AN
INVESTIGATION
OF THE
MUTOOROO COPPER MINE
SOUTH AUSTRALIA

HONOURS THESIS
by

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ABSTRACT

The Mutooroo Mine was the largest copper producer in the Olary province until its closure in 1914. Recent geophysical work and drilling have discovered a deeper massive sulphide body of over 8 million tons, averaging 1.66% copper. It is not yet economic, but the depth is unknown, and thick ore may occur in fold positions. The ore is epigenetic, and appears concentrated in one of the massive amphibolite dykes which have intruded the surrounding high grade schists and gneisses. Two narrow but distinct zones of hydrothermal alteration have been produced in the wall rocks. The ore was intruded before the last phase of metamorphism, and has been recrystallized and deformed.

This paper, being the first detailed investigation of the mine, examines general aspects of the petrology, mineragraphy, structure and economics.

INDEX

INTRODUCTION

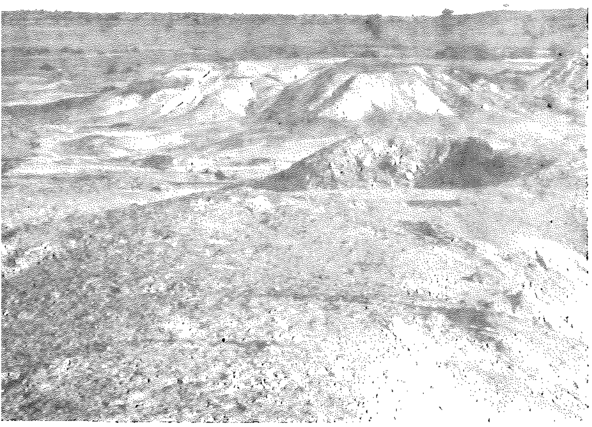
The Mutooroo Mines are situated 12 miles South of Cockburn, and 4 miles West of the New South Wales border. (see Figure 1).

The area is arid, with little vegetation except saltbush. Outcrop above the alluvium is poor, but massive amphibolite bodies are conspicuous as dark, low rises above the slightly undulating plain (see Figure 2).

Copper was first discovered at Mutooroo in 1887, and mined by several companies and then by tributers, intermittently until 1914. Prior to 1900, at least 5,560 tons of hand dressed oxidized ore were despatched, averaging over 6%. Between 1907 and 1917, 236 tons of 19.3% ore and 109 tons of precipitate from mine waters, averaging 36.3%, were sent to Wallaroo, making the mine the largest copper producer in the Olary province.

Exploration and surface mapping were done by the Zinc Corporation Ltd. in 1950, but their report was unavailable. The S.A. Department of Mines drilled three diamond drill holes, totalling 1,233 ft. at this time, but recovery was poor and results not encouraging (Parkin 1951b).

The area was covered by an aeromagnetic survey and reconnaissance mapping (1 in. = 1500 ft.) during the intensive regional programme of Broken Hill South Ltd. in 1962. Subsequently a good anomaly was found over the Southern workings by exploratory induced polarization, and follow up lines were laid out. Diamond drilling commenced in 1963, and since then 13 holes totalling 19,128 ft. have been completed, the deepest being to 1,900 ft. (vertical depth). MM14 is in progress. In conjunction with this exploration, ground magnetics and some bedrock geochemistry have been carried out.



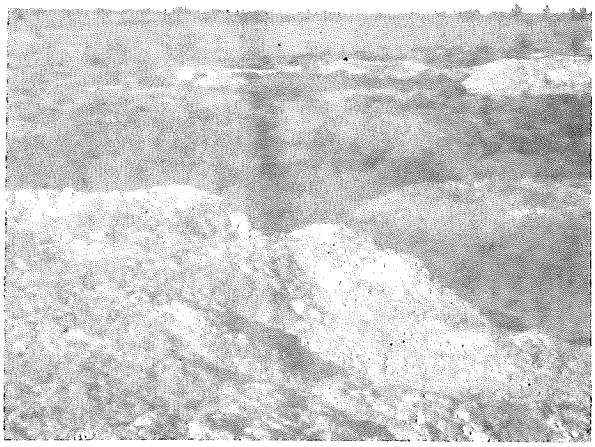


FIGURE [illegible] – Looking SW over part of [illegible] workings [illegible] 1COE, [illegible] showing [illegible] dark amphibolite hill in the right background.

FIGURE [illegible] – [illegible] from [illegible] [illegible] of the [illegible] typical [illegible].

Mapping at 1 in. = 400 ft. was done by the author, using pace and compass, in February and May, 1966, covering an area 10,000 ft. by 2,400 ft. in the vicinity of the old workings (see Figure 46, inside rear cover). The control was from survey pegs 100 or 200 ft. apart in lines every 500 ft. The existing aerial photographs were unsuitable for reasons of scale, poor quality and lack of landmarks. Unfortunately the old workings were inaccessible, and the scores of pits were collapsed or covered with mud and debris. Extensive dumps covered much information. Reasonable accounts of some of the workings are given by Parkin (1951a, 1951b) and Winton (1917).

GEOLOGY AND PETROLOGY

(a) ROCK TYPES

The rocks of the mine area are high grade metamorphics of the older Precambrian (Archaean), similar to many of those of the Barrier Ranges - amphibolites, schists and gneisses, with minor quartzites, pegmatites and quartz veins. Detailed petrological descriptions are given in appendix I.

The amphibolites (e.g. MU35, 36, 37, 61) are generally dark, medium grained granular hornblende - plagioclase rocks, with lesser quartz and minor ilmenite and haematite/ilmenite grains, with some magnetite. These iron oxides are believed to be primary constituents. The rocks commonly show banding (especially in cores) due to layers richer in hornblende, but this is neither readily apparent nor mappable on the surface. Quartz can represent up to 10% of the rocks, and is often concentrated in pods with hornblende (see Figure 11), or as granular intergrowths with single hornblende grains (see Figure 4). Many contain scapolite altered from plagioclase.

The amphibolites often crop out boldly, (see Figure 5) but they are either blocky, or jointed in several directions, sometimes curving or podlike, and foliation is difficult to recognize or map. Some show spheroidal weathering which can look like minor folding (see Figure 6). They also occur barely protruding through the alluvium, with an obvious trend, but with dips hard to asdertain (see Figure 7). Amphibolites have also been encountered in auger drill holes at depths of up to 12 ft.

The schists and gneisses on the other hand, generally crop out weakly. In diamond drill cores, three types have been distinguished.

(1) Augen Granite Gneiss (e.g. MU26, 27, 28, 49). This is a coarse grained texturally distinct rock containing large quartz-felspar "augen", and composed of quartz, microcline (perthite), plagioclase, biotite and muscovite, often in shear layers. A few very small garnet pieces were found in MU28, and some scapolitization was seen in MU39.

(2) Biotite - Sillimanite Gneiss (e.g. MU29, 30). This is also distinctive - consisting of layers of coarse quartz/plagioclase and biotite which has coarse sillimanite prisms randomly oriented on foliation surfaces. Less commonly it contains fractured garnets, altered to biotite (see Figure 8), and microcline (MU31).

(3) Quartz - Plagioclase - Biotite Gneiss (e.g. MU33, 34, 60). This is generally finer grained than the other two varieties, and contains more mica. It consists of quartz, plagioclase, biotite, muscovite and garnet, often with coarse staurolite, but no potash felspar. Very minor sillimanite was seen in MU34 and 60, but the texture differed from the biotite - sillimanite gneisses.

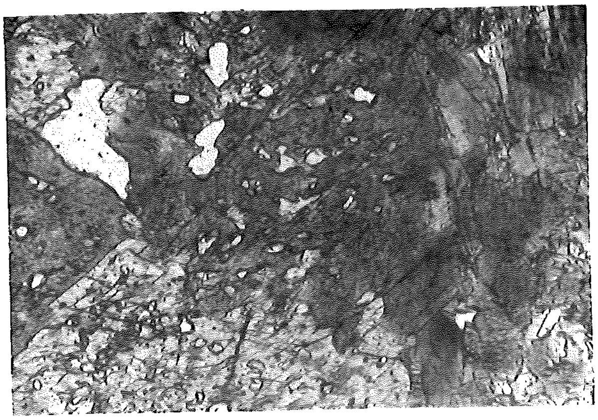


FIGURE 4 – Quartz intergrowths in hornblende crystals. Plane polarized light x25. MU35.

FIGURE 5 – Typical bold amphibolite outcrop, looking SE towards peg. [illegible]0CS 70CW, with quartz "float" in the background.

FIGURE 6 – Spheroidal weathering in amphibolite, with the appearance of folding.

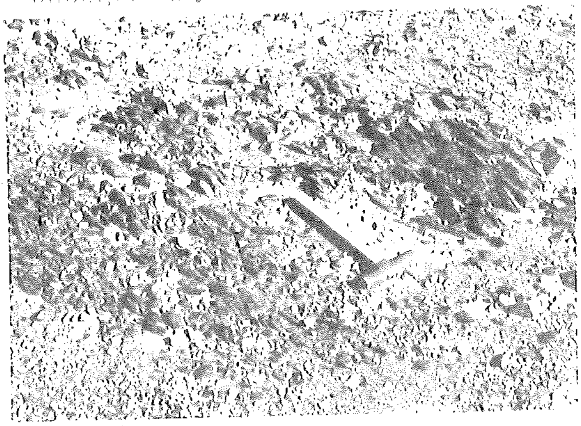


FIGURE 7 – Typical [illegible], [illegible] foliated [illegible] on the [illegible].

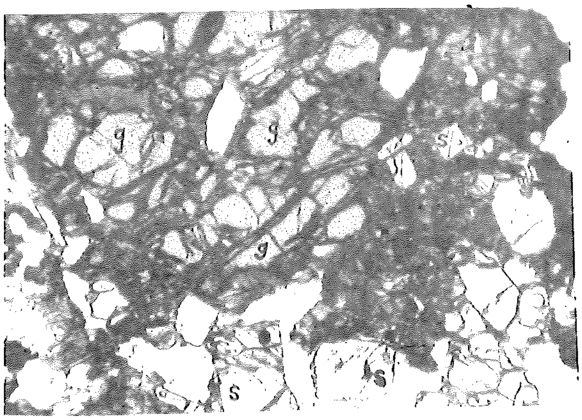


FIGURE 8 – Garnet (g) altering to biotite along fractures, and showing sillimanite prisms(s). Plane polarized transmitted light x25. [illegible]3.

FIGURE 9 – Typical [illegible] [illegible] foliation.

Kyanite was observed in the core of MM11; many crystals up to 2 cms. long were found in "float"; and King 'in Campana and King, 1958) reports "garnet and kyanite bearing schists", but none was seen in thin section, although some pseudomorphs after kyanite were found in MU29 - a typical biotite - sillimanite gneiss.

In the field the latter two types are hard to separate (cf MU32, 56, 57), due to the poor outcrop, similarity between weathered sillimanite and muscovite (sericite), and the abundance of micas, although some sillimanite gneiss was definitely confirmed. However, the granite gneiss can generally be identified because of the texture, relative paucity of biotite and comparatively slow weathering. It appears to exist closer to the surface, and crops out more commonly, often as only one or two isolated blades, whereas the others appear only in some of the few creek beds. However, the foliation in both types can be mapped fairly easily (see Figure 9). Because of the basic uncertainties in surface mapping, the lack of apparent connection between individual sillimanite gneiss intersections in drill cores, and the convergence seen in thin sections and cores, the biotite-sillimanite gneiss and the quartz-plagioclase-biotite gneiss have been grouped together for the purposes of interpretation.

Quartzites, consisting of granular quartz, with or without plagioclase, and with minor biotite or muscovite were seen in cores (e.g. MU51), and found in the field, usually as very small outcrops of only a few pieces. They are believed to be merely discontinuous, lenticular quartz rich members of the quartz-plagioclase-biotite gneisses. "Aplite" (a local name for a friable sandy quartz-felspar rock) is in the same category (e.g. MU53, 54). They seldom occur in granite gneiss.

The whole area has been thoroughly intruded with very small pegmatite and quartz veins, rarely more than a few feet thick, and these commonly form small isolated outcrops. In cores they are seen parallel to foliation and cross-cutting structures in all rock types. Some have probably formed by lateral secretion or local remelting. A few larger pegmatites exist near the orebody (e.g. MU52). They contain plagioclase more albitic than the normal rocks.

(b) METAMORPHIC GRADE

These assemblages assign the rocks to the almandine amphibolite facies of Turner and Verhoogen (1960), but not to any one sub-facies. Staurolite and kyanite belong to the lower two (staurolite - almandine; kyanite almandine - muscovite); sillimanite can belong to the sillimanite - almandine - muscovite or sillimanite - almandine - orthoclase subfacies (the upper two), while microcline can belong to any but the uppermost. No orthoclase was seen in any of the rocks, nor was any found by staining with sodium cobaltinitrite. The occurrence of a microcline-garnet assemblage (MU31) is anomalous, and indicates disequilibrium conditions. The alteration of garnet to biotite in fractures (see Figure 8) here may indicate a retrogression, the microcline belonging to the later stage. MU34 also indicates retrogression and probable influx of alumina. Here later staurolite has forced biotite layers apart, whereas garnet has not. The amphibolites could belong to any of the four subfacies.

Thus it can be concluded that the rocks indicate a range of conditions in the lower and middle almandine amphibolite facies, with temperatures perhaps 550 to 650°C, and pressures between 4,000 and 6,000 bars. The presence of microcline with up to 45% albitic exsolutions suggests a temperature slightly higher, perhaps greater than 650°C.

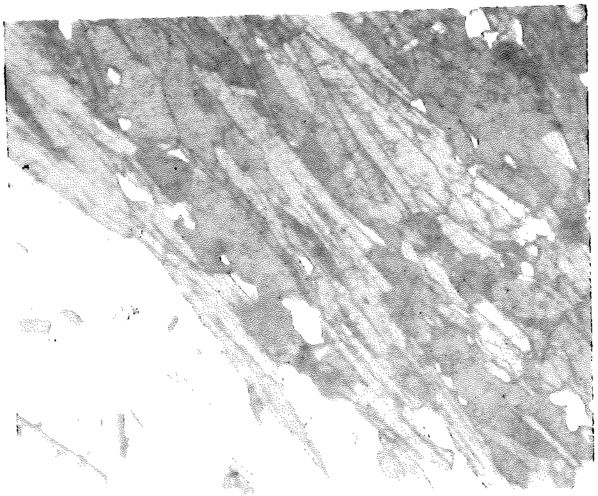
(c) ORIGIN OF ROCKS

The quartzites, aplites and gneisses, with the exception of the granite gneiss, were almost certainly originally sedimentary rocks - probably fairly aluminous pelitic sediments with some sandy lenses. The difference between the quartz-plagioclase-biotite and biotite - sillimanite gneisses is probably a function of original sediment type. The granite gneisses were most likely quartzo-felspathic sediments (arkoses or sandstones), but it is hard todisprove that they may have been acid igneous rocks, either intrusive or extrusive. However, in the light of some gradational boundaries and the associations, this seems less likely.

The origin of the amphibolites, in fact amphibolites in general, is a difficult matter. Some primary amphibolites do crystallize from aqueons basic magmas, but the textures observed at Mutooroo were obviously metamorphic. Amphibolites can be shown to form from either basic igneous rocks (ortho-amphibolites), or from some iron and magnesium rich sediments, such as impure dolomites or mafic tuffs (para-amphibolites). Many workers (e.g. Green et al, 1958; Poldervaart and Wilcox, 1958) have tried to distinguish between these in places where unaltered bodies can be traced into areas where metamorphic and metasomatic convergence produces identical rocks. However, they now agree that no reasonable criterion can be found. Mineralogy, chemical analyses (including trace element studies) and magnetic properties have all been tried, and found inconclusive. Thus it was useless to try to find the origin of the amphibolites by chemical means. The only reliable way of distinguishing them seems to be by field relationships, where applicable (e.g. Flawn, 1950).

The field relationships at Mutooroo are not always apparent. The amphibolites occur as massive bodies, up to at least 700 ft. thick (in MM7), and as very thin bands, sometimes regularly interbanded with augen granite gneiss (e.g. MM6 or MM9, where 15 bodies up to 1 ft. wide occur in the first 540 ft. of gneiss), which suggests a sedimentary origin. Unfortunately the surface outcrop is too poor to allow the relationships of these bands to be determined - they may be folded, lenticular (para - from mafic tuffs), or stringers from a mother intrusive (ortho). The contacts are generally very sharp (see figure 10), which also suggests an igneous origin.

Huang (1962) says that quartz is more conspicuous in amphibolites, from tuffaceous sediments, and that ortho-amphibolites have equal amounts of hornblende and plagioclase. The quartz in Mutooroo amphibolites seems to be concentrated in pods (see Figure 11), which may indicate either sedimentary banding or irregularities, relict igneous textures (e.g. phenocrysts), or metamorphic differentiation, as may the hornblende/plagioclase layering seen in many specimens (e.g. MU 36, 61). The scapolite observed is due to later alteration of plagioclase by calcic metasomatism, and has no bearing on the origin. The distribution of this alteration was apparently irregular, but more common at the surface.



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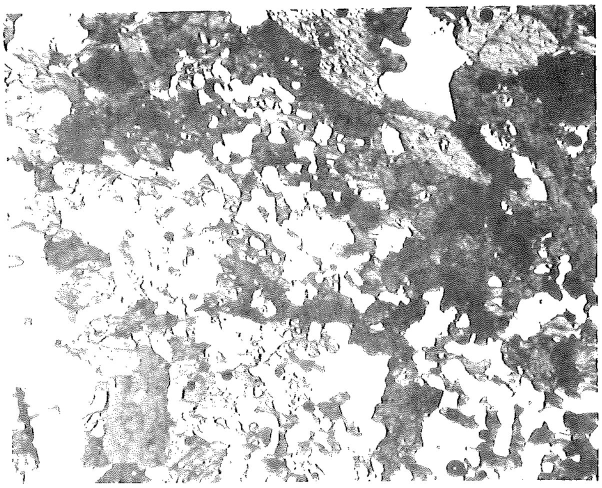

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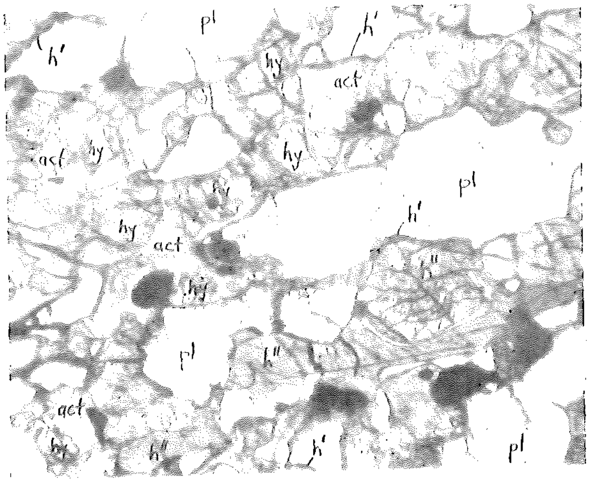


[illegible] (hy) [illegible] actinolite (act), [illegible] and subhedral [illegible] (al). [illegible]

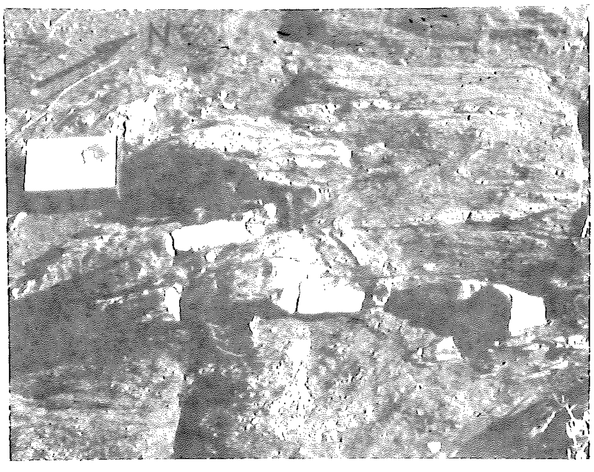
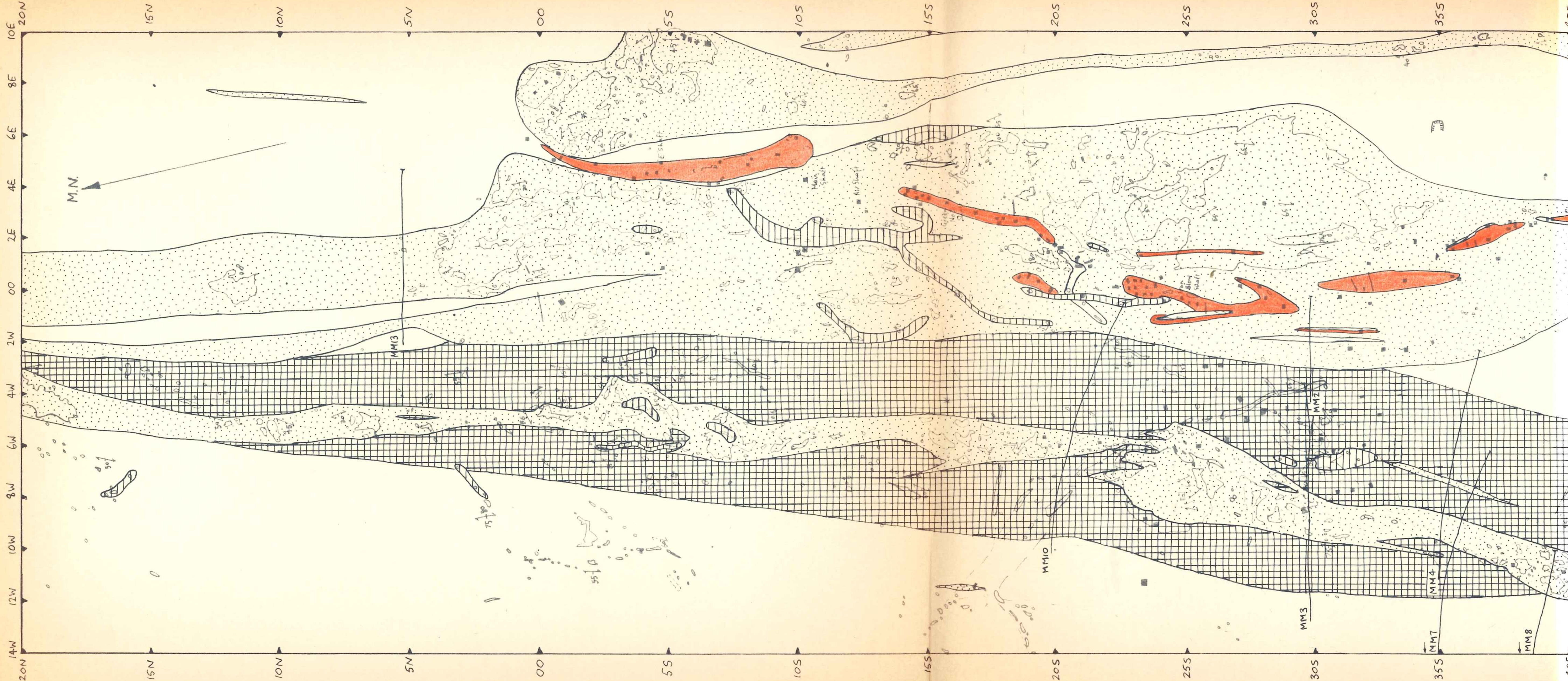


FIGURE 18 – Small [illegible] iso-clinal fold, [illegible] 45° North, in [illegible]. [illegible]


20N
15N
10N
5N
00
5S
10S
15S
20S
25S
30S
35S
10E
8E
6E
4E
2E
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2W
4W
6W
8W
10W
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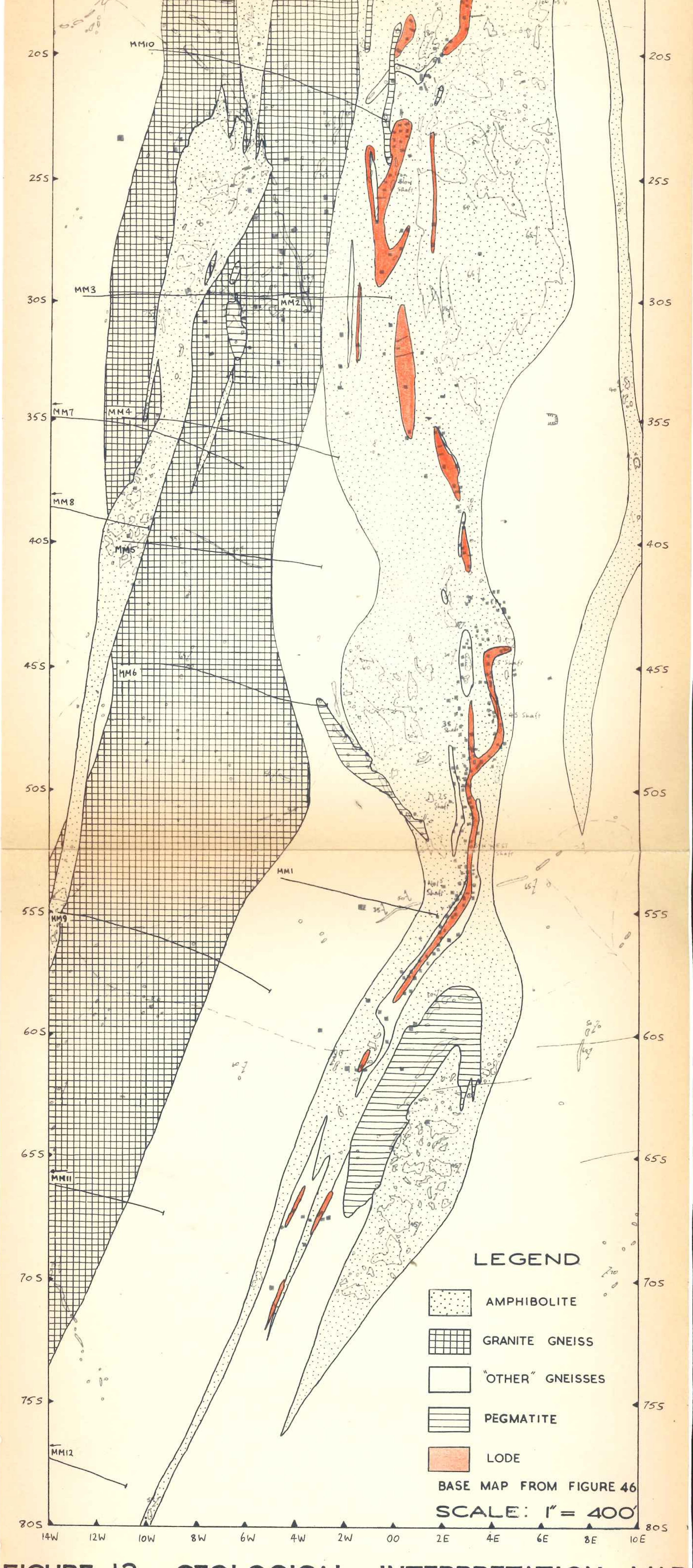


FIGURE 13 - GEOLOGICAL INTERPRETATION MAP

The opaques are commonly ilmenite/haematite intergrowths, which indicates a temperature greater than 500 to 600°C, with very slow cooling. This means that such opaques are at least pre-metamorphism, and probably syngenetic. If so, this supports an igneous origin, especially as definite intrusive dykes at Radium Hill, approximately 18 miles South-West (see Figure1) contain such intergrowths (Whittle, 1951).

MU38 (from near 3000S 200E) was quite different to all other amphibolites examined, in that it contained a disequilibrium assemblage of amphiboles, and uralitized hypersthene (see Figure 12) of igneous origin, although the rock was similar to other specimens. Some secondary fine grained actinolite aggregates appeared to be altering to normal hornblende crystals. It also contained dark felspar deficient bands up to 1 cm. wide, approximately perpendicular to observed mineral banding and foliation, which were locally quite abundant, but were seen to cross and diverge. They are believed to be a surface effect. MU61, from only 100 ft. away in the same body, also showed such bands, but no hypersthene, and was otherwise similar to other amphibolites. MU38 may thus be a later dyke partly altered to amphibolite, or it may be a portion of the original igneous body which has somehow escaped total metamorphism. Detailed field examination in conjunction with closely controlled petrological work may determine which is so.

The overall impression which these observations give is that the amphibolites were originally igneous, from an unusually quartz rich gabbro or norite. Most of the evidence in favour of a sedimentary origin can be alternately explained by metamorphism, except perhaps the interbeds with granite gneiss. If sedimentary, the rocks were most probably quartz rich mafic tuffs.

Some other workers have examined specimens of these amphibolites. Whittle (1951 and 1963) does not even consider a sedimentary origin; Campana (in Campana and King, 1958) believes that they are para-amphibolites, because of conformable relationships, following of local structures, interbanding with banded gneisses, and apparent similarities with reported gradations from dolomitic limestone to amphibolites at Ethiudna, S.A. (see Figure 1), and in the Ettlewood Limestone North of Broken Hill. However, there is doubt about many of the Broken Hill amphibolites (Edwards, 1957, presents a good summary), and definite ortho-amphibolites are known (e.g. Radium Hill, Weekeroo).

Detailed mapping and structural interpretation by the author has shown, that if the distinction between the augen granite gneisses and the biotite-sillimanite/quartz-plagioclase-biotite gneisses is valid, then the amphibolites, although having a similar trend to the gneisses, are actually discordant, and therefore igneous.

(d) STRUCTURE

A geological fact map of the area is shown inside the rear cover (Figure 46). A composite interpretation has been made using this, old records and drill hole information. (The contoured ground magnetic map was difficult to interpret, either in terms of amphibolite or ore, and was of limited use.) The results are shown in the surface interpretation (Figure 13), cross sections in the vertical plane of the drill hole (Figures 14, 15, 16) and the hypothetical 500 ft. and 1000 ft. levels (Figure 17). It should be stressed that these interpretations are general and idealized, and appear to fit the observed facts;

FIGURE 14 - CROSS SECTION INTERPRETATIONS - 1 inch = 600 ft.
(LOOKING NORTH)

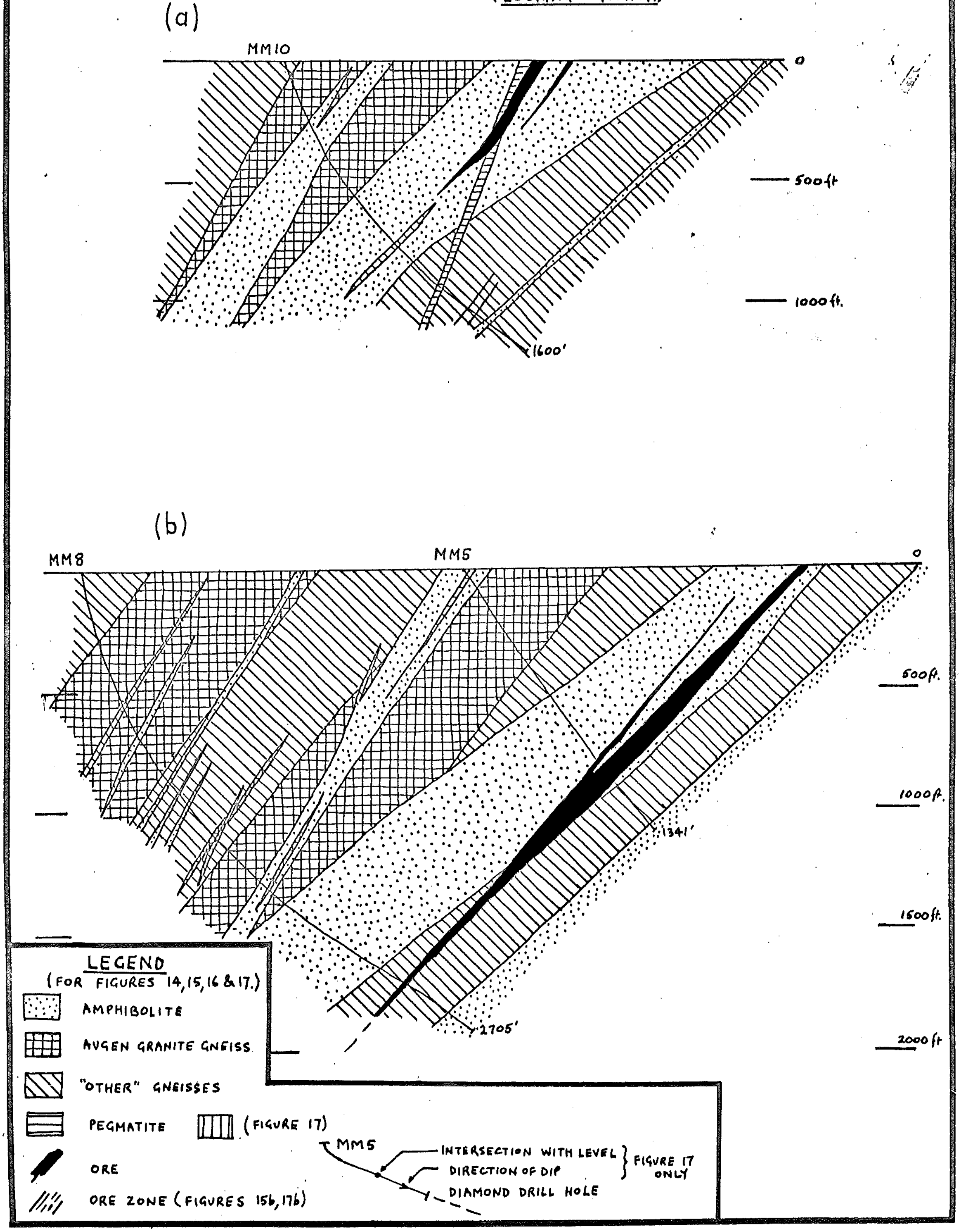


FIGURE 15 – CROSS SECTION INTERPRETATIONS – 1 inch = 600ft
(LOOKING NORTH)

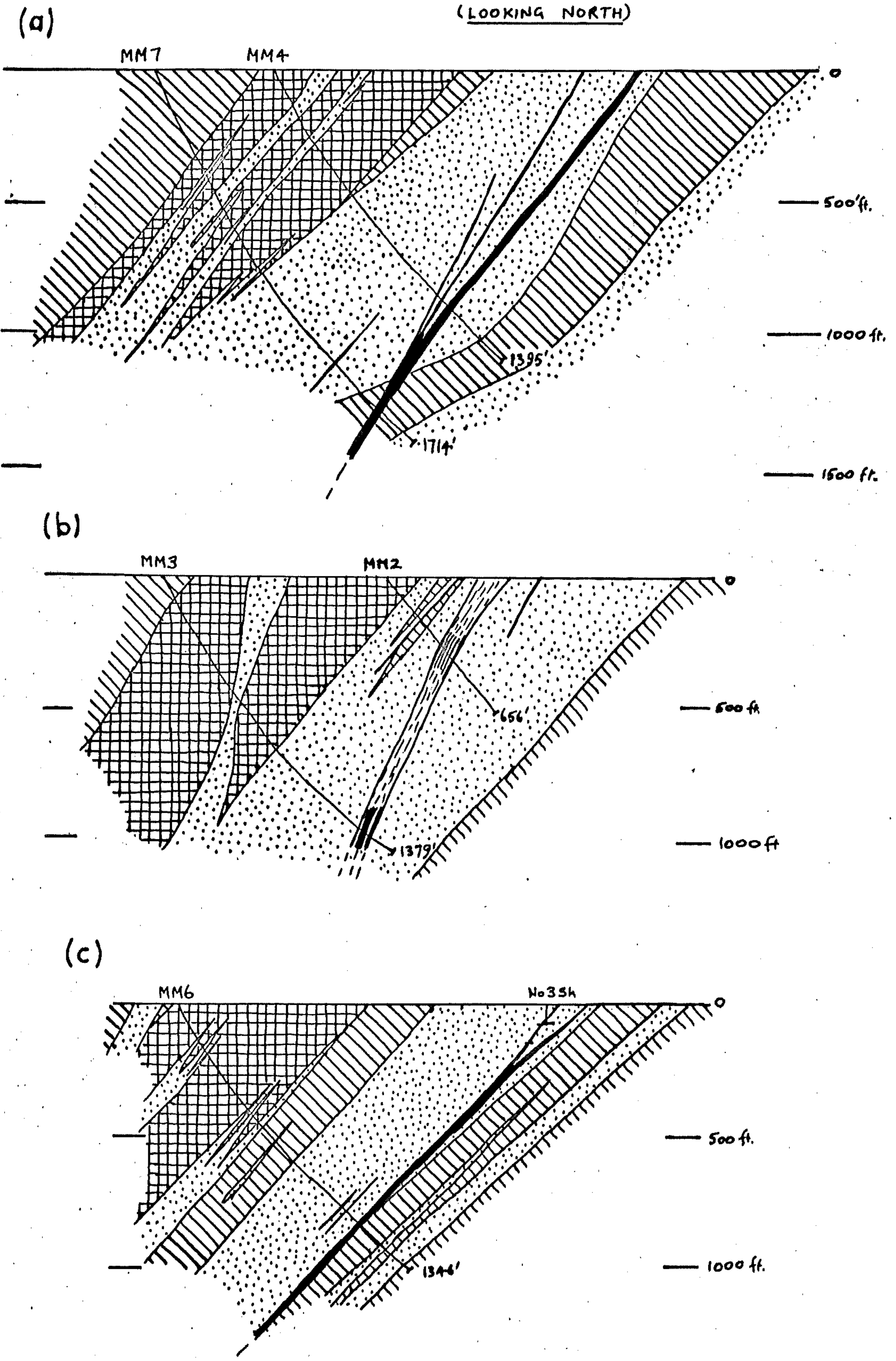
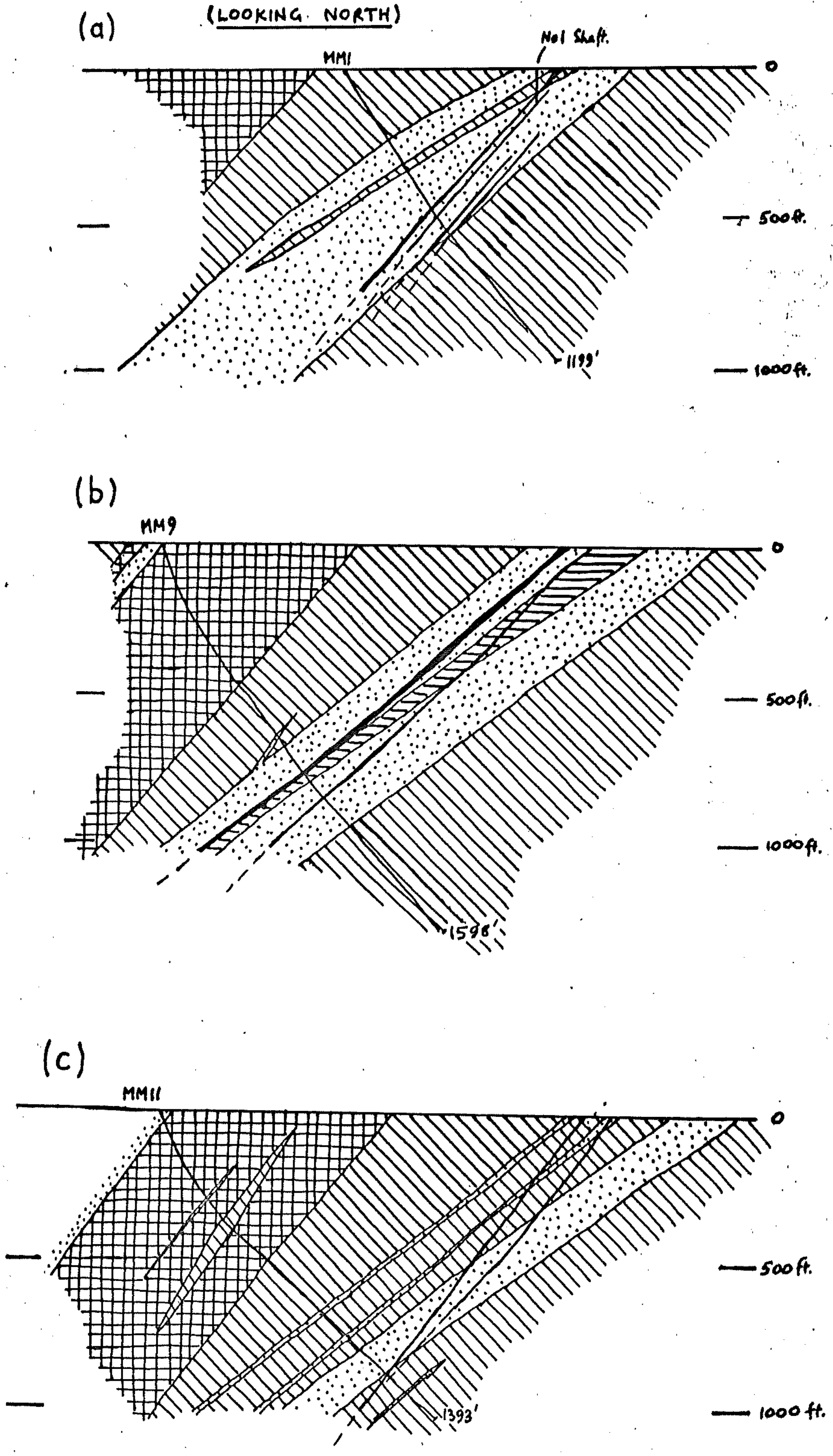


FIGURE 16 - CROSS SECTION INTERPRETATIONS - 1 inch = 600 ft
(LOOKING NORTH)



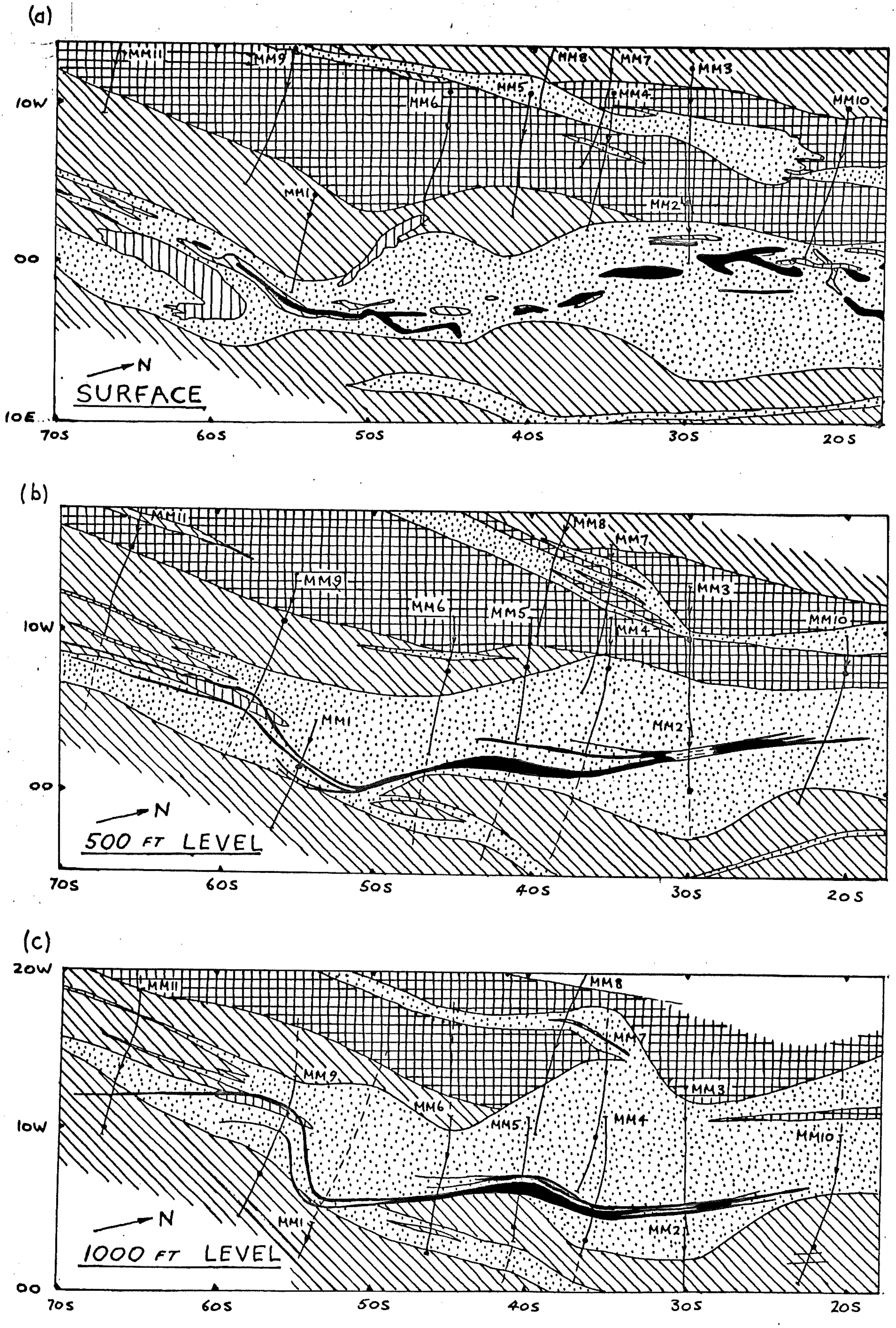


FIGURE 17 — HYPOTHETICAL 0, 500 and 100 ft LEVELS — 1inch = 900 ft

however, it is unlikely that straight lines exist, especially in such highly metamorphosed areas, and with more information it should be possible to put in more detail. Many faults may be "supposed" to explain irregularities in the surface plan, but it was found, that if these were correlated with similar structures on the 500 ft. and 1000 ft. levels, and then transferred to the sections from calculated apparent dips, that they were invalid. In fact, very few of the bulges could be correlated from level to level, and it appears that no definite plunge can be assumed on so large a scale. There does appear to be a moderate (approximately 45°) Southerly plunge shown by the intersection of the large amphibolite and the granite gneiss - "other" gneiss boundary on the three plans (Figure 17).

The region shows a fairly constant foliation trend expressed in the gneisses, varying from 0 to 030°, dipping 50 to 85° West. Some irregularities occur in the area bounded by 00, 500S, 300W and 500W, due to later minor faulting or folding. In the cores, however, there are many small folds and contortions, especially in the biotite - sillimanite gneisses, and also some crenulated schists (e.g. MU58). On the surface, structures were very scanty, due to poor outcrop. Two folds, expressed by quartzite bands, were seen in creek beds at 100N, 800W and 2250S, 200W (See Figure 18). The latter was isoclinal, plunging 65°N, with an axial plane striking 008°, dipping 55°West, which is compatible with the regional foliation. It is likely that the foliation is an axial plane schistosity; and the muscovite and biotite rich layers in the gneisses could represent planes of simple shear or laminar flow, as discussed by O'Driscoll (1964). The amphibolites, however, present many difficulties (see page 3). They do appear to follow the foliation in the gneisses roughly, and where their own was recognizable, it was in a similar direction. No mineral lineation was seen in the amphibolites.

On a larger scale, the structure appears to be a series of augen granite gneisses and "other" gneisses, isoclinally folded, or in alternating sedimentary sequence (see Figure 14b). They often contain small bands of each other. These gneisses are cut by two main amphibolites, probably one at depth (they were identical), with many smaller apophyses. The amphibolites, while being roughly tabular, have irregular bulbous outlines, and contain some large roof pendants or remnants of gneiss, still retaining the regional foliation.

OREBODIES AND MINERAGRAPHY

(a) ORE

The most noticeable things about the ore are the coarse grain size, paucity of gangue, and the sharp contacts. Single pyrite crystals much larger than the Ax core (1.1 ins.) were intersected. These are surrounded by massive pyrrhotite, the most dominant mineral, and chalcopyrite. The ore is mostly sulphide, with less than 20% gangue, which is mainly rounded quartz grains, often ½ in. in diameter. Minor flakes of biotite, and some larger patches of country rock or chlorite (e.g. MU19, 48) also exist. Rounded grains of magnetite occur, sometimes very abundantly (e.g. MU23, 48). Felspar is seen occasionally (e.g. MU5). The contacts with country rock are generally very sharp, and disseminated mineralization is rare, but sometimes sulphide veins a few inches wide (often in quartz) were intersected well away from the main orebody (e.g. MM6, 7).

Microscopically, the mineralogy is also simple - pyrrhotite, pyrite, chalcopyrite, magnetite and quartz being the main constituents. Minor minerals are valleriite (a copper-iron sulphide of uncertain composition - $Cu_2Fe_4S_7$, $Cu_3Fe_3S_7$ or $Cu_2Fe_3S_7$), ilmenite and haematite/ilmenite intergrowths, sphalerite (rare and fine grained - not positively identified), enargite (MU12 only), bismuthinite (MU3, 12 only). Lesser silicates were plagioclase, calcite, biotite, chlorite and stilpnomelane, with very minor siderite and stilphomelane, with very minor siderite, clay minerals and hornblende.

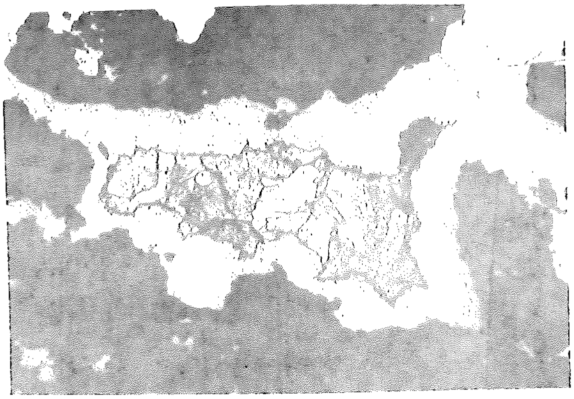
Whittle (1963) reports galena, sphalerite, marcasite and zeolites from a 1 inch sulphide vein in MM1. These cores were weathered and no longer examinable. Spectrographic scans did show ·03% lead and 1% zinc in MM1, however. No other holes were of this order. Total gold and silver analyses were done on all cores, but the highest total was 0.1 dwt. The highest nickel assay was ·028%.

Some of the cores showed more than one good ore intersection (e.g. MM3, 4, 5) but samples from each body showed no apparent differences. No zoning was observed in the orebodies, although MM8 (the deepest hole) seemed much richer in magnetite (and chalcopyrite) than the other holes. Magnetite was not reported in old records, but it was quite abundant in surface "float" and on dumps of primary minerals. The records make little mention of pyrrhotite and it appears that pyrite is more abundant higher in the lode. The lack of any definite zoning could be due to the sparse distribution of drill holes. However, the ore is so coarse that any zoning could be detected by comparison of cores, without need of the microscope.

(b) THE OXIDIZED ZONE

The oxidized zone was not studied in detail (only MU1, 2, 24, 25). These showed abundant limonite, quartz and secondary silica, with chrysocolla and malachite. Chrysocolla and spectacular colloform jasper were common on the old dumps. Lode rock was seen cropping out in several places (see Figure 19). The characteristic texture of the ore - quartz granules dotted through a sulphide matrix was preserved with hard red jasper replacing the iron sulphides (MU24). Quartz also occurred as excellent crystals. The oxidized ore has been subjected to secondary silicification shown by colloform banding (see Figures 20, 21), filling of spaces and vughs, and the abundance of chalcedony and chrysocolla. Lovering (1962) believes such silicification is caused by the reaction of acid (from oxidizing pyrite) and highly alkalic ground or surface waters which have leached silica from the nearby rocks, and hold it in solution.

Rosewarne (1908) reports atacamite, malachite, azurite, cuprite, chrysocolla and bornite in the oxidized zone. The University of Adelaide collection possesses a massive piece of native copper, the size of a fist, from Mutooroo. Winton (1917) mentions chalcocite, and also "black copper ore" with higher than average assays, and traces of gold. It seems that there has been some secondary enrichment. Stoping, however, was all in the oxidized zone, and was reported down to 146 ft. Primary sulphides were encountered at 100 ft. (Parkin, 1951a). Ore shoots were narrow and discontinuous in the North, which is good evidence that the orebody has been exposed for a comparatively short time, and that only the very top has reached the surface.



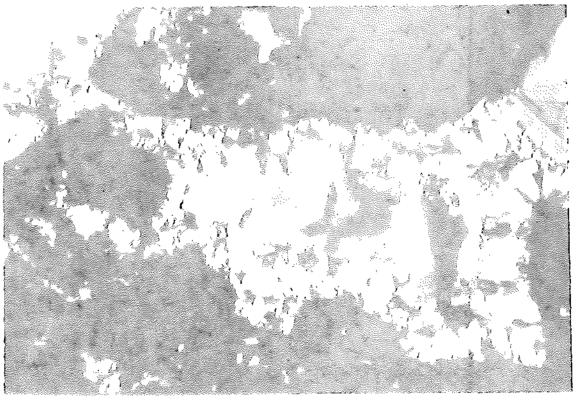


FIGURE [illegible] — [illegible] ...ed [illegible] in p[illegible] [illegible] [illegible], crossed [illegible] [illegible] [illegible].

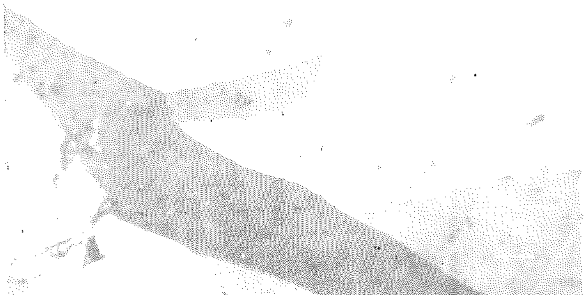


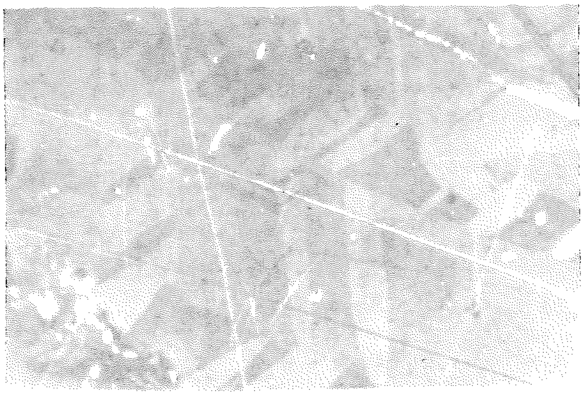
FIGURE 1[illegible] — [illegible] ...formatio[illegible] [illegible] ...eridotite, [illegible] light, crossed [illegible] x95. [illegible]

This is probably why only very minor copper stains are found in the centre section, and no resistant ironstone lode (cf Figure 19) crops out, in spite of the thick ore beneath. The water table is shallow (60 ft. in the North; below 110 ft. in the South (Winton, 1917) and probably static due to the aridity and mature topography. There appears to be no significant downward leaching, and the copper has been stabilized as carbonates and silicates in the oxidized zone. A combination of these factors has prevented the development of an extensive secondary sulphide zone. Development was done to 513 ft. in primary ore, and stoping would have been done if grades had been enriched.

(c) TEXTURAL RELATIONSHIPS

The massive pyrrhotite and chalcopyrite actually consist of grains comparable to the silicates in size. This is due to cataclastic re-crystallization, and the grain boundaries are visible only with crossed polars. Pyrrhotite shows this better (see Figure 22). It shows some spindle twinning (Figures 23, 33). Chalcopyrite develops much more, showing its greater susceptibility to plastic deformation. The twins are lanceolate, rectangular grids, and intersecting sets at various angles, often sharing "refraction" as they cross (see Figures 24, 25). They are commonly oriented differently in adjacent grains. Such textures are direct evidence of deformation (Edwards, 1947), and are similar to those observed in fault zone chalcopyrite at Broken Hill by Richards (1966). Xray diffraction (on MU21) showed that these were not two separate phases due to rapid cooling from a high temperature.

The quartz in the orebodies is free of undulose extinction, but



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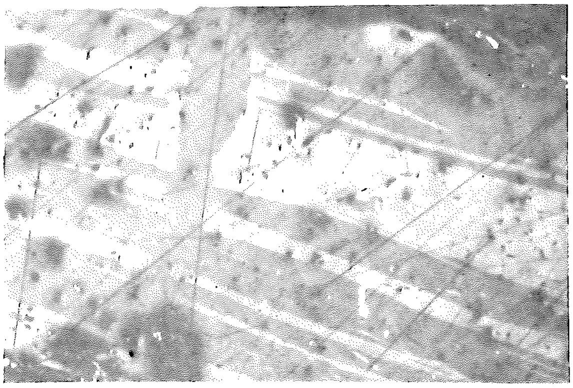
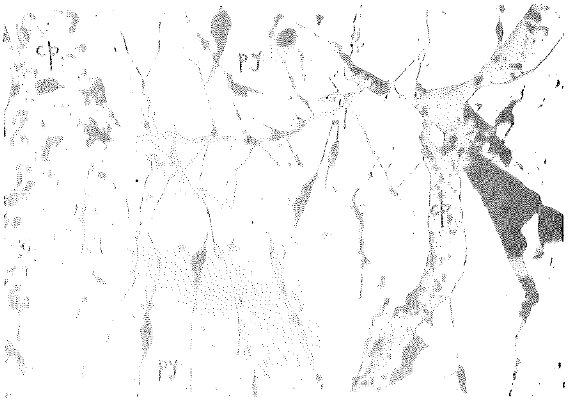


[illegible] intergrown [illegible] Polarized [illegible] crossed nicols, oil [illegible]

[illegible] showing [illegible] Polarized [illegible] nicols [illegible]



[illegible]

FIGURE 28 - Composite chalcopyrite (cp)-pyrrhotite (po)-ilmenite (ilm) grain in fracture in partly rounded magnetite (mag), showing cleavage. Plane polarized reflected light x125. MU8.

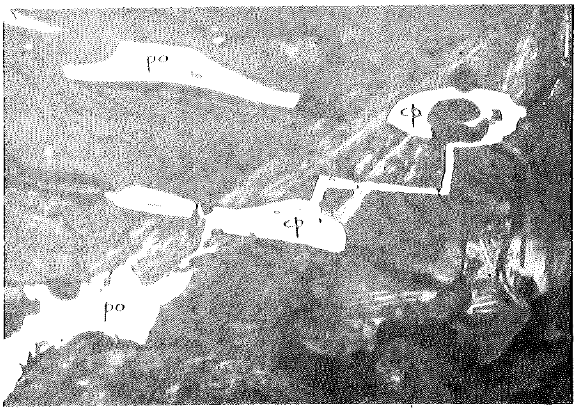


FIGURE 29 - Chalcopyrite (cp) in biotite (dark) cleavage; with pyrrhotite (po). Plane polarized reflected light x125. MU13.

often shows the triple junctions characteristic of polygonal recrystallization (see Figure 26). Pyrite and magnetite, being brittle, react to deformation by fracturing and brecciation. These fractures are often filled with the more mobile sulphides, especially chalcopyrite (e.g. Figure 27), or even gangue minerals (e.g. MU11, 15). Both MU11 and MU15 show evidence of two forms of pyrite. In MU11 a graphic quartz - pyrite intergrowth forms at the expense of pure pyrite; and in MU15 chalcopyrite contains relict embayed pyrite as well as large recrystallized enhedra.

Such evidence of deformation, and probably metamorphism, precludes the likelihood of many original depositional features being preserved, but several observations are noteworthy. Chalcopyrite and pyrrhotite have fairly similar histories, and they occur in similar positions, often with irregular inclusions of the other. They include rounded quartz grains, which have crystallized earlier, and sulphides sometimes fill intergranular cracks (e.g. MU10). Recrystallized pyrite, however, shows idiomorphic outlines against them. Magnetite varies from euhedral to rounded (e.g. MU6) or corroded - these are again relict, and in MU10 pyrrhotite can be seen leaving re-entrant cleavages in magnetite. With chalcopyrite it also penetrates fractures in magnetite (see Figure 28). Both pyrite and quartz show mutually idiomorphic outlines against magnetite, indicating simultaneous crystallization. Chalcopyrite invades biotite cleavages (see Figure 29), and fine pyrite veins cut flakes in the ore (see Figure 30) - evidence of some mobility. Biotite in the alteration zone shows straining where it is intruded by small sulphide veins (see Figure 31). In MU5, obviously later felspar veins cut chalcopyrite veins in pyrite (see Figure 32).

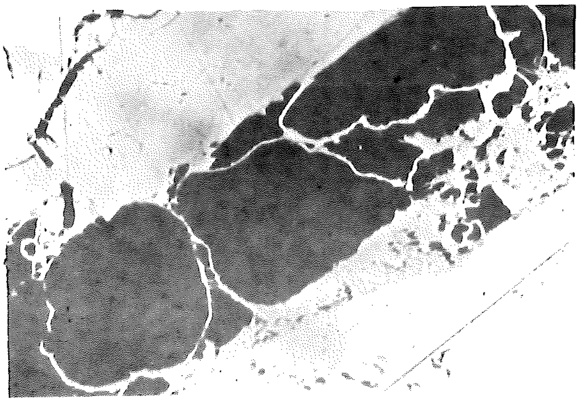


FIGURE [illegible] – Thin pyrite veins (light) cutting biotite (dark). Plane polarized reflected light x[illegible]. [illegible]

FIGURE [illegible] – Biotite attacked by [illegible] of sulphides. Polarized reflected light, crossed nicols, x[illegible].

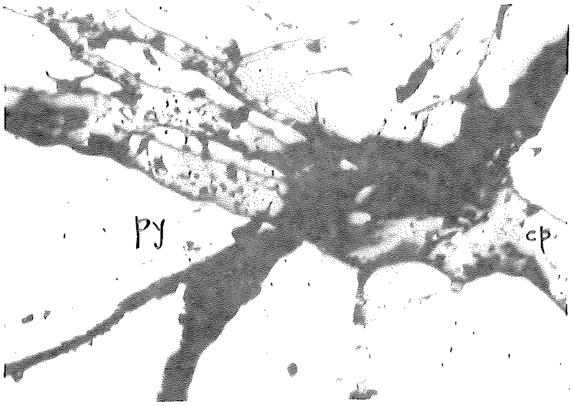


FIGURE 57 – Plagioclase vein (dark) cutting chalcopyrite (cp) vein in pyrite (py). Plane polarized reflected light x[illegible]. [illegible].

FIGURE [illegible] – Valleriite (vall) at interface of twinned and deformed pyrrhotite (po) and chalcopyrite (cp), with quartz. Polarised reflected light, crossed nicols, oil immersion x[illegible]. 7.

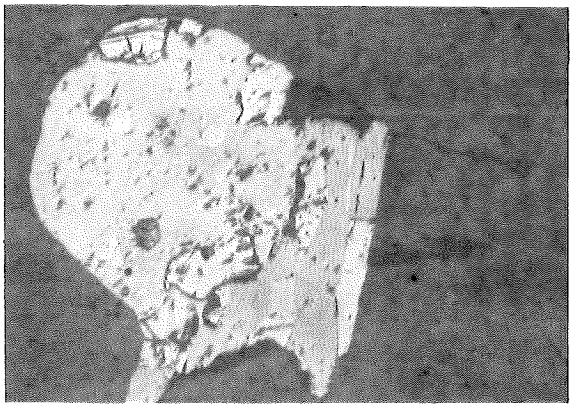


FIGURE 54 – Grain in quartz, showing exsolution of hematite (lighter) and ilmenite (brownish), each with exsolution bodies of the other. Plane polarised reflected light x125. [illegible]U13.

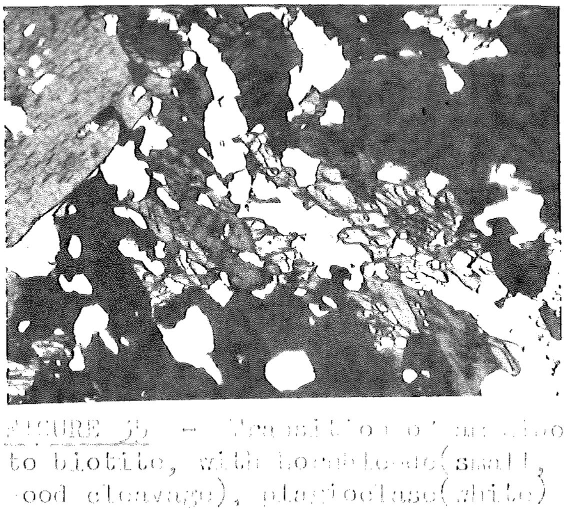


FIGURE 55 – Transition of amphibolite to biotite, with hornblende (small, with good cleavage), plagioclase (white) and large biotite flakes. Plane polarised transmitted light x25. [illegible]2.

Many of the cores contained crystals, usually pyrite, but sometimes chalcopyrite, in vughs. Other evidence of open spaces was given by extensive oxidation, even at depth (e.g. MU11 (1059 ft.), probably associated with a fault, and MU16 (1571 ft.), which shows delicate boxworks.) Many other samples were stained with limonite, especially around clay minerals, and in the alteration zone.

(d) GEOTHERMOMETRY

Evidence of the temperatures attained is given by some textures in the orebodies.

Valleriite is ubiquitous in chalcopyrite (see Figures 24, 25), occurring as exsolution lamellae, commonly but not always parallel to twin planes, and as disoriented blebs, especially at pyrrhotite grain boundaries (see Figure 33). This is indicative of temperatures greater than 225°C, when

$$\text{valleriite} \longrightarrow \text{pyrrhotite + chalcopyrite}$$

(Edwards, 1947), who also reports that pyrrhotite dissolves in chalcopyrite at 600°C, and that the reverse occurs at 300°C. These separated into laths on cooling in experiments, but mutual inclusions observed at Mutooroo were irregular in shape, which is indecisive.

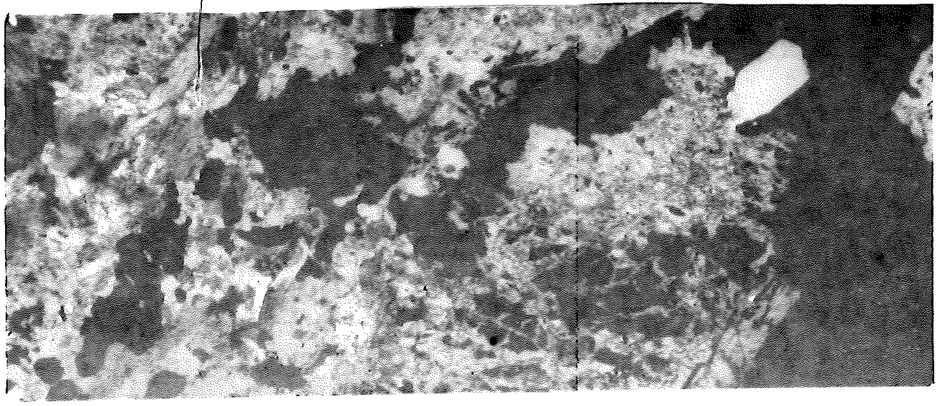
Several rounded grains showing intimate exsolution of ilmenite and haematite, on two different scales, were seen (see Figure 34). These indicate a temperature of greater than 700°C (coarser stage), or greater than 500 to 600°C (finer stage); with very slow cooling necessary to develop the exsolution bodies (Edwards, 1938), which is unlikely if a hot orebody were intruded into cooler, solid rocks. These, which were also seen in the amphibolites (rarely with both stages), may be relict, unreplaced grains or primary constituents. The exsolution textures suggest that they have undergone metamorphism; and if they are primary, then the orebodies have been metamorphosed, and cooled slowly. If relict, the temperature of intrusion of the ore was lower than this if post-metamorphism.

A few ilmenite rods appear in the magnetite, and this suggests a temperature higher than 700°C (Edwards). These are more likely to be primary.

(e) WALL-ROCK ALTERATION

The orebodies show a distinct wall-rock alteration effect. This is most noticeable in the amphibolite, where a zone rich in coarse biotite (similar to that in Figure 10) adjoins the orebody, and gradually decreases away from it (see Figure 35). It is commonly only a few inches in width, due to the lack of permeability in the crystalline amphibolite, or the overall similarity between chemical or physical conditions. It is a similar effect to that seen where pegmatites cut amphibolite, and it is caused by introduction of K_2O into the amphibolite, with a corresponding loss of CaO. Such alteration has been documented on many occasions (e.g. Barrell, 1907; Clarke and Ellis, 1939; Knopf, 1912; Lindgren, 1901; Schwarz, 1939).

Microscopically, a second stage of alteration was observed, between the biotite zone and the ore. This is essentially pale chlorite (due to the addition of MgO), with some sericite, calcite, limonite, clay minerals and secondary silica. It is only about ½ inch in width (e.g. MU14, 17, Figure 36). Such alteration also occurs within the ore (e.g. MU19, 48). Both biotite and



[illegible] alteration zone, from epidote [illegible] and chloritic zone, with [illegible] aggregate of biotite flakes. [illegible] 1041.

[illegible]

[illegible] and [illegible] Plane [illegible] 1043.

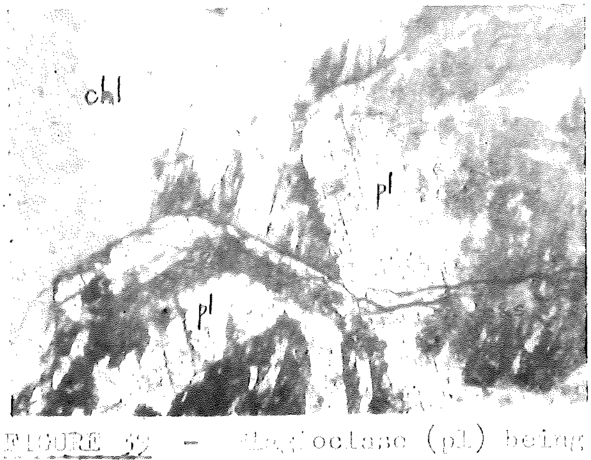


FIGURE 39 - Plagioclase (pl) being altered zonally to chlorite and sericite (c&s). Also shows fine chlorite (chl). Plane polarized transmitted light x75. 1043.

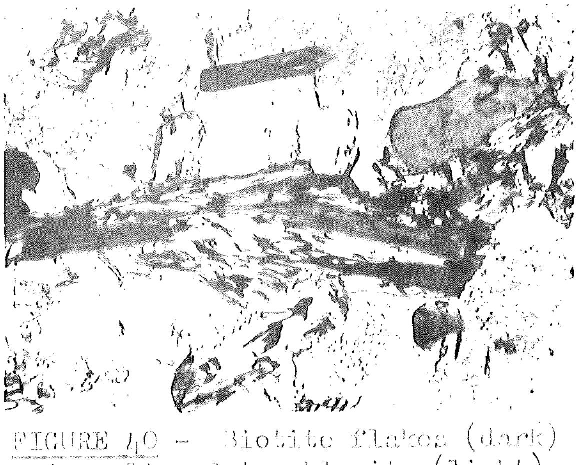


FIGURE 40 - Biotite flakes (dark) being altered to chlorite (light). Also shows sericitized plagioclase. Plane polarized transmitted light x75. 1045.

plagioclase have been altered; biotite often pseudomorphically (e.g. Figure 37), or along cleavages (Figure 38), and plagioclase occasionally zonally (see Figure 39), but usually along cleavages (e.g. Figure 38). Some biotite flakes further from the ore are rimmed or intergrown with greener chlorite (see Figure 40). These textures show that the chloritic alteration followed the formation of biotite, and it may be due to a later phase of deposition (sulphides do intrude biotite - Figure 31), or to metamorphism.

The alteration where the ore is in contact with quartz - felspar - biotite gneiss is less conspicuous macroscopically, but it is represented by a coarser, biotite rich zone, again narrow, with heavy alteration of plagioclase to sericite or fine clays (e.g. MU18), or to a choritic zone (e.g. MU43).

This alteration is strikingly similar to that seen at the Elizabeth Copper Mine, Vermont, U.S.A. In fact, there are many similarities (see appendix II).

(f) STRUCTURE

The old workings extend for 7,000 ft. (see Figure 46), with a great intensity between 4,000S and 6,000S (see Figure 3). These workings were shallower than those in the North. Relatively few pits were dug in the central portion, but gossan and malachite were seen on dumps. Records, especially Winton (1917), show that the primary lode was extremely variable in width, with many irregular bulges (e.g. 4 ft. to 14 ft. back to 6 ft. within 20 ft. distance), and it is likely that this structure is repeated in the thicker parts at depth. Unfortunately, surface indications were based mainly on material on dumps, and hence the shapes are not reliable, but the strike is variable (see Figure 17). Winton quotes it averaging 017° (North) and 039° (South). The Westerly dip of the orebodies is also very variable (e.g. 45-70° at E Shaft; 60° at Hamlyn Shaft; 25-30° at Iron Blow Shaft; 50° at Osborne Shaft).

It can be seen from the interpretations (Figures 13 to 17) that the lode is not conformable, and therefore epigenetic.

The presence of widespread deformation textures in the ore suggests that folding may have occurred, and this leads to the possibility of ore concentration at the folds, as at the Elizabeth Mine (see appendix II). No folding was apparent from drill-hole intersections or hypothetical level plans. If folding were present, it would be very attenuated, and possibly en echelon in style.

Faulting of the orebody has occurred - it was reported by Winton 36 ft. North of E Shaft, but the displacement is not recorded. MU11 is from a probable fault zone. Veins such as that in MU13 were seen occasionally, and are probably small post-ore faults of little consequence. The unusually shallow dip at Iron Blow Shaft is possibly due to faulting. Attempts to construct faults were fruitless (see page 10).

The factors controlling ore localization or causing a low pressure region are not known, but the amphibolites do appear favourable, at least along strike. MM12 and MM13, where amphibolite was narrow, intersected no ore (refer to Figure 41 for drill locations and results). The orebody appears to leave the amphibolite just before MM13 (See Figure 13). MM10, however, where wide amphibolite was encountered, found only two veins 1" and 6" wide, well into gneisses. MM7 and MM8 showed good ore intersections not in amphibolite, but there is a possibility that the orebodies return to the amphibolites at depth (see Figures 14b, 15a).

Many of the surface pits, apparently in amphibolite showed very sheared siliceous schists, and the ore may be associated with these, or with a large shear zone parallel to its strike. C.L. Knight (Zinc Corporation Report, 1950) believes this (King, in Campana and King, 1958). Both MM10 and MM12 ran into very bad ground, and such shearing may be responsible for the lack of ore here. The old records generally showed ore grades and widths but no geology; but Winton reports pale schist on the hanging wall, and amphibolite on the footwall, except at E Shaft, where amphibolite occurred on the hanging wall. Deep drill holes, however, showed no such schist zone near the orebody.

The abundance of open spaces and the sharp contacts suggest filling of a large open space or fracture, which almost certainly would have grown during crystallization, but the nature of the minor gangue suggests that some replacement has occurred.

"Replacement orebodies, especially those in tightly folded or schistose rocks very commonly follow the plunge of the folding. Even if the mineralization has a vein like form, oreshoots are rather likely to be elongated in the direction of regional plunge." (McKinstry, 1948). The only plunge determinable in the rocks was 65°N. Parkin (1951a) reports discontinuous ore shoots in the Northern section, pitching 60°N, but these wereprobably oxidized ore, and the regional plunge and its consequences are by no means certain.

It is unlikely that any real solution to the problem of ore localization can be reached until new underground openings are made in the primary ore zone, and a thorough geological examination undertaken.

GEOLOGICAL HISTORY

The geological history of any highly metamorphosed area is complex, and time relationships and extent of metasomatism are hard to determine. The lack of information makes this particularly so at Mutooroo.

As the amphibolites follow the regional trend, they were probably intruded (as quartz gabbros or norites) after some folding and metamorphism in the gneisses; but they have been metamorphosed to a similar grade by a later phase, and gneisses included in them show the regional foliation. Limited granitization or remobilization of the granite gneisses has formed the coarse augen, but no migmatites have developed. Metasomatic introduction of K_2O into narrow amphibolite bands has produced a coarse biotite rich zone (e.g. MU39, 40). A similar zone, not so well developed, was seen at contacts of amphibolite and quartz-plagioclase-biotite gneiss (MU41). Many quartz and albitic pegmatite veins intruded all types of rocks at this stage. Where they cut amphibolite, a similar alteration zone was often shown. Minor veins of mineralization exist away from the main body, and some of these cut such quartz veins.

The major orebodies were preceded by such a quartz rich phase, probably with magnetite. This produced the first alteration zone. Some biotite flakes and ilmenite/haematite grains were included. There may have been some pyrite in this phase. The second, sulphide stage of mineralization, dominantly pyrrhotite, pyrite and chalcopyrite, may have formed from the magnetite by introduction of copper and sulphur, or it may have brought the iron in simultaneously. This stage formed the second alteration zone, rounded quartz and magnetite grains, and intruded the biotite zone (now being chloritized) to some extent. Recrystallization of quartz, pyrite, pyrrhotite and chalcopyrite has since occurred, causing some of the observed sequential textures due to differences in mobility. An alternative, less likely explanation is that all mineralization, but not necessarily crystallization, was contemporaneous, and that the chlorite alteration zone was caused by metamorphism. The mineralization occurred at great depth late in the metamorphic history of the rocks, but it was subjected to the same physical conditions, thus producing a purely chemical alteration zone, and coarse grain size by eventual slow cooling. The intrusion may be related to the period of retrogression observed in the rocks.

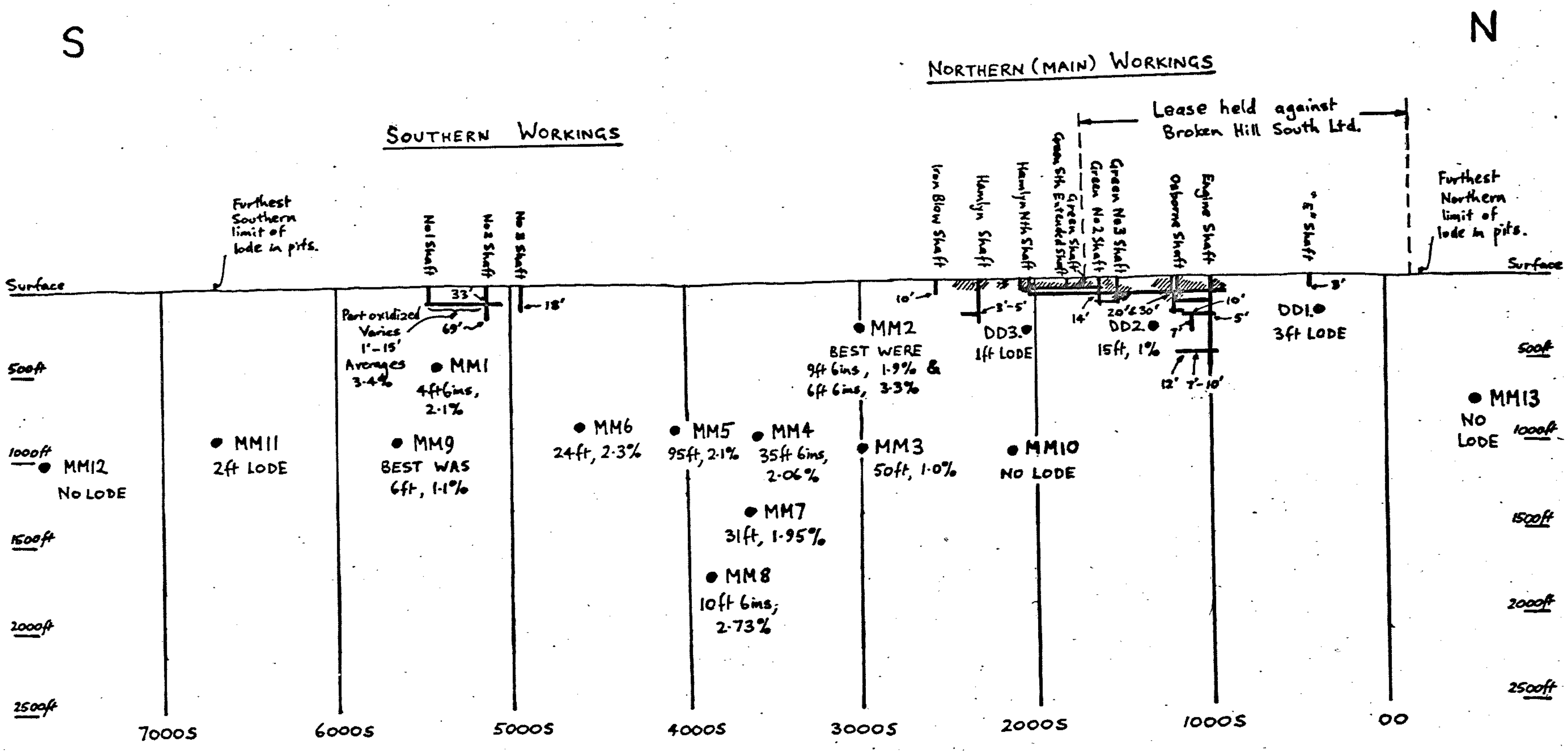
After deposition, faulting and probably folding, or at least deformation (with reduction of grain size) of the orebody has occurred. Some quartz and felspar veins were mobile after mineralization. Oxidation, both at the surface and locally at depth, secondary silicification and intrusion of both the ore and the amphibolites by calcite have then taken place (see Figures 20, 21). The calcite was possibly in several stages, by reaction of CO_2 (in surface waters, or hydrothermal) with CaO, from rocks (e.g. hornblende at biotitization) or from ground water. Minor formation of kunkar and development of scapolite, mostly near the surface, have also occurred in the amphibolites.

ECONOMICS

A longitudinal projection of the orebody is shown in Figure 41. Estimates of tonnages were made, using drill holes MM1, 2, 3, 4, 5,6, 7, 8 and 9. Although MM1 and MM9 were probably below minimum economic stoping width, they have been included to allow for irregularities in width which undoubtedly occur, and because ore is known to extend this far. Four different methods were used to estimate total tonnages and average grades (see appendix III). Two of these gave very unequal area distributions, and are not considered reliable. A weighted average of the other two (Figures 42 and 45) was therefore used to give an idea of the economics.

A total of 8,910,000 tons at 1·66% copper has been used. Assuming a 90% recovery (1·5% copper), and a copper price of $800 per ton, gives a total value of $106 million, or $12 per ton of ore. A price of $1000 gives $134 million or $15 per ton of ore. This has to cover mining, milling, transport, smelting, administration, capital, exploration, tax, royalties and profit, which should be certainly greater than 5% of the capital expenditure to make the venture worthwhile. Estimates can be made as follows (per ton of ore):

Mining	$6.00	
Milling	$2.00	
Adminstration	$1.00	
Capital	$1.50	(based on initial $10 million)
Exploration	$ .50	
Freight	$ .50	to Port Kembla (low because of high concentration)
Smelting	$2.50	(based on E.R. & S. tariffs)



Old workings, with lode widths (in feet).

Reported stoping.

● DD1 3ft LODE S.A. Dept. Mines Diamond Drill Hole (1950).

● MM3 50ft, 1.0% Recent Diamond Drill Hole, with assay vabe of intersection.

FIGURE 41 – LONGITUDINAL PROJECTION, MUTOOROO OREBODY

SCALE : 1 inch = 1000 ft.
REFERENCE PLANE bears 013°

This gives a total of $14 per ton of ore, excluding tax, royalties and profit.

The ore is very rich in sulphides, and there is a possibility of additional revenue from sulphur, from the iron sulphides mined with the chalcopyrite. This would lead to extra freight and smelting costs. The price of sulphur is at present $9 per ton, and so pyrrhotite (37% sulphur) would not pay for transportation at a rate greater than $3 per ton of concentrate (to Port Pirie), i.e., greater than 1·5 cents per ton mile for 200 miles. Pyrite, however, is 53% sulphur. At present tests on the cores are being carried out to determine the percentage sulphur as pyrite. The total sulphur content is over 30%, and up to 40% in several assays (Winton, 1917; Parkin, 1951b), which gives an additional value of $2·7 (30%) or $3.6 (40%) per ton of ore at the mine. However, some of this is in chalcopyrite, which contains 35% sulphur. As pyrrhotite is so dominant, it is worth considering the establishment of a sulphuric acid plant at the mine, if the expected lifetime were great enough. This would need extra capital and a cheap fuel, such as natural gas. The estimated ore would support an annual production of 500,000 tons for less than 20 years.

The cost is strongly dependent on the mining method, which in turn depends on the ground conditions. If schist exists on the hanging wall, as reported in the higher zones (Winton, 1917), square setting may be needed, which would be prohibitively expensive. Such conditions would also be unsuitable for cheaper caving methods. The dip of the orebody would present haulage and development problems in most types of mining. If ground were good, as it appears to be in the amphibolites, cut and fill, caving or sublevel open stoping may be applicable. If a mechanized cut and fill operation, similar to that at Cobar, were used, the inclines could follow the underlie in the footwall, thus solving the problem of shaft positioning for the dipping orebody.

RECOMMENDATIONS

It can be seen that at present, the mine would not justify a mining operation, even with a copper price of $1000 per ton. If the mining cost were down to $3 per ton, with this high price, a small profit may be possible. The risk, however, would be great, and the life too short for the high production needed to keep the costs down. The calculated reserves are probably conservative, as the depth of ore is unknown, but MM14 is at present testing this deeper zone. Good grades were intersected in some holes (see Figure 41). MM4, 6, 7 and 8 were all greater than 1.95%, and MM8, the deepest hole, was 2.73%, but only 10 ft. 6 ins. If the lower grade intersections (especially MM5) were minor patches, and the average higher than 1.66%, a mining operation would be less risky. Such richer ore may be associated with folding.

Thus before abandoning the prospect as uneconomic, two things should be done. The first and most important is to find the bottom of the ore, and information about the grade at depth. If a few holes make promising intersections, some systematic testing should be done, and it may be cheaper to carry out the second operation - that of a small shaft and development to test variations in grade and width and to provide cuddies for deep drilling - than to carry on surface drilling. The depth of such a drive or drives would depend on results of deep surface drilling. If this still showed the body as uneconomic, it may be possible (depending on the permeability of ore and wall rocks) to utilize the openings to break up the ground, and to recover exploration costs with a cheap leaching operation.

There appears to be more likelihood of ore at depth than along strike, especially as MM11 was weak, MM13 was barren, and MM10 and MM12 ran into very sheared ground without recovering ore. The lode was reported as discontinuous in the Northern workings (Parkin, 1951a), but whether this was primary or oxidized ore is not stated. This may be because the orebody is dying out to the North, or because MM10 and/or MM13 may be between shoots, but this seems a remote possibility. No definite pitch of the sulphide body was observed, but oxidized shoots pitch 60° North. If MM10 is a correct record, the bottom of the body shows a shallow Southerly pitch, but surface workings, MM11 and MM12 hardly support this. A deep hole (say to 2000 ft.) on section 3000S would test a vertical or North pitching continuation of the good ore; one on 4500S would test a shallow Southerly pitch on a steep pitch on MM6 and the area near Nos. 1 and 2 shafts. These would then give information for positioning deeper holes.

It is unlikely that detailed petrology or chemistry would be of any practical use at this stage, and structural work suffers because of lack of information. Exploratory development would no doubt make this more feasible. The wall-rock alteration is of little use as a guide to ore, because of its occurrence away from ore and its narrowness. Nevertheless, the drill should never stop within such a zone, as in the unfortunate case described by Clarke and Ellis (1939).

There are many problems of academic interest which have arisen from this preliminary study. These are connected with the zones of alteration, where detailed chemical and X-ray work would give a much clearer picture of the sequence of events, and the amphibolites. If the apparent metasomatism has occurred, the biotites near the orebody may differ chemically (especially in trace elements) from those in the unaltered rocks. The associated felspar should also be higher in calcium than that in normal amphibolite.

ACKNOWLEDGEMENTS

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APPENDIX I — DESCRIPTIONS OF THIN (T.S.) AND POLISHED (P.S.) SECTIONS.

MU1 (P.S.) - Surface (dump near 6700S, 300W)

Macro: Silvery yellow/white pyrite, crossed by many fractures. Secondary silica, often showing banded structure, forms around the inside of open cavities. The surface of the rock is covered with yellow to dark red/brown gossan.

Micro: Slightly anisotropic pyrite being altered to limonite around edges of grains, and along fractures or cleavages at 60° or 90°.

MU2 (P.S.) - Oxidized ore (near 2000S, 200E)

Macro: Black to red/brown waxy, resinous or earthy oxidized mineral, with minor green, white and deep blue staining (chrysocolla and malachite), and gossany structures. One surface is covered with earthy red, yellow brown and white ochrey material.

Micro: Probably goethite, showing good banded structure. Colloform portions show shrinkage crack fillings. Some quartz is present.

MU3 (P.S.) - ore - MM4 1138'.

Macro: Mostly pyrrhotite (65%), with rounded waxy resinous quartz granules (30% - approx. $\frac{1}{2}$ cm), and minor chalcopyrite and biotite (both less than 5%).

Micro: Pyrrhotite occurs as individual grains .2 mm to large optically continuous masses $>$ 4 mm in size. Cataclasis appears to be associated with included quartz grains, which appear to be rimmed by muscovite or calcite.

A small magnetite octahedron (.2mm) with minor associated ilmenite occurs within the pyrrhotite. Chalcopyrite occurs as aggregates, often twinned, and as small irregular pieces intimately associated with pyrrhotite. It contains exsolved valleriite, especially at the chalcopyrite/pyrrhotite interface. A few Pyrite grains occur - idiomorphic or rounded, about 1mm in size. A small piece of bismuthimite occurred with one. Minor Pyrite and pyrrhotite are found in intergranular cracks between quartz grains. Chalcopyrite was seen in veins cutting biotite flakes, and small veins of gangue (? chlorite) post-dated the crystallization of pyrrhotite and chalcopyrite.

MU5 (P.S.) - Ore - MM4

Macro: Mostly pyrite (50%), and coarse grey plagioclase (50%) and minor chalcopyrite.

Micro: Mostly pyrite, with chalcopyrite and felspar in very fine fractures between grains. The veins have matching walls, and are commonly only .02mm wide. A felspar vein crosses a chalcopyrite veinlets. Some rounded pyrite remnants occur within the chalcopyrite.

MU6 (P.S.) - Ore - MM5. 1023' (Eastern orebody)

Macro: Dominantely blue tarnished pyrrhotite (60%), and quartz with rounded edges (30%). Chalcopyrite (10%) occurs as irregular pieces scattered throughout the ore. Minor biotite flakes occur in the pyrrhotite.

Micro: Pyrrhotite consists of aggregated irregular grains, .2mm and coarser. Chalcopyrite is minor.

Magnetite ($\sim$ 1mm) occurs as many small rounded grains.

Pyrite (·3mm) occurs as a few scattered euhedra. Veins of gangue cut pyrrhotite and chalcopyrite.

MU7 (P.S.) - Ore - MM5, 1016' (Eastern orebody)

Macro: Mostly pyrrhotite (65%), with some chalcopyrite ($<$ 10%), one large pyrite crystal, (10%) and clear to waxy quartz gangue (15%), with rounded surfaces, up to 1 cm in size. Minor biotite.

Micro: Pyrrhotite occurs as coarse aggregates, often sharing rough twinning, and also as grains in chalcopyrite, along magnetite cleavages, or invading earlier biotite flakes. Chalcopyrite has abundant twinning and valleriite bodies, especially at pyrrhotite boundaries. It occurs as masses, and as small pieces in pyrrhotite and biotite. Relict magnetite (up to 3mm) contains some exsolved ilmenite rods and patches. The magnetite often shows an idiomorphic outline against quartz.

MU8 (P.S.) - Ore - MM5, 970' (Western orebody)

Macro: Mostly pyrrhotite (70%), with granular milky quartz (25%), sometimes bluish and up to $\frac{1}{2}$ cm, with scattered chalcopyrite (5%), which sometimes forms veins between quartz veins. Minor biotite flakes.

Micro: Pyrrhotite occurs as large masses, often granulated or roughly twinned and as small grains or veinlets in chalcopyrite. Chalcopyrite is minor, but shows good twinning and Valleriite exsolution, especially at pyrrhotite interfaces. It forms veinlets and isolated grains in pyrrhotite and gangue (biotite). Some small idiomorphic pyrite is present.

Magnetite occurs, often with rounded edges, inside the sulphides, and with inclusions of pyrrhotite, chalcopyrite and ilmenite, one in particular having its channel of entry visible.

MU9 (P.S.) - Ore - MM5, 978' (Western orebody)

Macro: Very coarse pyrite (25%) in crystals which would have been 2" in size, containing abundant quartz and biotite. Coarse, massive chalcopyrite 45%, pyrrhotite 20%, Quartz 10% and biotite $< 1\%$.

Micro: Idiomorphic pyrite, intruded by small chalcopyrite veins. Pyrrhotite as large masses, but granulated, and often as oriented twins. A chalcopyrite layer exists between the massive pyrrhotite and the large pyrite crystal. Minor magnetite (·2mm) occurs in pyrrhotite. Chalcopyrite shows twinning and valleriite inclusions, and is often very fractured.

MU10 (P.S.) - Ore - MM5, 1037' (Eastern orebody)

Macro: One very large pyrite crystal (25%), with coarse grained twinned chalcopyrite (25%) and pyrrhotite (30%), with 10% quartz and 5% biotite. Quartz is rounded or subhedral.

Micro: Abundant pyrrhotite in masses, as grains in chalcopyrite and magnetite, and in cracks in quartz aggregates. Chalcopyrite, with good intersecting twins and minor valleriite occurs as irregular pieces and fracture fillings in pyrrhotite. Magnetite occurs as 2 large grains, one being corroded along cleavages by pyrrhotite, and as minor, rounded grains inside sulphide bodies. Silicates are quartz, biotite flakes, and occasional euhedral hornblende.

MU11 - Ore - MM5, 1059' (Eastern orebody)

Macro: Pyrite (50%) with some chalcopyrite (10%). Appears highly altered, with some vughs containing sulphide crystals or gossan. The main alteration (40%) is associated with a planar feature at 45° to the core axis. It is a dark mineral with much biotite and quartz.

Micro: (P.S.): Pyrite very brecciated showing rectangular and octahedral partings. Some shows zonal structure and slight anisotropism. Two varieties of pyrite are present, one pure, with corroded edges, the other being a graphic intergrowth with quartz, and apparently forming at the expense of the first. Pyrrhotite occurs as minor grains and remnant veins in pyrite, while minor chalcopyrite, showing good twinning, is also granulated and widely intruded by gangue.

Micro (T.S.): Mainly quartz, showing uniform extinction, fractured, and showing some good triple junctions. Fractures and intergranular boundaries are filled with very dark material, with minor pyrite but much limonite staining. Aggregates of coarse biotite flakes are being altered to ?stilpnomelane or to fine chlorite aggregates surrounded by orange iron stained clay minerals. Some mamillary encrustations of ? pyrophyllite or similar clay mineral, heavily limonite stained, occur mostly in fractures in pyrite. Minor calcite occurs, apparently invading pyrite.

MU12 (P.S.) - Ore - MM5, 1061' - (Eastern Orebody)

Macro: Medium grained (2 or 3 mm) equigranular quartz/pyrrhotite aggregate (50% each), with minor chalcopyrite and pyrite. Some limonite with gossany structures occurs in vughs, and coats quartz. The vughs often contain crystalline pyrite.

Micro: Pyrrhotite and Quartz, with abundant fine grained chalcopyrite in both. Valleriite is common, especially rimming chalcopyrite veinlets in pyrrhotite. One grain (·4mm), showing mutual exsolution of haematite and ilmenite lamellae, was seen in a pyrrhotite mass. A larger ilmenite grain contained coarse oriented pyrrhotite and chalcopyrite inclusions, enargite and an unidentified sulpho-salt, both rimmed by bismuthinite. Some biotite is present, and small veins of gangue intrude pyrrhotite.

MU13 - Ore - MM5, 1066' (Eastern orebody).

Macro: Dominantly very magnetic pyrrhotite (90%), with minor chalcopyrite and waxy quartz (10%). A small "vein", possibly a small fault, crosses the length of the core specimen, and is 1·5 mm wide.

Micro (P.S.): Pyrrhotite shows granulation and twinning, and composes most of the specimen. It also occurs with chalcopyrite in rounded to euhedral magnetite, which appears to be a relic vein in, or surrounded by pyrrhotite. Minor chalcopyrite shows good twinning and abundant valleriite exsolution. It also invades cleavages in biotite. Very minor ilmenite and haematite grains occur, with some showing mutual lamellar intergrowths. Some quartz in small veins shows obvious displacement, and has minor included pyrite and pyrrhotite.

Micro (T.S.): The pyrrhotite contains fracture fillings of ?pyrophyllite (or other clay mineral) heavily stained with limonite, and odd flakes of biotite or stilpnomelane. Minor quartz and chlorite occur in the pyrrhotite.

The "vein" (see macro) is composed of very fine quartz, ·1mm to ·05mm, apparently granulated, but with some coarser in the centre. Very red-orange limonite stained clay occurs, in layers. Some quite coarse calcite (up to ·3 or ·4mm exists irregularly in the "vein".) There may be some relic zoning.

MU14 (T.S.) - MM5, 1079'

Macro: Contact of coarse pyrite with dense amphibolite, containing disseminated pyrite. An alteration zone 1·5 cm wide contains silica, very fine pyrite and limonite, which also penetrates cracks in the amphibolite. A slickensided surface on the amphibolite shows some sheared pyrite.

Micro: The amphibolite consists of amphibole, scapolite, and some pale biotite being altered peripherally to chlorite, but no plagioclase. Calcite veins occur in both the amphibolite and the orebody. The contact is marked by coarse calcite and fine chlorite aggregates, especially around corroded and brecciated pyrite, with scapolite and limonite. Recrystallized quartz in large pods is surrounded by rims of secondary, colloform silica.

MU15 (P.S.) - Ore - MM7, 1159'

Macro: Mainly coarse chalcopyrite (50%) and pyrite (30%) in large crystals (> 1"). Quartz masses, sometimes rounded, or subhedral (10-15%). Pyrrhotite (< 5%) occurs scattered as irregular masses throughout the chalcopyrite. Biotite flakes make up 1%.

Micro: Coarse idiomorphic pyrite, showing sharp contact with chalcopyrite, with good twinning and valleriite exsolution lamellae. It is brecciated in part, and intruded by veinlets of gangue, with matching walls. Minor pyrrhotite, containing fine grains of chalcopyrite, occurs within the main chalcopyrite mass. Composite grains of pyrrhotite and chalcopyrite invade the pyrite and also magnetite cleavages. Relict pyrite occurs within chalcopyrite. One relict haematite - ilmenite intergrowth grain (·1mm) was also seen.

MU16 (P.S.) - Ore - MM7, 1571'

Macro: Mostly pyrite (50%) often in crystals in vughs. Minor chalcopyrite (< 5%), and abundant gossany material (20%), showing layers and boxworks. Gangue is quartz (20%) and biotite (5%).

Micro: Dominantly very fractured pyrite with quartz, remnants of biotite or chlorite with cross-cutting pyrite veins. The pyrite is apparently in two forms, similar to MU11, one being pure, and the other characterized by holes and small inclusions of ?sphalerite. Pyrite shows euhedral outlines against quartz. Chalcopyrite, twinned and with some valleriite bodies, and pyrrhotite occur as minor grains in the pyrite, and one haematite - ilmenite grain (·2mm) was observed.

MU17 (T.S.) - MM7, 1323'

Macro: Sharp contact of ore (50% pyrite, 40% quartz, 5% chalcopyrite, with biotite flakes) with biotite rich amphibolite.

Micro: Amphibolite is almost entirely brown/white pleochroic biotite, altered in patches to fine grained chlorite, and with some zircons.

Some biotite is very strained, especially where pushed apart by veinlets of sulphides. Towards the orebody chlorite becomes much more abundant, and calcite, quartz (both strained) and odd felspar grains begin to appear. The ore itself is pyrite with veinlets of chalcopyrite, and inclusions of quartz, calcite, chlorite, and biotite flakes, altered peripherally to green chlorite, usually strained.

MU18 (T.S.) - MM8, 2242'

Macro: Contact of quartz - felspar - biotite gneiss with biotite layers, (adjacent to ore). A quartz rich zone marks the contact.

Micro: The biotite zone represents a coarse form of the quartz - plagioclase - biotite gneiss, which is rich in quartz, often as small veins. In the coarse zone the plagioclase becomes highly altered, and the quartz veins contorted. Minor chlorite and potassium felspar exist in veinlets.

MU19 (T.S.) - Ore - MM8, 2243'

Macro: Mainly pyrite, separated from massive chalcopyrite by area of dark gangue up to 1 cm wide.

Micro: Large, wedge shaped area contains cloudy quartz grains and crystals, with fine chlorite alteration or staining. The interstices contain limonite, stained clay minerals, siderite (sometimes veins) and flakes of stilpnomelane altering peripherally to brown biotite. Similar smaller areas occur within the sulphides.

MU21 (P.S.) - Ore - MM8 2248'

Macro: Pyrite (5%), chalcopyrite (40%) and magnetite (45%), with odd quartz (5%) and biotite flakes (5%) and minor pyrrhotite. One large relic pyrite contains abundant magnetite and chalcopyrite. Some small vughs contain crystals of sulphides.

Micro: Chalcopyrite tends to be granular (·2mm) under crossed polars; showing good twinning and abundant valleriite exsolution bodies (maximum size ·025mm X ·005 mm), both oriented and irregular, and often at granular or twin boundaries. Chalcopyrite also invades fractures in biotite, pyrite and magnetite, and occurs with spiky ? biotite included aggregates, sometimes within magnetite grains. These aggregates cut chalcopyrite grain boundaries. Pyrrhotite occurs as rounded grains or irregular pieces in chalcopyrite, and shows similar textures.

MU23 (P.S.) - Ore - MM8 2251'

Macro: Pyrite (40%), some euhedral, with quartz (35%) and crystalline magnetite aggregates (25%); minor chalcopyrite, and biotite. Individual quartz grains in aggregates are often surrounded by pyrite and magnetite, which show idiomorphic outlines against each other. Pyrite veins occur between magnetite grains, which also apparently "invade" pyrite.

Micro: Magnetite abundant, and also between quartz grains. It sometimes contains biotite/chalcopyrite intergrowths. Minor Chalcopyrite also occurs in fractures in magnetite and pyrite, and as grains showing spindle twinning, and some sets of intersecting twins. Quartz is subhedral. Pyrrhotite occurs as minor grains in chalcopyrite, and two or three small suspected sphalerite pieces were also seen here.

MU24 (T.S.) - Oxidized lode (jasper) - near 5000S, 400E.

Macro: Red/brown, very hard, ferruginous, jaspery rock, with granules of quartz (up to 1 cm) spotted throughout it. Minor green copper staining.

Micro: Coarsely banded, with limonite stained chalcedony (jasper). Large quartz grains, with secondary zoned quartz growing on them, and in vughs in limonite, which occurs as granules or compact masses. Some quartz grains show authigenic rims. Calcite is quite abundant, often with good concentric growth zoning. It is later than the secondary silica.

MU25 (T.S.) - Oxidized ore - near 2200S, 00

Macro: Chrysocolla, in wisps and thin veins, with quartz and yellow/brown earthy limonite.

Micro: Quartz rich rock, grains very fractured, showing some undulose extinction. Chrysocolla minor, as stringers and minor veins between grains. Limonite as granules cut by chrysocolla, and as stains in fractures in quartz. Some chlorite and clay minerals, and cross-cutting spherulitic ?chalcedony.

MU26 (T.S.) - MM8 464'

Macro: Well layered augen granite gneiss, consisting of quartz, felspar and biotite, with large elongated felspar augen up to 1 cm wide x several cms. (40%) and biotite concentrated in ?shear layers between them.

Micro: Quartz (45%), granular, ·1 to 1 mm, with some undulose extinction; in augen and especially with biotite and muscovite; also showing some graphic intergrowths (?myrmekite) with plagioclase. Microcline (30%), ·2 to 1 mm, with cross hatch twinning and perthite exsolution. Occurs mainly in augen, but also scattered throughout the rock. Plagioclase (10%), weak twinning, seritized; generally finer graned. Very dark brown to light brownish green biotite (10%) and muscovite (< 5%), as bladed, subhedral flakes (·05 to 1·5 mm) in layers with quartz, between augen. Some muscovite is aggregated in pockets and clusters. Odd subhedral ?pyrite (6.4 mm) and accessory zircons.

MU27 (T.S.) - MM8 768'

Macro: Aungen granite gneiss, more homogeneous than MU26, with better layers and smaller augen.

Micro: Quartz (45%), granular, up to ·5 mm. Microcline, (20%), twinned, but little perthite. ·5 to 1 mm, and very clouded with clay. Plagioclase (15%), twinned and weakly sericitized, as isolated grains and abundant in some augen. (·4 - 1mm). Muscovite (10%) and biotite (5%), as long, oriented blades, in compact, continuous masses right across the core. Odd enhedral pyrite.

MU28 (T.S.) - near 00, 800W

Macro: Granite gneiss, very contorted, and lacking banding, with only minor biotite.

Micro: Perthite (35%), and abundant fractured and granulated quartz (45%), with some myrmetite. Plagioclase (20%). Biotite and fine muscovite occur as odd flakes, and unoriented aggregates, one around broken garnet pieces. Zircon with pleochroic haloes abundant in biotite.

MU29 (T.S.) - MM9 1219'

Macro: Well banded quartz - felspar - biotite - sillimanite gneiss, with sillimanite randomly oriented on biotite rich planes.

Micro: Layering not so obvious. Quartz abundant (40%), both in layers rich in plagioclase (35% - generally untwinned with minor sericitization) and in between biotite (15%) flakes. The biotite rich areas have minor associated muscovite and coarse sillimanite prisms (up to ·7 mm diameter, < 5%). Several aggregates of pale chlorite or clay minerals are pseudomorphous after kyanite. Opaques minor.

MU30 (T.S.) - MM8, 933'

Macro: Well banded felspar - biotite - sillimanite gneiss.

Micro: Bands of euhedral sillimanite and biotite (30%), in random orientation, with interlayered heavily sericitized plagioclase (55%), twinned and strained. Much alteration is peripheral or following cleavage, but some grains are now entirely fine grained sericite (15%) aggregates. Quartz is very minor.

MU31 (T.S.) - MM7, 290'

Macro: Layering not so well defined as MU29 or 30, with abundant quartz, felspar and red garent. Biotite and sillimanite are obvious on broken surfaces.

Micro: Garnets are very fractured and altered to brown biotite, peripherally and along fractures. Some retain crystal outlines. Sillimanite occurs in coarse prisms up to ·5mm x 2mm, often fractured and associated with biotite, which also occurs as minor scattered flakes. Granular quartz is abundant, ·4 or ·5 mm, up to ·8 mm, with undulose extinction. The felspar is mainly perthite, but some pure plagioclase was observed. Scattered anhedral fine grained opaques exist.

MU32 (T.S.) - Open cut near 4500S, 200E.

Macro: Very weathered quartz - felspar - sillimanite - biotite gneiss, but lacking the characteristic texture of MU29 and 30.

Micro: Consists of broken and granulated quartz in aggregates and scattered grains, varying from 10 to 80%. Plagioclase is less common, often cloudy with alteration. Some is myrmekitic. Golden brown biotite (10 - 15%) and occasional muscovite flakes occur in patches, with 1 or 2% associated sillimanite. Opaques rare, but honey/brown ?rutile is a common accessory.

MU33 (T.S.) MM11 - 955'

Macro: Similar to MU34, with less regular layering, and less staurolite.

Micro: Granular quartz (45 - 50%), and minor twinned plagioclase, with felted layers of oriented muscovite (30%, up to 1 mm x ·02 mm), with biotite (20%). Staurolite occurs as odd grains, very corroded, with quartz inclusion. Several small rounded or elongated garnets were observed, and minor chlorite. Two large areas, 2 or 3 mm x 1 cm are secondary serpentine, with quartz inclusions. Their origin is not apparent. Coarse pyrite (up to 1·2 mm) occurs.

MU34 - MM9, 1147'

Macro: Medium grained quartz - felspar -biotite gneiss, with silky muscovite layers, and pods of staurolite.

Micro: (T.S.). Consists of quartz granules (40%, ·1 to ·6 mm) and fresh, twinned plagioclase, with strongly oriented silky, fibrous muscovite in rich layers ·5 to 1 mm wide. 40% up to 100% locally. Biotite, slightly coarser (·5 x 2 mm maximum) occurs with it (5 - 10%). Large (3 x ·5 mm) corroded staurolite grains occur, with numerous quartz inclusions. Small sub-rounded garnets up to ·4 mm were also seen. The micas bend around the staurolite porphyroblasts, but not around the garnet. Some layers of very fine, felted sillimanite needles occur. The habit of these is noticeably different from that in the typical biotite - sillimanite gneiss (e.g. MU29, 30).

Micro: (P.S.). The opaque minerals (up to ·3 mm) are mainly ilmenite, some with irregular haematite exsolution, which occurs scattered throughout the rock, and also as inclusions in staurolite and along biotite cleavages. Odd pyrite grains also occur.

MU35 (T.S.) - near 2500S, 900W.

Macro: Poorly banded amphibolite, with some white veins and dark streaks.

Micro: Coarse grained, granoblastic, no layering. Consists of granular twinned Plagioclase (20%), showing twinning and some sericitization: Generally ·5 mm up to 1 mm, and about An_{59}. Much is completely altered to scapolite (15%), showing cleavage, and often subhedral. Hornblende (65%)

is granular to enhedral, or bladed, up to 1·5 mm, but generally ·4 mm, down to small granules, less than ·1 mm, intergrown with quartz, (< 5%). Limonite staining occurs between hornblende grains, and opaques occur in fractures within the grains, cutting across cleavages. Some ilmenite occurs, altered to leucoxene or rutile and also isolated pieces of ? leucoxene. Some narrow veins of felspar fill fractures.

MU36 (T.S.) - South of 00, 400W.

Macro: Well banded amphibolite, with cross-cutting dark amphibole rich portion (not sectioned).

Micro: Granoblastic. Anhedral, twinned plagioclase (25%), An_{68}, generally ·5 mm, showing considerable alteration to scapolite (20%), which has amphibole inclusions, and occurs as granular aggregates or isolated grains. Hornblende (50%), bladed and subhedral, ·01 mm to 2 mm, generally less than ·5 mm. Banding is less conspicuous with magnification. Quartz, minor, < 5%, and no opaques, but some ?leucoxène was observed.

MU37 - MM10 283'

Macro: Medium grained, dark green massive amphibolite, with disseminated pyrite.

Micro: (T.S.) Plagioclase (20%), generally ·4 mm, approximately An_{47}, with minor zoning and sericitization, but no scapolite. Hornblende (75%), granular to subhedral, up to 1.5 mm, generally .1 to .5 mm. Strongly pleochroic X = pale brownish olive green, Y = dark bluish green, Z = dark olive green. Quartz (5%), generally .1 mm, as granules in pods with equidimensional hornblende. Opaques relatively abundant, and one cross-cutting calcite vein, 1 mm wide was seen.

Micro (P.S.): Very fine grained (.01 mm) disseminated pyrite and chalcopyrite grains, but quite abundant ilmenite (up to .4 mm, generally . 2 mm), rimmed by ?leucoxene or ?sphene alteration, and containing rare unoriented haematite bodies. Some very fine lath-like ilmenites occur along hornblende cleavages.

MU38 (T.S.) - near 3000S, 200E.

Macro: Amphibolite with narrow very dark bands, which are elsewhere seen to diverge and cross.

Micro: The rock is a disequilibrium assemblage of various amphiboles, hypersthene and plagioclase. Relict hypersthene grains are altering peripherally to fine grained pale green actinolite (35%) and some tremolite. These masses are rimmed with darker green hornblende. Subhedral to euhedral hornblende appears to be growing inside the secondary actinolite masses. Granular plagioclase (An$_{63}$ - 45%) and minor scapolite and quartz make up the rest of the rock. The dark bands consist of darker secondary amphibole, with very minor, ragged plagioclase and quartz grains. Opaques occur in cleavages of both hypersthene and euhedral hornblende, and as odd coarse grains.

MU39 (T.S.) - MM7, 675'

Macro: Contact of biotite deficient slightly contorted augen granite gneiss with schistose amphibolite.

Micro: Amphibolite is rich in biotite, with little hornblende. Biotite contains zircons with pleochroic haloes, and is parallel to the contact. Calcite veins occur in the amphibolite, being both concordant and cross-cutting. Quartz and plagioclase are also present. The actual contact, which is undulating, is defined by a biotite rich layer with a concentration of opaques in the amphibolite, and a zone with some chlorite (1 or 2 mm) in the gneiss. Scapolite is widespread in the granite gneiss, and the plagioclase is heavily sericitized. Microcline is minor, and quartz often occurs as veinlets. Biotite very minor.

MU40 (T.S.) - MM7 578'

Macro: Contact of biotite rich amphibolite and well layered augen granite gneiss.

Micro: Typical amphibolite, with abundant altered ilmenite grains, and rich biotite layers (? shears) parallel to the contact. Bifurcating calcite veins are also parallel to the schistosity. Hornblende disappears 2 mm from the actual contact, which is planar and quite sharp, and the biotite becomes strained, with some chlorite, microcline and scapolite appearing. The granite gneiss has a 2.5 mm zone rich in biotite and chlorite at the contact, with felspar grains elongated between biotite flakes, which are sparser and finer grained than those in the amphibolite. The plagioclase in the gneiss is heavily sericitized, quartz, is often in veins, and one twinned staurolite was seen.

MU41 (T.S.) - MM10, 1004'

Macro: Very sharp contact between amphbolite, with biotite rich layer (2 cms) at the interface, and well layered quartz - felspar - biotite gneiss.

Micro: Amphibolite consists of green hornblende with opaques along cleavages, and 20% plagioclase and fine granular quartz, which forms composite intergrowths with hornblende. Brown biotite is very abundant at the contact, but decreases away from it. The gneiss consists of quartz, often in coarse pods (grains up to 3 mm), plagioclase and biotite, in layers and lenses. Odd minor hornblende grains occur away from the contact. Zircons with pleochroic halves are abundant in both rock types, and minor coarse opaques are scattered throughout.

MU42 - MM11, 993'

Macro: Fine grained, dark, banded amphibolite becoming richer in large biotite flakes. A felspar vein parallel to the banding was sectioned.

Micro: (T.S.) Consists of 55% hornblende (X = faint pinkish green, Y = dirty green, Z = medium bluish green), with opaques along cleavages, granular to subhedral, .1 mm up to .6 or .7 mm; plagioclase (An_{46} - 35%), granular, up to 1 mm, showing irregular zoning and twinning, and also as .3 mm granules in concordant vein; biotite (10%) (X = colourless to pale brown/green, Y = brownish olive green, Z = darkish brown), up to 2.5 mm, with abundant zircons, and quartz as odd fragments in the rock and vein. There is no obvious formation of biotite from hornblende.

Micro: (P.S.) Large opaques were generally absent but one grain of magnetite (1 mm) bordered on one side by ilmenite with irregular haematite intergrowths was seen. One pyrite grain was observed. Most of the opaques were lathike haematite grains, with oriented ilmenite exsolution, along hornblende cleavages, or sometimes scattered throughout the rock.

MU43 (T.S.) - MM8, 2245'

Macro: Contact of coarse grained pyrite, minor chalcopyrite and magnetite grains with biotite rich schist, showing a zone of chloritic alteration.

Micro: Coarse pyrite etc. with small inclusions (?apatite, quartz, chlorite). Chlorite masses, made up of unoriented fine grained aggregates rim the pyrite, and penetrate fractures. The chlorite contains minor granular to subhedral limonite stained quartz grains and aggregates and some very fractured felspar being altered along cleavages. Further from the ore, coarse brown biotite appears, with zircons, and rimmed with darker green less pleochroic chlorite. In between the roughly oriented biotite flakes are plagioclase granules (60%) showing zonal alteration to pale chlorite and sericite near the dense chloritic zone. Limonite, chlorite and minor opaques are common.

MU45 (T.S.) - Ore - M4, 1142'

Macro: Core shows sharp diagonal contact of coarse quartz - pyrite ore, with greenish, massive gneiss, which adjoins a coarse Quartz - chlorite vein, with disseminated chalcopyrite.

Micro: "Gneiss" is mainly very cloudy plagioclase, (.2 to .5 mm), with scattered roughly aligned grains of biotite (with zircons and opaques often along cleavages) and pale chlorite, often as intergrown flakes. Some narrow veins of darker chlorite cut this mass. The "quartz - chlorite" is actually a coarse (3 to 4 mm) pegmatite vein, containing heavily altered plagioclase (to sericite and chlorite), with remnant twinning and idiomorphic outlines, and quartz.

MU48 (T.S.) - MM8, 2251'

Macro: Lode with gangue. Ore is quartz, pyrrhotite, unusually abundant magnetite, chalcopyrite, which rims pyrrhotite and quartz, and dark green micaceous gangue.

Micro: The rock consists mostly of very fine grained chlorite aggregates, sometimes spherulitic, apparently altered from biotite, and many are pseudomorphous after coarse biotite flakes. Some odd biotite flakes (up to .4 mm) exist, rimmed with darker chlorite. Quartz occurs as grains or aggregates near ore minerals, and also in chlorite masses. Some is granulated, and other grains show the triple junctions of polygonization. Magnetite occurs between biotite pseudomorphs, with limonite stained clay abundant in fractures. Chalcopyrite contains wispy needle-like inclusions.

MU49 (T.S.) - near 5000S, 400W.

Macro: Quartz rich granite gneiss, with some vein-like augen, sometimes folded.

Micro: Granulitic rock with heterogeneous grain size, up to .5 mm, with coarser bands (up to 3 mm). Quartz (45%), and microcline (20%) with cross-hatching, perthite and cloudy alteration occur in both veins and finer portions. Plagioclase (30%), twinned and partly sericitized, scattered fine grained greenish biotite (< 5%) and odd muscovite flakes make up the rest of the rock. Opaques are very minor.

MU50 (T.S.) - pits near 4000S, 200E.

Macro: Folded weathered quartz - biotite - sillimanite schist, but lacking the typical sillimanite gneiss texture.

Micro: Rock consists mainly of granoblastic quartz (75%) and plagioclase (15%) with some twinning, up to .5 mm, but generally .2 mm. Biotite (5%) occurs as small unoriented flakes (.1 mm) in the massive part of the rock, but it is larger (.8 mm), and concentrated in layers at the fold. Sillimanite is concentrated here, but is also spread throughout, being altered to flaky muscovite. Some limonite staining.

MU51 (T.S.) - MM9, 1202'

Macro: Quartz rock, with some felspathic patches and very fine grained biotite.

Micro: The body of the rock consists of quartz (.1 to .2 mm) and some strained poorly twinned plagioclase, with abundant fine muscovite flakes, often in "shear" layers, and scattered green/brown biotite, with minor chlorite. Some pegmatitic veins are composed of coarse, cloudy, albitic plagioclase, often strained and bent and coarse quartz aggregates, usually very strained.

MU52 (T.S.) - from 1500S, 600E.

Macro: Coarse grained felspathic rock.

Micro: Almost entirely granular, twinned plagioclase, of heterogeneous grain size up to 5 mm. Accessories are honey/brown rutile and minor sericite flakes.

MU53 (T.S.) - near 2000N, 800W.

Macro: Sandy aplitic quartzite, without layering.

Micro: Consists of granular quartz (90%) (.2 to .4 mm) with interstitial clouded plagioclase with some twinning, and scattered muscovite flakes, about .3 mm long. The quartz and plagioclase are generally much finer (granulated) near the muscovite flakes.

MU54 (T.S.) - near 6700S, 1000E.

Macro: Friable, sand size quartz - felspar rock ("Aplite"), lacking layering.

Micro: Fine grained, granoblastic. Mainly quartz (70 - 75%), and plagioclase (RI > quartz), and minor fine grained muscovite flakes, and dirty brown accessories. Grain sizes are heterogeneous, but generally .4 to .6 mm.

MU56 (T.S.) - from near 6000S 800E.

Macro: Very weathered felspathic biotite - sillimanite gneiss, with some layering of biotites.

Micro: Similar to MU32. Layering not obvious. Consists of sillimanite, biotite, quartz, sericitized plagioclase, which is often cloudy peripherally or between grains. Some myrmekitic intergrowths, with quartz especially along felspar cleavages. One green tourmaline accessory.

MU57 (T.S.) - from pits near orebody.

Macro: Very weathered, highly sericitized quartz - felspar - biotite gneiss, without layering.

Micro: Sericite along shear layers. No sillimanite. Some biotite, and opaques. Most of rock is granulated and broken quartz and plagioclase, of heterogeneous grain size.

MU58 (T.S.) - MM8, 818'

Macro: Crenulated schist.

Micro: Quartz, plagioclase, biotite, muscovite schist, showing crenulations in the mica layers, and no undulose extinction in the quartz.

MU60 (T.S.) - MM9, - 597'

Macro: Well banded quartz - felspar - biotite gneiss, with coarse pegmatite vein and biotite rich zone at one end (not sectioned).

Micro: Rich in quartz, with some plagioclase in the body of the rock and as occasional large very altered grains, and in the pegmatite. Oriented biotite flakes are comparatively uncommon. They sometimes form thin layers, with minor muscovite and odd chlorite flakes, which bend around plagioclase porphyroblasts. Some small sillimanite grains were seen in one of the layers. Opaques were relatively abundant, mostly fine grained but occasionally up to ·4 mm.

MU61 (T.S.) - near 3000S 200E

Macro: Amphibolite, well banded, parallel to foliation.

Micro: Typical amphibolite, with alignment of hornblende grains, abundant quartz often as inclusions in hornblende. Plagioclase is fresh, except where it alters to scapolite (abundant). Some bands rich in yellowish hornblende and quartz occur (similar to MU38). Cracks or cleavages in plagioclase, parallel to the banding, are filled with hornblende. The opaques are generally aligned also.

APPENDIX II — THE ELIZABETH COPPER MINE, VERMONT, U.S.A.

It is interesting to note the uncanny similarities between the known facts at Mutooroo and the Elizabeth Mine (McKinstry and Mikkola (1954); Howard (1959, I and II)), where underground openings yield much more information.

The orebodies here exist at the boundary of amphibolite and schists. The amphibolites are regarded as metamorphosed crystal tuffs because they contain felspar fragments. Fifteen separate beds are recognized, up to 200 ft. thick, lensing out both along strike and down dip. Some can be traced for 12 miles. The variation in thickness is unrelated to folding. They contain plagioclase (An_{17-38}), hornblende, calcite and fine grained epidote with minor quartz, and occur in and laminated with mica schists and quartzites, (in lenticular bands generally less than 20 ft. long). The schists contain sillimanite, kyanite, garnet and abundant staurolite. Quartz veins, often pegmatitic, occur widely, generally one or two feet long. They are both parallel to bedding and crosscutting.

The orebody is 6,000 ft. long, and mined over 20 to 50 ft. widths, with a grade of just less than 2% copper. It is 90% pyrrhotite, 9% chalcopyrite (with valleriite), with minor pyrite, sphalerite and molybdenite. Pyrite occurs as cubes up to 5 cm., and is more abundant higher in the mine. The gangue is quartz and partly replaced schist, with minor rutile, idocrase and tourmaline. Sulphides are strained only in post ore faults - pyrite is cracked, pyrrhotite shows flamboyant twinning, and fractures are filled with lighter pyrite and calcite. The orebody is folded, and thickest ore (60 ft.) is associated with drag folded positions. Zoning is marked - chalcopyrite is more abundant in the middle and crests of folds (300 to 400 ft. vertically), but the keels contain large tonnages not payable without revenue from iron or sulphur.

Two zones of wallrock alteration have developed; an outer zone where hornblende gives pale biotite pseudomorphs, with some chlorite, and an inner green sericite zone, replacing plagioclase and biotite pseudomorphically. Magnetite and ilmenite are absent in the alteration zone which varies from a few inches to 20 ft. The correlation between this width and the ore width is good where the ore is thin, but poor in folded regions. They are thought to have devloped contemporaneously by addition of K, Cu and S, and loss of Mg, Na, Ca and C due to decreasing ionic activities away from permeable channelways, and prevailing temperature and pressure conditions at the time of alteration (Howard).

The deposit is considered epigenetic.

APPENDIX III — CALCULATION OF ORE RESERVES

The longitudinal projection of the orebody, showing results of all drill holes, is shown in Figure 41. These values have been used for calculations of reserves. The four configurations tried are shown in Figures 42 to 45. The first estimate (Figure 42) was made using the "triangular grouping" method; the other three by the "area of influence" method.

1. Triangular grouping.

All the results are joined, forming triangles, and the averages value of each calculated thus: e.g. for triangle 4, 5, 7

Hole	Thickness X	Grade	=	Assay width	Average assay (weighted)
MM4	35.5	2.1%		73.1	
MM5	95	1.2%		114	= 247/161.5
MM7	31	1.95%		60.45	
	161.5			247.6	= 1.53%

The average thickness, the area, and hence the volume of the prismoid can be calculated, and multiplication by the average assay gives the "volume of copper". When all triangles are calculated, the total volume and "volume of copper" are obtained by addition. Division gives the average grade, and the tonnage can be worked out using an average density. A density of 4.1 (= 256 lbs. per cubic ft., or 1 ton = 8.8 cubic ft.) was used, calculated from an average volume composition of 35% pyrrhotite, 25% quartz, 20% pyrite, 15% chalcopyrite and 5% magnetite. In this method a given intersection is used a number of times, depending on the number of triangles in which it is included.

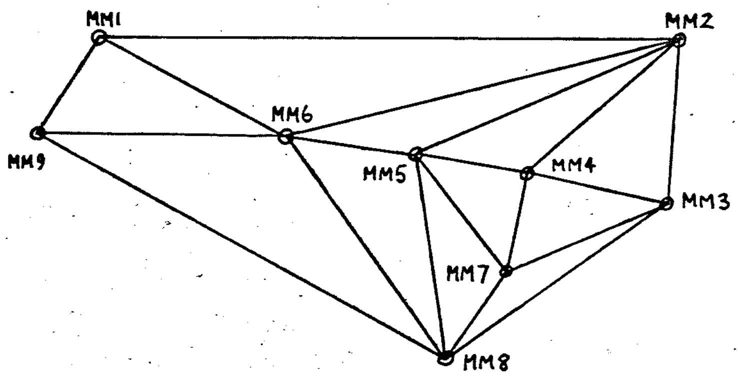

FIGURE 42 – TRIANGULAR GROUPING METHOD.

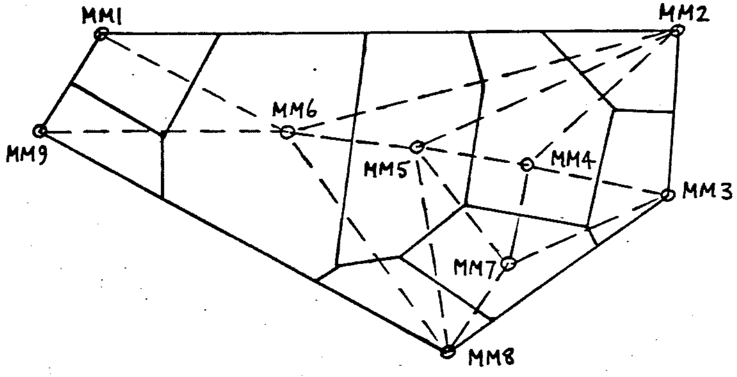

FIGURE 43 – AREA OF INFLUENCE METHOD (1).

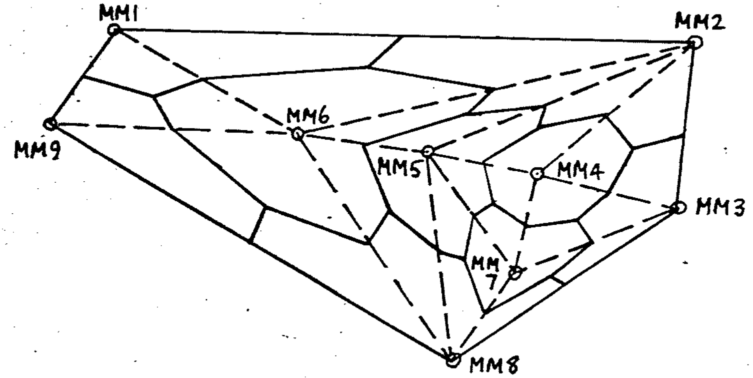

FIGURE 44 – AREA OF INFLUENCE METHOD (2).

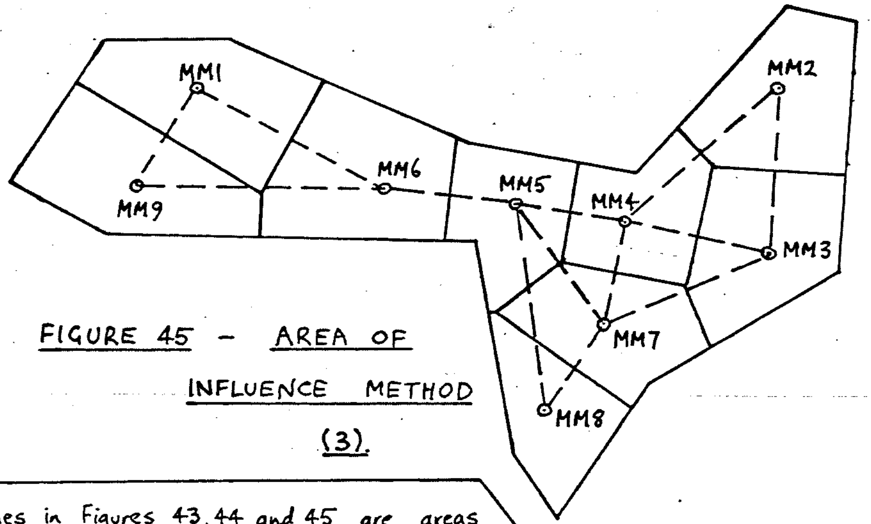

FIGURE 45 – AREA OF INFLUENCE METHOD (3).

Solid lines in Figures 43, 44 and 45 are areas considered as the intersection value.

SCALE : 1 inch = 800 feet in all Figures

2. Area of Influence.

In this method, the area surrounded an intersection is assumed to be of that value. If the triangles are roughly equilateral, the perpendicular bisectors of the sides are joined, to form areas around each value. This produced very distorted areas (see Figure 43). A second method, using the line joining the mid-points of the sides to the vertices (medians), gave "serrated" areas (Figure 44). Here the area around MM6 is very large, giving a higher grade than the previous method. Less MM5 influence gave a much smaller thickness and volume. The third configuration (Figure 45) used an area 20% larger, and gave a correspondingly lower grade, but the tonnage was less than the method of Figure 43. The areas around each hole were more uniform, and it is probably more realistic.

To obtain a tonnage, the area is measured (on graph paper), and the "volume of copper" calculated as above, using the width and assay of the intersection. Grade and tonnage are estimated as before.

The results of all methods are given below:

Method	as Figure 42	as Figure 43	as Figure 44	as Figure 45
Volume considered	68,000,000cft	91,500,000cft	64,600,000cft	84,500,000cft
Average grade	1.72%	1.68%	1.75%	1.61%
Average width	28.1 ft.	38.1 ft.	26.9 ft.	28.4 ft.
Tonnage of ore	8,150,000	10,050,000	7,400,000	9,670,000
Tonnage of copper	140,000	176,000	130,000	156,000

The drilling was designed to test the 1000 ft level, so using holes MM3, 4, 5, 6 and 9, the tonnage per vertical foot can be calculated, assuming an average dip. (50° was used, being the average of dips measured on cross sections). The value over 2,650 ft. (distance MM3 to MM9) was 16,650 tons at 1.43% copper. Assuming a constant width, length and grade over the known depth of ore (1650 ft.) minus the mined out portion (150 ft.) gives 25 million tons, worth $10.4 per ton at $800 ($13 at $1000) or a total value of $260 million ($325 million). There are obvious deficiencies in assuming these figures for the whole body.

FIGURE 46 – GEOLOGICAL OUTCROP MAP.