapolitic, cleaved meta-siltstones. Though the boulder beds show distinct lensing relationships, these lenses occur at well defined stratigraphic levels. Towards the top of the unit, there is an increase in pebbly horizons, and a general increase in the size and numbers of megaclasts.

In the east of the mapped area, the upper pebbly beds laterally phase into massive shaly siltstones with less than 5% isolated clasts, these clasts typically being 2 cm. diameter, though granite and pegmatite boulders up to 80 cm. occur. In this eastern area, there occur minor current bedded fine grain orthoquartzites and intraformational sedimentary breccias.

Interpretation

Megaclasts are confined to massive beds in which there is an incomplete framework of large clasts. This indicates deposition from a very viscous medium such as a subaqueous mudflow (Crowell, 1957; Landim et al, 1968; Van Loon, 1970). In general, deposition occurred in a quiet, shallow marine environment below wave base. However, intermittent current reworking of the diamictites has occurred, so forming reworked conglomerate beds up to 30 cm. thick in which most fine material has been removed by current activity. High angle cross bed sets within these beds indicate palaeocurrent directions from the west.

Although there is a lack of glacial clasts in the project area[+], subglacial deposition from grounded shelf ice could be a possible origin for the massive diamictites. Sparsely distributed angular clasts, including unweathered shale and muscovite schist cobbles, could indicate subglacial deposition.

The increase in clast size and numbers to the west indicates a source area in this general direction. A subaqueous mudflow being generated on the south-west or west margin of the basin of deposition might be expected to have the observed approximate westerly orientation of the clast long axes.

[+] Honours students G. Ambrose, S. Ashton, A. Belperio and C. Lindsay working on the Yudnamutuna and Yerelina Sub-group glacial sequences 25 kilometres to the south-west of the writer's project area (see figure 1.1) have recorded only rare faceted and no striated clasts.

The cross-bedded quartzites occurring in the eastern outcrops of the unit represent higher energy deposition in a shallow water environment. This shallowing towards the east is shown by Unit 4 being approximately 500 metres thick in the Mt. Shanahan area, and decreasing to 400 metres near Harrison Well.

UNIT FIVE

This unit is characterized by laminated and well bedded meta-siltstones and shales, which are interbedded with gritty and pebbly silts, pebbly quartzites and thin (50 cm. to 2 metres) orthoquartzites. The base of the unit is defined by a prominent, 7 metre thick, fine grain quartzite, which is very similar to the quartzite defining the top of Unit 3. Towards the east, this basal quartzite becomes very lenticular, and is overlain by lenses of similar quartzites, which have scoured contacts with the underlying massive siltstones.

Unit 5 is lithologically similar to Unit 3, with the exception that calcareous siltstones occur rather than the amphibolites of the lower unit.

Current bedding and laminations are well developed within the quartzites and gritty silts, with flaser bedding being particularly common (see plate A3). Conformable intraformational sedimentary breccias, though only minor in the lower units, are very common in Unit 5.

Interpretation

The current bedded quartzites and intraformational conglomerates undoubtedly represent high energy, shallow marine deposition.

Minor massive diamictite lenses are present, probably indicating intermittent influxes of sediments by subaqueous mass flow or from subglacial deposition. Unlike Unit 4, the pebbly horizons are interbedded with laminated sequences, which possibly represent reworked glacial deposits.

PLATE A3

Evidence of current activity

A. Flaser bedding within a Unit 5 orthoquartzite.

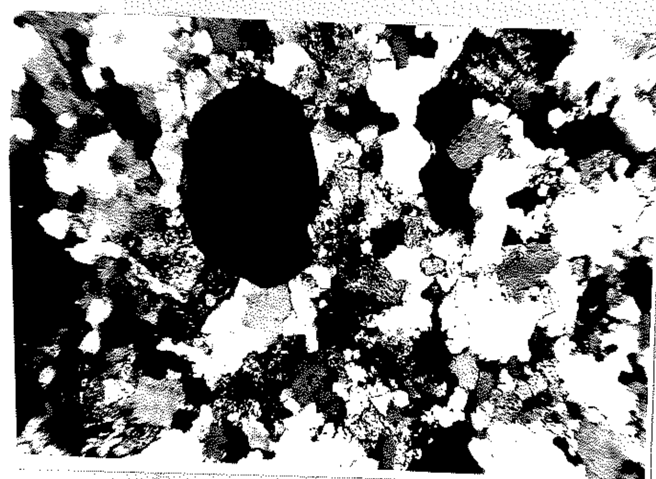
B. A photomicrograph (100x) of a rounded pyrite grain (of possible detrital origin?) within these Unit 5 quartzites. These quartzites consist of recrystallized quartz, biotite and minor calcite.

C. Ripple marks and a current reworked conglomerate lens within a Unit 4 diamictite.

D. A photomicrograph (30x) of a Unit 5 sedimentary breccia containing fresh, angular shale clasts in a fine grained, limonitic shale matrix.

PLATE A3

A



B

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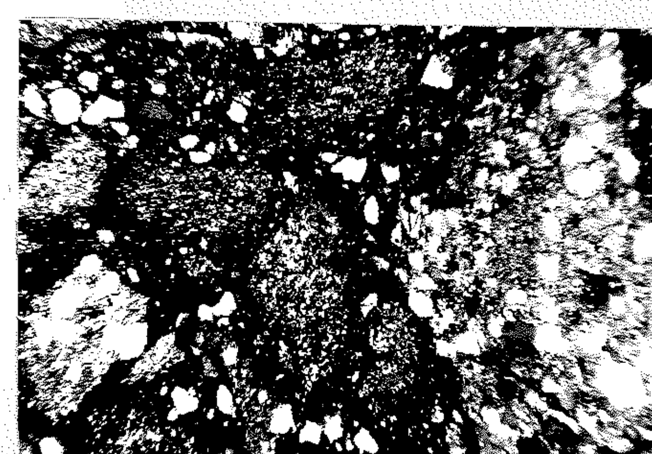


D

Isolated well rounded megaclasts of granite and pegmatite are common within the pebbly conglomerate horizons.

During the deposition of the lower four units, basin subsidence was occurring, so that transgressive onlap to the south-west occurred. The shallow water sedimentation of Unit 5 indicates a decrease in the rate of subsidence, so that the basin was almost filled with shallow water sediments.

UNIT SIX

This unit is sedimentologically very similar to Unit 5, with the major difference being the predominance of quartzites over silts and shales. The basal 100 metres consists of alternating 30 cm. to 1 metre beds of fine grain orthoquartzite and shales. Quartzite interbeds vary from laminated to massive (most common), and often have undulating, scoured bases.

Small scale ripple marks (wavelength = 5 cm., height = 1 cm.) indicate a current direction towards the north. Other significant sedimentary structures include flaser bedding and intraformational shaly sedimentary breccias.

These lower quartzites are overlain by approximately 50 metres of laminated shales containing minor interbeds of fine grain quartzite, pebbly quartzites and pebbly silts. Overlying this predominantly shale sequence is 60 metres of quartzites with interbeds of pebbly quartzite (up to 3 cm. rounded clasts) and laminated and gritty shales. Possible dropstones occur within these pebbly horizons. A distinctive horizon of pyritic massive pebbly siltstone occurs as lenses up to 40 metres thick, which laterally grade with decreasing pebble content into fine grain quartzites.

Intertonguing beds of non-pebbly, laminated shales and pebbly fissile, iron rich shales characterize the top of Unit 6. With an upward increase in clasts, these shales grade transitionally into the boulder rich shales and silts of the overlying Bolla Bollana Formation.

Interpretation

As with Unit 5, the current bedded quartzites and intraformational conglomerates represent high enregy, shallow water deposition, with the interbedded shales indicating lower energy intervals. These sediments may represent sand and mudflats of an intertidal zone. The flaser bedding and the non laminated fine grained quartzites are features associated with tidal flats (Reineck, 1972).

The massive pyritic pebbly siltstone lenses occurring within shallow water quartzites could indicate deposition from an ice sheet in the grounded shelf ice zone. These influxes of very poorly sorted sediment into the near shore environment occur at three separate localities along an eight kilometre strike length.

The presence of glacial influences is also implied by the limited occurrences of drop boulders, which may possibly have been rafted by shore ice (Ovenshine, 1970).

BOLLA BOLLANA FORMATION

The basal Bolla Bollana Formation is a fissile iron-rich shale containing up to 40% subangular to subrounded clasts. Boulders of quartzite up to 1 metre are present, often occurring as trains. Other common clast types include white medium grained, microcline granites, angular to subrounded fresh shale fragments, and yellow weathering dolomites.

Unlike the Fitton Formation, in which the diamictites are massive, the Bolla Bollana boulder horizons occur within moderately well bedded pebbly and gritty shales. Laminated, pyritic black carbonaceous shales are distinctive interbeds within the basal Bolla Bollana Formation. These black shales are common clast types within pebbly horizons. Angular intraformational breccias are quite common within the formation, but are generally absent from the massive diamictites of the Fitton Formation, such as those of Unit 4.

Interpretation

The lenses of massive pebbly silts and sands within the Bolla Bollana Formation, with their large percentage of megaclasts (up to 50%) and wide range of clast size and angularity, probably represent subglacial deposition. Exotic clasts occur much more commonly than in the underlying Fitton Formation. However, exotic clasts of possible Callanna Bed origin (see fig.11) occur infrequently throughout the entire Fitton Formation, from right on the basement unconformity (a very well rounded cobble of scapolitic amphibolite) through to Unit 6 (well rounded dolomite cobbles). The pebbly shales, with their predominance of angular sand grains in a very fine clay matrix (rock flour?), probably represent current reworked glacial deposits. Such reworking is to be expected in a high energy, shallow marine environment. The presence of carbonaceous shales deposited under anoxic conditions need not be contradictory to the postulated shallow, near shore environment (Heckel, 1972).

PLATE A4

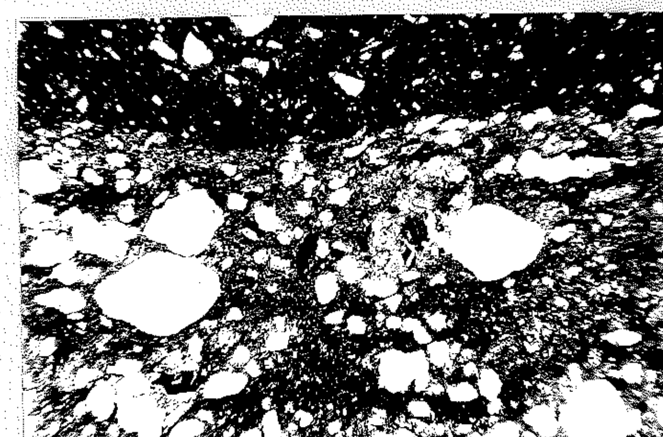
A. A photomicrograph (30x) of an intraformational conglomerate within the Bolla Bollana Formation. Clasts include shale, carbonaceous shale and angular quartz grains.

B. A photomicrograph (30x) of a laminated carbonaceous shale within the Bolla Bollana Formation.

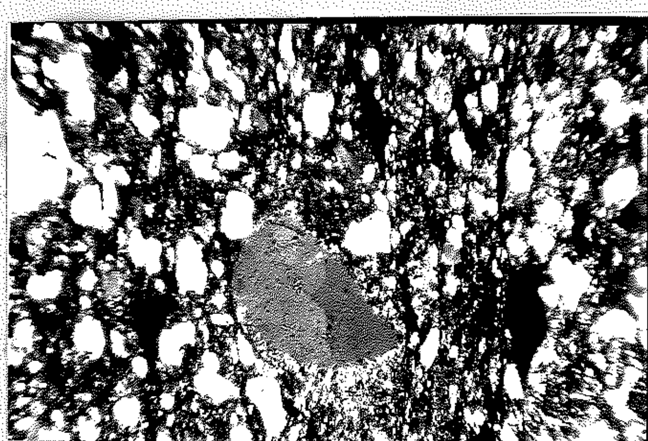
C. A photomicrograph (30x) of a moderately cleaved pyritic shale within the Bolla Bollana Formation. Note the "broken round" quartz grain showing pressure shadow biotite development.

PLATE A4

A



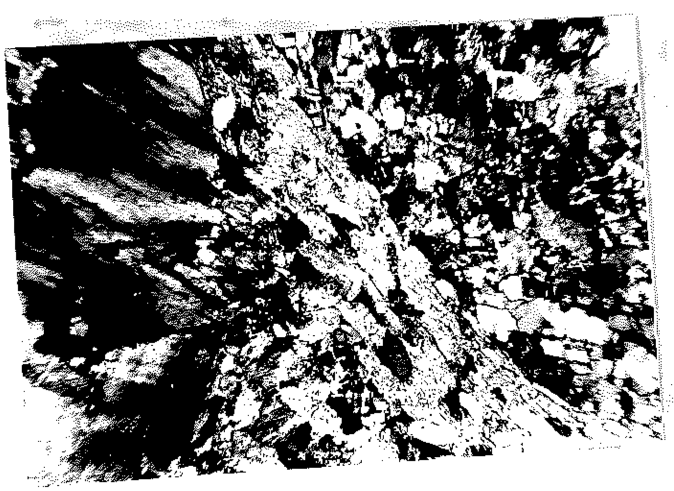
B



C

Petrography of the Mylonites

Quartz-microcline - sericite phyllonite



Ovoidal microcline porphyroclast in a quartz-microcline-sericite groundmass

Appendix 4.1

PETROGRAPHY OF THE MYLONITES

These rocks vary from quartz-sericite phyllonites through to Terrapinna flaser gneisses. The phyllonites have a banded texture, often having recrystallized quartz veins parallel to their schistosity. Any evidence of granulitization is obscured by the complete recrystallization of the quartz - sericite - biotite groundmass.

Dislocation metamorphism of the Terrapinna Granite gives rise to banded, sericitic flaser gneisses which are characterized by microcline and quartz porphyroclasts in a crystalloblastic microcline - quartz - sericite - biotite groundmass. The porphyroclasts have a dimensional preferred orientation, often showing pronounced mineral rodding, and are highly strained, as evidenced by their undulose extinction. The groundmass is completely recrystallized and strain free, and shows a crystallographic preferred orientation, with only sericite and biotite having a dimensional preferred orientation.

Appendix 5.1

Table of

BASE METAL GEOCHEMISTRY

1. Mt. Neill Granite Porphyry, unmineralized areas

Cu	Pb	Zn	Fe+	Mn	Remarks
15.6	10.2	7.4	0.38	56.1	unmineralized background
15.2	10.9	6.6	1.12	19.8	unmineralized background
17.5	8.6	5.9	0.20	11.0	unmineralized background
10.4	10.7	5.3	0.58	32.0	unmineralized background
48.9	7.2	11.9	0.98	52.7	zone of quartz veining
29.3	13.2	8.8	0.54	65.3	moderately sheared
28.2	12.7	6.0	1.51	25.0	strongly sheared
95.7	14.1	17.8	0.50	62.9	strongly sheared
17.0	12.4	8.4	0.45	59.8	silicified
13.0	12.0	3.8	0.24	22.2	silicified
10.0	13.5	2.0	0.24	30.8	silicified & quartz veined
27.4	11.4	7.6	0.61	38.9	mean
25.4	2.1	4.2	0.41	19.1	std. dev.

2. Mt. Neill Granite Porphyry, mineralized areas

Cu	Pb	Zn	Fe	Mn	Remarks
52.0	8.0	6.0	0.72	70.6	within 10 metres of Cu ore
41.8	6.0	1.8	0.81	23.6	within 10 metres of Cu ore
31.3	11.3	1.4	0.86	19.6	within 10 metres of Cu ore
32.3	6.8	1.0	0.93	15.2	within 10 metres of Cu ore
37.9	7.3	2.1	1.00	41.0	within 10 metres of Cu ore
35.9	6.8	1.0	0.56	57.4	within 10 metres of Cu ore
24.1	7.6	5.2	1.25	20.0	within 10 metres of Cu ore
47.7	8.7	8.4	1.09	43.1	within 10 metres of Cu ore
34.8	6.0	3.6	1.20	17.9	within 10 metres of Cu ore
55.1	4.3	8.2	0.72	48.5	within 10 metres of Cu ore
22.8	5.0	7.5	0.61	56.5	kaolinized
39.0	6.1	8.0	0.74	39.2	kaolinized
51.4	4.1	5.2	0.62	41.7	kaolinized
36.9	3.5	7.1	0.58	31.9	silicified
39.0	6.5	4.8	0.83	38.0	mean
10.0	2.6	2.9	0.22	16.0	std. dev.

+ In these base metal tables, Fe is listed as weight percent; Cu, Pb, Zn, Mn are in p.p.m.

3. Fine grained Mt. Neill Granite Porphyry

Cu	Pb	Zn	Fe	Mn	Remarks
15.9	9.3	4.5	1.29	26.7	
39.2	5.4	6.1	1.29	34.2	
21.3	6.6	5.5	0.42	26.7	
25.5	7.1	5.4	1.00	29.2	mean
12.2	2.0	0.8	0.50	4.3	std. dev.

4. Aplite

Cu	Pb	Zn	Fe	Mn	Remarks
66.3	21.7	54.8	2.60	22.4	quartz-feldspar dyke

5. Transitional Terrapinna Granite Variants

Cu	Pb	Zn	Fe	Mn	Remarks
40.0	9.7	13.0	1.90	90.7	adjacent breccia zone
40.7	12.4	18.3	0.81	56.4	
5.4	14.6	13.0	2.79	83.3	
6.2	8.6	8.8	0.50	93.1	
8.7	7.7	18.5	0.60	85.6	
5.1	10.2	10.6	0.50	38.0	
17.7	10.5	13.7	1.18	74.5	mean
17.6	2.5	3.9	0.95	22.2	std. dev.

6. Terrapinna Granite

Cu	Pb	Zn	Fe	Mn	Remarks
15.3	12.4	14.0	0.83	69.5	unmineralized background
17.6	25.1	60.5	0.20	283	unmineralized background
15.9	21.6	47.4	1.30	262	adjacent breccia zone
4.3	4.3	40.7	1.20	107	strongly sheared, quartz veined
8.4	5.0	12.0	0.80	65	strongly sheared, quartz veined
280	12.1	25.0	0.90	99	sheared, retrograded
51.4	24.0	56.6	1.80	295	100 metres from Pinnacles mine
132	17.2	38.8	1.30	312	100 metres from Pinnacles mine
18.8	15.4	38.5	1.02	180	mean
16.8	9.5	21.0	0.55	111	std. dev.

7. <u>Haematized and/or Brecciated Terrapinna Granite, Pinnacles Area</u>

Cu	Pb	Zn	Fe	Mn	Remarks
108000	34.1	64.1	5.7	484	
4631	53.3	61.9	4.1	368	
3674	62.3	74.9	3.3	495	
1707	33.4	67.5	8.2	436	earthy haematite from brecciated granite
907	16.7	62.9	4.3	362	feldspar-biotite from brecciated granite
584	18.3	29.0	4.0	152	
304	12.4	29.2	5.2	260	
					The next five samples represent a traverse across a brecia zone.
238	18.3	37.3	2.0	254	granite adjacent breccia zone
384	16.1	22.8	5.8	299	haematite-geothite-quartz
566	13.3	26.9	5.2	222	haematized, brecciated
6673	77.3	23.9	2.9	95	malachite stained
2610	11.5	26.2	3.3	219	sheared granite at breccia zone contact
					note: Zn, Mn show no correlation with Cu.
407	22.0	46.7	5.3	387	
27.6	8.9	24.3	3.9	231	
18.7	16.4	30.9	3.4	323	strongly sheared, haematized
28.9	9.4	31.7	3.2	200	
569	23	50	4.5	306	mean
904	17	38	1.6	145	std. dev.

8. Cover Sediments

Unit	Cu	Pb	Zn	Fe	Mn	Remarks
1	4.6	32.4	81.5	4.5	636	silty shale
	44.7	35.1	66.7	2.3	306	pebbly phyllite
2	27.8	31.5	108.9	3.5	573	black matrix diamictite
3	69.9	22.6	53.5	3.0	485	massive pebbly scapolitic silt
4	24.7	37.7	54.0	2.4	280	massive pebbly quartzose silt
	22.7	25.7	90.2	3.3	470	massive pebbly silt
	51.0	27.4	69.5	3.6	540	shaly silt
5	19.5	29.9	88.0	4.1	548	shale
6	39.0	18.3	9.2	2.8	18.5	pebbly silt
	29.6	51.8	89.1	3.8	605	dark shale
	29.7	23.9	28.7	2.7	412	massive pyritic silt
Pyb	34.6	31.0	70.3	3.0	329	fissile, pyritic pebbly shale
	39.2	27.5	55.9	2.7	368	massive, pyritic pebbly silt
	56.6	16.8	24.5	2.5	736	dark carbonaceous shale
	35.3	29.4	63.6	3.2	403	mean
	16.3	8.8	28.3	0.6	189	std. dev.

Pyb denotes Bolla Bollana Formation

9. Brecciated Cover Sediments from Fault Zones

Unit	Cu	Pb	Zn	Fe	Mn	Remarks
1	37.2	13.1	19.1	6.2	225	brecciated, haematized silt
2	9.8	13.9	20.1	9.0	452	brecciated, haematized diamictite
	221.6	32.7	53.5	4.1	397	brecciated, haematized diamictite
3	126.8	12.3	17.9	4.3	250	brecciated, haematized sandstone
	94.6	25.3	59.6	7.1	441	brecciated, haematized quartzite
	90.0	74.9	60.2	5.2	1485	brecciated sandstone
	4.2	23.3	54.2	4.7	962	brecciated shale
4	32.0	15.3	30.5	4.4	506	brecciated shale
	16.5	11.2	66.7	2.6	225	non-brecciated shale adjacent previous sample
	397.1	33.3	22.4	19.8	117	gossan associated with brecciated quartzite
	73.3	20.8	14.0	4.2	362	cover continuation of Pinnacles fault zone
5	5.2	24.2	31.7	3.3	637	cover continuation of Pinnacles fault zone
	10.1	26.1	50.6	3.2	539	breccia zone
	17.1	31.1	53.7	7.4	508	haematized breccia zone
	296.8	33.6	14.1	8.4	296	gossan in fault zone
6	31.0	12.5	157.0	2.5	573	brecciated ferruginous shale
	21.3	14.3	29.7	5.2	712	brecciated shale
	33.6	113.8	183.0	3.7	9182	brecciated shale
	79.1	33.4	45.1	5.7	1239 +	mean
	123.3	29.2	39.1	4.6	2412	std. dev.

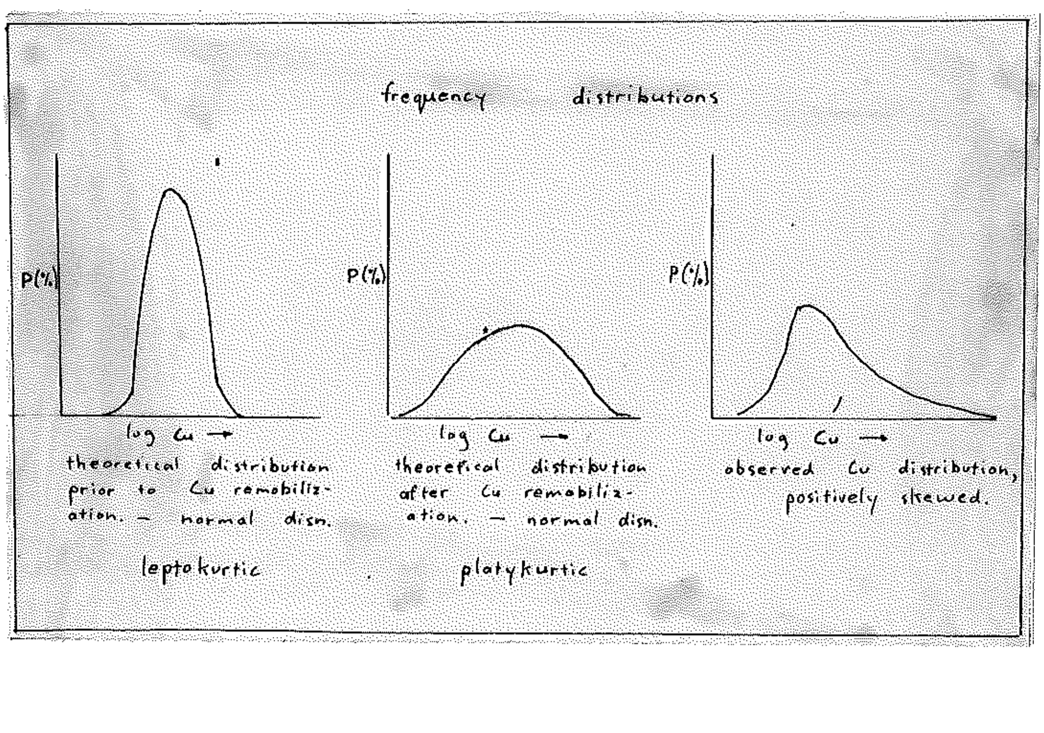
+ If values exceeding 1000 p.p.m. are excluded, the Mn mean = 494, std. dev. = 238.

Appendix 5.2

COPPER WITHIN THE TERRAPINNA GRANITE - PINNACLES AREA

It would be interesting to evaluate whether the anomalous Cu values in the Pinnacles area are a primary feature of the Terrapinna Granite, or whether the Cu is an epigenetic addition.

A cumulative frequency distribution of 493 Cu analyses from the anomalous area was plotted as a possible means of deciding the origin of the Cu. On the theoretical grounds, Cu within the Terrapinna Granite may initially have been homogeneously disseminated and log normally distributed. If mobilization of this Cu into shear zone concentrations did occur, then the Cu distribution within the area would still be expected to be log normal, except that the kurtosis of the distribution would be smaller.



However, the log probability distribution is positively skewed, which possibly indicates that the Cu within the granite is an epigenetic origin.

An example of the use of frequency distributions to evaluate the geochemical processes affecting an element may be found in Cameron and Baragar (1971). These workers were able to distinguish segregated and non-segregated Cu distributions on the basis of positive skewness.

Appendix 5.3

Table of

BACKGROUND BASE METAL GEOCHEMISTRY

	1	2	3	4	5	6	7	8	9	10	11
Cu	57	90	185	120	30-159	27	45	23	30	10	10
Pb	20				18-87	10	20	16	15	19	20
Zn	80						95		60	39	40
Fe+	4.7	3.4	4.1	3.5	1.9	2.2	6.7	5.9	3.0	1.4	2.7
Mn	850	1200	1700	900	400	200	1000	1000	540	390	400

1. Average recent near shore shale; Krauskopf, 1967
2. Antarctic glacial marine sediments, Ross Sea; Angino, 1966
3. Antarctic glacial marine sediments, Amundsen Sea; Angino, 1966
4. Antarctic glacial marine sediments, Bellingshausen Sea; Angino, 1966
5. Ave. Carboniferous marine shale; Spears, 1964
6. Precambrian shelf mudstone; Hirst et al, 1971
7. Shales; Turekian and Wederpohl, 1961
8. Ave. pelitic rock; Shaw, 1956
9. High Ca granites; Turekian and Wederpohl, 1961
10. Low Ca granites; Turekian and Wederpohl, 1961
11. Ave. granite; Krauskopf, 1967

+ Fe is listed as a weight percent; Cu, Pb, Zn, Mn are in p.p.m.

Appendix 5.4

This calculation is included to show the approximate concentration of metals that must be mobilized from an area of similar size to the project area in order to account for the area's mineralization.

Calculations

Volume of a large mine = 100 x 2 x h cubic metres

Volume of the metal source area = 8,000 x 3,000 x h cubic metres

where h = the depth of the mineralized vein and the depth of the metal source area.

Assume there are 20 mines within the area averaging 5% Cu.

The sum Cu content of all the mines will be

$(100 \times 2 \times h) \times 20 \times 50{,}000$ p.p.m.

$\therefore$ amount of Cu required from the source area

$= (100 \times 2 \times h \times 20 \times 50{,}000) \div (8{,}000 \times 3{,}000 \times h)$

$=$ 10 p.p.m. (approximately)

A density factor could also be included in this calculation, but for simplicity, such a factor is assumed to equal unity.

Appendix 6.1

STATISTICAL INTERPRETATION OF MINERALIZED VEIN TRAVERSES

Two statistical techniques have been used, these being correlation coefficients and cumulative frequency plots.

Correlation Coefficients

In this study, the writer is interpreting correlation coefficients as reflecting primary element associations, with high degrees of correlation being due to similar geochemical responses of the elements to geological processes. The correlation coefficients have been used as a criteria for grouping elements into "clusters" (a qualitative form of cluster analysis), with two basic groups assumed to be present. Group I could be termed the "ore solution" group, and is characterized by base metals having a high correlation with Cu. Group II is assumed to reflect element relations within the host rock, and ideally, elements of this group show antipathetic relations with Cu, and have a tendency to show sympathetic relations between the Pb, Zn, Fe and Mn. However, good correlation between Pb, Zn, Fe and Mn may also occur for ore samples (see appendix 6.2). Consequently, the probability distribution and geochemical profiles must also be used when deciding whether a distribution characterizes the "ore solution" or the host rock.

Cumulative Frequency Probability Plots

These indicate the number of base metal populations present in the traverse. If two or more populations are present, it is likely that these represent a background host rock population and a mineralized population, which together give rise to a positively skewed log normal distribution.

Appendix 6.2

Table of

CORRELATION COEFFICIENTS

The correlation coefficients shown in this appendix have been tested for significance at the 95% level, and coefficients significant at this level are denoted by "+". If tests for significant correlation at levels other than 95% are required, the following table may be used :-

Values of correlation coefficient for different levels of significance

n	P (%)				
	10	5	2	1	0.1
5	.669	.754	.833	.874	.951
7	.582	.666	.750	.798	.898
10	.497	.576	.658	.708	.823
15	.412	.482	.558	.605	.725
20	.360	.423	.492	.537	.652
25	.323	.381	.445	.487	.597
30	.296	.349	.409	.449	.554
35	.275	.325	.381	.418	.519

1. Mt. Neill Granite Porphyry, unmineralized background

number of samples = 10

Cu	1				
Pb	.56	1			
Zn	.93+	.56	1		
Fe	.15	.38	.23	1	
Mn	.55	.48	.80+	-.04	1
	Cu	Pb	Zn	Fe	Mn

This table is no more than an approximate guide to the correlation coefficient characteristics of the Mt. Neill Granite. The sample population is not large enough to overcome sample inhomogeneity due to shearing, brecciation and other factors. However, at lower significance levels, Cu, Pb, Zn and Mn tend to correlate. The lack of correlation with Fe is probably due to this base metal also being a major element.

2. Mt. Neill Granite Porphyry, background samples from mineralization traverses.

number of samples = 15

Cu	1				
Pb	-.12	1			
Zn	.20	-.41	1		
Fe	-.18	.56+	-.04	1	
Mn	.41	-.12	.39	-.60+	1
	Cu	Pb	Zn	Fe	Mn

The influence of mineralization has completely modified the Mt. Neill Granite correlation characteristics. This observation is at variance with the conclusion drawn in chapter 6.2, regarding traverse H 1. However, the lack of correlation may be accounted for by the fact that these background traverse samples would have been peripheral to the ore solutions, and so subject to the greatest variability.

3. Terrapinna Granite, unmineralized background

number of samples = 7

Cu	1				
Pb	.67+	1			
Zn	.53	.96+	1		
Fe	.57	.05	.17	1	
Mn	.67+	.92+	.92+	.20	1
	Cu	Pb	Zn	Fe	Mn

As with Mt. Neill Granite, there is significant correlation at lower levels between Cu, Pb, Zn and Mn.

4. Ore Samples from Traverses and breccia zones

number of samples = 20

Cu	1				
Pb	.13	1			
Zn	.20	.76^{+}	1		
Fe	.28	.83^{+}	.80^{+}	1	
Mn	-.14	.82^{+}	.65^{+}	.61^{+}	1
	Cu	Pb	Zn	Fe	Mn

The surprising aspect of this table is the lack of correlation between Fe and Cu. It appears that during the ore forming processes, Cu has been subject to controls (differentiation?) not affecting the other base metals.

Appendix 6.3

GROUP A: MYLONITIC BASEMENT SHEAR ZONES ASSOCIATED WITH QUARTZ VEINING

Traverse H3

see fig. 4.1

This traverse was sampled in a zone of extensive quartz veining and shearing. The zone represents a continuation towards the basement of the mineralization sampled in traverse H1 (see Chapter 6.2).

1. The host rock type is altered and jointed Mt. Neill Granite Porphyry.

2. Structural Data

   The ore is associated with a zone of quartz veining and shearing dipping on average 55^{o} towards 135^{o} (approximately a set I shear orientation, see fig. 4.2e). Shearing is strongly developed in the host granite, and generally dips 80^{o} towards 175^{o} (the regional trend of S_1), though this trend is modified in the presence of intense shear zones.

3. Structures at the vein contact

   Contacts with the mineralized quartz veins are very strongly sheared (mylonitic shearing), with granite often being incorporated within the quartz veins.

4. Alteration effects

   The host granite at the vein margin has been altered to a quartz-kaolinite rock, the alteration reaction possibly being :-

$$\underset{\text{microcline}}{4KAlSi_3O_8} + 2CO_2 + 4H_2O = 2K_2CO_3 + \underset{\text{kaolinite}}{Al_4Si_4O_{10}(OH)_8} + 8SiO_2$$

Adjacent to the malachite mineralization, the kaolinite is goethite stained.

5. Statistical Data

Correlation Coefficients

Cu	1				
Pb	0.186	1			
Zn	-0.167	0.526+	1		
Fe	0.1332	0.486+	0.666+	1	
Mn	0.141	0.359+	0.758+	0.489+	1
	Cu	Pb	Zn	Fe	Mn

+ denotes significant correlation at the 95% level.

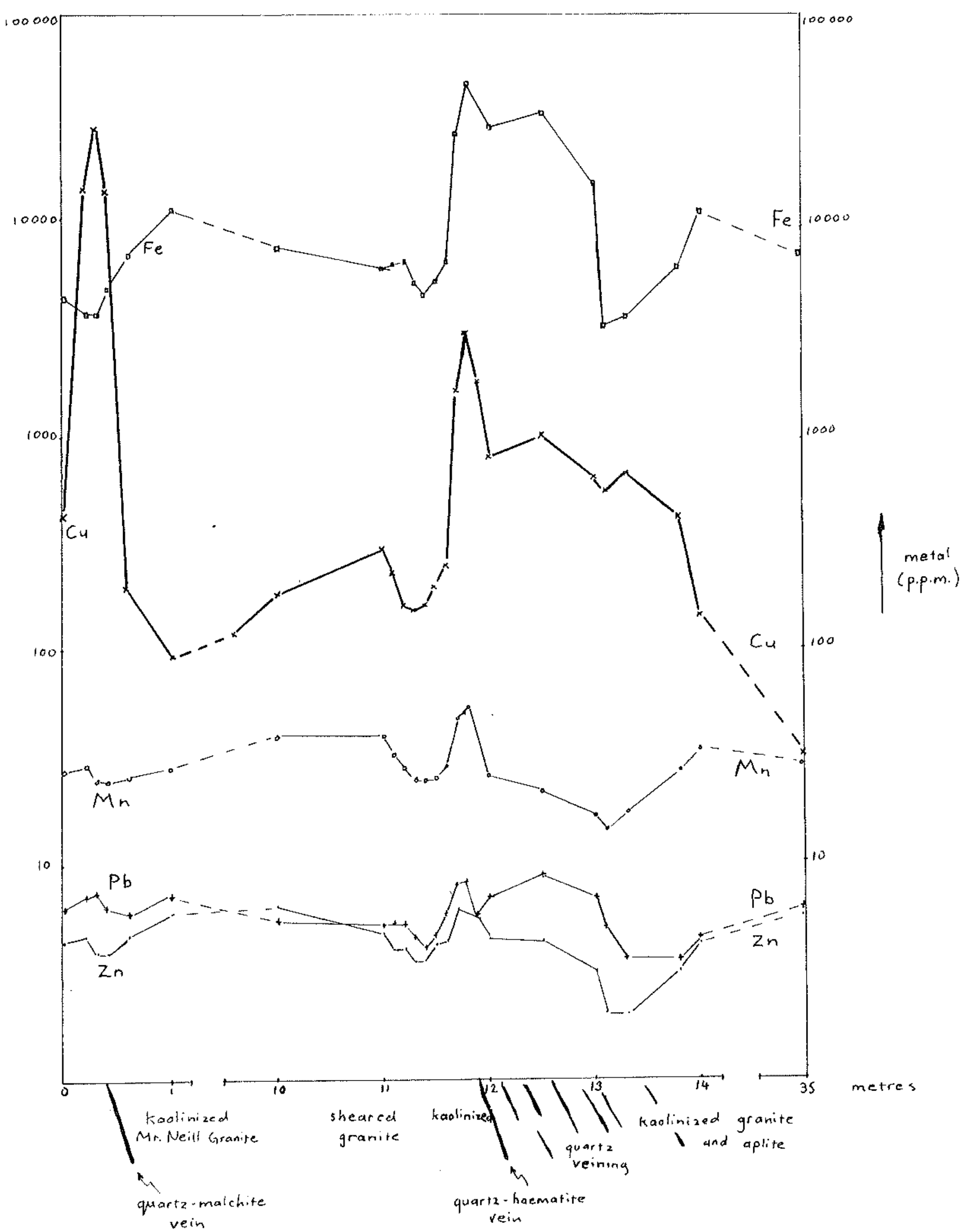
The high positive correlation between Pb-Zn-Fe-Mn is strikingly similar to that obtained for malachite ore samples. These correlation coefficients differ significantly from those of traverse H1 in that there is a complete absence of correlation with Cu. A highly interpretative explanation of this feature could be that the ore bearing solutions as sampled at traverse H3 had had their Cu geochemistry modified during solution migration through the host granites. The corollary of this inference is that the ore bearing solutions, as sampled at traverse H1 adjacent the basement-cover contact, possibly represent undifferentiated mineralizing solutions derived from the contact.

Cumulative frequency Distribution see Fig. 6.6

Pb, Zn, Mn and possibly Fe all have unimodal distributions. These cumulative frequency distributions could reflect either the host Mt. Neill Granite Pb-Zn-Fe-Mn distribution, or alternatively, they may be related to the Pb-Zn-Fe-Mn distribution within the ore solutions. The Cu distribution of the traverse is essentially unimodal, apart from a 5% upper population representing a sample from the malachite ore zone.

Figure A 6·1

Traverse H3



note : the intervals 1 to 10 metres and 14 to 35 metres were background

6. Geochemical Traverse see Appendix Fig. A 6·1

The base metal profiles indicate that quartz-goethite gossans and mylonitic shear zones are metal enriched, while the kaolinized alteration zones are metal depleted. Lateral secretion of metals from these alteration zones cannot be used to account for the amount of metal present in the mineralized veins.

Appendix II

PRECISION OF A.A.S. ANALYSES

Analytical work was done using an AA 100 atomic absorption spectrophotometer.

Sample Preparation

Between 100 and 200 grams of sample was crushed in a siebtechnic mill for between 2 and 3 minutes (depending on the sample size). The sample was then leached in perchloric acid at 200°C for approximately 14 hours.

Precision of Analyses

Between three and six standards were included for analysis in each sample batch. The results of duplicate analyses for one background and two mineralized samples are used in the following table.

1. Background Mt. Neill Granite

	Cu	Pb	Zn	Fe	Mn
	18.7	8.8	5.3	0.39	9.0
	17.5	8.6	5.9	0.20	11.0
	14.5	5.4	3.4	0.18	12.1
	13.6	7.2	5.7	0.49	9.8
mean	16.1	7.5	5.1	0.32	10.0
std. dev.	2.4	1.5	1.1	0.14	1.4

2. Traverse H1, sample marginal to ore zone

	Cu	Pb	Zn	Fe	Mn
	137	21.0	5.0	0.86	55.0
	135	20.8	8.4	1.09	56.5
	131	26.4	8.9	1.10	71.1
	124	18.0	7.8	0.61	65.5
	116	12.4	6.5	0.69	60.2
	118	15.1	9.1	0.96	68.2
mean	127	19.0	7.6	0.89	62.7
std. dev.	8.7	4.9	1.5	0.20	6.5

3. Traverse H1, sample in ore zone

	Cu	Pb	Zn	Fe	Mn
	1229	62.6	11.1	3.6	1524
	1309	64.6	9.0	2.7	1512
	1287	55.7	16.7	3.3	1346
	1346	63.3	11.3	2.6	1379
	1186	59.4	14.6	2.2	1462
	1275	49.0	14.3	2.5	1314
	1214	50.5	13.8	2.4	1290
mean	1264	57.9	13.0	2.75	1404
std. dev.	57	6.2	2.6	0.51	95

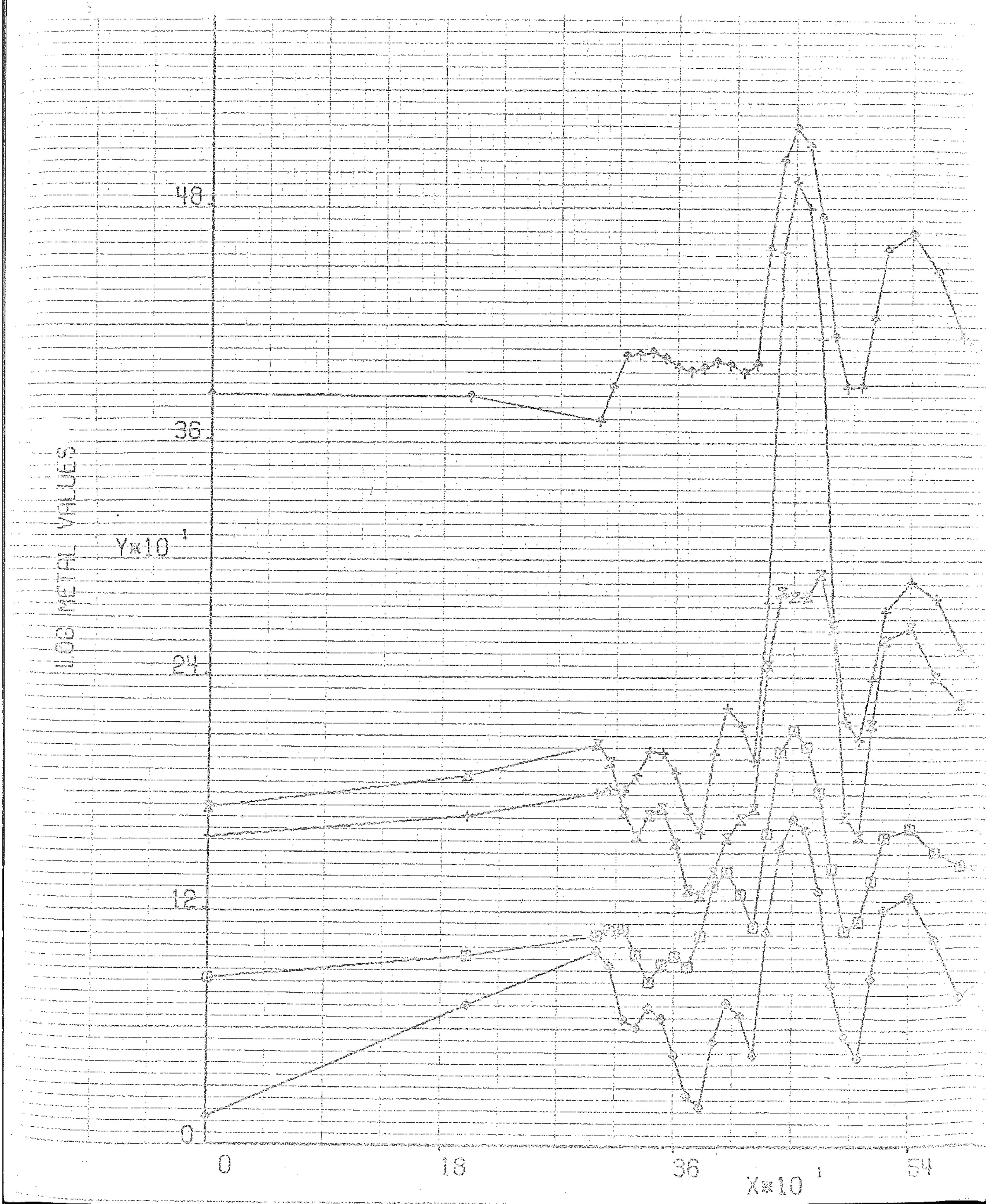
Within each analytical run, one or two samples were duplicated. These duplicate analyses invariably had a high precision, so indicating errors due to weighing, machine instrumentation and calibration are minor.

Appendix III

COMPUTER PROGRAM

A simple computer program was written to plot geochemical profiles for the mineralized vein traverses. In order to minimize "local noise", the program calculates a running mean. This value is then plotted using AUTPLOT.

As an example, a computer drawn profile of traverse H1 is included in this Appendix.



LOG METAL VALUES
Y*10 1
48
36
24
12
0
0
18
36
54
X*10 1

```
      PROGRAM ORE (INPUT,OUTPUT)
      DIMENSION CU(100),PB(100),ZN(100),FE(100),AMN(100),X(100),
     1XCU(100),XPB(100),XZN(100),XFE(100),XMN(100),
     2XA(31),YA(31,5)
     3,CUPB(100),CUZN(100),CUFE(100),CUMN(100),YYA(100,5),YY(100,5)
      COMMON N
      READ 15,N
   15 FORMAT(I3)
      PRINT 1
    1 FORMAT(1H1,4X,*DISTANCE*,6X,*CU*,8X,*PB*,8X,*ZN*,8X,*FE*,8X,*MN*)
      DO 2 I=1,N
      READ 3,X(I),CU(I),PB(I),ZN(I),FE(I),AMN(I)
    3 FORMAT(6F10.2)
      PRINT 4,X(I),CU(I),PB(I),ZN(I),FE(I),AMN(I)
    4 FORMAT(6F10.2)
    2 CONTINUE
      PRINT 101
  101 FORMAT(1H1,10X,*COPPER RUNNING MEAN*,/)
      CALL RUNMEAN(CU,XCU)
      PRINT 102
  102 FORMAT(1H1,10X,*LEAD RUNNING MEAN*,/)
      CALL RUNMEAN(PB,XPB)
      PRINT 103
  103 FORMAT(1H1,10X,*ZINC RUNNING MEAN*,/)
      CALL RUNMEAN(ZN,XZN)
      PRINT 104
  104 FORMAT(1H1,10X,*IRON RUNNING MEAN*,/)
      CALL RUNMEAN(FE,XFE)
      PRINT 105
  105 FORMAT(1H1,10X,*MANGANESE RUNNING MEAN*,/)
      CALL RUNMEAN(AMN,XMN)
      PRINT 106
  106 FORMAT(1H1,20X,*RUNNING MEAN DATA*,//,3X,*DIST.*,11X,*CU*,6X,
     3*PB*,8X,*ZN*,8X,*FE*,8X,*MN*)
      M=N-1
      DO 109 I=1,M
      PRINT 107, X(I),XCU(I),XPB(I),XZN(I),XFE(I),XMN(I)
  107 FORMAT(6F10.2)
  109 CONTINUE
      PRINT 108
  108 FORMAT(1H1)
      DO 200 I=1,M
      XA(I)=X(I)
      YA(I,1)=ALOG10(XCU(I))
      YA(I,2)=ALOG10(XPB(I))
      YA(I,3)=ALOG10(XZN(I))
      YA(I,4)=ALOG10(XFE(I))
      YA(I,5)=ALOG10(XMN(I))
  200 CONTINUE
      PRINT 666
  666 FORMAT(1H1)
      PRINT 788
  788 FORMAT(6X,*X*,6X,*CU/PB*,6X,*CU/ZN*,6X,*CU/FE*,6X,*CU/MN*)
      DO 601 I=1,N
      CUPB(I)=CU(I)/PB(I)
      CUZN(I)=CU(I)/ZN(I)
      CUFE(I)=CU(I)/FE(I)
```

```
00224          CUEN(I)=CU(I)/AMN(I)
00226          PRINT 799,X(I),CUPB(I),CUZN(I),CUFE(I),CUMN(I)
00240   799    FORMAT(     5F10.2)
00246   601    CONTINUE
00247          CALL PLOT10(5HSERPA,5)
00251          CALL XLIMIT(10.0)
00253          CALL ALTPLT(XA,YA,-N ,-5,14H*DISTANCE(M.)*,18H*LOG METAL VALUES*)
00263          CALL PLOT(17,5,0,0,-3)
00264          STOP & END



               SUBROUTINE RUNMEAN (X,Y)
000005         DIMENSION X(100),Y(100)
000005          COMMON M,N
000005          N=31$M=30
000007         DO 100 I=1,M
000010         IF(I.EQ.1)501,502
000014  501    Y(I)=(2*(X(I))+X(I+1))/3
000023         GO TO 100
000027  502    IF(I.EQ.M )503,504
000030  503    Y(I)=(X(I-1)+2*(X(I)))/3
000037         GO TO 100
000037  504    Y(I)=(X(I-1)+2*(X(I))+X(I+1))/4
000047  100    CONTINUE
000052         Y(N )=X(N )
000055         DO 101 I=1,M
000056         PRINT 102,X(I),Y(I)
000071  102    FORMAT(10X,2F10.2)
000071  101    CONTINUE
000075         RETURN & END
```

Appendix IV

Catalogue of Specimen Material Accompanying this Thesis

T.S.	indicates thin section
H.S.	indicates hand specimen
+T.S.	indicates thin section and hand specimen

BASEMENT GRANITE SPECIMENS

H.S. 409/62 — Mt. Neill Granite Porphyry

Pink, massive, coarse grained granite

texture: porphyritic to allotriomorphic

phenocrysts

40% pink microcline, average grain size is 1.5 cm.

30% clear, anhedral quartz, up to 1 cm. diameter.

groundmass

intergrowths of pink feldspar, quartz and minor sericite and chlorite.

H.S. 409/439 — Mt. Neill Granite Porphyry

Pink, massive, coarse grained granite

texture: equigranular intergrowths of quartz and feldspar, porphyritic to allotriomorphic.

phenocrysts

50% pink, ovoidal microcline, grain size is to 2 cm.

groundmass

fine to medium grained quartz and feldspar, lack of mafic constituents.

H.S. 409/414 Aplite (microgranite)

White medium grained microgranite

texture: minor 1 cm. rounded quartz phenocrysts in an equigranular groundmass

constituents

quartz and microcline, minor muscovite, sericite.

H.S. 409/180 Transitional Terrapinna Granite

Pink microcline granite

texture: porphyritic

phenocrysts

30% pink, ovoidal microcline, grain size 3 x 2 cm.

25% clear, rounded quartz grains

groundmass

predominantly second generation pink Kspar, with minor quartz, sericite and biotite.

H.S. 409/150 Transitional Terrapinna Granite

Pink, massive, coarse grained microcline granite, resembles Terrapinna Granite, but lacks "Rapakivi" weathering

texture: porphyritic

phenocrysts

50% pink ovoidal microcline, grain size 3 x 2 cm.

15% clear, rounded quartz, 1 cm. diameter.

groundmass

predominantly second generation pink feldspar, minor sericite.

H.S. 409/306 Terrapinna Granite

White, "Rapakivi" weathering, coarse grained, massive granite

texture: porphyritic

phenocrysts

40% white microcline ovoids, 3 x 2 cm.

20% rounded quartz, 1 cm. diameter.

groundmass

medium grained mosaic of quartz and feldspar (second generation),
10% biotite and sericite.

COVER SEDIMENTS

FITTON and BOLLA BOLLANA FORMATIONS

Unit 1

H.S. 409/467 — Crenulated Phyllite

Typical outcrop appearance of the basal phyllite. Crenulations are due to a cover shear zone associated with a basement mylonitic zone, and do not represent a second cover deformation.

H.S. 409/14 — Pebbly Phyllite

Light grey phyllitic lens towards the base of Unit 1. Granules consist of quartz and feldspar, with the matrix being schistose muscovite.

H.S. 409/463 — Granite Tillite (Conglomerate)

Pebbles of microcline (derived from the Terrapinna Granite?) and quartz within a schistose matrix.

+T.S. 409/486 — Scapolitic Silty Shale

Hand specimen

Green-black, massive, scapolitic silty shale occurring at the top of Unit 1.

thin section

mineralogy

60% green biotite, (low metamorphic grade)
30% quartz, angular to subangular
10% scapolite, poikiloblastic porphyroblastic aggregates containing inclusions of epidote and biotite.
minor clinozoisite (greenschist metamorphic grade)

texture

Irregular patches of sand size quartz grains within a very fine grained biotite (originally clay) matrix. Very poor sorting, quartz grains completely separated by the matrix.

Unit 2

+T.S. 409/27 Pebbly Meta-siltstone

hand specimen

Massive, pebbly, indurated diamictite.

thin section

mineralogy

60% silt size quartz

40% green biotite

texture

Subangular to subrounded clasts of quarta (similar appearance to clear rounded quartz phenocrysts occurring in the basement granites) and Kspar "floating" in a clay to siltsize matrix. Very poorly sorted.

Unit 3

+T.S. 409/31 Pebbly Meta-siltstone

hand specimen

Massive, grey-green, pebbly metasiltstone.

thin section

mineralogy

50% green biotite, silt size

40% quartz, silt size

10% scapolite, poikiloblastic, incorporates biotite

minor calcite, chlorite and plagioclase clasts

texture

Angular to subrounded quartz (including vein quartz with vacuoles) "floating" in a silt size quartz biotite matrix.

T.S. 409/42 **Arkosic Conglomerate**

hand specimen

Coarse, pebbly, white arkosic conglomerate containing pebbles of clear quartz and alkali feldspar. The rock is probably recrystallized.

thin section

mineralogy

70% perthitic microcline rounded to subrounded, minor sericitization
10% plagioclase, sericitized and kaolinized
20% quartz, includes clear, composite and strained varieties
minor myrmekitic feldspar intergrowths, muscovite, biotite

texture

Moderate sorting, lacks fine grain matrix, grains usually separated by thin films of biotite

note: Most of the feldspar dasts lack strong weathering, which possibly indicates a lack of prolonged transport. It may also imply a cold climate (lack of chemical weathering).

+T.S. 409/200 **Amphibolite**

hand specimen

Coarse grain massive amphibolite

thin section

mineralogy

55% actinolite, poikiloblastic, decussate
45% calcite, interstitial

Unit 4

H.S. 409/8 **Massive Pebbly Metasiltstone**

Quartzite and shale clasts within a quartz-biotite matrix. Very poorly sorted, clasts show alignment, possibly due to weak current reworking.

T.S. 409/24 Massive Pebbly Metasiltstone

mineralogy

55% silt size green-brown biotite, decussate fabric
40% subequant quartz clasts, subangular to subrounded, includes vein quartz and composite quartzites.
5% euhedral pyrite, occurs in association with aggregates of quartz with minor muscovite.

texture

Granule size clasts constitute 50% of the rock, and occur suspended within the silt size matrix.

T.S. 409/9 Massive Pebbly Metasiltstone

mineralogy

45% green-brown biotite, decussate fabric
50% quartz, occurs as subangular to subrounded sand size clasts
2% composite quartzite (-sericite) clasts, possibly Freeling Heights Quartzite
1% muscovite
1% calcite, occurring on quartz grain boundaries
minor rounded shale clasts
minor euhedral pyrite

texture

45% sand size subequant quartz grains "floating" in a biotite (-quartz) clay size matrix.

T.S. 409/270 Massive Pebbly Metasiltstone

mineralogy

40% green-brown biotite, decussate fabric.
45% quartz, including composite quartzite clasts
10% scapolite, poikiloblastic
5% pyrite, euhedral (recrystallized)

texture

20% quartz grains (dominantly sand sized) suspended in clay to silt sized matrix.

Unit 5

+T.S.409/212 **Fissile Pebbly Shale**

hand specimen

Brown weathering, fissile pebbly shale. Quartzite granules are limonitic and strongly weathered

thin section

mineralogy

60% quartzite, mainly sand sized, but includes composite quartzites, well rounded to subangular

35% biotite, brown and limonitic (weathering feature?)

2% chlorite

3% shale clasts, rounded

texture

Very poorly sorted, up to 50% quartz grains occurring in clay size matrix of biotite and minor quartz.

note: The weathered nature (ferruginous) of the clasts possibly reflects near shore deposition

+T.S. 409/12 **Poorly Laminated Shale**

hand specimen

Massive, quartzose shale with 1mm. calcareous and gritty laminae.

thin section

mineralogy

30% biotite, very fine grained, decussate fabric

45% quartz, very fine grained, subangular to subrounded

20% calcite, silt sized

5% chlorite, occurs with calcite in distinct laminae

texture

Even grained, poorly laminated.

+T.S. 409/209 **Well Laminated Calcareous Metasiltstone**

hand specimen

Laminated, calcareous metasiltstone, well developed slump structure.

thin section

mineralogy

- 45% biotite, decussate fabric
- 30% calcite
- 20% quartz, subangular to subrounded
- 5% chlorite
- minor muscovite
- minor scapolite, poikiloblastic

texture

Fine silt sized alternating laminae of quartz-biotite and calcite (and minor chlorite).

Slump structures

+T.S. 409/291 **Fine Grain Pyritic Orthoquartzite**

hand specimen

Grey orthoquartzite, 5% 1mm. pyrite.

thin section

mineralogy

- 80% quartz, fine sand size, often with strain shadows
- 10% calcite
- 5% pyrite, euhedral, 1mm. grain size
- minor plagioclase, biotite, muscovite

texture

Recrystallized, sutured grain boundaries, with calcite and biotite occurring as a film between grains.

T.S. 409/204 **Fine Grain Orthoquartzite**

mineralogy

- 90% quartz, fine sand size, often strain shadows
- 5% calcite
- 4% biotite

mineralogy (cont'd)

1% pyrite, euhedral, recrystallized, though minor detrital? rounding occurs

minor muscovite, zircon, tourmaline

texture

Completely recrystallized, sutured grain boundaries.

+T.S. 409/253 Sedimentary Breccia

Subangular to subrounded shale clasts within a silty shale matrix. Subrounded composite quartzite clasts are present, with sand size angular quartz grains occurring within the matrix.

Unit 6

+T.S. 409/259 Massive Pyritic Pebbly Diamictite

hand specimen

Massive, indurated, diamictite, sand sized quartz grains within a metasiltstone matrix. Quartzite clasts up to 2cm. with "vertical" (with respect to bedding) clasts being present.

thin section

mineralogy

55% quartz, well rounded to subangular

40% biotite, brown, fine silt size, decussate fabric

5% rock fragment clasts, including myrmekitic feldspar, composite quartzites, fine grain shales

minor pyrite, calcite, chlorite

texture

Very poorly sorted with a bimodal roundness - angularity distribution. Clasts "float" in a fine silt size quartz-biotite matrix.

+T.S. 409/260 **Flaser Bedded Orthoquartzite**

hand specimen

Very fine grained, recrystallized orthoquartzite. Flaser bedding structures are defined by rich layers within the otherwise massive quartzite.

thin section

mineralogy

90% quartz, silt size, equant

7% biotite, brown, decussate fabric

3% calcite

minor tourmaline and opaques

texture

Completely recrystallized, sutured, interlocking grain boundaries.

T.S. 409/255 **Fine Grain Orthoquartzite**

mineralogy

90% quartz, fine silt size, equant

6% biotite, brown, decussate fabric

3% calcite

1% muscovite

texture

Completely recrystallized, interlocking triple point grain boundaries, sutured contacts.

Basal Bolla Bollana Formation

+T.S. 409/238 **Massive Pyritic Diamictite**

hand specimen

Dark grey, massive diamictite, 5% pyrite (often associated with quartz clasts).

thin section

mineralogy

55% quartz, including fine grain matrix material and granule sized clasts (often strained)

25% biotite, brown, lepidoblastic fabrics aligned parallel to cleavage

20% rock fragment clasts, includes subangular to subrounded shale, composite quartzite, vein quartz (vacuoles), calcareous shales and carbonaceous shales

5% pyrite, streaked parallel to the cleavage, possibly indicating recrystallization during cleavage formation

texture

70% clasts separated by a very fine biotite - quartz matrix, very poorly sorted.

clast long axes are orientated parallel to the well developed cleavage.

T.S. 409/235 — Laminated Carbonaceous Shale

mineralogy

45% quartz, angular to subrounded

26% biotite, carbonaceous matter, very fine grain clay size, possibly a rock flour origin

25% clasts, including shales, carbonaceous shales, calcareous metasiltstones, composite quartzites (with biotite)

4% pyrite, streaked parallel to cleavage, tends to occur in quartz - biotite rich layers.

texture

Clasts occur in a fine grain matrix, possibly suggesting a subglacial origin.

H.S. 409/245 Fissile Shale

Shale, dolomite and quartz clasts within a strongly cleaved biotite - quartz matrix. Strain deformation of the clasts has occurred during cleavage development.
The matrix is unweathered, whereas clasts show strong weathering (limonite abundant, so giving the specimen an iron rich appearance).

H.S. 409/224 Fissile Shale

Fissile biotite - quartz shale containing clasts of quartzite, shale and carbonaceous shale. Clasts with their long axes perpendical to bedding are present, so indicating sub-glacial deposition.

SPECIMENS OF CLASTS WITHIN FITTON FORMATION

H.S. 409/461 — Ovoidal Microcline Granite Clast

Angular granite clast occurring at the basement - cover unconformity within the Unit 1 basal phyllite. The clast has undergone virtually no transport.

H.S. 409/454 — Ovoidal Microcline Granite

Sample of the basement granite directly underlying the location of sample 409/461.
These two specimens indicate the extremely localized provenance the basal 10 metres of Unit 1.

H.S. 409/469 — Scapolite Amphibolite Clast

This well rounded exotic clast occurs adjacent the angular localized clast specimen 409/461. Scapolitic amphibolites do not occur within the basement of the project area, and may be inferred to be derived from the Wywyana Formation occurring to the south west. Such specimens represent good evidence for a glacial origin for Unit 1.

H.S.409/192 — White Microcline Granite Clast

Typical specimen of the white granite clasts which occur within Unit 1. Megaclasts up to 3 metres occur.

H.S. 409/434 — Terrapinna Granite Clast

This particular variant of the Terrapinna Granite is not found within the basement of the project area. Such clasts only occur within Unit 1, and are restricted to localities west of Harrison Well.

H.S. 409/435 **Mt. Neill Granite Clast**

Variants of the Mt. Neill Granite are common clast types within Unit 1, particularly east of Harrison Well.

H.S. 409/405 **Muscovite Schist Clast**

Exotic schist clasts (Radium Creek Metamorphics?) could not survive transport by aqueous flow, so that deposition from density currents is favoured. The muscovite schist has been crenulated by the cover deformation.

H.S. 409/239 **Dolomite Clast**

Possibly a Skillogalee Dolomite clast derived from the Burra Group outcropping to the south west of the project area.

STRUCTURE RELATED SPECIMENS

H.S. 409/381 — Strongly Sheared Mt. Neill Granite

This specimen typifies the (mylonitic) sheared, kaolinized, silicified Mt. Neill Granite occurring in the Hamilton and Mt. Fitton (South) Mines area. Quartz phenocrysts have been intensely strained during the mylonitic deformation. The cross-cutting quartz - tourmaline vein is evidence of the metasomatism which is probably related to ore genesis.

+T.S. 409/106 — Terrapinna Flaser Gneiss

handspecimen

Strained micoline ovoids in a muscovite, quartz, feldspar groundmass.

thin section

mineralogy

60% microcline porphyroclasts, sutured contacts, undulose extinction, highly strained.

10% quartz porphyroclasts, undulose extinction, highly strained.

30% muscovite, microcline, quartz and biotite, occurring as recrystallized fine grained groundmass.

texture

Recrystallized microcline has no dimensional preferred orientation, but has a crystallographic alignment. Muscovite and biotite show lepidoblastic development.

+T.S. 409/473 — Phyllonite with Quartz Rodding

hand specimen

Strained, rodded quartz, minor microcline, sericite groundmass, probable mylonite.

thin section

mineralogy

50% quartz, recrystallized porphyroclastic aggregates, lacks strained extinction.

10% microcline, recrystallized with sutured grain boundaries.
40% quartz and sericite groundmass, cataclastic equivalent of porphyroclasts, with minor microcline and biotite.

texture

Lepidoblastic with respect to sericite and quartz.

+T.S. 409/111 Phyllonite

hand specimen

Quartz sericite schist (phyllonite), quartz veined parallel to foliation, banded texture.

thin section

mineralogy

50% quartz, recrystallized
45% sericite
5% biotite

texture

crystalloblastic, preferred dimensional and crystallographic mineral orientation. Lack of cataclastic textures, since recrystallized.

+T.S. 409/477 Mylonitic Shear Zone Quartz Vein

hand specimen

Quartz vein with "bedded" appearance.

thin section

Quartz, abundant inclusions.
Minor muscovite.

texture

Quartz shows triple point grain boundaries, complete lack of undulose extinction, crystallographic preferred orientation.

+T.S. 409/69 <u>Haematized Fault Breccia</u>

hand specimen

Dark, haematized shale, slickensided and brecciated, probably silicified. Haematite dispersed from the slickensided surface into fractures within the shale. These breccias are ubiquitous within cover fault zones.

thin section

Shale fragments within a chloritic, haematitic matrix.
Minor quartz veinlets.
Breccia factures are limonitic.

texture

Strongly brecciated.

ORE SAMPLES

H.S. 409/394 — Quartz Malachite Vein

The mineralization consists of supergene carbonates of copper, with the grey mineral probably being chalcocite.

H.S. 409/395 — Quartz Vein with Sulphides

Primary sulphides consist of pyrite (weathered to limonite) with possible chalcopyrite (evidenced by malachite staining).

H.S. 409/281 — Fault Zone Gossan

Brecciated quartz in a ferruginous, siliceous matrix.
Occurs in a fault zone within Unit 5 opposite the Hamilton Mines.

H.S. 409/264 — Haematite Gossan

Occurs in a fault zone within Unit 4 opposite the Hamilton Mines.

H.S. 409/P2R11 — Haematized, Brecciated Granite

Alternating bands of supergene azurite and malachite associated with haematized and brecciated Terrapinna Granite. Occurs in a basement fault zone near the Pinnacles Mine.

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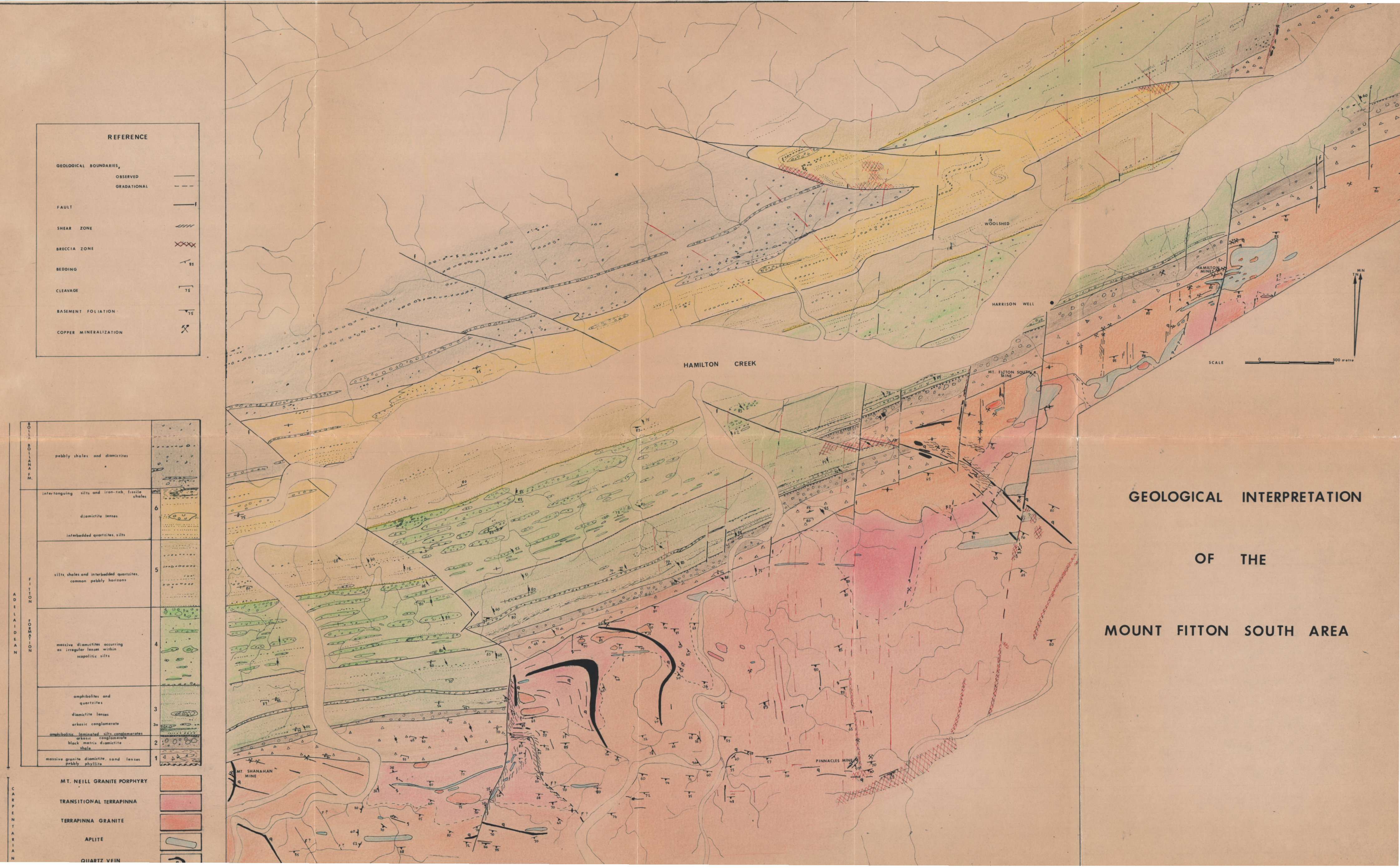
REFERENCE
GEOLOGICAL BOUNDARIES,
OBSERVED
GRADATIONAL
FAULT
SHEAR ZONE
BRECCIA ZONE
BEDDING
CLEAVAGE
BASEMENT FOLIATION
COPPER MINERALIZATION
ADELAIDEAN
BOLLA BOLLANA FM.
pebbly shales and diamictites
FITTON FORMATION
unit
intertonguing silts and iron-rich, fissile shales
6
diamictite lenses
interbedded quartzites, silts
5
silts, shales and interbedded quartzites, common pebbly horizons
4
massive diamictites occurring as irregular lenses within scapolitic silts
3
amphibolites and quartzites
diamictite lenses
3a
arkosic conglomerate
amphibolitic laminated silts, conglomerates
2
arkosic conglomerate
black matrix diamictite
shale
1
massive granite diamictite, sand lenses
pebbly phyllite
CARPENTARIAN
MT. NEILL GRANITE PORPHYRY
TRANSITIONAL TERRAPINNA
TERRAPINNA GRANITE
APLITE
QUARTZ VEIN
HAMILTON CREEK
WOOLSHED
HARRISON WELL
HAMILTON MINE
MT. FITTON SOUTH MINE
MT. SHANAHAN MINE
PINNACLES MINE
MN
TN
SCALE
0
500 metre
GEOLOGICAL INTERPRETATION
OF THE
MOUNT FITTON SOUTH AREA