GEOLOGY OF THE YUDNAMUTANA AREA, NORTHERN FLINDERS RANGES, WITH SPECIAL REFERENCE TO THE GEOCHEMISTRY OF THE MINERALIZATION AND THE WOOLTANA VOLCANICS

by

B.A. EBERHARD B.Sc.

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UNIVERSITY OF ADELAIDE
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Errata. Due to lack of space Sections 2 and 3 on Structure and Metamorphism have been removed from the main text of the thesis and placed in the Appendix after Appendix 1 on Stratigraphy.

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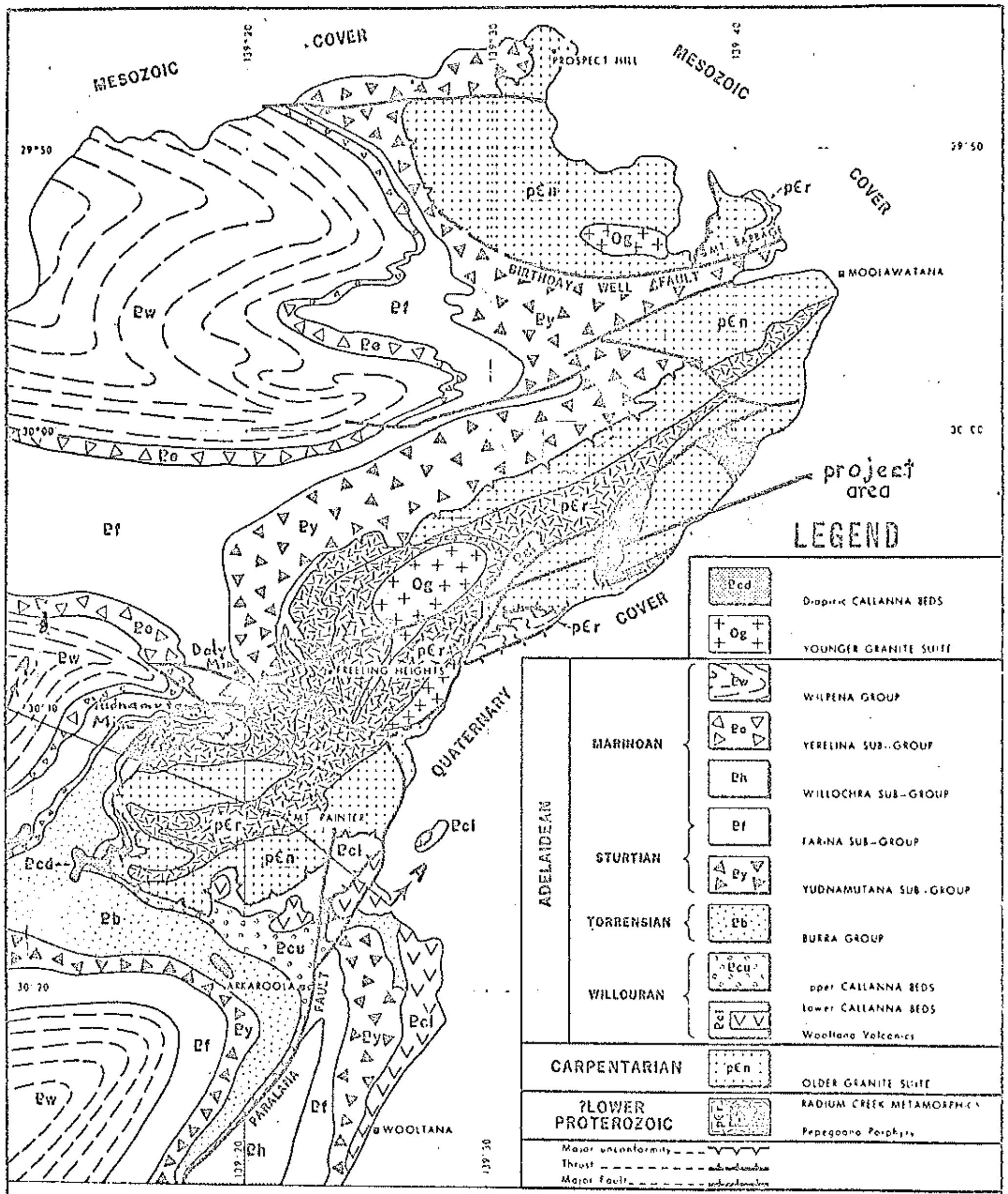

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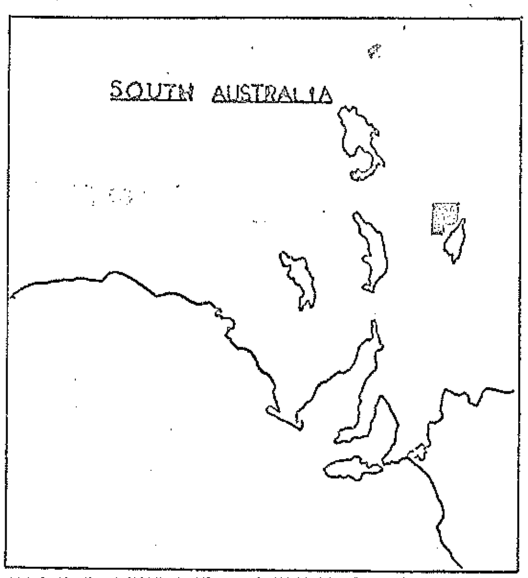


GENERALIZED GEOLOGY

and

LOCALITY MAP

ABSTRACT

The Wooltana Volcanics are a sequence of lavas having undergone intensive low grade alteration. The majority of lavas are now scapolitized biotite rich purple rocks in which the original igneous textures have been obliterated. Minor amygdaloidal lavas and rhyolites showing igneous textures remain. Geochemical and petrological evidence suggests that the majority of these lavas were originally basic lavas having undergone subsequent K and Fe metasomatism. The origin of the metasomatic solutions is considered to be the members of the "Younger Granite Suite" intruding the basement.

Mineralization within the area is largely found in the Wywyana Formation and is associated with metasomatic solutions. Structures caused by the Delamerian Orogeny have localized the mineralization. Statistical evidence suggests that some of the mineralization may be due to subsequent enrichment of disseminated metasomatic copper, possibly augmented by disseminated copper from the Wooltana Volcanics.

1. INTRODUCTION

The area under investigation is that immediately surrounding the Yudnamutana Mine and other copper prospects in the vicinity of Yudnamutana Creek, and is situated within the Mount Painter Province of the Northern Flinders Ranges, approximately 560 kms. north of Adelaide (see Figure 2). An area of 18 square kilometres was studied.

The topography of the area is comprised of a series of ridges running parallel with the strike which changes from a north-east, south-west trend in the western half of the mapped area to an east-west direction in the eastern portion. The basement rocks in the south-western section of the area constitute a dissected plateau reaching a height of about 700 metres above sea-level. The land surface is dissected by numerous creeks resulting in good geological outcrop except in major creeks or on scree slopes.

The climate of the area is semi-arid with the rainfall averaging less than 10 inches per annum. Vegetation is sparse and consists mainly of mallee growth and spinifex with larger eucalypt trees growing in some of the major creeks.

The area under study has been the subject of interest in the mining and exploration field since 1860 when the Yudnamutana deposit containing ore which included 300 tons of 50% copper was discovered. The discovery of many other prospects in the same area followed, these being found especially in the Wywyana and Wooltana Volcanic formations, and mining continued until 1920 when production ceased owing to the fall in the world price of copper after the end of World War I. Detailed investigation of the mineral deposits aided by geochemical and geophysical surveys, have been undertaken by the Department of Mines and numerous mining companies over recent years and is still being undertaken at the present time.

The Wooltana Volcanics were originally mapped as a formation in the Yudnamutana Area by Coats et.al. (1971) following the recognition by Blisset (1967) of amygdaloidal lavas in the district. Other rock types present such as chlorite and biotite schists were considered to represent altered equivalents of the lavas, being "readily identifed by the preservation of round to elliptical quartz blebs, assumed to represent original siliceous infillings of the vesicles".

Elsewhere within the Mount Painter Block, the Wooltana Volcanics have been mapped on a regional scale by Crawford (1963) and Coats et.al. (1971) and have also been described by Mawson (1912, 1926, 1949), Woolnough (1926), Woodmansee and Johnson (1956), Jones et.al. (1962) and Fander (1963). Mawson considered that the lavas were all of basic character. However, Fander (1963) classified most of the lavas as sodic trachytes, on the ground of their mineral assemblages, with minor micro-syenites, microdiorites and andesites also being identified. In addition, Crawford (1963) and Jones et.al. (1962) have noted the spilitic character of some lavas within the Wooltana Volcanics.

The major portion of this thesis will be devoted to the discussion of various aspects of the nature of the mineralization using geochemical techniques as the basis of investigation, and to a study of the chemistry and petrology of the Wooltana Volcanics with a view to discovering the nature of the lavas and their alteration as well as determining the significance of the volcanics in connection with the local mineralization. Consequently other aspects of the geology of the area will be dealt with in much less detail and detailed stratigraphy of all formations with the exception of the Wooltana Volcanics are dealt with in Appendix I. Throughout this thesis the stratigraphic nomenclature used by Coats in Coats and Blissett (1971) will be adopted.

4. WOOLTANA VOLCANICS

4.1 Stratigraphy

In the area studied the Wooltana Volcanics is a boomerang shaped formation about seven kilometres in length and approximately 300 metres at its thickest. This is a very variable formation and will be discussed in more detail in Section 4.2.

Relatively unaltered amygdalitic lavas are found only in the upper part of the formation being confined to two relatively small areas. These are found approximately one half of a kilometre north-west from the Wheal Austin Mine and approximately one half of a kilometre north-west of the Cockscomb mine. In both places the lavas occur at the top of the formation and cover an area of approximately one quarter of a square kilometre, being 100 metres long by 30 metres thick in both cases, forming what appear to be quite small thick flows.

Rhyolite flows have also been recognised in the area mapped and these are also confined to the upper half of the formation forming areas of higher relief. These lavas are far less amygdalitic than the grey lavasand their linear outcrop pattern is suggestive of a layering. These rhyolites are associated with and are commonly interbedded with biotite rich rocks.

The lower part and the major proportion of the formation are commonly made up of purple massive weathering biotite rich rocks often with well developed schistosity and commonly intensively scapolitized. In the vicinity of the Yudnamutana and Cockscomb Mines the lower part of the formation is made up of chlorite schists. The biotite and chlorite schists often contain small elliptical quartz blebs which are very similar to infilled amygdules within trachytic lavas in the upper part of the formation (Plate 2 Photograph P1).

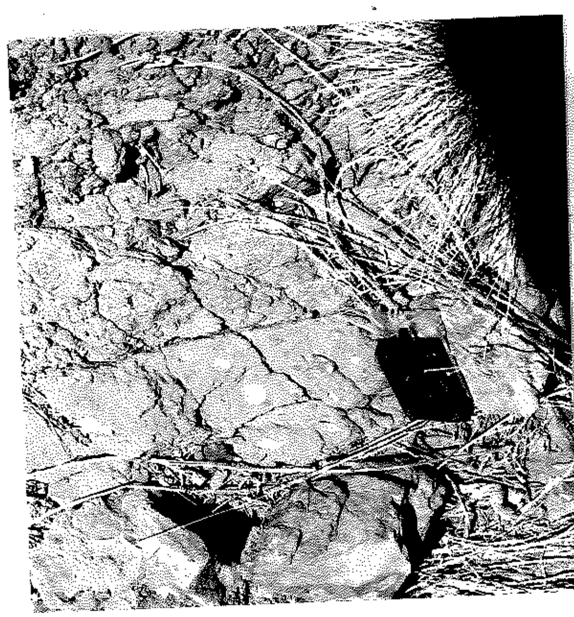
A section through the Wooltana Volcanics to the west of the Wheal Austin Mine reveals the existence of several sedimentary interbeds at the base of the sequence. These include pebbly mudstones, fine siltstones and actinolite marble. They are of limited extent however, and pass laterally into purple weathering massive scapolitized biotite rocks which constitute the major part of the sequence. Near the top

PLATE 1

P.1 View looking northwest across the Pinnacles Mine. The jagged ridge in the background is faulted Wortupa Quartzite and the rolling hills in the foreground are Wooltana Volcanics. The flat lying ground in the foreground is Wywyana Formation with the Pinnacles Mine in the low craggy hillock caused by a siliceous replacement body.

P.2 Section across the Wooltana Volcanics to the north west of the Yudnamutana Mine. The distinct massive outcrop just before the top of the Wortupa Quartzite Ridge consist of rhyolitic lavas. These are interbedded with biotite schists which have no apparent igneous textures in the upper half of this sequence.

P.3 Quartz blebs within biotite schist to the north-west of Yudnamutana Mine. These are elliptical in shape and are considered to be amygdular infillings of very altered lavas.



of the sequence harder, more siliceous biotite rocks appear and a layering becomes apparent. These are overlain by massive grey amygdaloidal lavas.

Four hundred yards north-west of the Yudnamutana Mine a good section of the volcanics is exposed beneath the Wortupa Quartzite on an easterly facing ridge slope (Plate 1 Photograph P2). Here the lower half of the sequence consists of biotite schists which contain small elliptical and elongate quartz blebs higher in the sequence. The upper half of the sequence contains grey coloured siliceous beds which become more common towards the top where they exist in a prominent massive outcrop as highly feldspathic grey pink lavas to hard green black more micaceous rocks. Softer biotite schists are interbedded throughout the upper part of the sequence.

4.2 Petrology

Geological mapping has shown that in the area mapped the Wooltana Volcanics consist superficially of several distinct rock types. These are:

1) A dense massively weathering, grey amygdalitic lava.
2) A very fine grained light-grey coloured rhyolitic lava with a layered appearance.
3) Massive purple weathering biotite rich rocks which are often scapolitized and chlorite schists.
4) Interbeds of Sedimentary material.

A. Amygdaloidal lavas

Mineralogy

Typically the main body of the rock consists of a fine grained aggregate of subhedral and anhedral laths of feldspar, between ten and fifteen percent of finer grained (.2 mm.) anhedral hematite and varying amounts of biotite (See Plate 2 Photograph 2).

In some cases the lava consists almost completely of a densely packed aggregate of fine-grained (.5-1 mm.) feldspar laths with only very minor biotite present in the matrix. More commonly however biotite is present as a matrix within which the coarser grained feldspar laths exist. In thin section 415/44D, metamorphic biotite occurs as large anhedral porphyroblastic crystals with which are associated euhedral tourmaline. The amount of biotite varies from ten to twenty five percent, but is as high as thirty percent in some cases. The biotite rich lavas generally consist of more loosely packed feldspar laths which appear to be less fresh than their non-biotitic counterparts, the feldspars having many more inclusions of sericite and opaque minerals.

Feldspar exists predominantly in the form of simple twinned feldspar with a minor amount of microcline and little plagioclase. Opaque minerals believed to be mainly magnetite occur within the matrix of the rock as anhedral grains and as small inclusions within feldspar and biotite grains, but also sometimes occur as coarser subhedral and euhedral grains (up to .5 cm). Iron staining is common in these lavas, often coating grain boundaries between feldspar laths.

Texture

The texture of the lavas is largely governed by the feldspar laths. In some cases they have a trachytic texture due to sub-parallel alignment of feldspar laths. In other cases the arrangement of feldspar laths appears to be completely random. A distinctive textural feature of these lavas is their generally non-porphyritic nature. Other variations in texture are brought about by the amount of biotite present in the matrix and the presence or absence of amygdules which may be absent or may occupy 20% by volume of the lavas.

Amygdules

Amygdules are generally less than 1 cm. in diameter though some are as large as 3 cms. in diameter. They vary from elliptical to highly irregular shapes and are most commonly infilled with fine grained quartz and K-feldspar. The quartz usually exists as composite grains and sometimes show the development of sub grains and strain extinction. The feldspar is slightly more coarse grained, untwinned and shows sutured textures. Another major amygdule infiller are opaque minerals and these very often coat the outside of quartz feldspar infilled amygdules. In many cases veinlets of quartz, feldspar and opaques sometimes with biotite may be seen to interconnect the amygdules. Stilpnomelane infilled amygdules were found half of a kilometre north-west of the Cockscomb Mine.

These also contained a certain amount of feldspar, opaques and chlorite appears to be present as a small amygdule infilling in thin section 415/44E.

Secondary and later stage minerals.

These amygdular lavas appear to be very altered rocks, and evidence for secondary and later stage minerals and for metasomatic alteration abundant. The presence of a small veinlet containing zeolite minerals in thin section 415/44A emphasizes the low grade of the alteration of the lavas. These commonly appear as amygdule infillings in certain low grade altered lavas, although no such infillings were observed within the area mapped. However, several generations of amygdule infillings are evident and it is possible that any such evidence has been destroyed by later solutions.

Biotite is common both as a metamorphic mineral within the matrix of the rock and associated with feldspar, quartz and opaque minerals in veinlets. Much of the magnetite is secondary as it occurs as amygdule infillings, within veins and as inclusions within feldspar and biotite. Petrological evidence, such as opaque infilled veinlets cutting across feldspar infilled amygdules and coating of quartz-feldspar amygdules with opaques is proof that the magnetite was mobile after the deposition of feldspar and quartz in the amygdules. Geochemical evidence indicates that even the potassium feldspar may be secondary after plagioclase although there is not a great deal of petrological evidence for this alteration actually taking place. Other secondary minerals found are chlorite, tourmaline, and apatite.

Discussion

The mineralogy of these lavas suggests that they may be classified as biotite trachyte having undergone extensive low grade alteration with the absence of quartz and feldspathoid minerals showing that it is exactly saturated with silica. Some of these lavas appear to be similar to those described by Fander (1963).

Several features of the lavas indicate relatively rapid cooling of the lavas. These are:

1) The shape of the lava flows which are relatively small and thick.
2) The presence of amygdules due to the infilling of vesicles left after the escape of gases through rapidly cooling lavas.

PLATE 2

P.1 From T.S. 415/44F

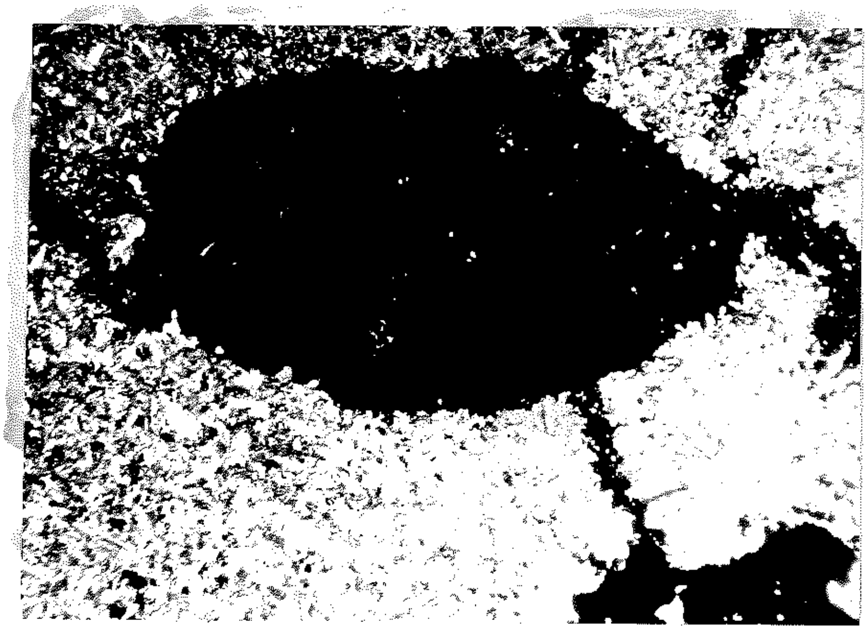
A magnetite infilled vesicle within massive amygdular lavas found one half of a kilometre northwest of the Wheal Austin Mine. The groundmass consists of K-feldspar laths in a very fine grained biotite matrix. Numerous veinlets interconnect amygdules.

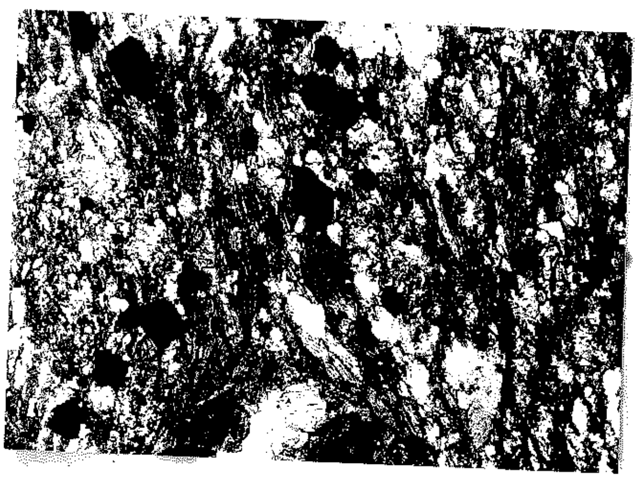
P.3 From T.S. 415/44B

A quartz feldspar infilled amygdule within lavas from the same location. A veinlet filled with opaque minerals cross cuts the amygdule. Opaque minerals coat the surface of the amygdule and are common in the groundmass which consists dominantly of K-feldspar laths.

P.2 From T.S. 415/702

A chlorite schist from the Wooltana Volcanics. Aligned chlorite and biotite grains in a matrix of quartz and feldspar. Note the high percentage of opaque minerals.





3) The poor development or absence of trachytic textures generally believed to be the result of alignment of crystallizing feldspar laths during a lava flow.

4) The non-porphyritic nature of the lavas.

Another striking feature of these lavas is the compositional inhomogeneity of the lavas over a small area. Some samples are characterized by the general absence of mafic minerals whereas others have up to 30% biotite. This could be due to differences in the original composition of the lava, or to the effects of metasomatism.

B. Rhyolites

These lavas consist almost exclusively of quartz feldspar and biotite. Staining of feldspars with sodium cobaltinitrite reveal that the feldspars are potassium rich.

Thin sections were made from a series of rocks taken from a section of the upper half of the Wooltana Volcanics 300 metres northwest of the Yudnamutana Mine. These showed a marked variation along the section in the nature of lavas identified as rhyolites.

Rhyolites found at the top of the sequence are non-porphyritic and are essentially a granular microcrystalline aggregate of anhedral quartz and untwinned feldspar. Biotite and opaque minerals occur in the matrix and are concentrated in long thin streaks probably indicative of flow (Plate 3 Photograph 2).

Lower in the sequence biotite becomes much more common and constitutesover 30% of the lava. Again biotite and minor opaque minerals are concentrated in broad diffuse streaks. The biotite is dark brown and iron rich and opaque minerals are not present in amounts greater than 5% in contrast to the iron richness of most of the Wooltana Volcanics. Porphyroblasts of scapolite occur within these concentrations of biotite. In thin section 415/572 the biotite appears to be recrystallized and less iron rich and is associated with tourmaline and large euhedral crystals of chlorite.

This is interpreted as metasomatic alteration of the lava.

The rhyolites found lowest in the sequence have a "knotty" texture due to the presence of aggregations of more coarse grained quartz crystals within the lava. These are elliptical to elongate in shape and are often coated on their boundary with the matrix by opaque minerals. Accordingly they are interpreted as being highly deformed amygdules, the more intense deformation than noted in other areas of the volcanics being explained by the proximity to the nose of the westerly dipping anticline. The matrix has an inequigranular texture due to the presence of larger (but still very fine grained) crystals of quartz. Thin section 415/560 has well defined areas of sericite which could possibly be pseudomorphous after porphyritic plagioclase. The opaque minerals magnetite and hematite are abundant in these rocks and occur as coarse anhedral crystals and as numerous very fine grained crystals disseminated throughout the rock. The presence of chlorite opaque tourmaline and limonite in this rock also points toward a metasomatic alteration of the lava.

Discussion

These rhyolites are similar to the massive amygdaloidal lavas in their generally non-porphyritic nature, compositional inhomogeneity and the presence of amygdules. The effects of metasomatism on these lavas were observed in lavas sampled in the vicinity of the quartz vein traverse described in Section 6.5. New minerals were chlorite, opaques, tourmaline and limonite and biotites were recrystallized to coarser grained, green, euhedral crystals.

The change in the nature of the rhyolites from the non-porphyritic mafic poor lava at the top of the sequence to the amygdular more uneven-grained mafic rich lava further down the sequence implies that the upper lavas may have cooled more rapidly than the lower ones.

C. Massive Biotite rich Rocks and Biotite and Chlorite Schists

These rocks, which show no obvious igneous textures, constitute the major portion of the Wooltana Volcanic Formation.

The most common of these is a massive purple weathering scapolitized biotite rock which often contains up to 50% euhedral crystals of scapolite within a fine-grained matrix containing more than fifty percent biotite. Anhedral quartz and untwinned feldspar crystals make up the remainder of the matrix. The scapolite crystals vary from less than 1 mm. in size up to 4 mm. but are usually about 2 mm. in diameter with a poikiloblastic texture containing inclusions of quartz feldspar and biotite.

Most of the schistose biotite rocks are harder and less scapolitic than their massive counterparts usually containing greater than 60% biotite and lesser quartz and feldspar although some of the biotite schists contain little or no quartz and feldspar and consist almost entirely of biotite. Common accessory minerals are tourmaline and apatite. The biotite schists have a close relation in outcrop to rhyolitic lavas. For example a biotite schist containing coarse euhedral crystals of actinolite (T.S.415/568) and a rhyolite (T.S. 415/569) were sampled within the same conspicuous outcrop at the top of the volcanic sequence north-west of the Yudnamutana Mine (See Plate Photograph 2). Green biotite is common in the biotite schists.

The chlorite schists have the same texture as many of the biotite schists with the only difference in mineralogy being the presence of chlorite in place of biotite (Plate 2 Photograph 2). A universal feature of all these rocks is the relatively high percentage of opaque minerals they contain and the presence of quartz-feldspar blebs which look similar in thin section to amygdule infillings of the volcanics with recognizable igneous textures.

Discussion

The close proximity of the chlorite schists to the Yudnamutana Mine, and the presence of numerous very fine opaque minerals disseminated throughout the rock which is a feature of the alteration near the Yudnamutana Mine, (compare T.S. 415/702 with 415/Y2), is almost certainly indicative of the fact that they are biotite schists altered by outward moving metasomatic solutions from the Yudnamutana Mine, and shearing of the rocks.

The occurrence of high opaque mineral abundances in these metamorphic rocks and the presence of what appear to be amygdules are striking similarities with recognizable lavas from the formation.

D. Sedimentary interbeds within the Volcanics

Sedimentary interbeds within the volcanics include siltstones, pebbly mudstones and limestones.

Limestone interbeds were converted to an actinolite marble.

The development of coarse euhedral poikolitic sheaths of actinolite and coarse perthitic textured microcline crystals are the main effects of the alteration. Veinlets of feldspar were seen within this unit.

Mudstones have been altered to mica rich rocks. New Minerals produced by their alteration include Actinolite, tremolite, anthophyllite, calcite, and scapolite.

4.3 Geochemistry

The chemistry of the Wooltana Volcanics was studied with the aid of whole rock analyses obtained using standard X-ray fluorescence techniques. Due to the fact that lavas displaying a rhyolitic texture were not recognized until later petrological study, more intensive analyses were not undertaken for this rock type. Ten whole rock analyses of the massive grey amygdaloidal lavas with trachytic textures were done, and nine other samples representative of the varying character of the Wooltana Volcanics were analysed. These are listed in Tables 5.2 and 5.3 and short descriptions of their character are given in Table 5.1. (To be found at the end of the Appendix)

A. The nature of the Amygaloidal lavas

Analyses (Table 5.) show that the massive amygdaloidal lavas, classified as trachytes on the basis of their mineralogy do not correspond to the chemical composition of any common igneous rocks, in spite of their obviously igneous textures. In particular, the percentages of iron and potassium oxide are significantly higher than in common igneous rocks. The percentage of silica present in these lavas is typical of a basic igneous rock rather than a trachyte.

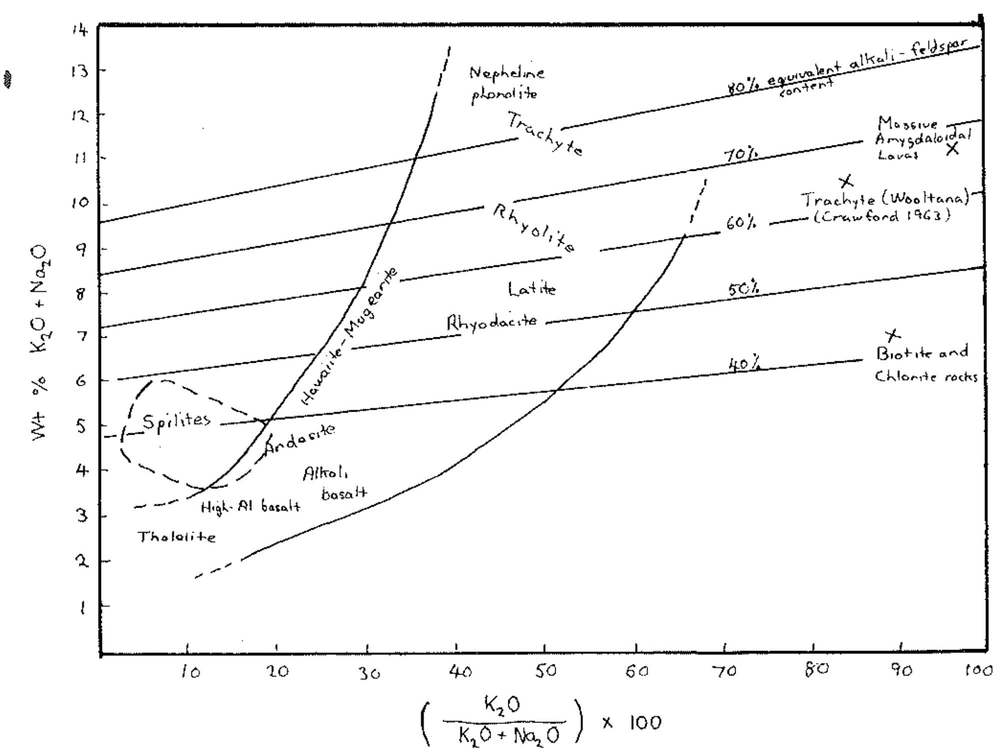
Figure 5.1 shows the plot of the average alkali composition of these lavas on a diagram defining an igneous spectrum. The lavas analysed plot well outside the igneous spectrum and have an equivalent alkali-feldspar content (the weight percent of alkali-feldspar assuming all the alkali content of the rock to be in the form of alkali-feldspar) of approximately 77%. Because of this unusually high potassium content and the evidence for potassium metasomatism in the area, it is concluded that the analysed lavas are the product of potassium metasomatism.

TABLE 5.3 AVERAGES FOR WOOLTANA VOLCANIC FORMATION AND OTHER IGNEOUS ROCKS

	Massive Grey Amygdaloidal Lavas (Mean of 10 analyses)	Massive biotite rocks Biotite schists Chlorite Schists (Mean of 8 analyses)	Massive soft scapolitized Biotite Rocks (Average of 2 analyses)	Chlorite Schists (Average of 2 analyses)	Biotite Schists (Average of 4 analyses)	"Trachyte" Wooltana Triangle of Volcanics (from Crawford 1963)	Average Rhyolite (After Nockolds 1954)	Average Trachyte (After Nockolds 1954)	Average Basalt (After Nockolds 1954)	Average for mica schists of Pelitic Origin (Simonen 1953)
SiO_2	50.7234	45.939	47.860	36.173	48.132	59.2	73.66	58.31	50.83	60.42
Al_2O_3	14.057	14.259	13.358	15.361	14.163	11.2	13.45	18.05	14.07	16.41
Fe_2O_3	17.78	18.503	19.237	21.815	16.47	12.07	1.25	2.54	2.88	9.71
FeO						nil	0.75	2.02	9.00	
MgO	2.183	7.184	7.415	11.912	7.669	0.73	0.32	2.07	6.34	3.76
CaO	.234	0.732	0.155	0.141	1.162	2.02	1.13	4.25	10.42	0.96
Na_2O	.291	0.594	0.930	0.450	.62	0.24	2.99	3.85	2.23	1.60
K_2O	10.735	6.371	8.552	1.024	7.056	10.20	5.35	7.38	0.82	3.25
TiO_2	1.370	1.243	1.030	1.981	1.004	1.02	0.22	0.66	2.03	0.91
P_2O_5	0.185	0.304	0.303	0.262	0.263	0.10	0.07	0.20	0.23	0.21
MnO	0.015	0.054	0.060	0.057	0.062	0.44	0.03	0.14	0.18	0.09
H_2O^+	1.11	4.78%	1.87%	8.22%	2.91%	0.50	0.78	0.53	0.91	2.39

FIGURE 5.1

THE IGNEOUS SPECTRUM (AFTER HUGHES 1973)



B. Potassium Metasomatism in the Wooltana Volcanics

High potassium values exist throughout the rest of the Wooltana Volcanics though they vary from five to ten percent. Plotting of these samples on a Na_2O, K_2O, CaO triangular diagram assuming all three of these elements were derived from feldspar (Figure 5.2) indicates this is not due entirely to variation in feldspar content of the various samples. The wide variation in the potassium content for the very similar biotite rich volcanics may indicate the varying stages of potassium metasomatism in these rocks. Of the seven rocks analysed, two were significantly scapolitic and were not included in Figure 5.2.

An interesting feature of this figure is the uniformly high potassium content and its small variation in the grey amygdaloidal lavas. Another point of interest is the fact that the two chlorite schists which in an earlier section were concluded to result from metasomatic alteration of biotite schists near the Yudnamutana Mine have both a low weight percent potassium and plot farthest from the K_2O corner of the triangular diagram.

Petrological evidence for potassium metasomatism is discussed in section 3 (Metamorphism).

Summary and Conclusions

The Wooltana Volcanics consist dominantly of biotite rich metamorphic rocks showing no recognizable igneous textures. Small amounts of lavas showing recognisable igneous texture occur within the formation, and appear in two forms. The first is a massive grey amygdular lava with feldspar laths sometimes displaying a trachytic texture, and the second is a rhyolitic lava generally having an equigranular texture consisting of anhedral microcrystalline K-feldspar and quartz. Several features of these lavas, and the association of the Wooltana Volcanics with shallow water sediments suggest they were deposited sub-aqueously.

The relation between the Various rock Types Analysed

Chemically and mineralogically there appears to be little difference between the biotite rich rocks of the Wooltana Volcanics

FIGURE 5.2.

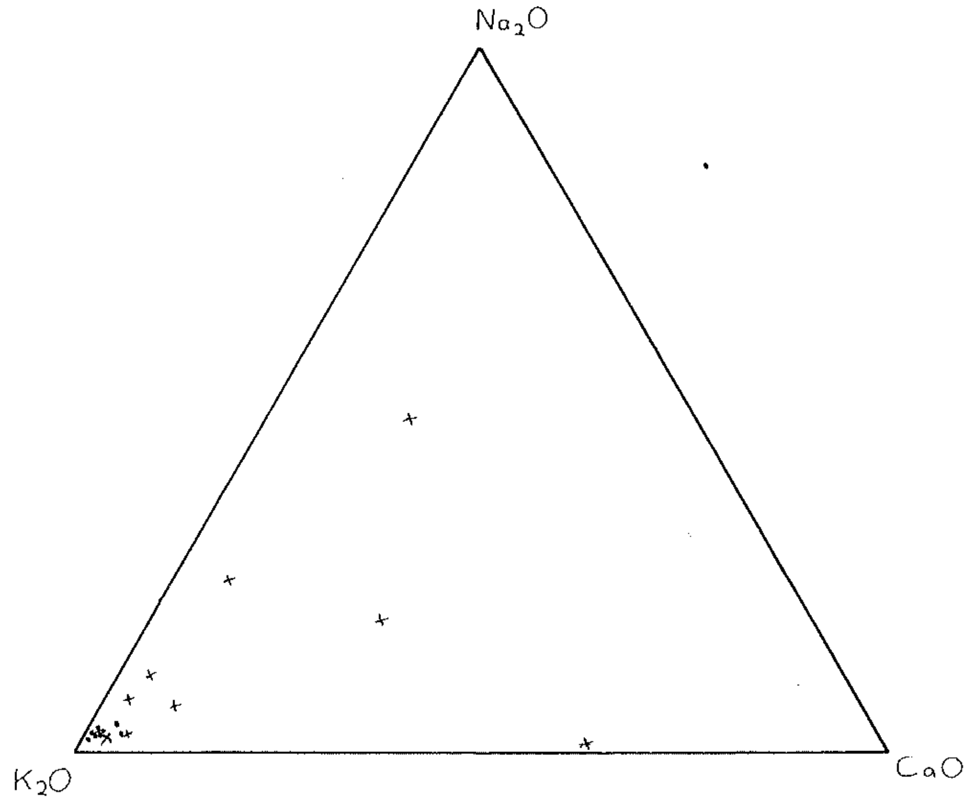
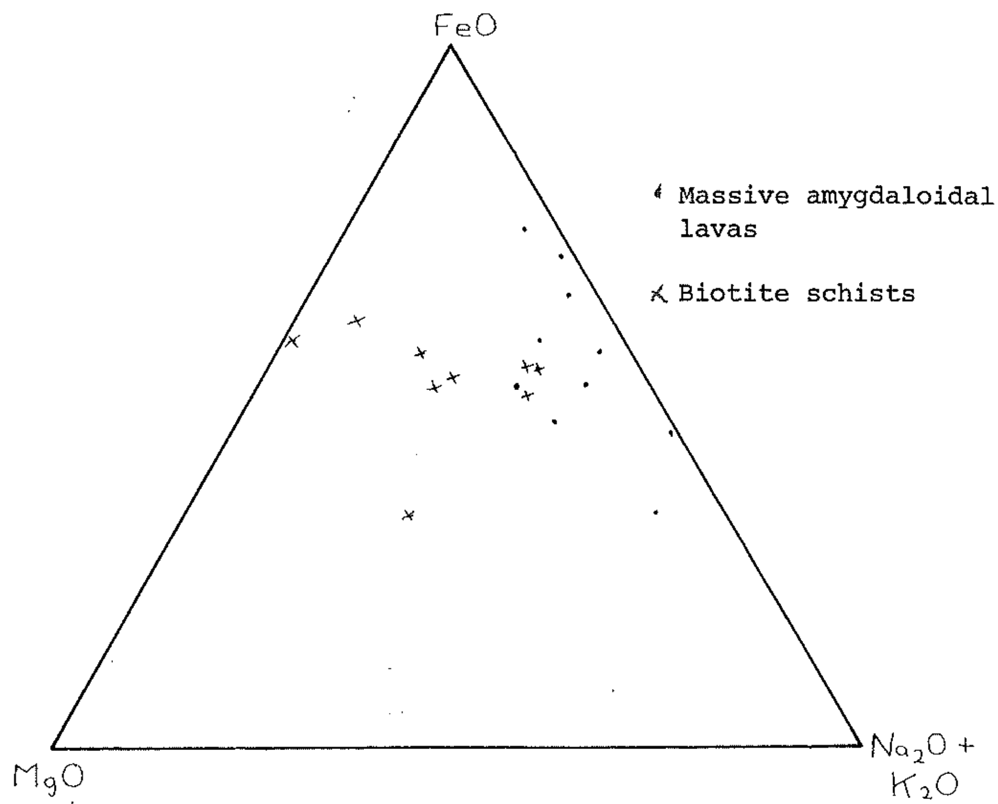


FIGURE 5.3.



formation and it is concluded that these are essentially the same.

The chlorite schists are found only in the vicinity of the Yudnamutana Mine. Their similarity in mineralogy with the biotite rich rocks and their highly schistose nature indicates they are biotite schists altered by shearing and the action of hydrothermal solutions in the vicinity of the mine.

Points of interest in a comparison of biotite rich rocks with lavas of recognisable igneous texture in the Wooltana Volcanics are:

1) The much higher biotite content and the absence of igneous texture in the biotite rich rocks.
2) The occurrence of high opaque mineral abundances in both types although these are higher in the amygdaloidal lavas.
3) The presence of what appears to be amygdules in the biotite rocks.
4) The close relationship of rhyolites and biotite rich rocks in the vicinity of Yudnamutana Mine.
5) The apparent isolation of massive grey lavas to distinct areas and the absence of feldspar laths in the biotite rocks.
6) The difficulty in relating the chemical composition of the biotite rocks with those of biotite rich metasediments, and their similarity in chemical composition to the massive grey amygdaloidal lavas.

It is concluded that these biotite rich metamorphic rocks were once igneous lavas whose alteration has obscured any igneous texture that it may once have had. The relatively lower silica and higher Mg composition of these rocks indicate that the original lava may have been of a more basic composition than the massive grey amygdaloidal lavas. The higher Mg composition, whether primary or epigenetic in character explains the biotite richness of these rocks.

The Original Composition of the Grey Amygdaloidal lavas

Petrological evidence and the composition of the massive grey amygdaloidal lavas, in particular the abnormally high amounts of K_2O and Fe_2O_3, suggests that these lavas have been metasomatised.

In such circumstances the prediction of the original composition of the lavas has obvious limitations. Recalculations of the percentage composition of the amygdaloidal lavas to account for the composition of amygdules in the analyses (assuming 10% amygdules by volume) shows that the presence of amygdules infilled with secondary, quartz, feldspar and opaque minerals has little effect on the analyses.

The chemical composition of the lavas, disregarding the Fe_2O_3 and K_2O abundances appear to fit most closely the composition of a basaltic lava, with the major difference being in the lower MgO abundance for the Wooltana lavas.

There is also a possibility that the chemical composition of these lavas could correspond to that of a trachyte, but the SiO_2 abundance appears to be as much as 8% too low. However the very low silica content of the biotite rich rocks indicates that they would have to be undersaturated in silica and no petrologic evidence for the presence of feldspathoids exists in these rocks. This may indicate that there has been a loss of silica from the volcanics, accounting for the low SiO_2 abundance in the amygdaloidal lavas, and the abundance of quartz veining within the area.

The idea of an original basaltic composition is preferred due to the acute iron deficiency in trachytic lavas.

The Nature of the Metasomatism affecting the lavas

Assuming an original basaltic composition for the massive grey amygdaloidal lavas, it may be seen that up to ten percent K_2O and six percent Fe_2O_3 must have been introduced to the lava with potassium almost completely replacing sodium and calcium within the feldspars. The low MgO abundance indicates that this element would have been lost from these lavas.

Infilling of amygdules, veining of lavas and the assemblage of secondary minerals in the vicinity of metasomatically emplaced copper in the area suggests the mobility of elements resulting in the final deposition or alteration of minerals to quartz K-feldspar magnetite limonite tourmaline chlorite biotite pyrite chalcopyrite scapolite and sericite. In addition the element Ti is enriched in biotite schists in the vicinity of Yudnamutana Mine. This suggests the mobility of the elements, Si, Fe, Mg, Cu, Ca and B in the Wooltana Volcanics.

The Origin of the Metasomatic Solutions

Two possible explanations for the metasomatic effects that have taken place in the Wooltana Volcanics are a redistribution of elements within the formation itself, or an introduction of elements from an outside source.

Assuming an original basaltic composition for the Wooltana lavas and redistribution within the formation, the low silica content of the biotite rich rocks may be explained by loss of silica and re-distribution in quartz veins. Similarly the deficiency of MgO within the massive grey amygdaloidal lavas may be compensated by the slight magnesia rich nature of the much more abundant biotite rocks. Figure 5.3 shows the low Mg content of the massive grey amygdaloidal lavas and the quite variable Mg content of the biotite rocks. The high percentage of secondary iron might possibly be explained by the contemporaneous formation of iron rich sulphides or oxides with the extrusion of the lava and the later redistribution of this Fe.

However, this theory of redistribution within the lavas does not explain the consistently high amount of potassium within the feldspars in all samples taken from this formation. Although there is a variation in potassium content of the feldspars sampled, none were particularly Ca or Na rich, and this feature must be explained by introduction of potassium rich fluids from outside the formation, presumably from the younger granite suite from the basement. It is interesting to note however, that the most potassic feldspars occur in the least altered looking amygdaloidal lavas near the top of the formation (Figure 5.2). Here, although minor microcline does occur there is little evidence of replacement of feldspars. Lower in the formation porphyroblasts of microcline occur within an altered carbonate rock interbedded in the volcanics and in the Wywyana Formation porphyro blasts of K-feldspar and microcline occur in veinlets and within actinolite marble near the Pinnacles Mine.

Near the Yudnamutana Mine in the Wooltana Volcanics, where copper has been deposited from metasomatic fluids, there is no evidence of feldspathization.

Most of the features of metasomatism within the Wooltana Volcanics may be explained by a source of metasomatic solutions from the Younger Granite Suite in the basement. The major difficulty with this theory is that no such granites outcrop within miles of this area although of course this does not exclude the possibility of their presence at depth. Other aspects which are not consistent with this extraneous source of metasomatic solutions are the widespread dispersion of the metasomatic elements, in particular iron and potassium. In such circumstances redistribution of many elements in the Wooltana Volcanics may have taken place anyway.

5. MINERALIZATION

5.1 General

Mineralization within the area occurs exclusively within the cover, and mainly in the Wywyana Formation. Seven mines are found in the area mapped, occurring in various formations. These are:

Black Queen Mine	-	Wywyana Formation
Cockscomb Mine	-	Wywyana Formation
Wheal Austin Mine	-	Wywyana Formation
Pinnacles Mine	-	Wywyana Formation
Yudnamutana Mine	-	Wooltana Volcanics
Wealthy King Mine	-	Wortupa Quartzite
Wheal Gleeson Mine	-	Tapley Hill Formation

In addition, numerous small workings are present, these again being most abundant in the Wywyana and Wooltana Volcanic Formations, but are generally found throughout all of the cover.

5.2 Description of Ore Occurrence

In general the mineralization occurs as secondary copper minerals, mainly malachite with some azurite and cuprite. Primary copper was found as specks of pyrite and chalcopyrite within certain mines. The proportion of sulphides to secondary copper minerals is low, suggesting that most have been oxidized.

The ore is always associated with quartz and iron rich minerals such as magnetite, specular hematite and limonite. Other minerals associated with mineralization in places are calcite and tourmaline.

Mineralization was seen to occur in various forms within the area mapped. These are:

1) Disseminated ore
2) Associated with shear, fault and breccia zones
3) Associated with quartz veins.

Disseminated ore is often seen along bedding planes within the less silica indurated beds of the Skillogallee Dolomite Formation in the form of brown rust stains resulting from the weathering of copper sulphide minerals. Sulphide minerals are also commonly found disseminated within the Bolla Bollana Formation and malachite was seen within the slightly actinolitic marble unit of the Wywyana Formation.

5.3 Structural Control of Mineralization

The association of all major copper occurrences with shear, fault and breccia zones suggests a strong structural control on ore deposition. The Yudnamutana copper deposit occurs within a north-south trending breccia zone caused by faulting of the Wywyana Formation against the Wooltana Volcanics. Mineralization within the Black Queen, Wheal Gleeson, Cockscomb and Wheal Austin Mines is related to north-west striking shear zones. At the Pinnacles Mine the ore is associated with a siliceous and ferruginous replacement body which trends in an east-west direction, parallel to the bedding of the Wywyana Formation. The Cockscomb and Wheal Austin mines are also closely associated with such replacement bodies though the trend of the ore bodies is northwest and across the bedding plane. At the Black Queen (East) Mine, a small adit was dug parallel to the bedding from a larger one following the trend of a shear zone. At the Wealthy King Mine mineralization is associated with large quartz veining which trends parallel to the cleavage within the Wooltana Volcanics. Throughout the Wooltana Volcanics Formation, many minor workings are associated with small quartz veins trending toward 110^{o} parallel to the cleavage and towards 160^{o} parallel to shearing zones. Several of the larger quartz veins which had associated mineralization were seen to contain vughs in which malachite, specular hematite and euhedral quartz grew.

5.4 The Role of Metasomatic or Hydrothermal Solutions in Ore Deposition.

The evidence for metasomatism in the Yudnamutana area is discussed under section 3 on metamorphism and in section 5.2 on the Geochemistry of the Wooltana Volcanics. In connection with the mineralization, the primary sulphide minerals pyrite and chalcopyrite are seen to be associated with the metasomatic minerals and in particular magnetite limonite and hematite in the vicinity of several of the mines.

At the Pinnacles Mine highest copper values were found within a metasomatized siltstone interbed within the Wywyana Formation. The siltstone had been altered to a quartz biotite rock containing patches of coarser grained euhedral calcite quartz and opaques and chlorite which is similar to the assemblage of minerals growing within tension gashes within the actinolite marble country rocks.

5.5 Geochemical Investigation

In order to further investigate the nature of the mineralization and to make possible the use of statistical analysis of the mineralization, geochemical traverses were carried out across several copper deposits. The absence of unweathered outcrop or the inaccessibility to mineralized outcrop hampered the investigation of several mines. However, relatively good sections were obtained from the Pinnacles and Yudnamutana Mines and a traverse was also carried out across a mineralized quartz vein in the Wooltana Volcanics. Analyses were carried out for the ore elements, copper, lead and zinc, and for iron because of its apparent close association with mineralization within the area. Manganese analyses were carried out to test for any possible strong correlations with the ore elements due to its "scavenging" effects.

A. Background Values for the Wywyana Formation

Background values for the Wywyana Formation, together with the average distribution of elements in carbonates are given in Table 6.1. These show that Pb, Zn and Mn abundances are low compared with average carbonates. The background values for Pb and Zn vary little throughout the formation but Mn abundances are quite variable. Iron and Cu abundances are well above the average for carbonate rocks, and evidence suggests that this may be attributed to epigenetic processes.

In this study, 1% will be taken as the upper limit for significant correlation between elements (significance is the percent probability that the correlation coefficient resulted from an uncorrelatable population). Although no significant correlation coefficients are seen between the background values (Table 6.3) the very poor correlation of copper with any element but Fe supports this contention.

B. Background Values in the Wooltana Volcanics

Background values in the Wooltana Volcanics show that all elements except iron are low compared with igneous rocks. The low values for Cu suggest the possibility of the Wooltana Volcanics as the source of the copper mineralization found in the cover, as these low abundances could be the result of a depletion of copper during

TABLE 6.1 BACKGROUND VALUES IN THE WYWYANA FORMATION

	Slightly Actinolitic Marble (ppm)	Slightly Actinolitic Marble (silicified)	Actinolite Marble	Biotite Scapolite Hornfels	Calcareous Siltstone	Average Carbonate After Turekian
Cu (ppm)	425	490	4.3	34	21	4
Pb (ppm)	1.32	1.22	.97	1.22	.42	9
Zn (ppm)	7.54	6.1	9.9	2.6	10.9	20
Fe (ppm)	71,500	137,200	20,600	24,000	9,000	3,800
Mn (ppm)	2,900	105	1,100 (very variable)	140	216	1,100
	Average of 2 analyses	Average of 3 values	Average of 4 analyses	1 analysis	1 analysis	

TABLE 6.2 BACKGROUND VALUES IN THE WOOLTANA VOLCANICS

	Biotite schists (often scapolitized)		Basaltic rocks (After Turekian)
Cu (ppm)	37	58	87
Pb (ppm)	1.14	1.44	6
Zn (ppm)	6.1	20	105
Fe (ppm)	30,500	100,500	86,500
Mn (ppm)	165	400	1,500
	Average of 5 samples	1 analysis	

subsequent segregation of background copper into mineralized populations.

C. Pinnacles Mine Traverse

A geochemical section (Figure 6.1) was carried out across the entrance of the main adit which extends into a silicified and ferruginous body, parallel to the bedding of actinolite marbles and slightly actinolitic marbles of the Wywyana Formation.

An interesting feature of this section is the fact that high metal values were not intersected over the adit itself, and instead uniformly low values were obtained where a very silicified actinolite marble was sampled from the roof of the adit. Highest copper values were instead found within a siltstone interbed in the sequence which had locally been converted to a biotite quartz rock and shows evidence of metasomatic alteration. (See Section 3. Metamorphism).

All copper values are above the background in this section except for those within the slightly actinolitic marble which occurs fifteen metres away from the adit. However the only values that are significantly higher than the background are those within the ferruginized actinolite marble. Zinc and lead values are consistent with background values and do not vary significantly with change in rock type. Manganese values vary a great deal across the section reflecting both the change in lithology and its very variable abundances even within similar rock types.

D. Yudnamutana Mine Traverse

This geochemical section was carried out around the "U" shaped wall of an open cut portion of several adits and shafts scattered along a north-south trending fault zone along which the Wooltana Volcanics and the Wywyana Formation are in contact. Here the Wooltana Volcanics are represented by green weathering chlorite rich rocks and the Wywyana Formation consists of actinolite marble. The fault zone consists of brecciated country rock with iron minerals and quartz occurring in the breccia and as small veinlets. Chlorite veins are also common in the country rock.

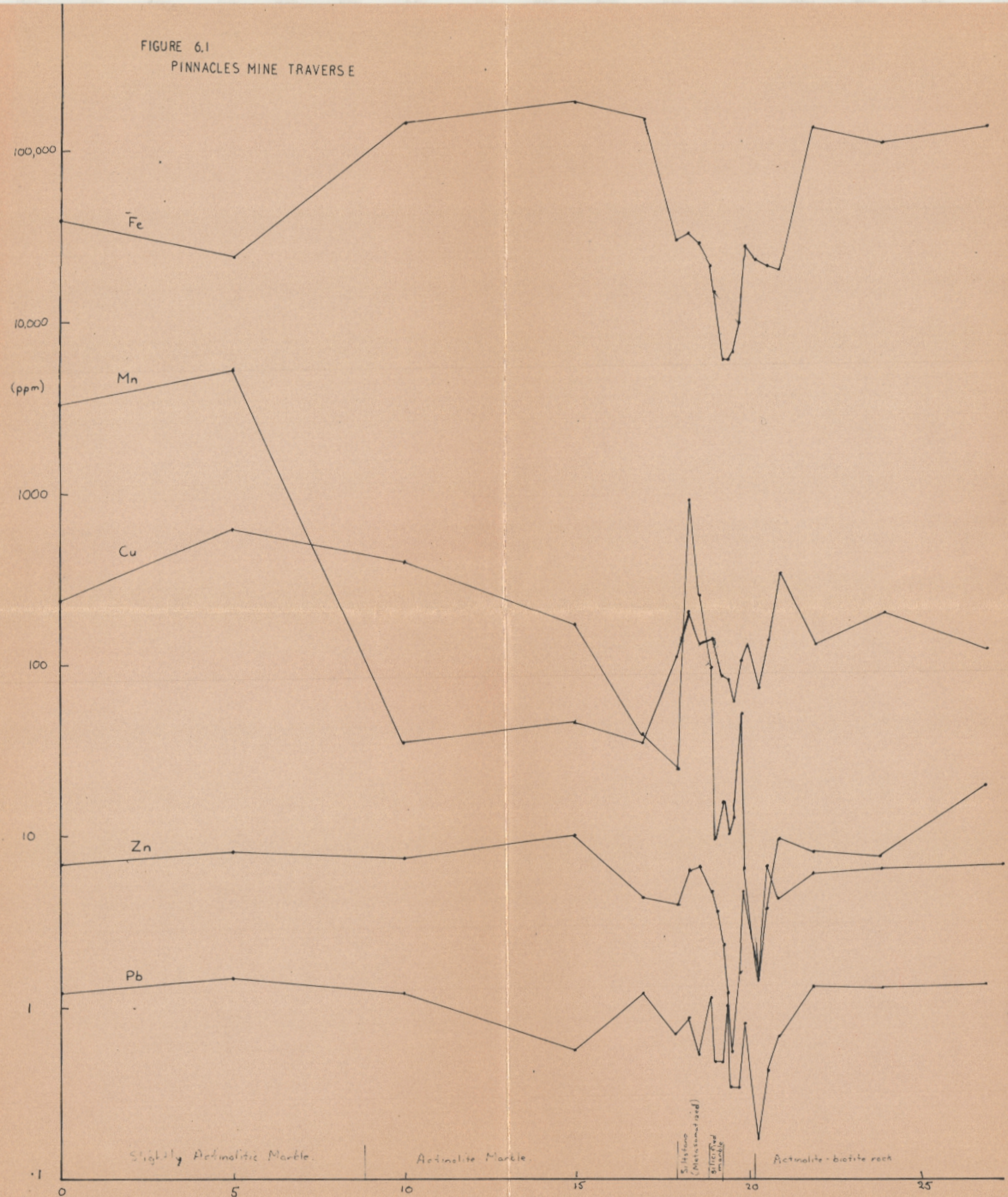


FIGURE 6.1
PINNACLES MINE TRAVERSE
100,000
10,000
(ppm)
1000
100
10
1
·1
Fe
Mn
Cu
Zn
Pb
Slightly Actinolitic Marble.
Actinolite Marble.
Siltstone (Metasomatised)
Silicified marble
Actinolite - biotite rock
0
5
10
15
20
25

FIGURE 6.2.

YUDNAMUTANA MINE TRAVERSE

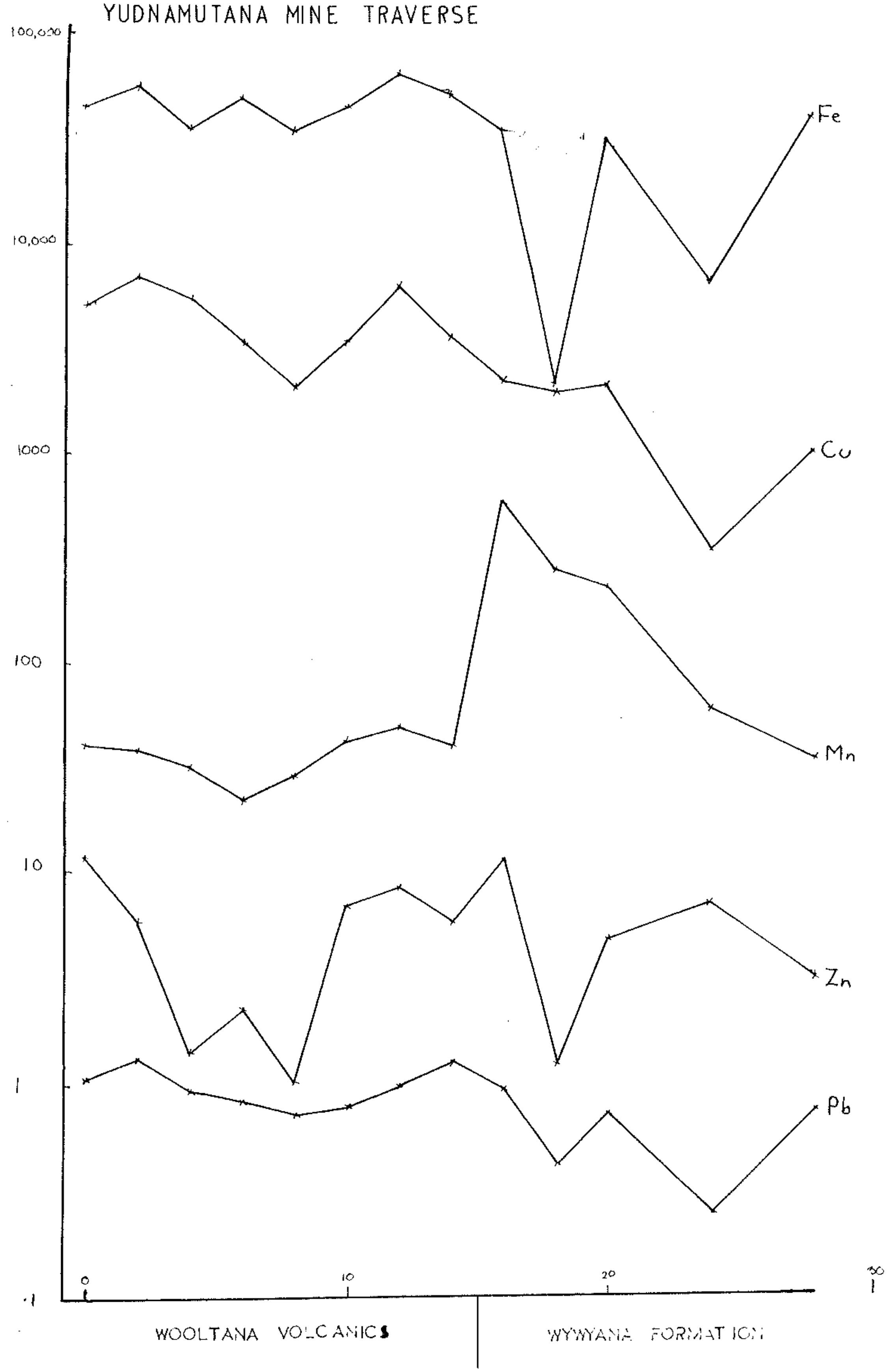
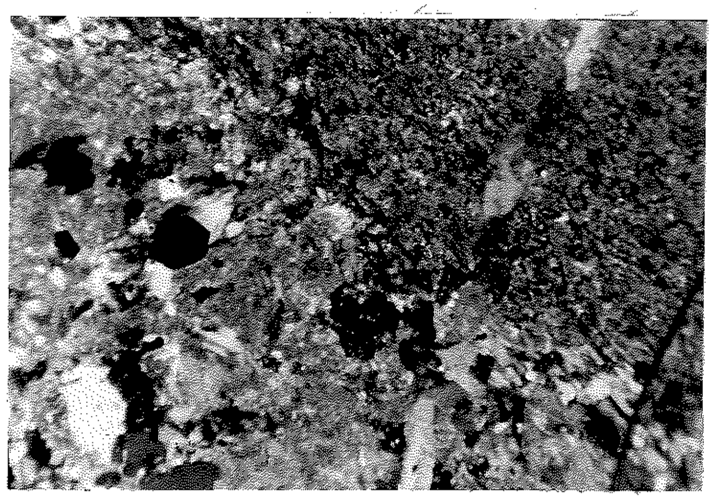


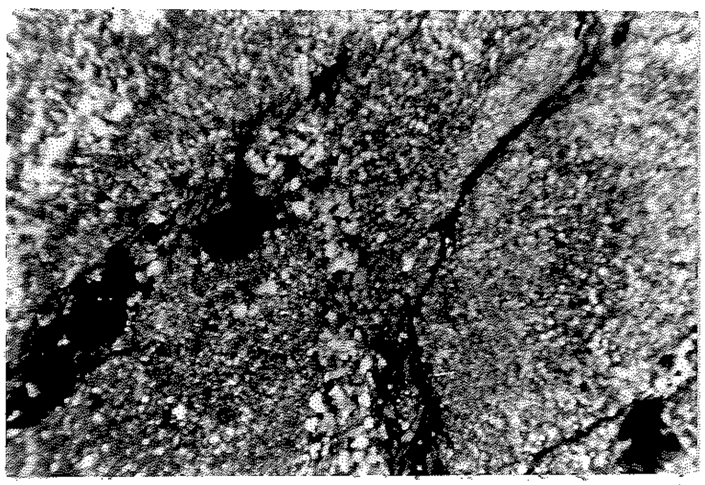
PLATE 3

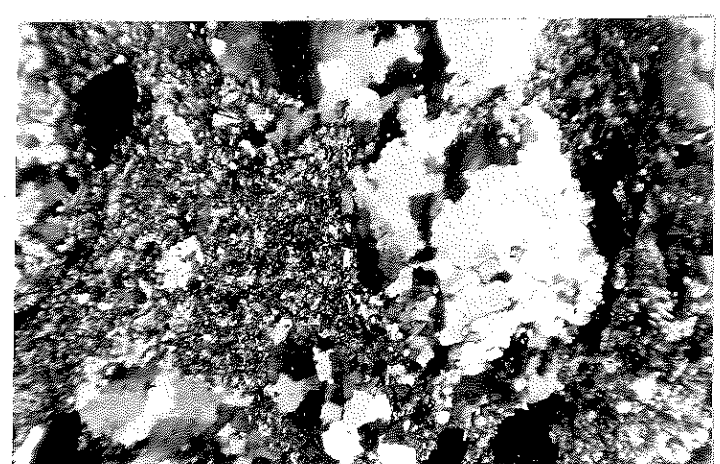
P.1 From T.S. 415/WA8.
A siltstone from the Wywyana Formation having undergone metasomatic alteration. A veinlet containing calcite runs from an area of fine-grained area consisting of euhedral magnetite, chlorite, feldspar and quartz.

P.2 From T.S. 415/571
A rhyolite from the Wooltana Volcanics showing the fine-grained anhedral nature of the groundmass.

P.3 From T.S. 415/560
An amygdular rhyolite from the Wooltana Volcanics formation showing the deformed nature of the quartz infilled amygdules in an inequigranular matrix of anhedral quartz and feldspar.







Unfortunately, lack of good outcrop did not enable a wider traverse to be taken across the fault zone, and all copper values are well above background values, giving an incomplete section (Figure 6.2). However, certain features of the mineralization may be seen from the section. Although all copper values are well above background values, it is obvious that the mineralization is much more pronounced in the Wooltana Volcanics, and appears to continue to a greater lateral extent from the fault breccia zone before beginning to wane, although the latter observation may only be inferred due to the lack of a complete coverage of the lateral extent of the mineralization.

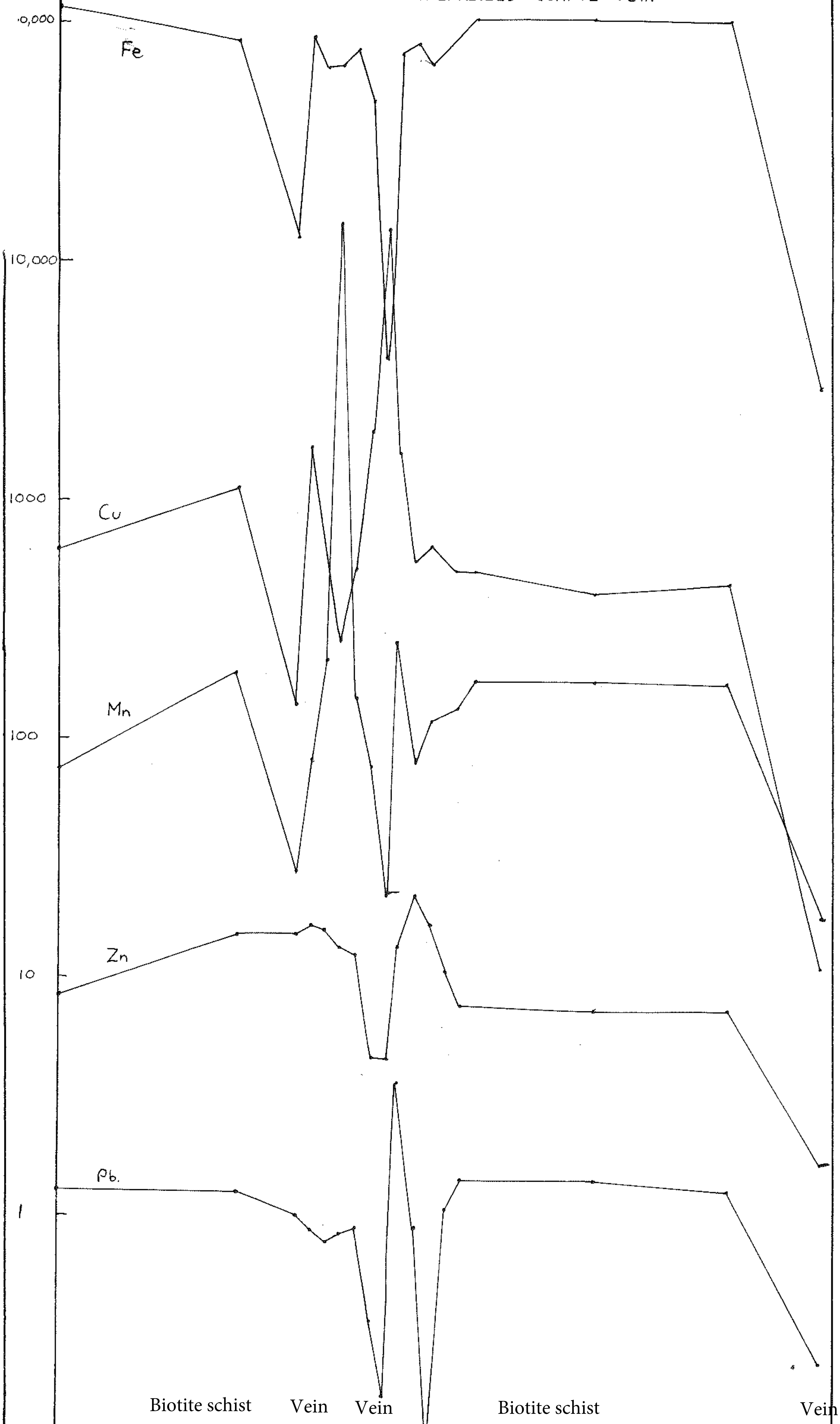
Lead and zinc values are consistent with background values, as at the Pinnacles Mine, although zinc abundances vary widely over the ore zone. Manganese values are uniformly low in the Wooltana Volcanics and show a wide variation within the Wywyana Formation. Conversely, iron values appear to be uniformly high in the Wooltana Volcanics and show a wide variation within the Wywyana Formation. These two observations may be readily explained by the igneous and sedimentary natures of the two formations.

E. <u>Quartz Vein Traverse</u>

This traverse was carried out across a one metre wide quartz vein trending parallel to the schistosity within the Wooltana Volcanics Formation, approximately one hundred metres northwest of the Yudnamutana Mine. A small abandoned working exists nearby and the country rock consists of biotite schists which are often scapolitised. The mineralization occurs as malachite crystals from a vugh within the quartz vein. Several other small quartz veins and veinlets occur within the limits of the traverse, but none of these are mineralized. Micaceous hematite is associated with much of the quartz veining within the area, but this is absent here.

All copper values within the traverse were significantly above background values, demonstrating a wide lateral extent of high copper values. Corresponding with the copper peak over the mineralized quartz vein are marked drops in all other elemental values. Lead and zinc values are within the limits obtained for

FIGURE 6.3.
TRAVERSE ACROSS A MINERALIZED QUARTZ VEIN



background values within the Wooltana Volcanics. As for Zn, Fe values are higher than the Wooltana Volcanics, but these values have been obtained in background analyses.

F. Statistical Analysis of Element Abundances

In order to make statistically valid analyses of elemental abundances possible, results from the three sections were pooled together for the two formations. Normal frequency, log frequency and log cumulative frequency curves were drawn for the two formations and these are shown in Figures 6.4 to 6.9.

Cameron et.al. (1968) have shown that in any population elements obeying a normal distribution are not segregated to any marked extent but remain fairly evenly dispersed through the rock mass, and strong segregation of elements varying in sizes from mineable ore bodies to microdeposits result in positively skewed distributions approaching log normal.

Plots of normal and log frequency histograms for the Wywyana Formation show that Cu, Fe and Mn have positively skewed normal distributions which are a close approximation to log normal frequency distributions in the case of Cu and Fe. Mn however still remains negatively skewed when plotted as a log normal distribution indicating a high frequency of larger values.

The same plots for element abundances from the Wooltana Volcanics show a positive skewness for the elements Cu, Zn and Mn for normal frequency distributions, and show a better approximation to log frequency distributions. The distribution curves of Mn again display a high frequency of anomalously large values.

G. Ore Genesis

In the Yudnamutana Area the association of copper bearing minerals with metasomatic solutions is obvious. These solutions profoundly altered the mineralogy and composition of the Wooltana Volcanics. In Section 4 it was concluded that despite the two possible sources of the metasomatic solutions, widespread redistribution of elements within the Wooltana Volcanics may have taken place in either case. Because of the fact that the Wooltana Volcanics have a low

WYWYANA FORMATION

FIGURE 6.4. NORMAL FREQUENCY PLOTS

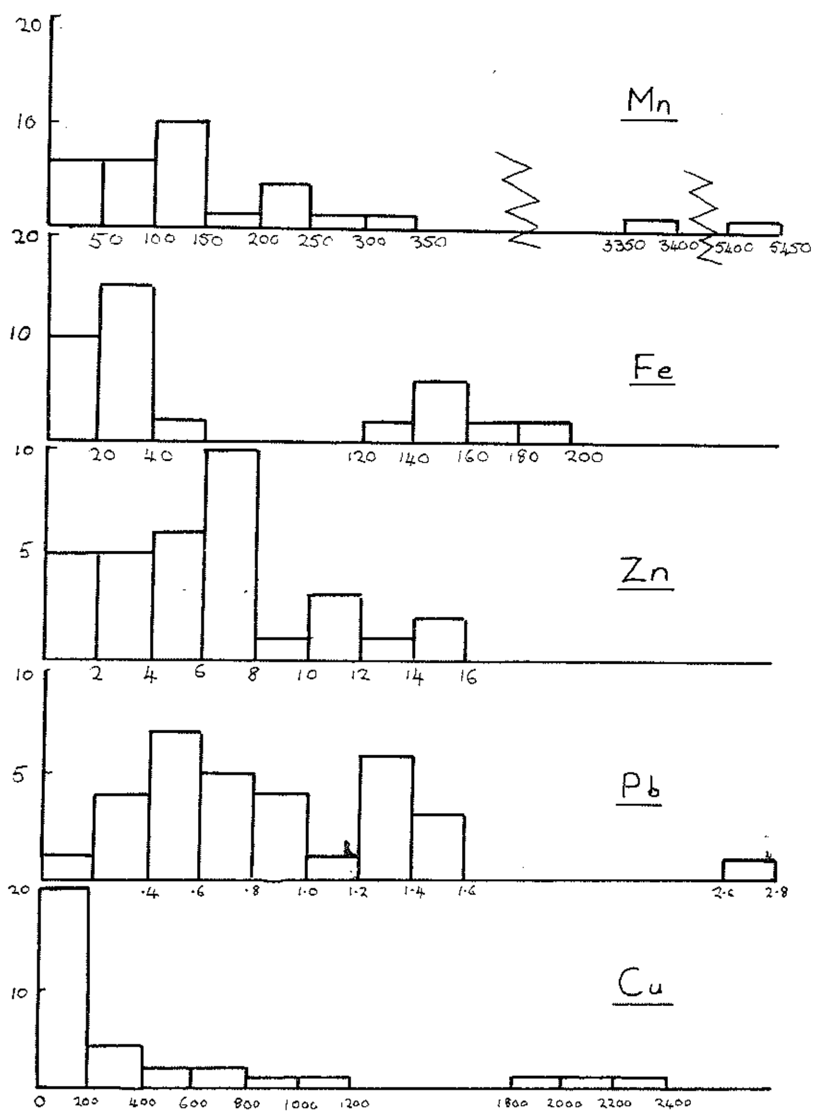
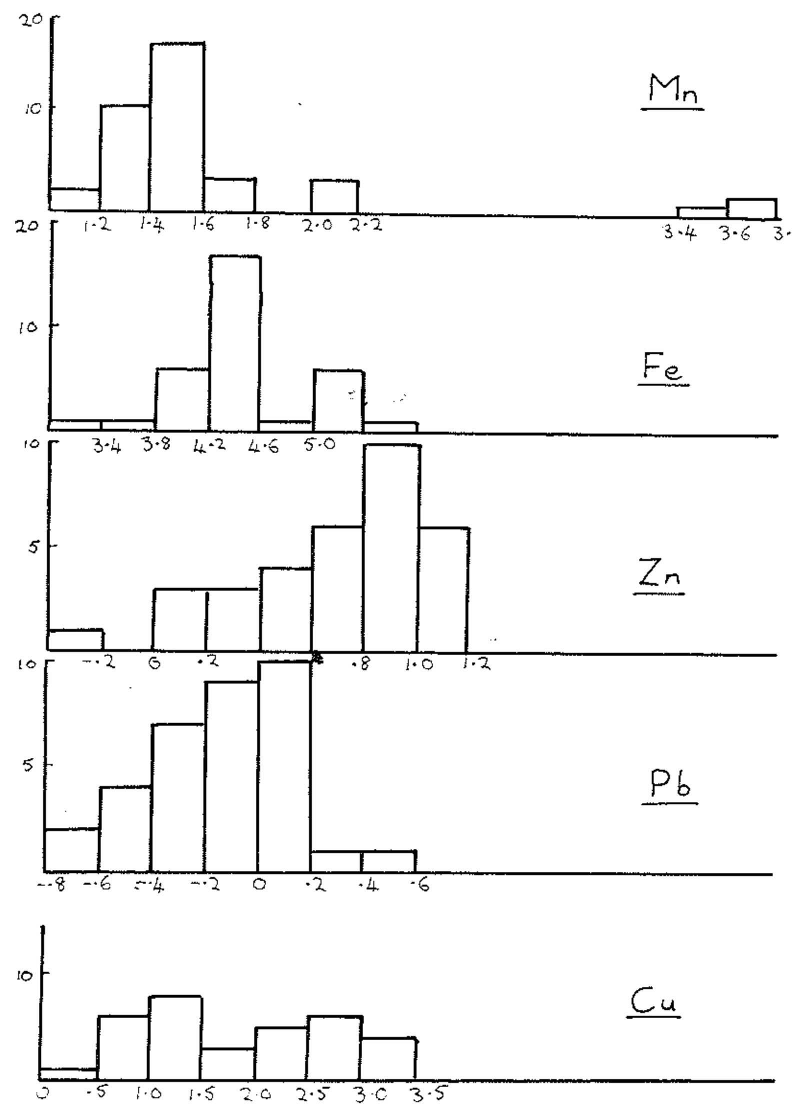


FIGURE 6.5. LOG NORMAL FREQUENCY PLOTS



WOOLTANA VOLCANICS

FIGURE 6.6.

NORMAL FREQUENCY PLOTS

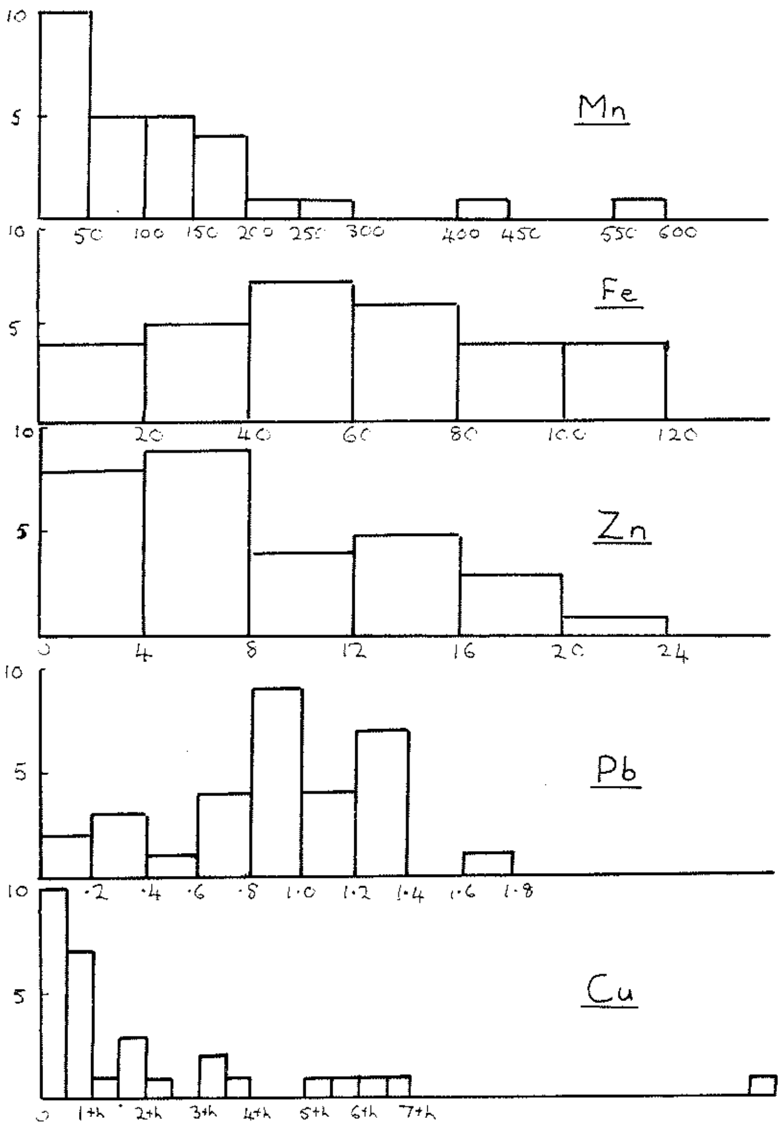
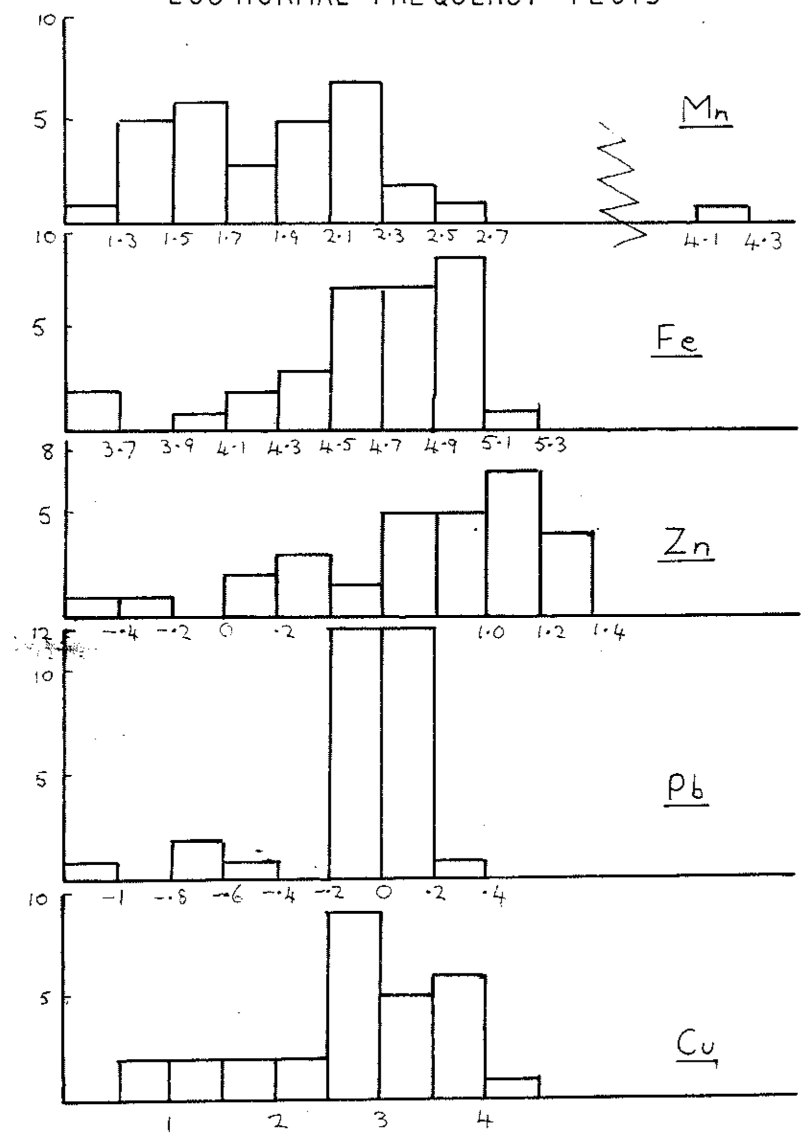


FIGURE 6.7.

LOG NORMAL FREQUENCY PLOTS



background copper abundance it may be possible that this formation may have been the source of copper, rather than the Younger Granite suite in the basement. A fact that seems to support this contention is the absence of mineralization within the basement. The wide dispersion of high copper values laterally from mineralization in the Wooltana Volcanics is also consistent with this theory as is the low kurtosis frequency distribution curve for iron in this formation (Figure 6.6), indicating widespread dispersion of iron values.

H. Discussion of the Mineralization within the Wooltana Volcanics

In the Wooltana Volcanics correlation coefficients for the background values (Table 6.4) show a high correlation between elements which appear to show no distinct segregation of elemental abundances (i.e. Fe, Zn and Pb). Although this is probably a true background feature of the rocks in the case of Zn and Pb the lack of segregation of iron is probably due to its widespread metasomatic dispersion in the Wooltana Volcanics. AT the same time Cu shows a high correlation with Fe but a negligible correlation with other background elements indicating that the same process causing the dispersion of Fe destroyed the normal background relationship of Cu with these elements.

Correlation coefficients for the Quartz vein traverse (Table 6.7) however show that where mineralization occurs in the volcanics copper appears to be introduced independently of all other elements and may even show a negative correlation with Fe.

One would expect that if copper were introduced into the Wooltana Volcanics then Cu values would show a high number of values around the background value for the volcanics and a smaller number of distinctly higher values. If copper were derived from the volcanics one would expect a smaller number of values around the background values and scattered higher values reaching up to the ore percentages. This in fact does occur in the Wooltana Volcanics (Figure 6.6). A plot of log cumulative frequency curves (Fig. 6.9) show two populations for Cu in the Wooltana Volcanics, the first including values up to greater than 2,000 parts per million and another population including all higher values. Thirty percent of all values are included in the

Table 6.3 Correlation Coefficients for Background values from Wywyana Formation

	Cu	Pb	Zn	Fe	Mn
Cu	1	-.030 (>10%)	-.350 (>10%)	.468 (>10%)	-.333 (>10%)
Pb		1	.339 (>10%)	-.204 (10%)	.790 (<1%)
Zn			1	.387 (>10%)	.328 (>10%)
Fe				1	-.173 (>10%)
Mn					1

Table 6.4 Correlation Coefficients for Background Values from the Wooltana Volcanics Formation

	Cu	Pb	Zn	Fe	Mn
Cu	1	-.225 (>10%)	-.242 (>10%)	.871 (1-2%)	.071 (>10%)
Pb		1	.833 (1-2%)	.871 (1-2%)	.161 (>10%)
Zn			1	.871 (1-2%)	-.076 (>10%)
Fe				1	.443 (>10%)
Mn					1

Table 6.5 Correlation Coefficients from Yudnamutana Mine Traverse

	Cu	Pb	Zn	Fe	Mn
Cu	1	.386 (>10%)	.213 (>10%)	.460 (5-10%)	.200 (>10%)
Pb		1	.240 (>10%)	.309 (>10%)	.107 (>10%)
Zn			1	.218 (>10%)	.531 (2-5%)
Fe				1	.287 (>10%)
Mn					1

N.B. The significance of coefficients are given in brackets as the percent likelihood that these coefficients may have resulted from an uncorrelatable population.

Table 6.6 Correlation Coefficients from Pinnacles Mine Traverse

	Cu	Pb	Zn	Fe	Mn
Cu	1	.304 (>10%)	-.435 (<5%)	-.138 (>10%)	.435 (<5%)
Pb		1	.465 (<5%)	.646 (<1%)	.541 (<1%)
Zn			1	.619 (<1%)	.251 (>10%)
Fe				1	.164 (>10%)
Mn					1

Table 6.7 Correlation Coefficients from the Quartz Vein Traverse

	Cu	Pb	Zn	Fe	Mn
Cu	1	-.338 (>10%)	-.306 (>10%)	-.467 (2-5%)	-.107 (>10%)
Pb		1	.298 (>10%)	.562 (1-2%)	-.014 (>10%)
Zn			1	.269 (>10%)	.095 (>10%)
Fe				1	.041 (>10%)
Mn					1

second population. However, it is not a valid assumption to assume that this effect is due solely to a derivation of copper from within the volcanics as the major portion of the data was obtained from incomplete traverses across mineralization. Other interesting features of the log cumulative frequency plots for the volcanics are the fact that Pb and Zn show a weak division into two populations. The negative skewedness of the normal frequency plot for the Wywyana implies that the lower population containing about 15% of the analyses and having a median below that of background values, is due to a small number of spurious analyses lower than the background. However, it does appear that Zn is slightly enriched in the volcanics.

I. Discussion of the Mineralization within the Wywyana Formation

Correlation coefficients for background values in the Wywyana Formation show a negligible correlation of Cu with all elements but Fe, which shows a definite dispersion into two distributions. This supports the theory that the high background values for Cu in this formation is epigenetic.

Correlation coefficients for the Pinnacles Mine Traverse (Table 6.6) show that where mineralization occurs in the Wywyana Formation copper again shows a poor correlation with all other elements including iron, implying its independent introduction even though much of this iron appears to be of epigenetic character. Another interesting point is the strong correlation of iron with lead and zinc in the vicinity of the mine.

A log cumulative frequency plot for the Wywyana Formation (Figure 6.8) shows that there are two populations for copper, the lower one with a mean similar to background values only taking up about 20% of the data. This implies that most of the copper above 10 ppm in the Wywyana Formation comes from a mineralized population.

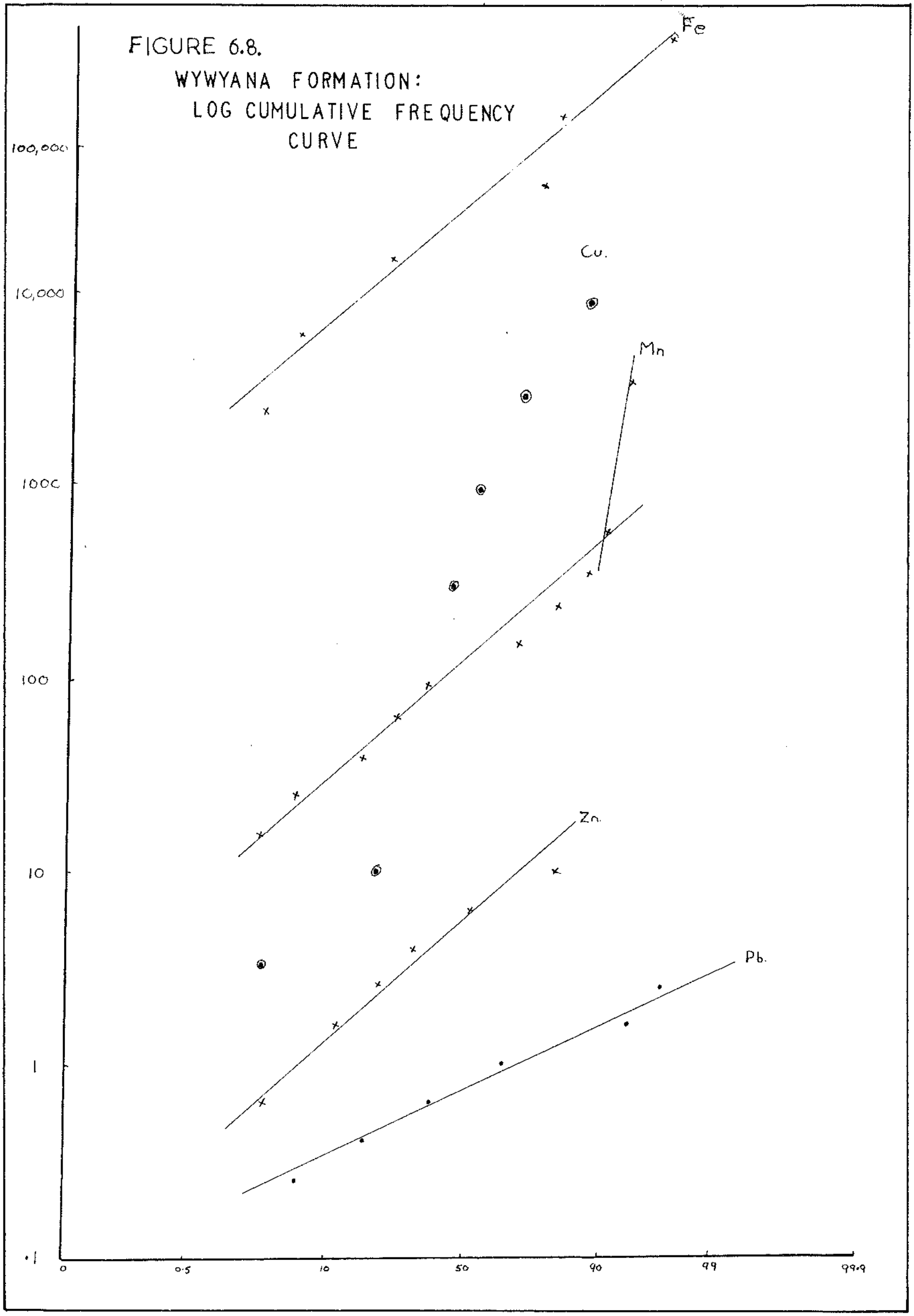


FIGURE 6.8.
WYWYANA FORMATION:
LOG CUMULATIVE FREQUENCY
CURVE
Fe
Cu.
Mn
Zn.
Pb.
100,000
10,000
1000
100
10
1
·1
0
0·5
10
50
90
99
99·9

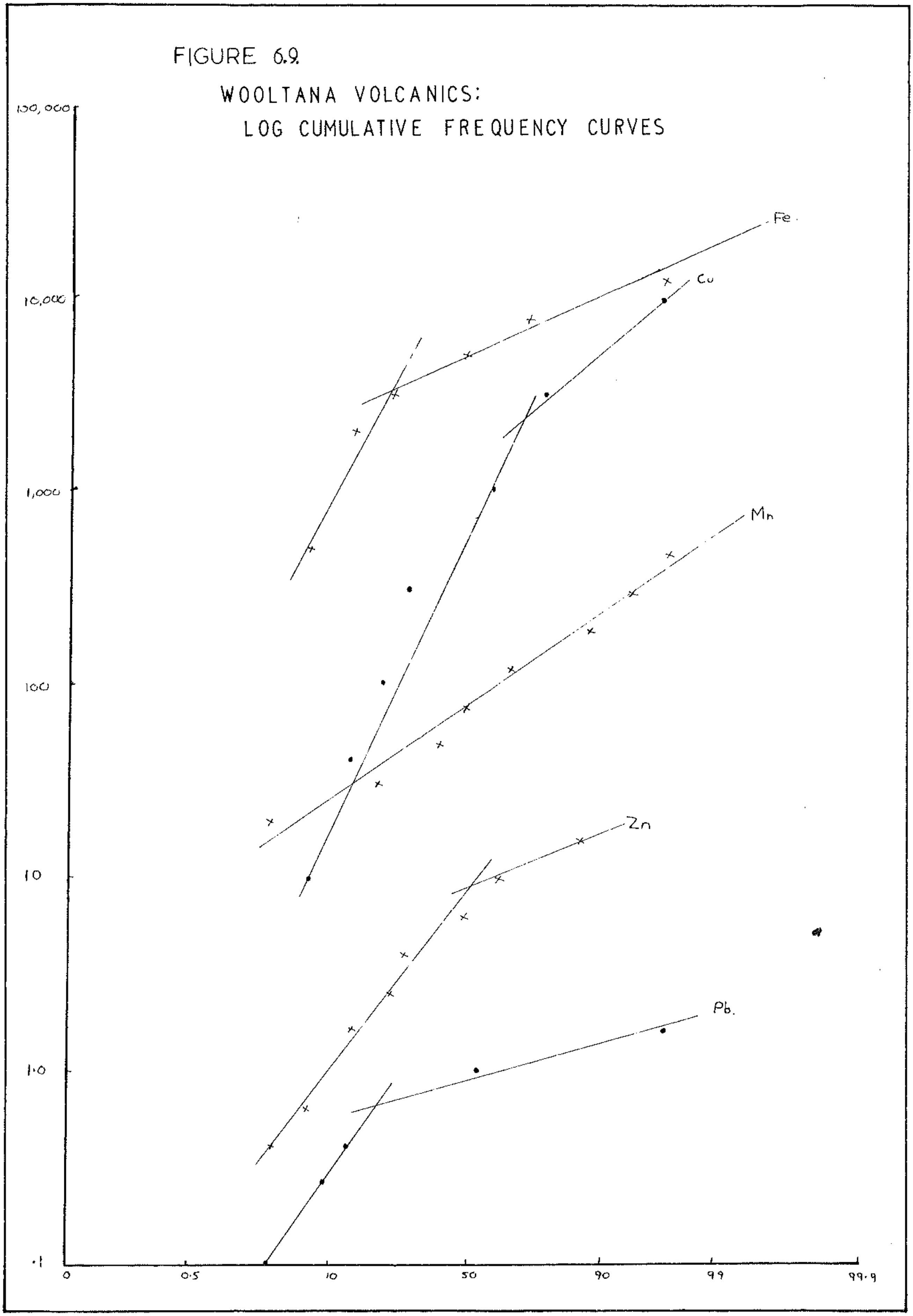


FIGURE 6.9.
WOOLTANA VOLCANICS:
LOG CUMULATIVE FREQUENCY CURVES
100,000
10,000
1,000
100
10
1·0
·1
0
0·5
10
50
90
99
99·9
Fe
Cu
Mn
Zn
Pb.

Summary

In the Yudnamutana Area the ore bearing minerals are closely associated with metasomatic activity and their deposition with gangue minerals such as quartz and iron is strongly controlled by structures created by the Delamerian Orogeny.

Statistical information is not complete due to the fact that most data was taken from incomplete sections across mineralization. This, however, shows that iron and copper both show segregated populations and although copper is related to iron and shows no correlation with other background elements in areas of low Cu abundances, it is not necessarily related to iron in areas of mineralization. This may be taken as evidence for an epigenetic source for copper and later enrichment of this element in many cases.

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APPENDIX I

STRATIGRAPHY

2.1 RADIUM CREEK METAMORPHICS

A. Freeling Heights Quartzite (Unnamed Upper Member)

This member consists mainly of a very thick monotonous sequence of light grey-green weathering, well bedded, medium to fine grained sericitic quartzites which display heavy mineral laminations, and have sedimentary structures such as ripple marks and cross bedding with steeply angled foreset beds. Coats (1971) considers that these testify to near shore deposition, possibly in a deltaic or shoal water environment.

At intervals in the sequence are found horizons of a sericitic sub-arkosic sandstone, containing occasional rounded pebbles and boulders of basement quartzite, ranging from a few centimetres up to a metre in diameter. This sandstone also occurs as the matrix of conglomerate beds containing well rounded and sub-angular pebbles of quartzite.

Within the Freeling Heights Quartzite are also found layers of fine grained biotite schists which are interpreted as amphibolites which have undergone retrograde metamorphism. These range from ten to fifteen metres in thickness, are parallel to the bedding and commonly scapolitized. They vary in character along strike, probably reflecting the amount of retrogradation undergone, as well as variations in the original composition of the rocks. They occur mainly as schists but a decussate texture is not uncommon. Some are almost entirely micaceous, whereas others are more siliceous and contain abundant quartz and sericite. Relict higher grade minerals found are staurolite and amphiboles. Deformed ovoids consisting of aggregations of quartz (T.S. 415/558) are similar to deformed amygdules within the Wooltana Volcanics. This supports Coats' (1971) suggestion that these rocks represent near surface emplacement of a basic igneous rock as sills. These "amphibolites" are older than the Pre-Cambrian basement cover, as they terminate at the basement-cover contact.

2.2 MOUNT NEILL GRANITE PORPHYRY.

This member of the "Older Granite Suite" intrudes the Freeling Heights Quartzite within the map area, having a strong discordant contact relationship with the quartzite. It is a massive pink weathering porphyry consisting of ovoids of quartz and feldspar within a structureless microcrystalline matrix of quartz feldspar, sericite and biotite. The quartz ovoids are typically blue coloured. The porphyry is commonly strongly sheared resulting in the formation of cataclasites.

2.3 LOWER CALLANNA BEDS

A. Paralana Quartzite

The Paralana Quartzite unconformably overlies the basement and may be divided into eight distinct units. These are in ascending order:-

1) The Shanahan Conglomerate Member. This member is 15 metres thick in the eastern part of the map area but narrows toward the west and disappears. It consists essentially of boulders of fine to medium grained sandstone and quartzite identified as Freeling Heights Quartzite and a minor amount of Mount Neill Granite Porphyry. The matrix consists of sandsize grains of quartz in very fine grained grey-

black material. The matrix has been largely replaced by hematite and a little quartz in the far eastern portion of the area, causing this member to be an area of conspicuous outcrop.

2) Twenty metres of well bedded, medium grained grey pink recrystallized quartzite. Minor fine grained biotite in the rock suggests an originally slightly muddy matrix.

3) Twenty metres of a medium grained, heavy mineral banded feldspathic quartzite alternating with more pure quartzite beds.

4) A dark green black weathering micaceous sandstone which is sometimes scapolitic, and consisting essentially of rounded fine sand-size fragments of quartz quartzite and feldspar in a fine grained matrix of biotite.

5) Twenty metres of fine grained biotite rocks. These twice alternate from thinly bedded schistose rocks to more massive scapolitic and tremolitic beds. The schistose rocks consist largely of very fine grained green biotite with minor fine grained actinolite and tourmaline. The more massive beds are coarser grained with large well formed crystals of tremolite randomly growing in a biotite matrix.

6) Fifteen metres of a dark grey medium grained recrystallized quartzite with minor opaque minerals.

7) Ten metres of a clean grey white medium to coarse grained recrystallized quartzite.

8) A thin bed of a fine grained light green schistose chloritic and actinolitic micaceous rock.

B. Wywyana Formation

This formation is a metamorphosed carbonate sequence consisting essentially of three distinct rock types. The first of these is a very altered actinolitic rock consisting of coarse grained crystals (2 cms.) of actinolite within a fine grained dark brown earthy matrix. The density of actinolite crystals growing in this rock varies between 30% and 70%. The matrix is composed mainly of siderite with a little calcite and is very iron stained. This is interpreted as being a ferruginized equivalent of the actinolite marbles that make up the major part of the sequence.

Forming areas of higher relief is a slightly actinolitic marble, brown weathering and grey white on fresh surface. Fine to coarse grained actinolite crystals grow within the recrystallized carbonates, characteristically in radiating clusters, with their long axes parallel to the bedding plane. In places thin discontinuous bands of cherty iron material are present parallel to the bedding. This unit has undergone replacement by iron and silica in many parts of the area, and these replacement bodies form elongate areas of distinct outcrop parallel to the bedding, anything up to 100 metres in length. Thin interbeds of shales and laminated calcareous siltstone which are often scapolitized, are interbedded within the marble. In the vicinity of the Pinnacles Mine a siltstone interbed is locally converted to a quartz-tremolite-biotite hornfels (H.S415/WA15).Interbeds of fine grained equi-granular biotite rocks appear in place of the siltstones in many places. These biotite rocks are often scapolitized or tremolitic and probably represent altered equivalents of a more argillaceous facies of the siltstones.

The majority of the sequence consists of a thick sequence of actinolitic marble consisting of radiating sheaths of actinolite in a calcitic matrix. Feldspar is also common in the marble in the form of microcline which has a perthitic texture containing inclusions of quartz, calcite and actinolite. Other minerals present in minor amount are quartz and biotite. In the vicinity of the Pinnacles Mine biotite becomes a much more important mineral and replaces calcite as the main mineral in the matrix.

C. Wooltana Volcanics Formation

See main text of thesis.

2.4 UPPER CALLANNA BEDS

The Upper Callanna Beds represent ninety metres in thickness of shallow water sediments. They occur in the western half of the map area unconformably overlying the Lower Callanna Beds, but terminate abruptly at a fault uplifting the Wooltana Volcanics suggesting that the deposition of these sediments was prevented on a local scale by minor faulting which formed high level areas.

A. Blue Mine Conglomerate

This unit consists largely of a heavy mineral laminated arkosic conglomerate reaching a thickness of thirty metres in the area studied. The conglomerate characteristically consists of well rounded pebbles, rarely larger than .5 cm. in diameter, of blue quartz, quartzite, feldspar and siltstone in a fine grained pink-grey matrix. The presence of abundant pebbles of blue quartz and pink feldspar and of basement quartzite within the conglomerate indicates that the Blue Mine Conglomerate was probably largely derived from erosion of the Pre-Cambrian Basement granite porphyry and quartzite seen within the mapped area. Interbeds of heavy mineral laminated medium grained sandstones, scapolitized purple coloured calcareous shales and silts, are common in the Blue Mine Conglomerate.

B. Opaminda Formation

The base of this formation is marked by a grey-green scapolitized calcareous shale followed by sixty metres of a well bedded non-calcareous dark grey weathering siltstone. This sequence contains many examples of small scale ripple marks. At the top of the formation is found an actinolite calc-silicate rock consisting of medium grained sheaths of actinolite growing in a carbonate matrix and containing interbeds of scapolitized green weathering calcareous siltstones and cherty bands. This calc-silicate member decreases markedly in thickness toward the west.

2.5 BURRA GROUP

A. Wortupa Quartzite

The Wortupa Quartzite conformably overlies the Opaminda Formation in the western portion of the area and unconformably overlies the Wooltana Volcanic Formation in the eastern portion. In the eastern portion of the area the Wortupa Quartzite shows a discontinuous outcrop pattern due to substantial erosion of the formation. The formation is dominantly composed of a well bedded feldspathic quartzite which is heavy mineral laminated and ripple marked. Near the top of the formation is found a polymictic conglomerate consisting of well rounded pebbles and cobbles of pink and clear quartz, calc silicate rock, feldspar, siltstone and Mount Neill Granite Porphyry in a medium grained quartzitic matrix. The pebbles are rounded, up to 2 cms. in diameter and reasonably well sorted. The top of the formation is a grey black micaceous hematitic siltstone, fairly massive and current bedded.

B. Skillogallee Dolomite

In the area studied, this formation is largely metamorphosed to a succession of tremolite actinolite rocks, and is made up of two sedimentary members. The lower member is characterized by many beds of well bedded fine grained laminated siltstones. These are often scapolitized and contain mudcracks. At the base of this sequence is a brown grey weathering schistose dolomitic quartzite with flattened pebbles having a sacharoidal texture. Minor thinly bedded fine grained silicified dolomites occur in which are found harder chert like bands. A distinctive metasomatized calc silicate rock occurs within this sequence, being a white quartzite in which quartz may be seen to replace the calc-silicates. Several quartzite members are also present and the boundary to the unnamed upper member was arbitrarily placed at the top of the last of these major quartzite beds. The upper unnamed member consists dominantly of fine to medium grained, well bedded silicified calc-silicate (tremolite and actinolite) rocks with minor siltstones, tremolitic marbles and chert bands.

2.6 UMBERATANA GROUP

A. Bolla Bollana Formation (Yudnamutana Sub-Group)

The Bolla Bollana Formation has a strong unconformable relationship with underlying sediments. In the west of the mapped area it overlies the Skillogallee Dolomite with an angular unconformity, and in the east of the map area it unconformably overlies the Wooltana Volcanics or the Wortupa Quartzite.

This formation is essentially a tillite sequence composed of several distinct rock types. The most common is a massive green weathering sub-greywacke tillite. Also present are quartzite beds, bedded-green weathering siltstones which are often scapolitized, and blue coloured scapolitic siltstones. In the area mapped it is generally found that the pattern of outcrop consists essentially of bedded green weathering siltstones characterized by the absence of erratics, separating more massive tillite at the top and bottom of the formation. Angular and subangular erratics are rarely larger than 30 cms. and are predominantly quartzites although boulders of Mount Neill Granite Porphyry were identified as well as a soft very altered scapolitic rock which may have been derived from the Wooltana Volcanic Formation.

B. Tapley Hill Formation (Farina Sub-Group)

This formation overlies the Bolla Bollana formation and the lower half consists dominantly of calcareous and non calcareous fine grained dark grey shales and laminated silts with lenses of buff weathering silty limestones. The upper half of the formation is the Yankaninna Siltstone Member. This begins with two massive limestone beds but consists largely of green weathering laminated calcareous siltstones. This member commonly shows well developed slump structures.

2. STRUCTURE

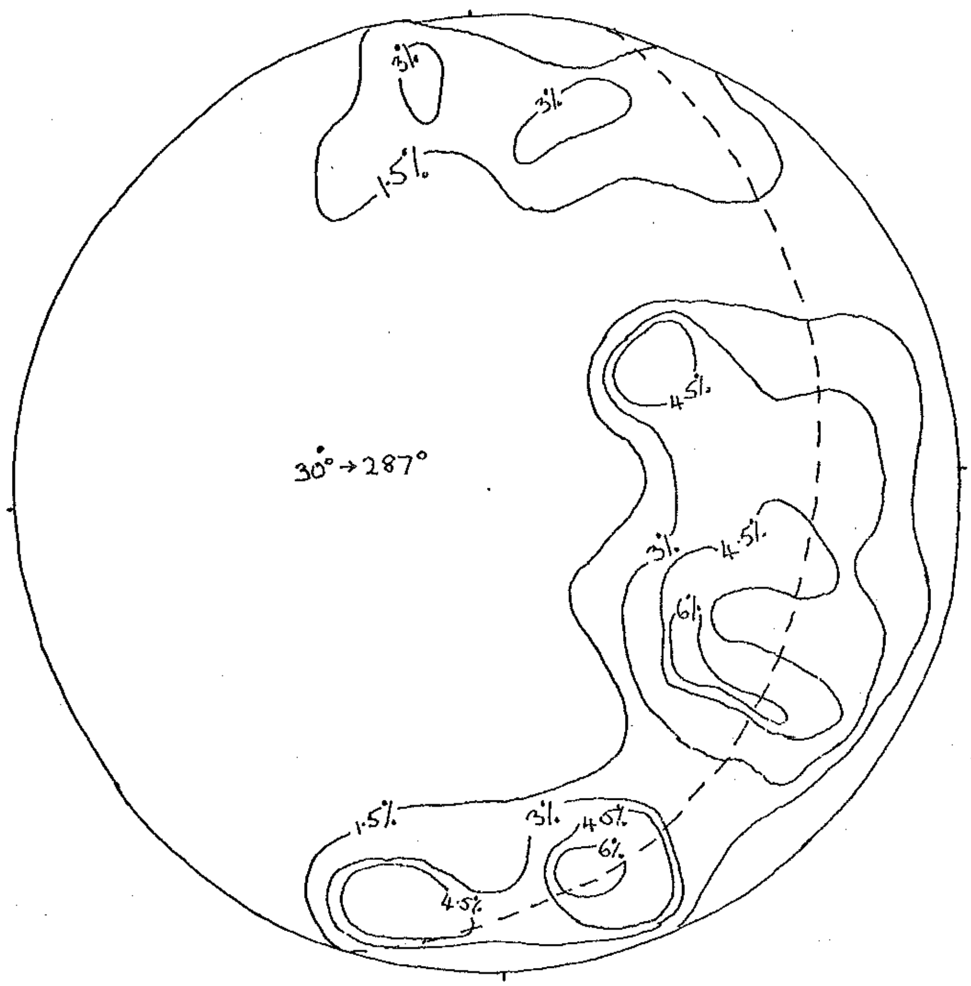
The area essentially consists of a metasedimentary basement block overlain by cover sediments belonging to the Adelaide system. The basement sediments dip steeply toward the north and are overlain with a small angular unconformity by the cover sediments. The presence of angular unconformities within the cover between the Lower and Upper Callanna Beds, the Callanna Beds and the Umberatana Group and the Bolla Bollana Formation and the Tapley Hill Formation, reflect continuing movements during the depositional history of the cover.

The most recent structural feature of the sediments is a westerly dipping anticline the axis of which passes through the centre of the area. A stereographic plot of poles to bedding (Figure 3.1) shows that the axis of the anticline dips at 30° towards 287°. Fold structures are continuous from the cover into the essentially metasedimentary basement. However the more rigid Mt. Neill Granite Porphyry which intrudes the basement is extensively sheared and foliated by the deformation in a 280° direction. Deformation within the cover also shows the differing responses of different lithologies to the deformation. For example, the dominantly carbonate formations the Skillogallee Dolomite and the Wywyana Formation are extensively sheared and display much minor folding whereas the more competent beds are less highly deformed and sheared.

Steep easterly dipping faults are common within the area mapped. Faulting of the basement cover contact is very common and block faulting of the basement and Lower Callanna Beds has locally had a strong influence on sedimentation within the area, locally preventing deposition of the Upper Callanna Beds due to the creation of local high areas (see Appendix 1.2 Upper Callanna Beds) and probably creating high areas for the erosion of the Wortupa Quartzite in the western part of the area. Anomalous schistosities near the limb of the fold north-west of the Yudnamutana Mine probably is the result of p ost schistosity faulting of the western limb of the anticline.

Quartz veins are common throughout the area, varying in size from small veinlets up to three metres in thickness. These are especially common in the lower Callanna Beds and predominantly occur trending parallel to the cleavage but also trend towards 160^{o} which is parallel to the shear zones within the area.

FIGURE 3.1
STEREOGRAPHIC PLOT OF
POLES TO BEDDING



3. METAMORPHISM

The grade of metamorphism throughout the area is low grade greenschist facies. The most common metamorphic minerals found within the area are actinolite tremolite, scapolite, these being most commonly found within metamorphosed carbonate sequences. Biotite, chlorite, anthophyllite and calcite are also abundant. Zeolitesare also found in limited amounts within the Wooltana Volcanics, emphasizing the low grade of metamorphism. Other minor metamorphic minerals present are stilpnomelane, spinel, and sericite.

The basement also displays a low-grade greenschist facies of metamorphism, but evidence of higher grades of metamorphism are found within horizons of mica schists within the Freeling Heights Quartzite, where higher grade minerals such as staurolite and muscovite are found (see Appendix IA).

There is much evidence for metasomatism within the area mapped. This is most readily seen in the field in the vicinity of the Pinnacles Mine where coarse grained euhedral microcline and biotite occur in veinlets and grow with rhombohedral crystals of calcite, magnetite and some quartz in tension gashes within the actinolite rocks. In this area, amphiboles are sometimes altered to chlorite, and euhedral opaques are associated with biotite or tourmaline. Further evidence for the activity of hydrothermal solutions near the mine is found in the feldspathization of parts of the slightly actinolitic marble unit, or the growth of large crystals of microcline within the actinolitic marble.

The Wooltana Volcanics also hold many examples of metasomatism. At the top of the Wooltana Volcanics sequence 300 metres northwest of the Yudnamutana Mine a soft altered looking bleached biotite schist contains up to two percent tourmaline and contains evidence of alteration to chlorite. Euhedral tourmaline and apatite crystals are common within the Wooltana Volcanics. The activity of moving solutions is again emphasized by feldspar veining in the rocks and the amygdule infillings of the volcanics, where there are several types of infilling fluids.

APPENDIX II

List of Thin Sections

Freeling Heights Quartzite

415/558	Mica schist
415/605	Mica schist
415/606	Mica schist

Mount Neill Granite Porphyry

415/55	Sheared granite porphyry

Paralana Quartzite

415/547	Micaceous sandstone
415/546	Biotite schist
415/545	Tremolitic biotite schist
415/550	Tremolitic biotite schist

Wywyana Formation

415/S1	Actinolite marble
415/WA18	Ferruginized actinolite rock
415/WA7	Actinolite marble
415/WA20	Marble
415/WA15	Metasomatized siltstone
415/WA3	Actinolite microcline rock
415/562	Quartz, biotite tremolite harnfels
415/500	Actinolite marble
415/508	Actinolite marble

Wooltana Volcanics Formation

415/44A	Trachyte
415/44B	Trachyte
415/44C	Trachyte
415/44D	Trachyte
415/44E	Trachyte
415/44F	Trachyte
415/44G	Siltstone
415/44H	Trachyte
415/602A	Trachyte
415/602B	Trachyte
415/602C	Trachyte

APPENDIX II (continued)

415/602D	Trachyte
415/602E	Trachyte
415/602F	Trachyte
415/567	Biotite schist
415/568	Biotite schist
415/569	Rhyolite
415/571	Rhyolite
415/572	Rhyolite
415/576	Rhyolite
415/591	Biotite schist
415/Y2	Chlorite biotite schist
415/Y5	Chlorite rock
415/702	Chlorite schist
415/Y1	Biotite chlorite schist
415/S40	Scapolitic biotite rock
415/480	Scapolitic biotite rock
415/22B	Scapolitic biotite rock
415/520	Amphibolite
415/522	Micaceous siltstone
415/523	Biotite schist
415/524	Pebbly mudstone
415/416	Trachyte
415/28B	Conglomerate
415/519	Wooltana Volcanic
415/560	Rhyolite

APPENDIX III

Description of Thin Sections

Amphibolites (From Freeling Heights Quartzite)

415/605

Macro-Description

Dark grey-black weathering mica schist.

Thin Section

Constituents

40% Biotite

30% quartz

15% Staurolite (possibly)

10% Muscovite

5% Scapolite

3% Feldspar

2% Opaques

Minor Tourmaline-euhedral

Texture

A fine-grained rock consisting essentially of larger crystals of actinolite and muscovite in a fine grained matrix of biotite and quartz. The rock has a schistose texture due to parallel alignment of biotite grains.

415/606

Macro-Description

Dark grey-black weathering biotite schist.

Thin Section

92% Biotite-euhedral, green.

8% Quartz

1% Tourmaline-euhedral

Texture

A schistose texture due to alignment of biotite grains. Tourmaline is abundant, and of ten zoned, with inclusion filled centres.

415/558

Macro Description

Grey-green micaceous schist.

Constituents

35% Biotite

30% Sericite

20% Quartz

10% Opaques

5% Muscovite

Texture

Fine grained aggregate of quartz, sericite and muscovite. A schistose texture due to alignment of micas. Opaque minerals are concentrated in lines parallel to the cleavage.

Mount Neill Granite Porphyry

415/550

Macro-Description

Phenocrysts of quartz, opaques and biotite in a fine grained grey-white matrix. A massive sheared rock.

Thin Section

Constituents

50% Quartz

4% Biotite

10% Opaques

36% Feldspar

Texture

Phenocrysts of quartz and opaques in a micro crystalline matrix

Paralana Quartzite

415/547

Macro-Description

Green-black weathering fine grained micaceous sandstone.

Thin Section

Constituents

50% Biotite-green

45% Quartz

5% Feldspar

Minor Tourmaline

Texture

Fine grained sand size (.5 - 1 mm.) grains of rounded quartz and feldspar in a matrix of green biotite.

415/545

Macro Description

Green black massive weathering rock. Bladed crystals of tremolite up to .5 cm. in length growing in a fine-grained biotite matrix.

Constituents

77% Biotite - green

15% Tremolite

5% Quartz

3% Opaques

Texture

Bladed poikolitic crystals of tremolite with biotite and opaque inclusions growing in a slightly schistose matrix of green biotites.

Tremolite crystals appear to be intergrowing with quartz crystals.

415/546

Macro Description

Green black weathering fine grained mica schist.

Constituents

95% Biotite - mainly green

5% Tremolite

minor Quartz

Texture

A very fine grained schist with a small amount of fine grained tremolite.

415/550

Macro Description

Dark green-black weathering massive rock. Bladed crystals of tremolite up to 1 cm. in length, and red iron stained specks about 1 mm. in diameter in a fine grained green matrix.

Thin Section

Constituents

80% Biotite

15% Tremolite

5% Blebs of Fe staining

Texture

Bladed crystals of tremolite in a very fine grained matrix of biotite. Tremolite has poikolitic texture due to crystals of biotite and opaques growing within it. Iron staining is common, and often forms circular specks.

Wywyana Formation

415/S1

Hand Specimen

Medium grained laths of actinolite in a weathered brown matrix.

Constituents

80% Actinolite

5% Calcite

5% Opaques

10% Biotite

Texture

Euhedral, fine to medium grained crystals of actinolite in a matrix of calcite, biotite and opaques. The opaques appear to be associated with biotite and calcite.

415/WA18

Hand Specimen

A ferruginized actinolitic rock.

Thin Section

Constituents

60% Actinolite

40% Opaques

Texture

Holocrystalline aggregate of fine to coarse grained actinolite. Boundaries between grains of actinolite are iron stained and anhedral opaque minerals grow between actinolite laths.

415/WA7

Hand Specimen

A soft rock consisting of sheaths of medium grained actinolite and biotite.

Thin Section

Constituents

80% Actinolite

8% Quartz

10% Biotite

2% Opaques

Texture

Fine to medium grained aggregate of actinolite with minor quartz, biotite and opaques.

415/WA20

Hand specimens

A marble with radiating sheaths of actinolite growing in the plane of the bedding.

Thin Section

Constituents

92% Calcite and Carbonate

4% Actinolite

4% Opaques

Texture

Fine grained recrystallized carbonate rock with medium grained actinolite crystals growing within it.

415/WA15

Hand specimen

A very dark coloured fine grained micaceous rock with lighter coloured areas of carbonate and chlorite.

Thin Section

Constituents

20% Carbonate

20% Chlorite

30% Biotite

30% Quartz

Opaques

Texture

The matrix is a very fine grained aggregate of aligned biotite grains and quartz with minor carbonate. Lighter coloured patches having a "swirling" boundary with the main body of the rock, consist escentially of fine grained chlorite, quartz and carbonate with coarser grained crystals of the same minerals occasionally present.

415/WA3

Hand Specimen

A coarse grained aggregate of K feldspar and actinolite. A K-feldspar, biotite infilled vein cuts the rock.

Thin Section

5% Biotite (coarse grained, in a vein), also fine grained.

Actinolite - fine-medium grained, poikolitic texture.

Microcline - perthitic texture, coarse grained.

K-Feldspar - fine and coarse grained.

Texture

A vein consisting of coarse grains (up to .5 cm.) of biotite and K-feldspar runs through centre of slide. The main part of the rock consists of a fine to medium grained aggregate of microcline, actinolite with fine grained biotites. Biotites and feldspar often grow within the poikolitic grains of actinolite and perthitic microlines.

415/WA500

Hand Specimen

Medium grained rock consisting of sheaths of actinolite and minor biotite.

Thin Section

Constituent

85% Actinolite

10% Biotite

5% Quartz, euhedral

Texture

Fine to medium grained aggregate of euhedral actinolite and biotite grains.

415/508

Hand Specimen

Actinolite marble.

Thin Section

Constituents

75% Actinolite

10% Biotite

10% Calcite

3% Quartz

2% Opaques

Texture

Medium and coarse grained sheaths of actinolite comprise most of the rock. Biotite occurs as inclusions in the actinolite as well as in the main body of the rock. Calcite occurs in veinlets.

415/562

Hand Specimen

Thin Section

Constituents

10% Biotite

60% Quartz

10% Opaques

20% Actinolite

Texture

Rounded fine to medium sand-size quartz grains in a fine grained matrix of actinolite, biotite and opaques.

Wooltana Volcanics

415/44A

Hand Specimen

Fine-grained grey-brown rock. Oval and irregularly shaped amygdules up to 1 cm. in diameter infilled with quartz.

Thin Section

Constituents:- Amygdules (20%)

60% Quartz - undulose extinction, composite grains, anhedral

37% Feldspar - undulose extinction, anhedral

3% Opaques

:- Matrix (80%)

88% K-feldspar - subhedral

5% Opaques - anhedral, some red flakes (probably hematite)

5% Microcline

2% Minor Biotite

Texture

Amygdules have a sharp boundary with the ground mass. The matrix is interpenetrated by many small veinlets often linking amygdules. Matrix consists primarily of laths of albite displaying a trachytic texture. Biotite appears to be altered and is often associated with hematite.

415/44B

Hand Specimen

Fine grained grey rock. Elliptical and irregular shaped amygdules infilled with quartz, feldspar and opaque minerals.

Thin Section

Constituents:- Amygdules (15%)

80% Feldspar - undulose extinction, biaxial (+ve) and (-ve)

20% Quartz - subhedral

Biotite - minor

:- Matrix (85%)

88% K-Feldspar

5% Microcline - anhedral

5% Opaques - anhedral

2% Biotite - minor

Texture

Veins often interlink amygdules. Opaques are disseminated in ground mass, within veins and concentrated on boundaries of amygdules. Opaque filled veinlet seen cutting across a feldspar infilled amygdule. The matrix consists of feldspar laths displaying trachytic texture.

415/44C

Hand Specimen

Fine grained grey-white rock

Thin Section

80% Feldspar - subhedral, inclusions of sericite

10% Opaques - subhedral

10% Biotite

Texture

Fine grained holocrystalline rock consisting of fine grained laths of feldspar in a much finer grained matrix of biotite. Hematite is disseminated throughout the rock.

415/44D

Hand Specimen

Fine grained grey lava.

Thin Section

Constituents

65% Feldspar - sericitized

10% Biotite

20% Opaques

5% Schorl - subhedral and euhedral ore twinned

Texture

Fine grained holocrystalline rock consisting of fine grained feldspars aligned in a sub-parallel manner, and opaques in a fine grained matrix of biotite. Many biotite crystals are coated with opaques. Tourmalines are associated with biotite.

415/44E

Hand Specimen

Fine grained grey rock

Thin Section

Constituents

70% Feldspar - subhedral

10% Opaques - anhedral

20% Biotite - anhedral

minor Chlorite

minor Tourmaline

Texture

Similar to 44D except that it appears to be more altered due to the presence of sericite inclusions within the feldspar. Chlorite is present in what appears to be an infilled vesicle.

415/44F

Hand Specimen

Fine grained grey rock with infilled amygdules up to 4 cms. in diameter varying from spherical to highly irregular shapes. Some amygdules are infilled by quartz, and others by hematite. Hematite veinlets appear throughout the rock.

Thin Section

Constituents :- Amygdules (20%)

90% Opaques

10% Quartz

minor Biotite

:- Groundmass (80%)

63% Feldspar (Albite or Oligoclase), absence of albite twins

7% Opaques

30% Biotite - anhedral

Texture

Fine grained laths of Feldspar aligned in a sub-parallel manner in a finer grained groundmass of biotite. Opaques are disseminated throughout the groundmass and aggregated in amygdules and veins interconnecting amygdules. Amygdules are either filled substantially with opaques or with feldspar in which case opaques coat the outer walls. Several veinlets infilled with feldspar exist and one infilled with biotite may be seen.

415/602A

Hand Specimen

Dark grey micaceous rock with altered scapolite spots. A feldspar vein cuts the rock.

Thin Section

3% Scapolite

50% Biotite

5% Opaques

42% Feldspar

minor Apatite - coated with Fe.

Texture

Basically a fine grained aggregate of anhedral biotite and feldspar. Running down centre of slide is a bein consisting of more coarser grained crystals of biotite feldspar and opaques.

415/602B

Hand Specimen

Fine grained rock consisting of lighter grey feldspathic areas and grey black micaceous areas. Amygdules up to .5 cm. in diameter and infilled with iron occur.

Thin Section

40% Feldspar

30% Biotite

25% Opaques

Texture

A holocrystalline rock consisting of fine grained feldspar laths displaying a trachytic texture. Superimposed on this are areas of biotite in definite veins or in broad elongate aggregations. An anhedral feldspar, coarser grained than the feldspar laths in the matrix is associated with the biotite. Opaques are numerous and also appear to be present in broad aggregates. A small amygdule is present infilled with feldspar.

415/602C

Hand Specimen

Fine grained grey-black rock

Thin Section

Constituents

88% K-Feldspar

7% Opaques

5% Quartz

minor Biotite

minor Zircon

Texture

Fine grained laths of simple twinned feldspar giving a trachytic texture. Also areas of coarser grained anhedral feldspar, microcline and opaques.

415/602D

Hand Specimen

Fine grained grey-black rock with white weathered scapolite up to 3 mm. in diameter.

Thin Section

Constituents

45% Feldspar - inclusions of sericite, simple twinned, also sericite

5% Opaques

45% Biotite

5%

Texture

Fine grained holo-crystalline aggregate of feldspar laths in a biotite matrix.

415/602E

Hand Specimen

Fine grained light-grey rock.

Thin Section

Constituents

40% Feldspar

40% Biotite

15% Opaques

5%

Texture

Fine grained laths of subhedral, simple twinned feldspar in a finer grained matrix of biotite giving a volcanic texture. Slide also has broad streaks of more abundant biotite and finer grained anhedral feldspars with no observable twinning. Veinlets containing feldspar also exist.

415/602F

Hand Specimen

Fine grained grey-black rock with biotite infilled amygdules.

Thin Section

Constituents:- Amygdules (5%)

70% Biotite - bright orange colour

15% Feldspar - biaxial (-ve)

15% Opaques

:- Matrix (95%)

35% Feldspar

3% Microcline

40% Biotite

15% Opaques

10%

Texture

The matrix consists of fine grained laths of feldspar, biotite and opaques. Amygdules range from 2 mm. to 1 cm. in diameter.

415/22B

Hand Specimen

Massive purple-black weathering rock consisting of many blocky scapolite crystals growing in a biotite matrix.

Thin Section

Constituents

50% Scapolite

24% Biotite

25% Quartz

1% Opaques

Texture

Fine to medium grained euhedral crystals of scapolite in a much finer grained matrix of green biotite and quartz.

415/540

Hand Specimen

A massive green black weathering scapolitized biotite rock.

Thin Section

Constituents

50% Scapolite

29% Biotite

20% Quartz

1% Opaques

Texture

Euhedral crystals of scapolite in a much finer grained matrix of quartz and biotite.

415/520

Hand Specimen

Green weathering rock consisting of laths of actinolite in a feldspar matrix.

Thin Section

45% Actinolite - Poikolitic texture

30% Microcline Perthitic texture

20% Calcite

5% Scapolite

1% Opaques.

3% Feldspar - biaxial (-ve), albite twinned.

Texture

Fine to medium grained holocrystalline rock made up of euhedral crystals. Microcline and calcite exist as grains within poikolitic crystals of actinolite and feldspar.

415/522A

Hand Specimen

A greenish brown micaceous siltstone.

Thin Section

Constituents

25% Biotite - fine grained, subhedral.

30% Quartz - anhedral

5% Feldspar - anhedral

5% Scapolite, fine-medium grained

20% Actinolite - subhedral

minor Tourmaline and Apatite

15% Calcite

Texture

415/523

Hand Specimen

A fine grained brown weathering micaceous rock.

Thin Section

Constituents

73% Biotite, brown subhedral, and altered orange "knots"

20% Quartz

5% Feldspar

2% Opaque
Apatite

Texture

Alignment of biotite grains giving schistose cleavage.

415/524C

Hand Specimen

Rounded mudstone and quartzite pebbles within a micaceous matrix.

Thin radiating crystals of anthophyllite present throughout.

Pebbles up to 3 cms. long.

Thin Section

Constituents:- Pebble

70% Quartz

25% Biotite

5% Opaques

:- Matrix

70% Biotite - subhedral

10% Anthophyllite - euhedral, medium grained

5% Opaques

15% Tremolite - euhedral

Clinozoisite
Apatite
Feldspar - (biaxial (-ve)

Texture

A siltstone pebble within a fine grained matrix. The siltstone pebble is penetrated by veinlets containing quartz and feldspar. Acicular crystals of anthophyllite grow throughout the rock.

415/606

Hand Specimen

Fine grained biotite schist

Thin Section

Constituents

95% Biotite - green subhedral, fine grained

5% Feldspar - fine grained

Zircon Tourmaline - Fo concentrated in core?

Texture

Alignment of biotite crystals to give schistose texture.

415/567

Hand Specimen

A soft grey white fine grained mica schist.

Thin Section

Constituents

70% Biotite

2% Opaques

5% Quartz

5% Chlorite

3% Tourmaline

15% Sericite

Texture

A fine grained schistose rock due to the orientation of the micas. Clear small tourmaline crystals are very common. Chlorite occurs as small clusters of subhedral acicular crystals throughout the rock and quartz occurs throughout the groundmass.

415/568

Hand Specimen

A hard black schistose biotite rich rock.

Thin Section

Constituents

50% Biotite

10% Scapolite

30% Feldspar

10% Quartz

Texture

Alignment of biotite grains gives a rough schistosity. Euhedral grains of actinolite and scapolite in a biotite feldspar rock.

415/569

Hand Specimen

A dense light grey weathering rock. Very fine grained, pink coloured (due to K.feldspar) on fresh surface and penetrated by feldspar veinlets.

Thin Section

Constituents

60% Feldspar

25% Quartz

10% Biotite

5% Opaques

Texture

A fine grained holocrystalline aggregate of anhedral feldspar and quartz. Biotite occur in long thin streaks within the rock and in veinlets cutting across the rock.

415/571

Hand Specimen

Dark grey weathering fine grained micaceous rock.

Thin Section

Constituents

30% Feldspar

20% Quartz

35% Biotite

5% Opaques

Texture

Equigranular holocrystalline rock made up of anhedral quartz, feldspar and biotite. The feldspar is untwinned. Biotite occurs in streaks due to flow banding.

415/572

Hand Specimen

Green black fine grained biotite schist.

Thin Section

Constituents

35% Feldspar

20% Quartz

30% Biotite

15% Chlorite

Texture

Fine grained anhedral aggregate of crystalline quartz feldspar and biotite. Larger crystals of euhedral chlorite associated with biotite occur.

415/576

Hand Specimen

Dark grey fine grained quartz and biotite rich rock.

Thin Section

Constituents

50% Quartz

20% Feldspar

20% Biotite

7% Opaques

Texture

Matrix is a fine grained aggregate of anhedral feldspar quartz and biotite. Opaques and more coarse grained biotites are concentrated in elongate strips. The rock is very uneven grained with coarser grained quartz occurring occasionally within the matrix but usually aggregated in broad elongate.

415/591

Hand Specimen

Fine black biotite schist.

Thin Section

Constituents

Matrix

95% Biotite

3% Opaques

2% Tourmaline

minor Apatite

Vein

50% Quartz

5% Feldspar

Texture

Crude alignment of biotite grains give a schistose texture. Anhedral quartz and Feldspar grains fill a vein in which the feldspars are much coarser grained.

415/Y2

Hand Specimen

Very fine grained green weathering micaceous schistose rock.

Thin Section

Constituents

15% Opaques

50% Chlorite

25% Sericite

10% Quartz

Texture

Fine grained aggregate of anhedral and acicular chlorite quartz and sericite. Coarser grained acicular chlorite and opaques exist in a vein.

415/Y5

Hand Specimen

Fine grained grey green weathering rock.

Thin Section

Constituents

58% Chlorite

30% Quartz

10% Opaques

2% Tourmaline

minor Malachite

Texture

Holocrystalline aggregate of anhedral chlorite and quartz.

415/702

Hand Specimen

Schistose green micaceous rock.

Thin Section

Constituents

55% Chlorite

5% Opaques

20% Feldspar

minor Zircon

15% Biotite

Texture

A holocrystalline schistose fine grained rock due to alignment of chlorites and biotites. Feldspar is disseminated within the rock and in bands parallel to the cleavage. There is one ovoid aggregation of feldspars which could be an amygdule, (.5 mm. diameter). The schistosity bends around the "amygdule".

415/Y1

Hand Specimen

Fine grained grey-black micaceous schist.

Thin Section

Constituents

25% Chlorite

30% Biotite

15% Feldspar

3% Opaques

7% Quartz

20% Tremolite

Texture

415/520

Hand Specimen

Light grey weathering fine grained lava.

Thin Section

Constituents

20% Biotite

20% Quartz

35% Feldspar

12% Opaques

5% Chlorite

Sericite

Limonite

Tourmaline

Texture

Irregular shaped quartz infilled amygdules in a matrix of fine grained anhedral quartz, feldspar and opaques. Sericite appears to have pseudomorphically replaced a porphyritic mineral. The matrix is inequigranular due to the random growth of larger crystals.

Table 5.1 Rocks analysed using X.R.F.

Rock No.	Description
415/44A	Massive grey amygdular lava twenty percent quartz-feldspar infilled amygdules.
415/44B	Similar to 44A.
415/44C	Massive lava. 80% fine grained laths of feldspar in a biotite opaque matrix.
415/44D	Massive lava similar to 44C.
415/44E	Massive lava similar to 44C.
415/44F	Massive lava with 20% of magnetite infilled amygdules.
415/602A	Massive lava. Laths of K feldspar in a biotite and opaque matrix.
415/602B	Massive lava containing up to 25% opaques and 30% biotite.
415/602C	Massive lava 30% quartz-feldspar amygdules in a feldspar matrix.
415/602D	Massive lava - 40% biotite.
415/512A	Biotite schist.
415/545	Biotite schist - slightly scapolitized.
415/568	Biotite schist - 50% green biotite 40% quartz and feldspar 5% actinolite.
415/609	Biotite schist.
415/703	Chlorite schist.
415/Y15	Chlorite biotite rock.
415/22B	50% euhedral scapolite crystals in a fine grained biotite rich matrix.
415/25	Massive scapolitic biotite rock.
415/WA8	Actinolite marble from the vicinity of the Pinnacles Mine.
415/WA18	Ferruginized actinolite marble from the Pinnacle Mine area.
415/YB	Actinolite marble from the Yudnamutana Mine.
415/531	Actinolite marble.
415/561	Actinolite marble.
415/537	Actinolite marble.
415/555	Slightly actinolitic 5% marble.
415/529	Slightly actinolitic marble.
415/540	Slightly actinolitic marble.

Table 5.2 Chemical Composition of Wooltana Volcanics

	415/44A	415/44B	415/44C	415/44D	415/44E	415/44F	415/602A	415/602B	415/602C	415/602D
SiO_2	62.06	49.27	46.31	48.68	52.19	52.02	47.14	52.05	51.05	46.48
TiO_2	1.06	1.16	1.30	1.37	2.33	1.39	1.19	0.98	1.52	1.38
Al_2O_3	13.23	11.30	14.47	18.06	16.69	9.63	14.09	15.02	12.93	15.16
Fe_2O_3	10.88	27.54	25.93	17.45	8.52	29.16	19.26	15.15	20.22	16.65
MnO	0.0	0.01	0.01	0.0	0.02	0.02	0.03	0.0	0.03	0.03
MgO	0.2	0.54	1.22	1.05	1.96	1.48	5.68	1.82	3.15	4.74
CaO	0.03	0.03	0.05	0.08	0.37	0.06	0.13	0.10	0.12	0.08
Na_2O	0.21	0.22	0.35	0.33	0.48	0.20	0.27	0.26	0.26	0.33
K_2O	11.82	9.84	11.33	10.84	12.76	7.48	10.53	10.69	9.75	12.32
P_2O_5	0.09	0.14	0.21	0.17	0.40	0.12	0.23	0.15	0.20	0.15
Loss	0.89	0.18	2.21	1.39	1.43	0.86	5.11	3.00	2.07	5.04
Total	101.45	100.24	103.39	99.40	97.14	102.42	102.66	99.20	100.30	102.36
H_2O^+	0.52	0.69	0.87	1.07	0.81	1.11	1.57	1.36	1.34	1.79

Table 5.2 Chemical Composition of Wooltana Volcanics

	415/545	415/22B	415/25	415/568	415/609	415/512	415/703	415/Y15
SiO_2	47.41	48.44	47.28	50.03	43.95	63.63	40.60	31.75
TiO_2	1.45	0.67	1.39	0.77	1.27	0.84	1.38	2.48
Al_2O_3	14.44	14.60	12.10	15.42	13.26	10.15	14.16	16.56
Fe_2O_3	16.07	17.69	20.79	18.50	20.31	13.27	22.76	20.91
MnO	0.07	0.08	0.04	0.08	0.04	0.02	0.06	0.0
MgO	6.50	4.98	9.85	3.92	8.41	3.82	10.62	13.21
CaO	2.49	0.13	0.18	0.20	0.25	0.17	0.21	0.08
Na_2O	1.66	0.97	0.89	0.16	0.17	0.12	0.68	0.22
K_2O	4.74	10.05	7.05	10.22	5.93	5.22	1.88	0.17
P_2O_5	0.23	0.26	0.35	0.28	0.24	0.19	0.22	0.31
Loss	4.82	6.75	2.61	2.25	3.64	4.04	8.32	13.57
Total	99.87	104.62	102.52	101.81	102.48	101.46	100.89	99.25
H_2O^+	1.74	1.91	1.83	1.62	2.53	1.54	5.95	10.49

Table 5.4 Chemical Composition of Wywyana Formation (assuming 1% Na)

	415/WA8	415/WA18	415/531	415/561	415/537	415/Y13	415/S12	415/555	415/529	415/540
SiO_2	32.60	30.0	55.60	64.48	31.41	69.07	53.05	3.52	2.92	0.77
TiO_2	0.23	0.03	0.25	0.23	0.0	0.38	0.54	0.0	0.0	9.09
Al_2O_3	4.45	0.60	5.68	5.28	0.78	5.54	13.52	0.25	0.44	0.27
Fe_2O_3	39.43	51.46	5.54	7.88	6.44	15.44	11.01	5.02	18.14	9.52
MnO	0.09	0.09	0.11	0.16	0.39	0.01	0.06	0.86	1.24	1.11
MgO	13.15	8.62	9.83	9.52	11.90	4.16	11.85	20.25	17.29	14.87
CaO	5.54	5.75	13.72	8.78	4.18	0.26	0.81	8.30	4.12	3.93
Na_2O	1.0	1.00	1.0	1.0	1.0	1.0	0.5	1.0	1.0	1.0
K_2O	2.47	0.13	4.37	1.66	0.05	1.29	7.34	0.05	0.04	0.06
P_2O_5	0.28	0.09	0.16	0.20	0.11	0.14	0.30	0.14	0.15	0.15
Loss	1.54	3.25	6.29	5.50	19.64	3.46	5.18	46.25	39.68	46.71
Total	100.75	101.02	102.52	104.69	75.88	100.74	104.16	85.62	85.01	87.47

TABLE 5.5 AVERAGES FOR THE WYWYANA FORMATION

	Actinolite Marble (5 analyses)	Slightly Actino-litic Limestone (Average of 4 analyses)	Actinolite Marble near the Pinnacles and Yudnamutana Mines (3 analyses)	Actinolite Marble Average in country rock (2 analyses)
SiO_2	50.348	[illegible]9.651	43.89	60.036
Al_2O_3	4.309	0.434	3.538	5.48
Fe_2O_3	23.944	7.006	35.43	6.715
MgO	9.058	15.878	8.646	9.674
CaO	6.808		3.849	11.248
Na_2O				
K_2O	1.984	0.050	1.298	3.013
TiO_2	0.222	0.[illegible]0	0.216	0.473
P_2O_5	0.173	0.138	0.167	0.181
MnO	0.092	0.899	0.063	0.135

Table 7.1 Repeat AAS analyses

	Cu	Pb	Zn	Fe	Mn
415/S45	6.52	1.62	6.00	36,000	
	6.20	1.12	4.96	28,000	
415/S1	6.95	.274	13.58	76,000	
	5.88	.220	13.87	28,000	
415/Y5	6450	2.741	12.6	14,500	4100
	6330	2.2	13.9	22,000	4800
415/Y9	2150	.966	8.2	65,000	49
	2550	1.1	7.5	80,000	64

Table 7.3 Repeat Na Analyses and Standards

415/513	1.17%
	.97%
BHN_2	

Table 7.4 Repeat H_2O^+ Analyses

415/Y15	10.61	415/602A	1.58
	10.37		1.56
415/22B	2.03	415/602B	1.35
	1.79		1.37
415/44A	0.54	415/703	6.02
	0.51		5.88
415/44C	0.81		
	0.93		
415/545	1.58		
	1.90		

Table 7.2 Standards for XRF analyses

	SiO_2	BR	DTS-1	G.R.1	G_2	AGV.1	PCC.1	BCR.1	GSP.1
Fe_2O_3	0.018	11.842	9.429	4.351	2.493	7.321	9.168	12.335	4.707
MnO	0.0	0.146	0.140	0.051	0.002	0.186	0.086	0.135	0.043
TiO_2	0.001	2.143	0.003	0.657	0.390	1.065	0.0	1.883	0.663
CaO	0.007	13.832	0.142	2.50	1.719	5.192	1.988	6.122	0.605
K_2O	0.035	1.308	0.078	4.562	4.066	3.055	0.053	1.603	5.728
P_2O_5	0.052	1.04	0.002	0.280	0.180	0.447	0.055	0.431	0.344
SiO_2	100.009	39.242	40.195	67.115	69.211	60.448	44.029	54.828	67.282
Al_2O_3	0.065	8.473	0.369	14.605	15.510	17.504	0.785	13.377	15.323
MgO	0.170	14.626	47.736	2.752	0.801	1.980	43.006	2.933	1.434
Na_2O	0.0	3.050	0.01	3.800	4.070	4.760	0.010	3.270	2.800
Loss		0.15							
Total	100.351	96.505	98.163	100.692	98.482	101.958	99.173	96.917	98.932

APPENDIX VI

Atomic Absorption Spectrophotometry Results

Table 7.5 Geochemical Data : Pinnacles Mine Traverse

Sample	Position (metres)	Geology	Cu (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
415/WA21	0.0	Slightly actinolitic marble	240.0	1.20	6.9	39600	3400
415/WA20	5.0		624.0	1.5	8.2	24750	5400
415/WA19	10.0	Ferruginized actinolitic	411.0	1.2	7.6	150000	37
415/WA18	15.0	rock. Sheaths of actinolite	179.0	0.6	10.4	220000	48
415/WA17	17.0	in an iron matrix	41.4	1.3	4.6	160000	36
415/WA16	18.0	Metasomatized	26.0	0.7	4.2	32450	116
415/WA15	18.33	siltstone	980.0	0.9	6.6	36550	217
415/WA14	18.66		265.0	0.5	6.9	31600	139
415/WA13	19.0	Actinolite, biotite rock	100.3	1.2	4.9	23750	149
415/WA12	19.17		10.2	0.5	3.7	16650	88
415/WA11	19.34	Silicified actinolite	16.4	0.5	2.4	6300	75
415/WA1	19.50	marble	10.7	1.1	1.3	6400	62
415/WA2	19.67		13.6	0.4	0.6	7000	65
415/WA3	19.84	Actinolite, biotite rock	54.9	0.4	1.7	850	111
415/WA4	20.0	Biotite Scapolite Hornfels	6.8	0.9	5.0	950	133
415/WA5	20.33	Actinolite, biotite rock	1.5	0.2	1.7	5300	77
415/WA6	20.66	Euhedral magnetite, calcite	3.9	0.4	7.0	23250	144
415/WA7	21.0	and K.feldspar occur in	10.1	0.7	4.6	22650	357
415/WA8	22.0	veinlets, tension gashes and	8.6	1.4	6.5	150000	140
415/WA9	24.0	scattered throughout the rock	8.1	1.4	6.8	122350	215
415/WA10	27.0		21.8	1.4	7.2	150000	130

Table 7.6 Geochemical Data : Yudnamutana Mine Traverse

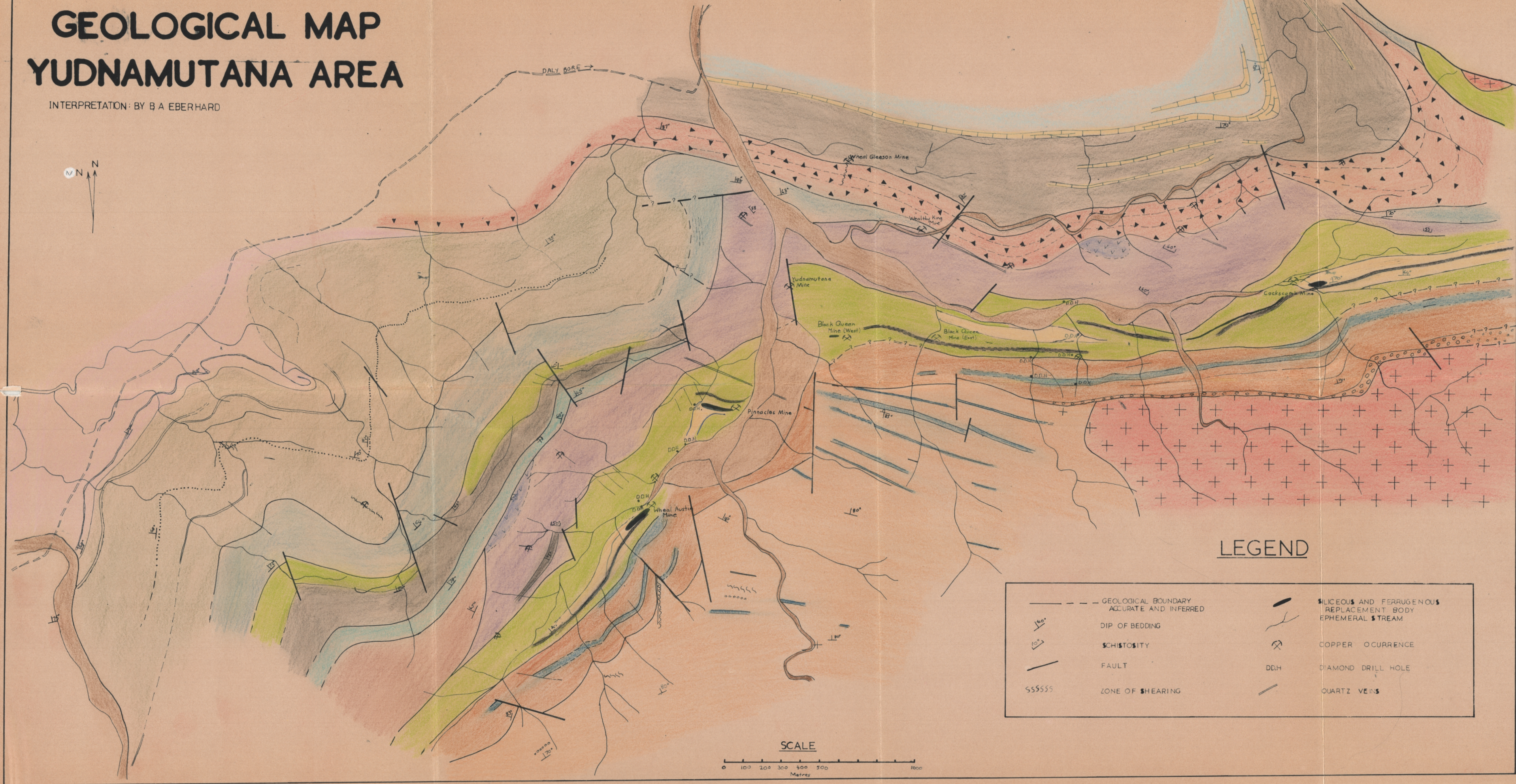
Sample	Position (metres)	Geology	Cu	Pb	Zn	Fe	Mn
415/15	0.0	Wooltana	5280	1.00	11.9	43100	41
415/14	2.0	Volcanics	6970	1.3	5.8	55400	39
415/1	4.0	Chloritic	5560	0.90	1.4	30500	31
415/2	6.0	Schists	3450	0.80	2.2	50000	24
415/Y3	8.0		2100	0.70	1.0	34300	29
415/Y4	10.0		3450	0.80	6.8	40400	43
415/Y5	12.0		6450	1.0	8.2	65000	49
415/Y6	14.0		3650	1.2	5.7	51900	39
415/Y7	16.0	Wywyana	2200	0.9	11.2	30700	80
415/Y8	18.0	Formation	1950	0.4	1.2	2200	278
415/Y9	20.0		2150	0.7	4.7	32300	223
415/Y12	24.0	Actinolite	350	0.3	7.0	6800	58
415/Y13	26.0	marble	1025	0.7	3.1	43100	35

Table 7.7 Geochemical Data : Quartz Vein Traverse

Sample	Position (metres)	Geology	Cu	Pb	Zn	Fe	Mn
415/593	0.0	Wooltana	620	1.3	8.5	113000	76
415/592	2.0		1150	1.3	15.3	85700	191
415/591	2.66	Quartz vein (malachite staining)	140	1.1	15.4	12900	28
415/590	2.83		1720	0.9	16.7	80700	83
415/589	3.0	Volcanics	910	0.8	16.1	65600	218
415/588	3.17		260	0.9	13.5	68900	
415/587	3.33		540	0.9	12.7	79800	149
415/586	3.50		1990	0.4	4.6	47500	79
415/585	3.67		13760	0.2	4.6	4200	23
415/577	3.84	Mineralized quartz vein	1640	1.4	13.6	77300	257
415/578	4.0		580	0.9	22.3	85100	80
415/579	4.17	Biotite schists	660	0.1	17.2	69400	120
415/580	4.34		510	1.1	10.7	92000	135
415/581	4.50		510	1.4	7.7	4800	178
415/582	6.0		420	1.4	7.5	3500	179
415/583	8.0		460	1.3	8.6	3400	178
415/584	8.33	Quartz vein	10.0	0.3	1.7	3200	18

GEOLOGICAL MAP
YUDNAMUTANA AREA

INTERPRETATION: BY B A EBERHARD



STRATIGRAPHIC COLUMN

Recent Alluvium

Tapley Hill Formation: Yankaninna Siltstone Member: Base marked by a grey weathering silty limestone. A sequence of blue weathering siltstones. Lower Member: Grey weathering siltstones with limestone interbeds.

Balla Ballana Formation: Massive green weathering subgreywacke tillite, quartzites green weathering and blue weathering siltstones.

Skillogallee Dolomite: Upper Member: Fine to medium-grained well bedded, silicified calc-silicate rocks, and minor siltstones, tremolitic marbles and chert bands. Lower Member: Well bedded fine grained laminated siltstone, quartzites, dolomites and cherts.

Wortupa Quartzite: Heavy mineral laminated and ripple-marked feldspathic Quartzite. A polymictic conglomerate occurs near the top of the sequence.

Opaminda Formation: Dark grey weathering siltstone, Actinolite marble.

Blue Mine Conglomerate: Heavy mineral laminated conglomerate.

Humanity Seat Formation: Brown weathering heavy mineral laminated sandstones.

Wooltana Volcanics: Massive grey weathering amygdaloidal lavas, rhyolites biotite and chlorite schists.

Wywyana Formation: Actinolite marble and slightly actinolitic recrystallized limestone. Interbeds of siltstones and contains siliceous and ferruginous replacement bodies.

Paralana Quartzite: Quartzites feldspathic quartzites, micaceous sandstones and actinolitic biotite schist.

Freeling Heights Quartzite: Light grey green weathering well bedded medium to fine grained sericitic quartzites.

Mount Neill Granite Porphyry: Massive pink weathering porphyry consisting of ovoids of quartz and feldspar in a microcrystalline matrix.