The Geology of the Walparuta and Ethiudna Mine Areas, Olary Province, South Australia.

Submitted by J.D.Waterhouse, Department of Geology,
University of Adelaide.

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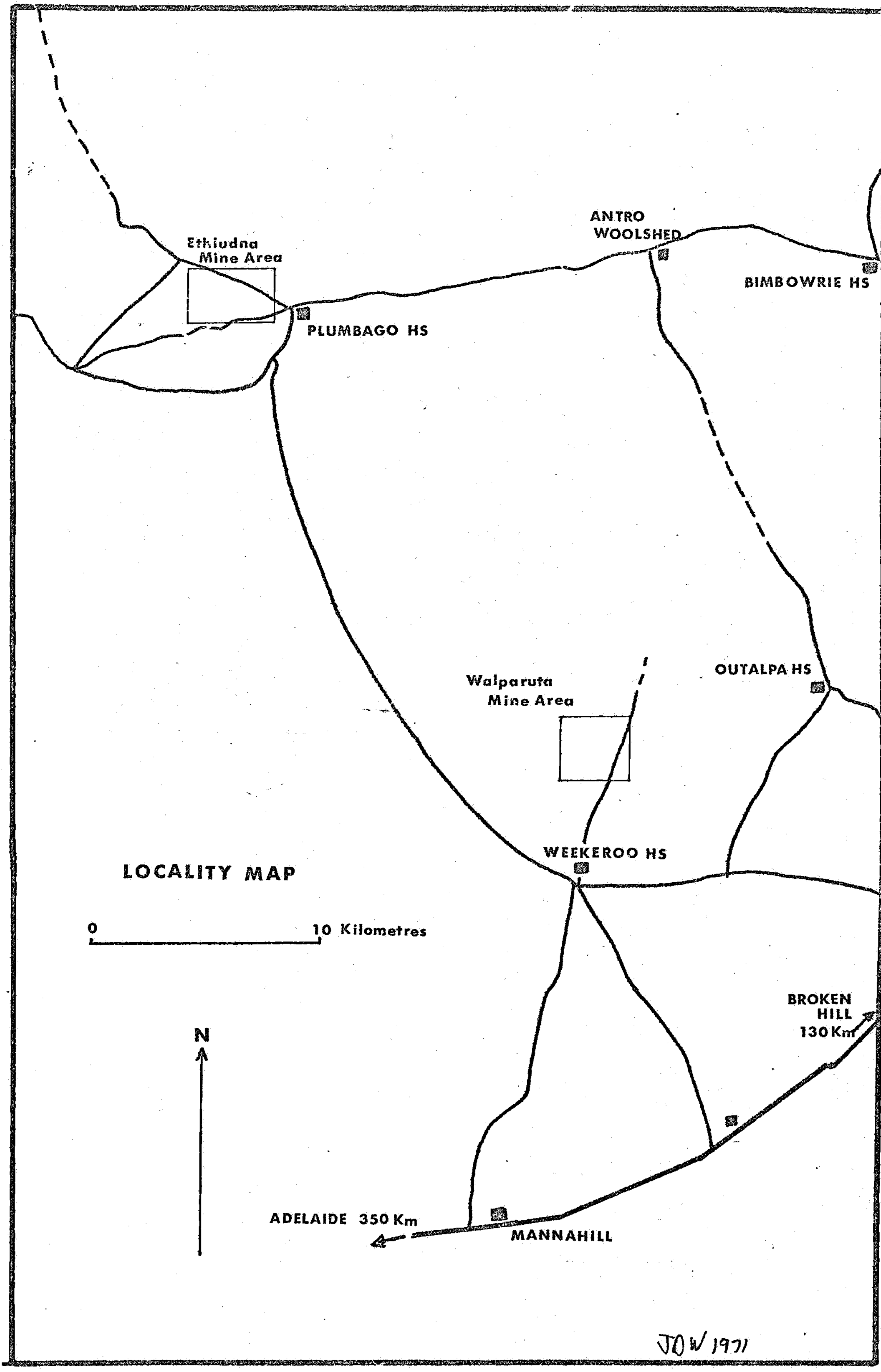
Honours thesis 1971
Supervisors: R L Oliver, M A Etheridge, A W Kleeman

Sillimanite neddles in quartz host. X625

Plane polarized light.

INDEX


Ethiudna
Mine Area
ANTRO
WOOLSHED
BIMBOWRIE HS
PLUMBAGO HS
Walparuta
Mine Area
OUTALPA HS
WEEKEROO HS
LOCALITY MAP
0
10 Kilometres
N
BROKEN
HILL
130 Km
ADELAIDE 350 Km
MANNAHILL
JOW 1971

BACKGROUND

The project was initiated by Dr.T.P.Hopwood of Analytical Exploration to study certain areas of copper mineralization in their S.M.L. in the Olary Province, with a view towards the determination of the structural and lithological controls of the mineralization.

During the latter stages of field work, in March, this support from Analytical Exploration, and more particularly from Dr Hopwood and Dr Coward, was withdrawn for various reasons beyond the control of all concerned.

The project subsequently changed somewhat in emphasis, and became a more general study of basement rocks in the areas mapped, with a bias towards structural history and the controls of the mineralization.

Field mapping took place in February and March 1971, with approximately one month being spent in each of the two areas. After an initial period to become familiar with the rock types, as large an area as was possible in the time was mapped.

Laboratory work during the remainder of the year included the cutting of some 80 thin sections (Appendix A contains the more important descriptions), and a limited amount of chemical analysis work.

INTRODUCTION

The two areas mapped are both north of Mannahill, South Australia, and lie in the Willyama Complex. Both areas are arid to semi-arid, having average annual rainfalls of about 5 inches.

Rocks are metamorphic Precambrian (Archean?) basement, with unconformably overlying Adelaidean metasediments. These Adelaidean rocks do not occur in the Ethiudna area, and mark the eastern edge of the mapped area at Walparuta.

The areas are both hilly, Walparuta having much greater relief than Ethiudna. The results of this work are summarized in the following pages, divided into two sections.

PART ONE - WALPARUTA MINE AREA

FIELD MAPPING

A maximum enlargement of the relevant area was obtained but the resolution was poor, especially around the edges. It was later discovered that a colour negative had been used for the black and white print. Regrettably, sufficient time was not available to wait for a better copy prior to mapping. The photo proved reasonably satisfactory, although in some cases accurate location was quite impossible - this governed the southern limits of the area mapped. Smaller scale contact prints were also used to help define field locations more accurately.

Photo-interpretation was most useful in some respects but quite misleading in others. Some trends (and a major lineament) were visible, but lithological boundaries, e.g. the basal conglomerate of the Adelaide system, were not found to be accurately mappable by this technique. In addition, many trends inferred by the photo were not apparently related in any way to the geology.

Outcrop varied from very good to very poor. In some areas cover of any sort was absent - e.g. hills in the southern and northern schist bands, but many hills of gentler slope had either complete soil cover or soil with rock "float"on the sides. Creek banks and beds frequently had excellent outcrop, often of relatively unweathered rock. Outcrop on some hills and hilltops was often highly weathered - felspathic rock being seen as saccharoidal sandstones, and soil creep frequently rendered dip values unreliable, particularly where steep dips were involved.
Plate 2(d) illustrates folded quartzo-felspathic bands exposed in a creek bank, but quite undetectable on the hillside beyond.

At the beginningit was attempted to map in detail such features as pegmatites bodies, but this was found to take considerable time, and had this beem continued the area covered would have been much reduced, and the major fold structure would not have been recognized.

The author therefore recognizes three main rock types which are described in a later section.

The accuracy of magnetic north on the map is estimated at about plus or minus 5 degrees, due to the lack of prominent landmarks between which a measurement could be made.

LITHOLOGIES

The rocks in the Walparuta Mine area are divided here into three broad categories. Each may include several rock types but it was not practical to map these in detail for several reasons.

1. The minor lithologies are often quite difficult to trace in the field due to poor outcrop in many places, discontinuities of the bands due to tectonic thinning and minor faulting.

2. The minor lithologies are often not distinctive in the field- it is therefore not possible to distinguish a particular rock from another with similar lithology where continuous outcrop is present.

3. Highly detailed mapping was beyond the scope of the project except for a few detailed geological sketches of selected area (e.g. the actual area of mine shafts.) It would have been impossible to map a reasonably large area in the time allotted if such detail had been included.

The prominent iron formation and laminated marble bands are exceptions to the above, due to their reasonable persistence, and extremely distinctive nature.

A. LAYERED QUARTZO)FELSPATHIC ROCKS.

These rocks outcrop in the area that was mapped in the greatest detail, and the number of marker beds is probably related to this.

The major rock type is a finely layered, pale grey to white quartzo-felspathic rocks (Plate 1(a)) with very little or no mica, except in fractures, which grades to a similar rock with up to 40% biotite. Migmatites are commonly developed. The rock weathers to a dark brown generally, except where well exposed in a creek east of the mines, where it is paler in colour with the banding very obvious. Analysis of these rocks reveals them to be highly albitic (maximum 79.2% albite, in the felsic fraction), and thin sections (numbers W 11,19a,25) also reveal that the banding is due to fine layers rich in magnetite, with one slide (W12) revealing a well defined, continuous band containing zircon, and rutile or xenotime, all of which are likely to be found as detrital bands. Definite cross bedding is also well exposed in the creek east of the mines (TS W24) with the banding again due to fine magnetite, confirming a sedimentary origin for the layering in these rocks.

Due to the definite sedimentary features, these rocks are probably best described as albitized metasiltstones.

Pegmatites with a large size range are found in these rocks, and are commonly cross cutting in their relationships with the layering and schistosity, and show different types of deformation according to their orientations. Those presumably at a low angle to the direction of maximum shortening (and generally at a high angle to layering) show well developed folds, whilst those at lower angles to layering show some pinch and swell structures, or develop into a number of small blocks, rotated slightly with respect to the vein and slightly displaced with respect to one another (Plate2a).

The first phase schistosity is often developed parallel to the layers, in rocks containing mica, with the second phase schistosity completely overprinting the layering in the more mica rich rocks. A weak layering, usually within 20-30 degrees of the major schistosity, is occasionally present.

The biotite free albitized metasilts show varying degrees of fracturing, grading from weak, fine fractures resembling a layering to strongly brecciated rocks (TS W2,4,21,23 and Plates 3c,3d), the fractures being infilled with biotite and magnetite. The copper occurrences are apparently related to this brecciation. Frequently microfaults lacking this mafic infilling are developed in these rocks, presumably a younger feature, and their orientation is similar to the orientation of the larger faults shown on the small scale map of the mine area. Two intergrown quartz veins, both seemingly undeformed, but the relative times of their formation are not obvious.

It has already been mentioned that the layered quartzo-felspathics grade into migmatites in places. The typical migmatitic layering (Plate 1b) consists of coarse grained layers of twinned albitic plagioclase, K-felspar, and quartz, with rare muscovite, (TS W3,9) generally less than 2cm thick, with thicker but much finer grained layers of quartzo-felspathic rock between. The first phase schistosity is parallel to these layers. It was not found practical to use the small scale structures in the deformed migmatites as indicators of larger scale structures due to their inconsistency. Plate 1c shows small scale folds in the migmatites with opposite fold senses in one outcrop. This inconsistency could be due in part to the possibility of some isoclinal second phase structures in the area, as some isoclinally folded schistosities were observed.

The migmatites do not occur as distinct lithological units, but rather irregularly within the quartzo-felspathic rocks, which show varying degrees of migmatization. They probably formed during a period of reasonably high grade metamorphism, certainly amphibolite facies or higher, and therefore pre-date the last recognizable metamorphism (lower greenschist).

The migmatites appear to have undergone a minimum of two phases of deformation, (see Plate 2c) assuming they were first formed parallel to unfolded layers, and later deformed. Field observations suggest that the formation of migmatite veins was almost definitely controlled by the original lithological layering, and some outcrops in the mine area show a complete gradation from albitized metasilts to migmatites, both along and across strike, simply as the result of an increase in the number of individual migmatitic veins until all original layering is obliterated. Examination of single veins showed them to be of finite length with lenticular type terminations, and they gave the impression of being overall intrusive, as oppose to developing in situ. The complexity of some of the fold structures exhibited by these migmatites also tends to suggest that they were deformed after their formation rather than developing in situ as a pseudomorph after a complexly folded layer. Furthermore, if the migmatites were injected, and injection does not imply that they were formed at any great distance from their present location, then it seems exceedingly unlikely that the vein would be controlled in its emplacement by the complexly folded layer. Mechanical planes of weakness such as schistosity would seem more reasonable controlling influences. The field evidence does not suggest that the migmatites are spatially related to the intrusive granitic body at Walparuta.

To sum up, it is felt that the migmatites were formed within the rocks in which they now occur, and were partially mobilized, with their present location controlled probably by several factors such as the permeability of the host rock and the amount of water present, of great importance when melting granitic composition assemblages.

The difference between migmatite veins and pegmatite veins which also conform with the layering, rather than cutting across it, may be one of origin rather than of mineralogy. It is suggested that the migmatites have undergone two periods of deformation, and must therefore have formed during or before the earlier pre-Adelaidean deformation.

<u>Marker Beds</u>

Within the layered quartzo-felspathics are two distinctive lithologies with which it was hoped to delineate structure.

(1) Iron Formations: These are distinctive black layers of predominantly magnetite and quartz (TS W7, Polished section W7) The formation is generally 1-3m thick, and persistent, but limited in occurrence to the area near the mines. It is Conformable with the other lithological layers, and probably represents original sedimentary layering, perhaps simply richer in magnetite than the surrounding rocks, which are far from free of magnetite, and perhaps accentuated by metamorphic segregation. It is not certain whether more than one distinct layer occurs, because the area in question is complicated by faulting, but in any case no obvious structure

can be seen from the outcrop pattern.

(2) Quartzites: these are quite clean, medium grained, white to grey quartzites, 1-3m thick, similar in persistence and distribution to the iron formations, and presumably derived from clean sandstones.

These two horizons (interpreted as original sedimentary layers), are apparently unfolded, although it is of course possible that the sudden discontinuities observed in them are the result of sheared out isoclinal folds. They are parallel to layering in nearly adjacent layered quartzo-felspathic rocks, but do not extend far enough in the area mapped to allow delineation of any major structure.

B. SCHISTOSE ROCKS

This term refers to an essentially uniform band of coarse quartz-mica schists, which is present defining the two limbs of a ~~pr~~ proposed major fold. The regional schistosity is well developed, with very flaggy outcrop often developed. A less well developed schistosity is also visible in places, and was observed to be axial planar to large, gentle folds in the regional schistosity. The minor schistosity is therefore a later one than the regional schistosity.

uccasionally a compositional layering was visible in small outcrops in creeks and it is probably analogous to the compositional layering observed to the south, i.e. an original sedimentary layering.

A well developed nearly vertical mineral lineation, and a rare parallel fine crenulation are well developed on the planes of regional schistosity.

Thin sections (W20a, 20b, 22a, 22b) reveal the mineralogy of the schists to be quartz-albite-garnet-muscovite-biotite-chlorite. The schistosity is predominantly muscovite-biotite-chlorite, with minor biotite and chlorite aligned across the major direction of preferred orientation (PO), presumably the weaker schistosity which was observed in the field.

Within the schist bands are two (one in each ~~limb~~ band) ~~bands~~ layers of calcareous, laminated quartzite (TS W13a) which are traceable for sev several hundred metres in both the northern and southern bands of schist. In the northern band this grades to the east into a very distinctive laminated marble (TS W13b) . This bed is unfolded and and quite straight in outcrop trace, with one well developed isoclinal fold (Plate 2b). In the southern band this marker bed is not traceable as far to the east and no laminated marble was found.

At one location the laminated marble graded to a small amount of tremolite rich rock, which in thin section is seen to contain relict tremolite in a carbonate-quartz assemblage. (Plate 5b)

C. BANDED GNEISSES

Rocks in the core of the major fold are predominantly banded gneisses, with migmatites, pegmatites, granites and some small amphibolite bodies. The area was not mapped in any detail, and no attempt was made to determine the distribution of such features as intrusive granites, due to lack of sufficient time.

The banded gneisses are composed of quartzo-felspathic bands with coarse mica rich layers of highly variable thickness between them. A schistosity is developed parallel to this layering, and both are folded with slight developed axial plane schistosity (the major schistosity). Minor thin ironstones, pyritic layers etc are developed in places.

Intrusive granites.

Immediately to the north of the mine area is a major granitic body, with contact relationships suggestive of an intrusive origin. Other similar bodies are present in the mapped area, but none were included in the mapping as discrete bodies as they outcrop in the core of the major fold, which was not mapped in detail.

Contacts between the body and the country rock are sharp, and cut across both schistosity and layering. Inclusions of country rock are found within the body.

Two stages of intrusion can be seen in the granite. The first is a very coarse grained rock, which is itself intruded by a finer grained material, with sharp contacts.

The edge of this mapped granite has a well developed biotite schistosity, roughly parallel to the regional schistosity. This suggests that the granite has been deformed, rather than the schistosity being the result of the physical process of intrusion. Since the granite is cut off by the major unconformity it must have been deformed by the deformation affecting the Adelaidean rocks. The schistosity in the granite seems parallel to the regional schistosity (see Structure section) which suggests that it was emplaced prior to the second phase of deformation. It cannot be established with any certainty whether the granite formed during a previous period of high grade metamorphism, or whether it was emplaced after this metamorphism but before the second deformation, although the former seems more likely.

ORIGIN OF THE LAYERING

Layering in some rocks in the area is regarded as being of sedimentary origin for several reasons.

(1) Several marker beds are recognized in the area, and are thin and persistent. They seem unlikely to have formed by metamorphic processes.

- (a) The thin quartzites within the layered quartzo-felspathic rocks are regarded as metamorphosed clean sandstones. The iron formations are also regarded as having sedimentary origins. The layering in the surrounding rocks appears to be parallel to these beds.
- (b) Several thin and persistent bands of pyritic albititic rock were observed in the area, also parallel to the banding in the surrounding rocks.
- (c) The laminated marble rock (W13) seems unlikely to have anything but sedimantary origins. The laminations in it are lithological layers parallel to the marble layer, and the marble horizon is quite unique, and markedly different from any surrounding rocks.

(2) Banding on a small scale has been interpreted as being sedimentary in the mine area for two reasons.

(a) Thin sections (eg W24, 25) show a fine layering of grains of magnetite. Thin section W12 shows fine layers of high density minerals such as zircon, xenotime and seem likely to have detrital origins. (Plate 5a)

(b) The well exposed rocks in the creek have well developed cross bedding in the fine layers. It is realized that this may have tectonic origins in some cases, but examples of double truncations seem to confirm the sedimentary nature of these structures. See hand specimen W24.

It is therefore considered that some of the layering at Walparuta is sedimentary. Furthermore the migmatites appear to be controlled by the sedimentary layering.

The origin of layers in the banded gneisses is not demonstrably sedimentary however, although in view of this discussion it is certainly plausible that the banding is due to sedimentary inhomogeneities in the rocks. If the layering is partially unrelated to sedimentary banding, it would be quite possible to map structures of different generations without realizing it, especially where the exposure is poor.

STRUCTURE

Three phases of deformation can be demonstrated to be recorded in the basement at Walparuta.

The first of deformation folded the original sedimentary layering, and is associated with an often well developedschistosity parallel to the layering. This phase appears to have produced essentially isoclinal folds, and fold hinges of first phase folds are exceedingly rare. Most isoclinal fold hinges observed which were not second phase structures were in mica free rocks, with no schistosity developed, and as a result it is not possible to assign them to the first phase with certainty anyway. One outcrop was observed in the area by Bruce Finlayson containing numerous small isoclinal fold hinges, with an axial plane schistosity usually parallel to the layering. A more strongly developed, later schisosity was present cutting across the first phase schistosity at an angle. This more pronounced schistosity is the regional, second phase schistosity.

The second phase of deformation is the most obvious one in the area. Frequently layering, witha parallel schistosity is observed to be folded (e.g. W3), and an axial plane schistosity is developed in some of these folds. The folds are quite variable in intensity, some being isoclinal in nature (Plate 3b) and others being irregular in one outcrop (Plate 3a). A major second phase fold is proposed in the mapped area, but since the nose is truncated by the major unconformity it cannot be established with absolute certainty whether the fold is a first or a second phase structure. The regional schistosity seems to be axial planar to the fold, and since this is a second phase schistosity it seems likely that the fold is also a second phase fold. Several factors make the nature of this major structure hard to ascertain.

(a) Reversal of dips on the two limbs are not observed with any certainty, due in part to their steepness, and the difficulty of obtaining true dip values where outcrop is subject to slope creep.

(b) No nose of the fold can be traced in the field because any such nose id cut off by the unconformity at the base of the Adelaidean.

As a result the plot of poles to layering (fig 1) shows two areas of concentration of points, but no girdle of points which would give an estimate of the direction and plunge of the fold axis.

The fold is believed to exist for the following reasons:

(a) Distinctive, similar schists are present in two bands in the area, as shown on the map.

(b) Within the schist bands, at appropriate positions near the "inside" of the limbs, are the distinctive laminated marble marker beds. They are found as a laminated calcareous quartzite in both schist bands to the west, but the laminated marble is only found in the northern schist band. This suggests that the schist bands may be equivalent horizons on the opposite limbs of a fold.

(c) The senses of small scale folds, and the relationship between regional schistosity and layering reverses across the area from north to south.

This all suggests a major fold with an axial plane striking about NE and closing to the NE. A mineral lineation observed in the field in the schists was generally close to vertical, and this might be indicatiee of a vertical fold axis, but this lineation was also rarely observed to parallel to a fine crenulation, and it is felt that it may be a third phase feature. The small scale fold axes fall roughly in the NE and SW quadrants when plotted on a stereonet, but no regular pattern could be discerned. The larger small scale folds observed had shallow plunges to the NE (Plate 2d) and it is felt that the major structure is probably a NE plunging fold, with the plunge somewhat uncertain. The structure is an antiform, in view of its inferred closure to the NE.

The persistence of the schist bands as distinct units on the scale observed suggests that they have maintained their integrity despite the first isoclinal period of folding. The sudden discontinuity of the laminated marble, and the loss of the north schist band to the west could be sedimentary features or the result of shearing parallel to the axial planes of the first phase folds. It seems quite reasonable to have a large scale isoclinal fold, later refolded, but preserving the bulk stratigraphy, with some original smaller scale stratigraphy affected by the tight folding. This is the overall impression conveyed by field observations in the Walparuta area. Fig 2 illustrates two possible, similar mechanisms.

Other areas mapped in tha Province by the author and T.Michelmore (e.g. Ethiudna, Mount Howden, also have major structures believed to be second phase structures, and studies in the Broken Hill area, also in the Willyama Complex, suggest that the major structures are Group une structures (Hobbs, 1966), and an earlier phase of tight folding is currently recognized.

These two phases of deformation have occurred before the deposition of the Adelaidean metasediments, as the unconformity cuts the nose of the major second phase fold.

Rocks in the core of the structure appeared to be unfolded when first observed, but examination of rocks exposed in creeks revealed the presence of quite complex second generation folds (see Plate 3a). The outcrop on hillsides is generally so rubbly that folding could not be readily detected even after its presence was realized (Plate 2d).

The third phase of deformation was not observed frequently, but where present was seen as folds in the second phase schistosity, with the development of an axial plane schistosity, which was seen to fan gently around the third phase folds. The schistosity is not as strongly developed as the regional schistosity, but was often detected in schistose rocks in the field, and in thin sections (e.g. W20a, 20b, 22a, 22b). The variation of plunge of second phase folds could also be the result of the third phase of deformation, although this could not be confirmed. This phase of deformation is the one responsible for the deformation of the Adelaidean rocks, and probably for the spread in orientations of the schistosities plotted on fig 1.

FAULTING

A pronounced N-S lineament is obvious on the aerial photograph and is thought to be a large fault. The lineament is difficult to detect on the ground, but appears to be associated with a slight dextral displacement of the southern schist band, in which the second phase schistosity is curved, suggesting that the fault is at least more recent than this deformation. The straight nature of the lineament may suggest that it is entirely post-deformational.

The northern band of schist is not visible at the intersection with the fault due to lack of any outcrop, but a slight dextral displacement seems likely.

Several small sinistral and dextral faults are present in the mine area (see small scale map), with displacements ranging from the order of metres to the order of millimetres. There is no suggestion that these are particularly well developed only in the mine area, but the distinctive quartzites and iron formations make it possible to detect them more readily.

The trenches in the mine area also reveal a number of quite shallowly dipping shears, which may be genetically to the major N-S fault, but the only common feature is that they both appear to be post-deformational features, and no further conclusions can be drawn within the scope of this study.

METAMORPHIC HISTORY

The mineral assemblages present at Walparuta suggest two distinct phases of metamorphism.

A high grade of metamorphism is suggested by the general aspect of the rocks (banded gneisses, migmatites etc), and by observations made in certain thin sections.

(1) Relict tremolite reacting to give carbonate + quartz, as illustrated on the frontispiece (TS W13c).

(2) Chloritized biotite, e.g. TS W16,22a,22b.

(3) Clinopyroxene altered to amphibole, as seen in TS W18.

Now both tremolite and biotite, although apparently retrograded, are found in mineral assemblages characteristic of both amphibolite and greenschist facies metamorphism, but the clinopyroxene almost certainly suggests amphibolite grade metamorphism.

However the general mineralogy of the rocks, quartz-albite-microcline-biotite-chlorite-muscovite, is characteristic of the greenschist facies of the Barrovian type facies series (Winkler, 1967) The reactions giving quartz + carbonate from tremolite, and the chloritized biotite suggest lower to middle greenschist facies, with a higher grade event at an earlier time. The greenschist facies metamorphism is also in accord with the metamorphism affecting the Adelaidean rocks in the area (Talbot, 1967).

Not enough information is available to be very specific about the earlier higher grade metamorphism, but the clinopyroxene and the obvious effects of partial mobilization suggest at least lower to middle amphibolite facies. The early phase recognized here seems to have been associated with the first phase of deformation for the following reasons.

(1) TS W9 shows a folded migmatitic vein, which is likely to require the appropriate grade for its development, with a parallel schistosity (probably a first phase schistosity) folded, with the

development of an axial plane schistosity, probably a second phase schistosity.

(2) Plate 2c shows a twice folded migmatite vein. Since it has been shown that three deformations are present, this vein must have formed prior to the second, suggesting a fairly high grade of metamorphism prior to the second deformation.

(3) The intrusive granite has a weak schistosity, which appears to correspond with the regional (second phase) schistosity, which suggests emplacement prior to the secod deformation, and also supports the idea of an earlier high grade metamorphism.

The evidence suggests that there was an amphibolite facies metamorphism associated with the first phase of deformation, and a lower to middle greenschist facies metamorphism after the second deformation, presumably associated with the third deformation. Since there was a second phase of deformation, and no apparent second development of migmatites, the pressure temperature conditions were probably less extreme during this second deformation. There was either a period of retrograde metamorphism associated with the second deformation, or the second deformation occurred during the later stages of the first metamorphism. There is no direct evidence to enable a distinction to be made between these two alternatives.

The rocks in the mine area, and elsewhere, contain up to 80% albite (see Appendix C) and retain sedimentary features. It is felt unlikely that this would be an original sedimentary composition, and the presence of checkerboard albite in these rocks appears to confirm that the reason is Na metasomatism of sediments. Common sericitization in the albitic plagioclases suggests a later K metasomatism.

Three phases of deformation appear to have affected the rocks at Walparuta, with lower grades of metamorphism for each successive less intense deformation.

MINERALIZATION

Shafts at Walparuta are the result of small scale mining operations carried out intermittently from 1894 to the present day.

The mineralization appears to be related to a zone of brecciated albite rich rocks. The brecciation is well developed in places (TS W23, plater3d) but varies in intensity and is often seen as a series of parallel fractures, infilled with the characteristic black magnetite/biotite matrix (Plate 4c) Chalcopyrite is common as disseminated grains in these rocks, mainly concentrated in the matrix. The breccia is not apparently related to Na metasomatism, as quite unaffected albite rich rocks are common in the near vicinity (500m). As the matrix of the breccia seems to be well crystallized it seems likely to predate the last metamorphism, and no brecciation was observed in the Adelaidean rocks to the east of the mines, although Cu was present as rare stainings.

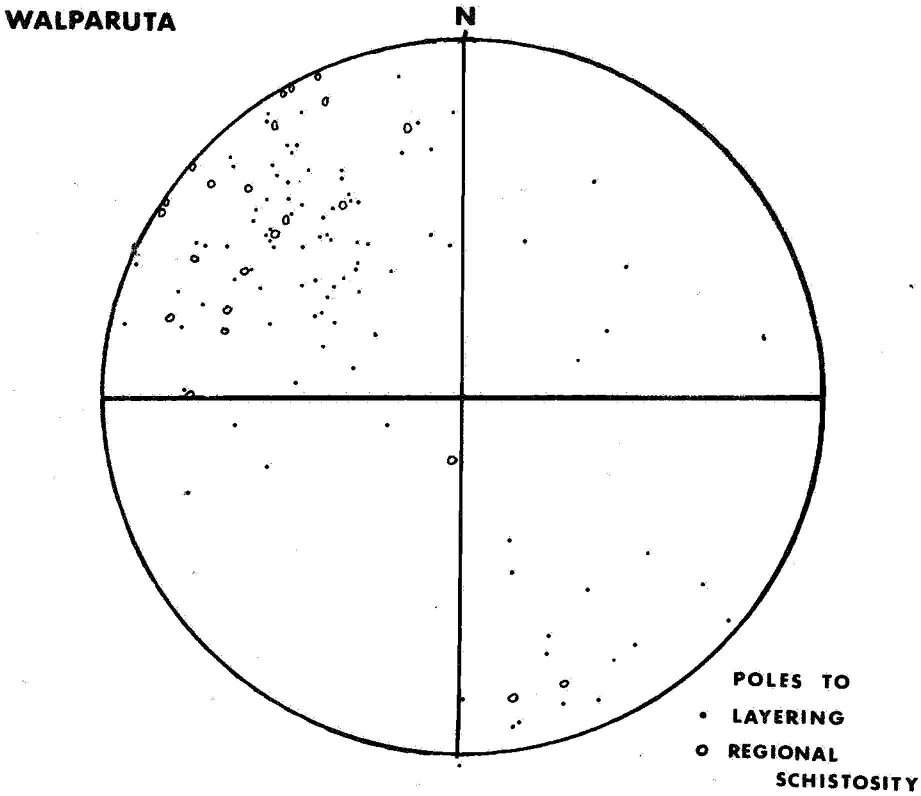
The presence of Cu stains in the Adelaidean rocks suggests a post-Adelaidean mineralization.

The mineralization is most strongly developed at the intersection of the creek and the largest fault on the small scale map of the mine area, and as the faults have been interpreted as post-deformational features this also points to post-Adelaidean min mineralization.

The rocks are unweathered within 1m of the surface along the creek in the mine area, with the weathering apparently controlled by the subhorizontal shears. Above the shears Cu carbonates and rare native Cu is found, and below, within a few cm, sulphides are seen. Polished section work (W26a,26b) reveals that the main sulphide is chalcopyrite, with secondary bornite. Well developed pyritahedra to 2cm are also found, and commonly observed iridescent blue sulphides are tarnished chalcopyrite, not bornite as was at first thought. The sulphides show fracturing controlling the secondary enrichment.

The early field observations in the province showed an apparent relationship between Cu occurrences and felspar rich rocks. 20 apparently felspar rich rocks were analysed by XRF methods for Ca, K and Na after crushing, magnetic separation to remove mafics, and then for Cu by atomic absorbtion techniques. The results are tabulated in Appendix C, and it may be seen that although the mine rocks are rich in Na, other rocks at least as high do not show such significantly high Cu values. There does not appear to be any significant correlation between the amount of copper in the rocks

FIGURE 1


WALPARUTA
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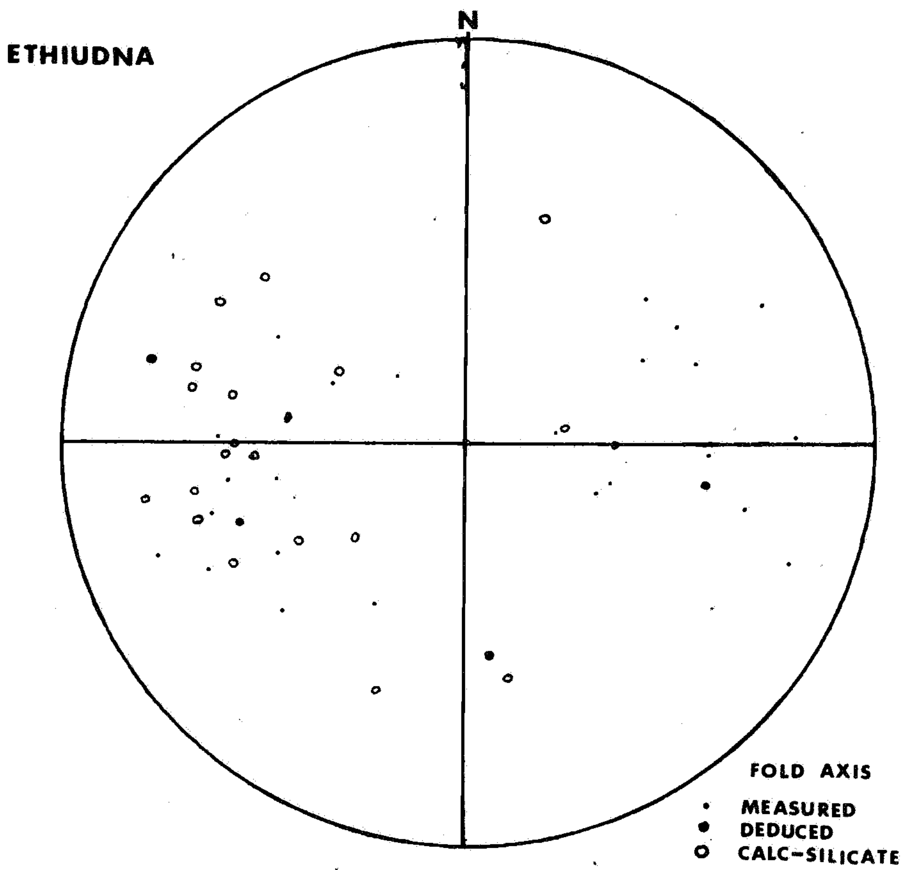
SCHISTOSITY


ETHIUDNA
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o CALC-SILICATE

FIGURE 2

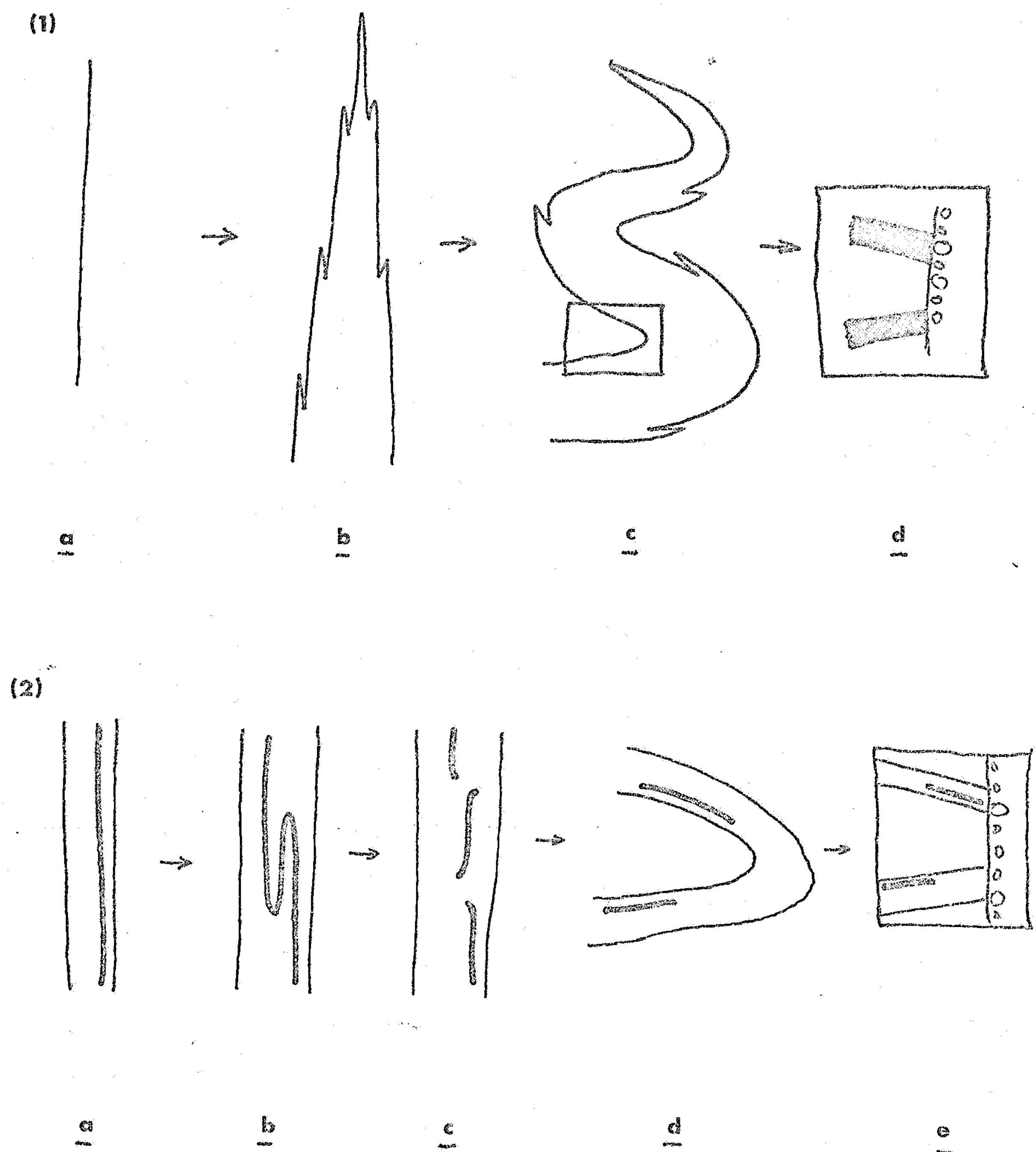

PLATE 1

(a) Typical migmatite layering. Gentle folding of layering and parallel schistosity.

(b) Fine, sedimentary layering in quartzo-felspathic rock with commonly developed dextral microfaults.

(c) Contorted migmatite veins in layered quartzo-felspathic rocks. Note opposing sense of the small scale folds.

(d) Large "slab" outcrop of typically gently folded migmatites.

PLATE 1

(a)

0 10
cm

(b)

0 1
m

(d)

(c)

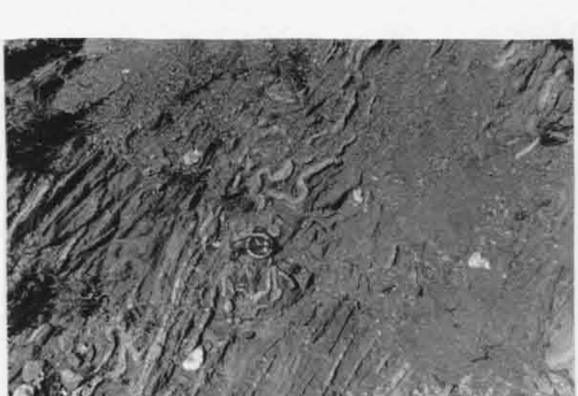

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PLATE 2

(a) Deformed pegmatite cutting across lithological layering. Note vein is not folded, but has broken into numerous small blocks which have been rotated and displaced.

(b) Isoclinal fold in laminated marble.

(c) Migmatite vein showing two phases of deformation.
   (1) Tight fold with development of an axial plane schistosity. Probably a first phase deformation.
   (2) More open folding with the axial plane at a large angle to the first axial plane. The first phase schistosity is folded by this second deformation.

(d) Folding in lithological layering exposed in creek. Rubbly outcrop on hillside in background prevents recognition of structure except where exposed.

PLATE 2

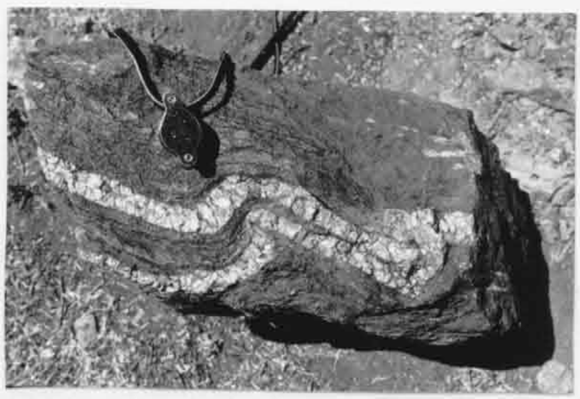
(a)

0 — 1
m

(b)

0 — 0·5
m

(c)



0 — 10
cm

(d)

0 — 10
m

PLATE 3

(a) Complex small scale second phase folds in banded gneiss. Schistosity parallel to layering, with a weakly developed second phase axial plane schistosity.

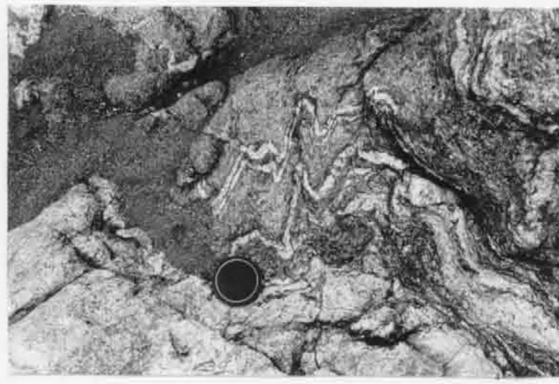
(b) Isoclinal folds in layering with a parallel schistosity.

(c) Layered quartzo-felspathic rocks with a cross cutting fracture zone partially obliterating the layering. Note compass needle parallel to layering due to high magnetite content of rocks.

(d) Brecciated rock in mine area. White felsic fragments with black magnetite-biotite matrix.

PLATE 3

(a)



0 — 0.3 m

(b)

0 — 0.2 m

(c)

0 — 20 cm

(d)

0 — 0.3

and the amount of felspar in the rocks.

Specimen W 27 is a distinctly gossanous ironstone. Examination revealed boxworks typical of chalcopyrite in a band 2cm thick, and polished sections W 27a and 27b revealed similar features (Blanchard).

The origin of the Cu mineralization is not certain, but it appears quite definitely related to the breccia at Walparuta.

PART TWO - ETHIUDNA MINE AREA

FIELD MAPPING

A maximum enlargement of the aerial photograph covering the area had extremely good resolution, but it was found virtually impossible to locate field stations on the low, rounded hills due to uniform tree cover and the number of tree deaths since the photographs were taken. Photo-interpretation was only found useful for mapping the limits of outcrop, and deceptive even then.

Outcrop is variable, with some large slabs of rock and large areas of soil cover on the hillsides. The outcrop was patchy at best, and it was found impossible to trace similar rock units with any certainty, with the exception of the marker beds, and difficult to establish contact relationships.

LITHOLOGIES

The rocks at Ethiudna are essentially part of a "granitic" terrain, with most rocks rich in felspars, medium to coarse grained, and containing few micaceous units. They are divided into three basic units in this study.

A. MASSIVE GRANITE

The rock is a light coloured, slightly porphyritic, coarse grained felspar rich rock with a weakly developed biotite schistosity. The rock outcrops mainly in the core of an antiform in the area, but is not restricted to this region. Sharp contacts between this rock and the surrounding rocks were not apparent, and similar material is found throughout the area in migmatites, closely resembling the classic lit-par-lit gneisses. Although it is possible to be dogmatic, it is felt that this material formed essentially in situ, with minor mobilization. TS E31 is an example of this type of rock, and other thin sections described in Appendix D show similar features, often with greater amounts of microcline, which appears to have replaced the plagioclase.

B. LAYERED FELSPATHIC ROCKS

These rocks are essentially uniform, layered, medium grained, felspathic rocks, with minor quartz, biotite and graphite.

Layering (Plate 4a) appears in the field to be due to differences in grain size between the various layers. Thin section work (e.g. E19, E28) shows that this is partially correct, but most of the observed layering is due also to variations in the amount of biotite and graphite.

The mineralogy of these rocks is microcline (frequently dominant), albitic plagioclase, minor quartz, biotite and graphite.

The rocks frequently grade into migmatites, with layers of coarse felsic material forming layers parallel to the layering in the normal layered rocks. Well developed ptygmatic structures are found in these rocks (Plate 4b,c), and they grade to the agmatite stage of migmatization (Mehnert 1968). Partial assimilation of the layered rocks was also observed in many places (Plate 4e).

Thin section studies reveal certain significant differences between specimens that were not apparent in the field, such as the well defined chloritoid layering in E15, and the often seen presence of graphite in the rocks, often associated with biotite laths. Plate 6B shows one of the graphite rich rocks observed in a few scattered locations (TS E22). A more important discovery was the prescence of sillimanite in several thin sections (E 15, see frontispiece), in particular in E20, where the sillimanit defines a layering. Plate 6A shows a kinked sillimanite layering in E16.

C. MARKER BEDS

These may be divided into two categories:

(1) Marker "A" is a dark highly weathered rock with large (to 5mm) white weathered clay porphyroblasts of indeterminate origin, with a well developed schistosity in part, parallel to the bands. Thin sections (E21,27a,27b) also contain minor sillimanitein quartz.
(2) Calc-silicate rocks.

It is not feasible to discuss these rocks in detail in the space available due to the variability of, and the great number of different lithologies. Rocks rich in quartz-epidote (E10,12) were distinctive and are represented on the large scale map as "Epidote-quartzites". The other rock types were grouped as "Calc-silicates" for the large scale map, and include many rocks, e.g. diopside-scapolite, quartz-clinopyroxene, clinopyroxene-garnet-scapolite and clinopyroxene-quartz-vesuvianite rocks. One common and prominent lithology is described by the Mines Dept (Bulletin 34) as a Tremolite-diopside rock, but a powder photograph revealed it to be wollastonite, not tremolite. The small scale map of the Ethiudna Mines shows a wollastonite-diopside rock, grading to a diopside marble, and a quartzite as the calc-silicates, but other areas frequently had a greater number of different lithologies.

INTRUSIVE DYKES

Two types of intrusive dykes are found in the area.
(1) Aplite dykes (quartz, plag, K-spar, biotite and opaques) are seen as distinctly finer grained long straight dykes with a definite cleavage parallel to the dykes. They seem likely to be controlled by faults with some movement after their emplacement, but seem undeformed. (TS E4)
(2) One amphibolite dyke is found in the area,(TS E18) composed of hornblend with minor quartz, felspar and opaques, but does not outcrop over a long enough distance to be certain whether or not it is folded.

THE ORIGIN OF THE LAYERING

The marker beds contain very distinctive lithological layers which are parallel to the marker itself. Layers only 1-2cm thick were seen in the field to persist for up to 5-10 metres. Thin sections (e.g. E10) showed the layers to be compositional, rich in minerals such as epidote, garnet, quartz etc. No sedimentary structures were observed in the area.

The layering in the felspathic rocks varies in nature, but is generally due to grain size variation or varying proportions of the platy minerals, with the schistosity expressed by these minerals parallel to the layering. The interpretation of three phases of folding with the first essentially isoclinal suggests that the layering is sedimentary in origin.

The origin of the layering in the calc-silicates is believed to be sedimentary, accentuated by metamorphic differentiation.

STRUCTURE

Mapping reveals three distinct phases of deformation in the area.
(1) The felspathic rocks frequently have a schistosity parallel to the layering. This is interpreted as being the result of a period of deformation producing essentially isoclinal folds, in which the axial plane schistosity will be generally parallel to the layering except in the rare fold hinges. This is the first recognizable period of deformation in the area.
(2) On a large scale the map shows an overall antiformal structure, with some layering trends suggesting closure to the NE, that is a fold that plunges to the NE. The weak schistosity in the massive granite appears to be axial planar to this structure, and shows an interesting correlation with the regional schistosity at Walparuta (interpreted as a second phase schistosity in that area). It is felt that the antiform is not the result of doming by an intrusive graite, but that the granite was in place before the second deformation, and was deformed during it. If this is incorrect then only two phases of deformation could be demonstrated on a macroscale at Ethiudna.
(3) Small scale folds are present in the layering throughout the area, are consistently of the same sense on both sides of the major structure, responsible for early confusion when it was attempted to use these folds as indicators of major structure in the area mapped. These plunge ENE on the NE flank of the antiform, and WSW on the SW flank, with some

exceptions, and these are believed to be the result of a third phase of deformation.

On a microscale E20 shows a folded layering, with a crenulation developed at a high angle to the fold axis. Thin section shows the layering to be due to concentrations of sillimanite with a good P.O. suggesting that a deformation may have occurred before the obvious folding of the layering. This rock records three phases of deformation.

MARKER BEDS AND THEIR RELATION TO OVERALL STRUCTURE

In a broad sense markers (calc-silicates) are present on both limbs of the antiform at Ethiudna. However if the situation is examined in any detail other factors become apparent.

(1) The more detailed lithological relationships between different outcrops of calc-silicate rocks are not simple. For example the epidote-quartzites are more strongly developed to the south, and thewollastonite -diopside rock is more common in the north. The massive garnet rock E8 was observed only at the Lookout Hill mine.

(2) The calc-silicate outcrops in the north do not form any readily recognizable structure, and their relationship to the major structure is not understood. The marker "A" was only seen in the north and it shows an inconsistent relation to any fold model proposed for the calc-silicate outcrop pattern in this area.

A stereoplot of the orientation of small scale fold axes for layered felspathic rocks and the calc-silicates (Fig 1) shows a reasonable correspondence, and suggests that the two layerings are conformable, as is to be expected if they both represent a sedimentary layering. The marked discontinuity of the outcrop of the marker beds is probably due to a combination of the following.

(1) Original sedimentary variations and discontinuities.

(2) Isoclinal folding and possible shearing during the first phase of deformation.

(3) Faulting, obliterated by later metamorphism in thefairly homogeneous felspathic rocks., and not easily definable due to lack of readily traceable markers.

The interpretation of the structure at Ethiudna Main Shaft (see small scale map with stereoplot) as an overturned antiform (Bulletin 34) appears to be correct, with later third phase folds confusing the situation.

METAMORPHIC HISTORY

The mineral assemblages suggest two phases of metamorphism in the area.

An early high grade event is suggested by minerals such as diopside, cordierite, wollastonite, and sillimanite, and this is believed to be associated with the first phase of deformation (TS E20 shows a twice folded P.O. of sillimanite). The overall aspect of the rocks with common migmatites etc also suggests that there has been a highggrade of metamorphism.

Two similar metamorphic facies appear to both describe the grade of metamorphism.

(1) The orthoamphibole subfacies of the K-felspar-cordierite-hornfels facies of contact metamorphism, and

(2) The sillimanite-cordierite-orthoclase-almandine subfacies of the cordierite-amphibolite facies of Abakuma-type metamorphism.

The mineralogy and field observations suggest regional metamorphism (2 above) with wollastonite in particular defining a low pressure environment.

Minerals such as chloritoid, albitic plagioclase are likely to form under less extreme conditions, and the relict sillimanite and amphibole suggest a later greenschist retrograde metamorphism. It is not easy to be more specific, but middle to upper greenschist facies seems likely, as none of the features characteristic of lower greenschist facies were observed in the rocks.

The abundant microcline apparently replacing albitic plagioclase suggests quite large scale K-metasomatism after the development of the plag, i.e. probably after the second phase of metamorphism. This may have been associated with a later metamorphic event, but no other evidence is apparent.

The later retrograde metamorphism is much less obvious than it is at Walparuta, and the higher grade metamorphism is well preserved, especially in some calc-silicate horizons (TS E3).

MINERALIZATION

The Ethiudna Mines were worked for 9 years from 1899 and more recently by Petrocarb, who smelted selected ore at the mines.

Workable Cu mineralization appears to be restricted to the areas of calc-silicate rocks., and more specifically those areas which seem to be more intensely folded or faulted, such as the Ethiudna mines (see small scale map), the Lookout Hill mine (which appears to be situated on a minor fault in the calc-silicates) and the Ethiudna East Cobalt Prospect (which is folded). As most observed mineralization is secondary chrysocolla , malachite and azurite in fissures, this may well be due to the increased fracture density in these areas.

At the Ethiudna mines botryoidal chrysocolla (E35) is found in fractures in calc-silicate rocks, with rare chalcopyrite grains, and also in fractures in the felspathic rocks (E33) in a shear zone (the Central Workings, see small scale map).

Cu traces were also observed in the felspathic rocks in many places, but appear not to have yielded much beyond minor staining, with one exception. The Eastern Workings (several hundred yards east of the main shaft area) have been worked on a small scale, and are associated with a siliceous ironstone (E36) which appears very similar to the ironstones at Faugh-a-Ballagh, which have been interpreted as shears, (T.R.Michelmore, pers. comm.).

No Cu traces were observed in the massive central granite.

ORIGIN OF THE MINERALIZATION

There are several possible interpretations of the origin of the mineralization at Ethiudna.

(1) The mineralization could have original sedimentary origins using two lines of evidence.

A. Restriction of the workable mineralization to the calc-silicate rocks.

B. The presence of Cu in the layered rocks is seen in the south of the area to roughly follow the line of strike of the rocks. Not ehough observations were made for this to be at all conclusive.

(2) The mineralization may be better developed in the calc-silicate rocks as a result of their suitability as host rocks for mineralization, in either a physical or a chemical sense.

It is felt that alternative (2) above is more likely due to the known suitability of limestones as host rocks, the observed correlation between mineralization and deformation in the calc-silicates, and certain Cu occurrences in the area apparently not related to outcrop of calc-silicate rocks.

There is no direct evidence for the origin of the Cu, except that it is not felt likely to have been deposited with the sediments.

The secondary mineralization in fractures appears to post-date the last metamorphism, as the fractures cut individual grains within the rocks (TS E33).

CONCLUSIONS

Studies of two areas in the Willyama Complex in the Olary Province have revealed three phases of deformation, two of them occurring prior to the deposition of the Adelaidean sediments.

The first phase of deformation was intense enough to produce isoclinal folding, and was associated with metamorphism of fairly high grade (and with quite low pressures at Ethiudna) accompanied by widespread migmatization and intrusion of granites.

The second phase varied in intensity of deformation, and was associated with less extreme pressure-temperature conditions. It is not certain whether it was associated with a second metamorphic event or whether it occurred in later stages of the first metamorphism.

The third phase of deformation was less intense, and was associated with a greenschist facies metamorphism, of lower grade at Walparuta than Ethiudna, and also affected the overlying Adelaidean rocks at the same time.

Definite sedimentary layering is preserved at Walparuta, and it seems likely that much of the layering in the region has this origin. A strong second phase schistosity obliterates this layering as a rule in the more schistose rocks.

Small copper occurrences are quite common in the region, and in the basement they appear to fall into two distinct categories.

(1) Those associated with the calc-silicate rocks, and

(2) Those associated with shears or breccias.

Marker horizons were sometimes found useful in delineating major structure, although small scale folds were not much use in this respect.

It is felt that more could be learned by mapping larger areas than was possible mapping two separate areas, although the author personally found the exercise most instructive.

ACKNOWLEDGEMENTS

I would like to thank Analytical Exploration, in particular Dr Hopwood and Dr Coward for initiation of the project, field support and much useful advice in the early stages of work. Dr Oliver, Dr Etheridge and Dr Kleeman were also of great assistance during the year, and I would like to thank them, and all the other members of the academic and technical staff who contributed in any way.

I would also thank Central Mineralogical Services, in particular MR Fander for extreme generosity with photomicrograph work, and other Honours students, especially T.R.Michelmore and B.Finlayson for many stimulating discussions.

My wife's extreme patience was greatly appreciated.

PLATE 4

(a) Typical layered felspathic rock

(b) Well developed ptygmatic structure in felspathic rock.

(c) Folded migmatite layers. Note control of fold amplitude by thickness of layers, with thin intensely folded vein to upper right of lens cap. (Ramsay, 1967)

(d) The "agmatite" stage of migmatization (Mehnert)

(e) Folded layering partly assimilated by coarse granitic material.

PLATE 4

(a)

0 20
cm

(b)

0 20
cm

(c)

0 20
cm

(d)

0 30
cm

(e)

0 30
cm

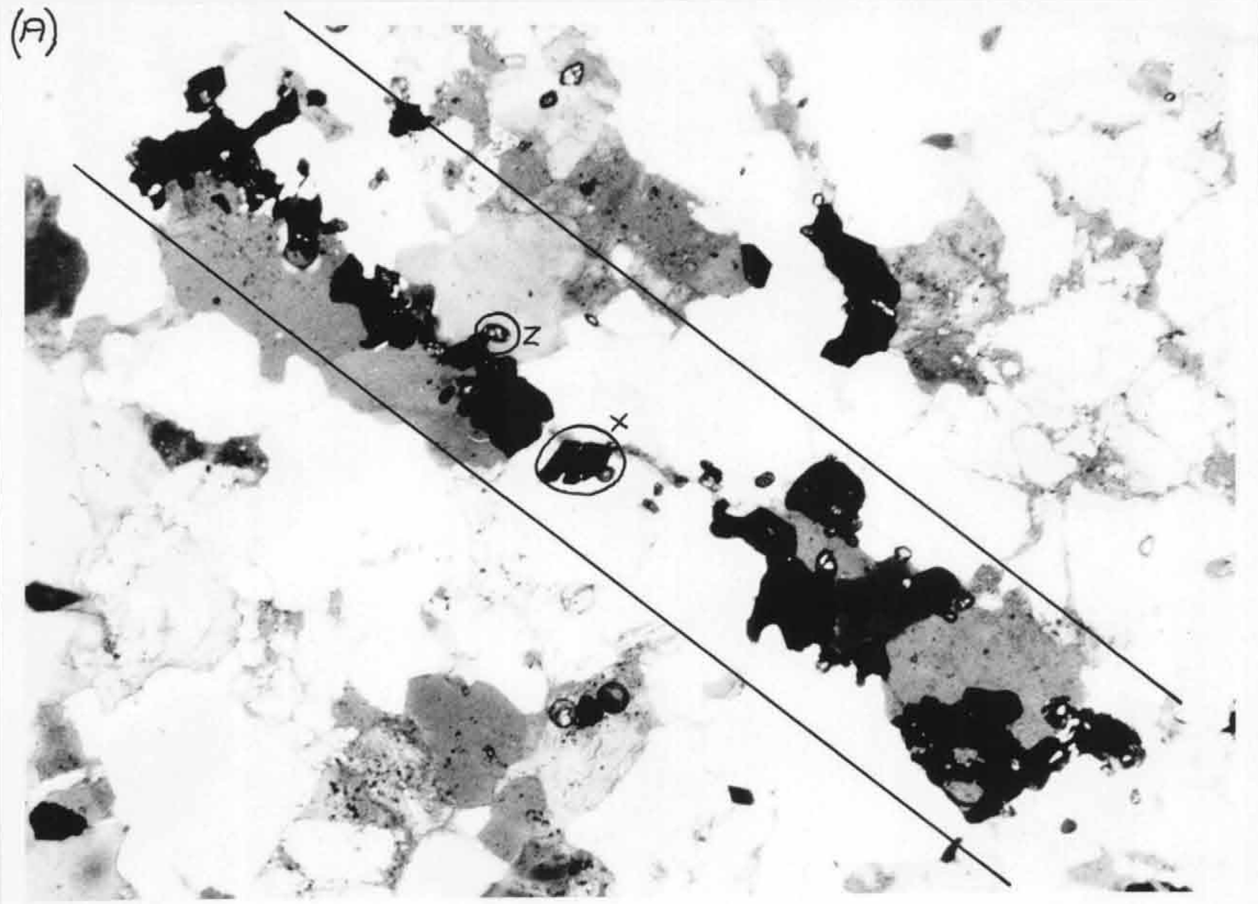
PLATE 5

(A) Detrital layering of zircon (z) and xenotime (x)
X30, Partly crossed nicols. W12

(B) Relict tremolite (large extinguished blades, in a carbonate-quartz assemblage. W13c
X30, crossed nicols.

PLATE 5

(A)



(B)

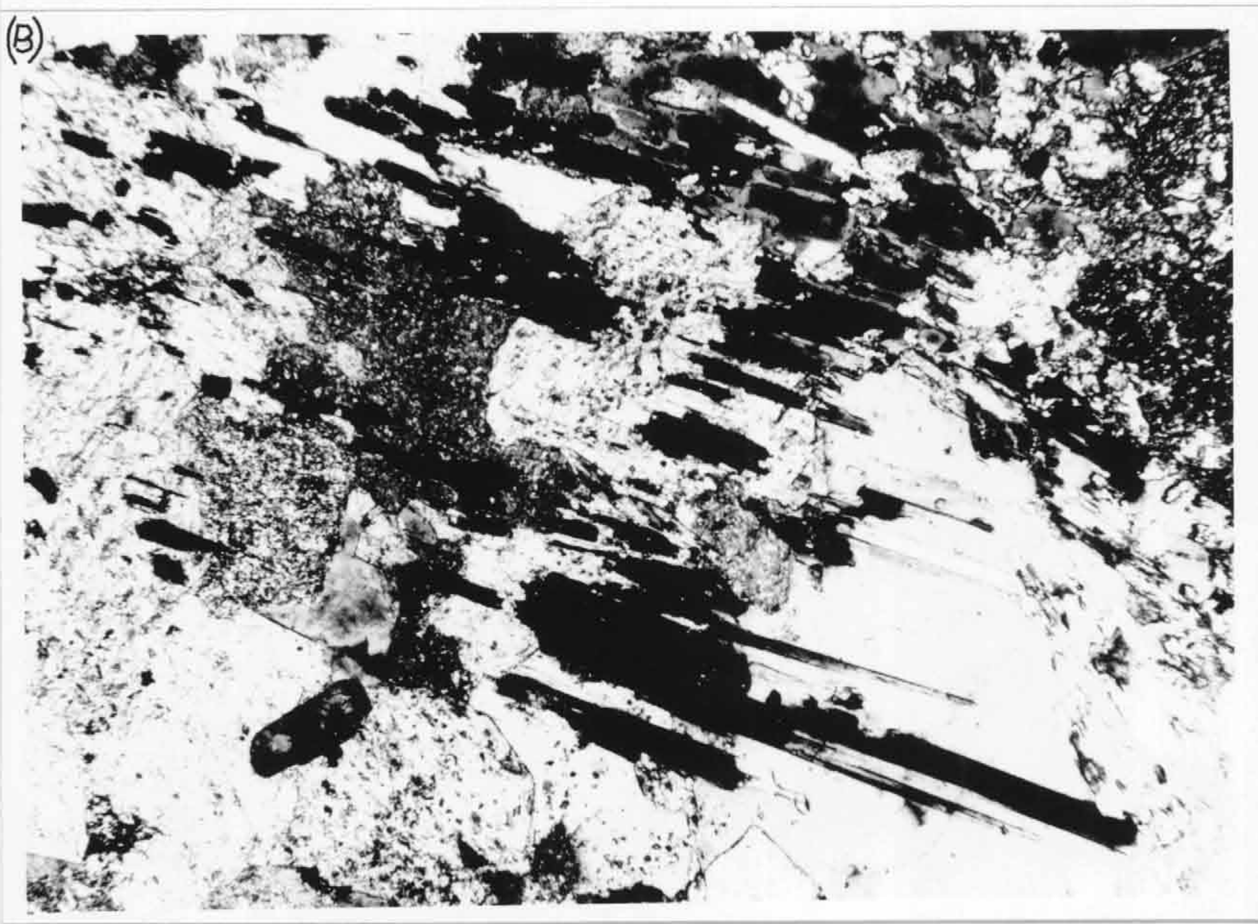


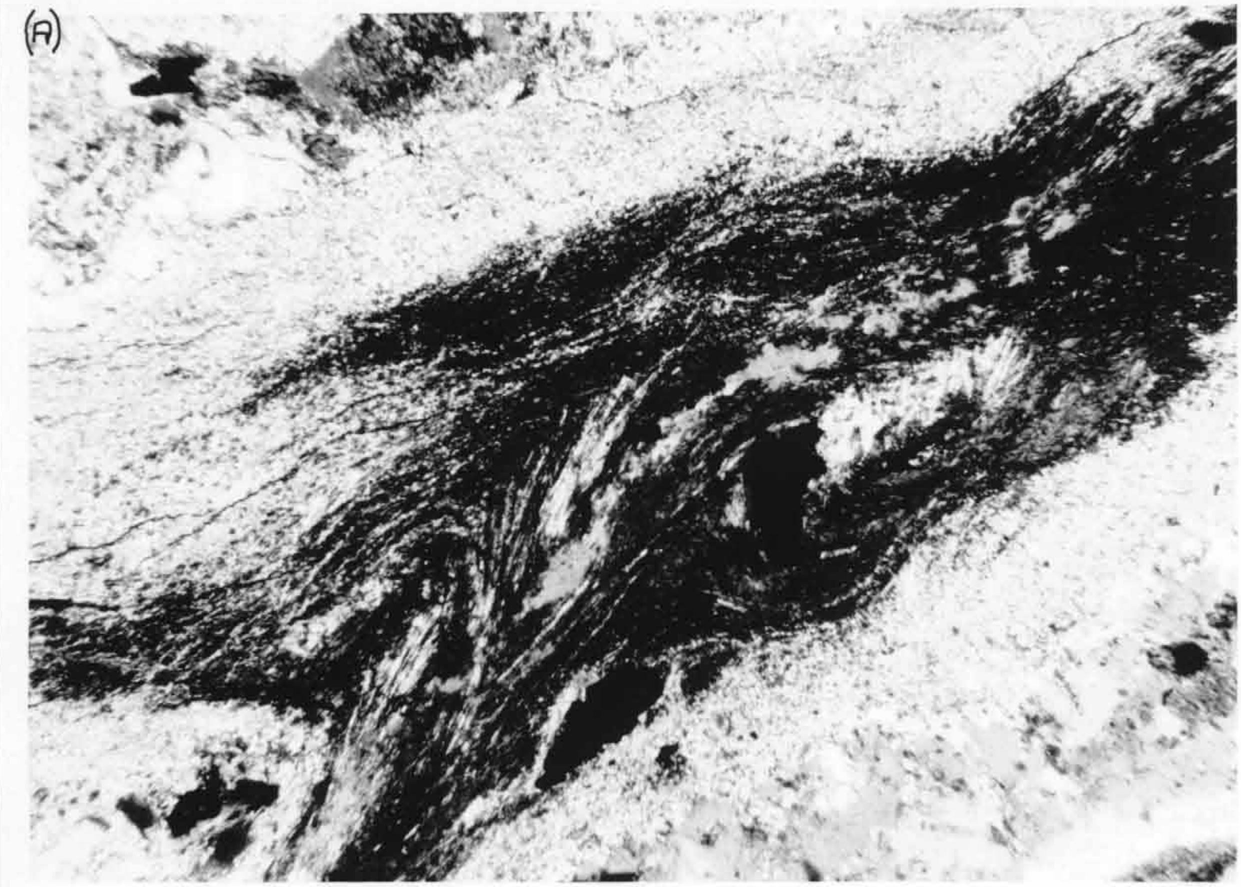
PLATE 6

(A) Kinked fibrolite in a sericite band. Note rotated opaque. E16.
X30, partly crossed nicols

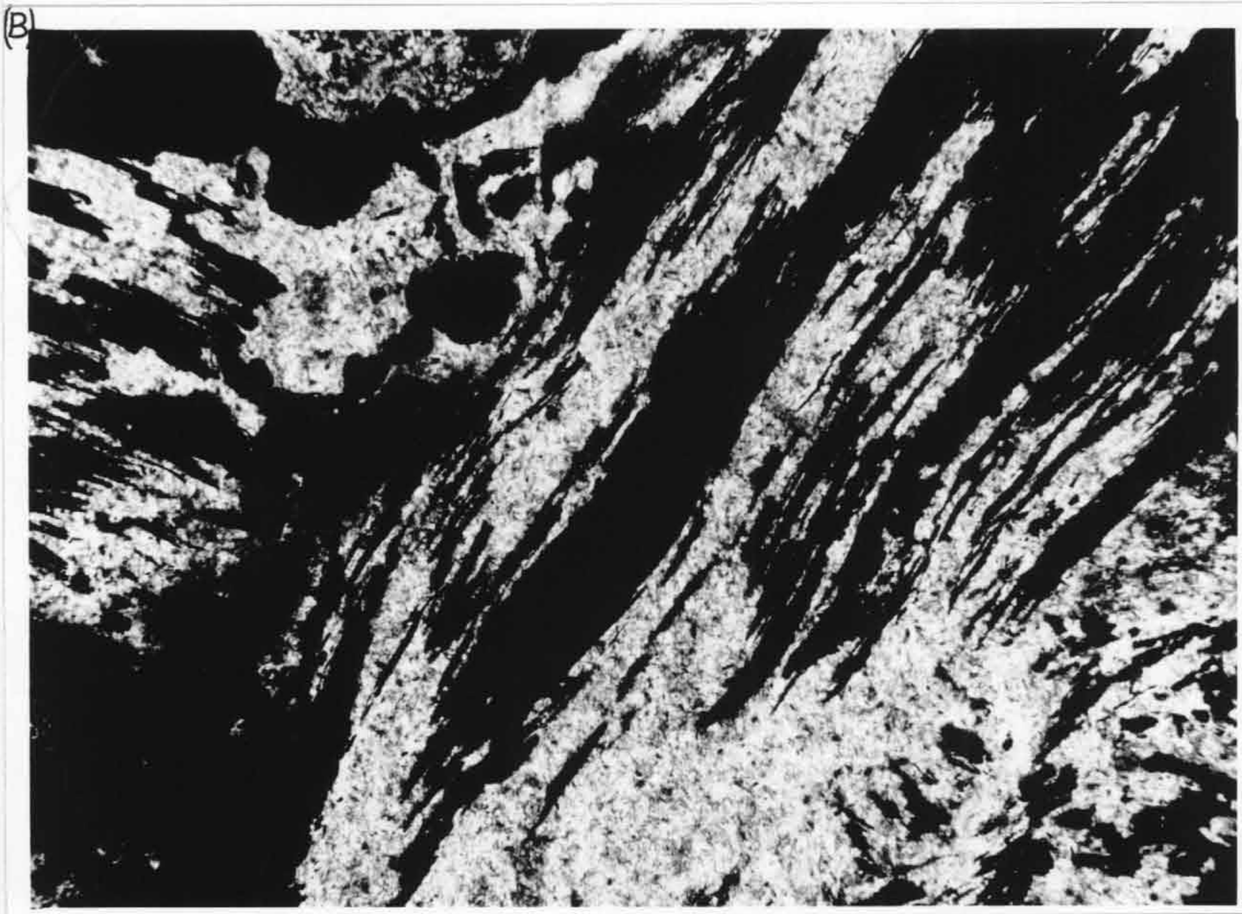
(B) Graphite plates (black) in a sericite/clay matrix E22. X30, plane polarized light.

PLATE 6

(A)



(B)



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APPENDIX "A"

Walparuta Mine area - Thin section descriptions.
(Nos. W1 to W25)

Abbreviations: P.O. = Preferred orientation

The terminology anhedral-subhedral-euhedral has been used throughout to describe the form (or lack thereof) of the constituent minerals.

Walparuta Samples prefixed by 6933

362/W1 R5 592

Macro: A medium grained, massive, quartzo-felspathic rock with minor fine biotite.

Micro: Uneven grained rock (0.1-1.5mm.), mainly quartz-plagioclase-biotite. Generally irregular grains with no obvious layering or P.O. of grains.

Plagioclase: 40-50%, Ab_{95}. Max. 2mm., anhedral, rarely elongate parallel to multiple twinning. Highly and irregularly sericitized. Some grains show central alteration, some quite irregular alteration. Inclusions of rounded quartz, subhedral to euhedral garnets. Some grains show very well defined altered zone with unaltered rim (possibly later growth).

Quartz: 40-50%, anhedral, to 1.5mm. but generally finer than plgioclase. Sutured, irregular when in contact with other quartz grains, and smaller, rounded and approximately equidimensional when as inclusions in felspar grains.

Muscovite and Biotite: 5-10%, often intergrown, max. 1mm. Some as well defined laths, but irregular when seen as basal section. Rare much larger muscovites, irregular, to 2mm. Minor chlorite intergrown with biotite.

Garnet: less than 1%. Irregular to euhedral. Larger grains appear corroded, with embayments.

Opaques: less than 1%. Fine, black, anhedral, often with biotite.

362/W2 593

Macro: A fine to medium grained, even quartzo-felspathic rock with minor biotite bands.

Micro: Fairly even grained quartzo-felspathic rock (av. 0.3-0.4mm.) with simple, straight grain boundaries and common triple point junctions. Thin well defined shears are developed with biotite infilling. Pale brown stain between grains.

Plagioclase: 10-20%, anhedral, multiple twinning common. Ab_{95}. Some kinked twinning. Most grains 0.3mm., rarely to 0.5mm.

Quartz: 70% anhedral, rarely to 1mm. May be confused with an uncertain amoumt of untwinned albite. Some seen to be grown across plagioclase grains.

Muscovite: 1-2%. Rare, almost fibrous clumps to 1mm.

Biotite: 1-2%. Aligned parallel to minor fractures, suggesting some degree of shearing. Subhedral laths to 0.5mm. Chloritized.

Chlorite: Rare anhedral grains to 0.3mm.

Epidote: Rare corroded grains to 0.3mm.

Opaques: 1-2%. Black, 0.1-0.3mm. Anhedral to subhedral, with cubic to hexagonal outline. Rarely blebby with biotite.

362/W3 RS 594

Macro: Isoclinally folded compositional layering with a parallel schistosity also folded. No development of an axial plane schistosity.

Micro: Rock shows a folded biotite-muscovite schistosity, with a coarser quartz-muscovite vein parallel to the axial plane of the fold. No axial plane schistosity is seen, but biotites are kinked in the hinge zone. The layering is due to medium grained sericite-quartz-muscovite-biotite layers and fine sericite-muscovite layers.

Body of Rock:

Quartz: 40%. Anhedral, irregular grains (fine to 0.3mm.)in a sericite matrix. Grains undulose, rarely touching.

Biotite: 20%. Often intergrown with muscovite. Grains to 2mm., grain aggregates to 5mm. Most as well developed laths, well kinked in part.

Muscovite: 40%. Sericite included in %. Some fine laths intergrown with biotite, some larger grains to 2mm, not concordant with kinking,

Vein:

Quartz: 75%. Very undulose, varies from very fine secondary fracture filling, to 3mm. Well sutured grain boumdaries. Grains sometimes show fracturing with later rehealing with fine quartz.

Muscovite: 25%. Some as euhedral laths to 2mm, some anhedral. Very fine sericite rim between muscovite and quartz. No apparent P.O. within the vein.

B

362/W3 (cont.)

Biotite: Rare grains in vein.

362/W4 RS 595

Macro: Fine grained quartzo-felspathic rock, with biotite bands and some associated copper staining.

Micro: Fairly even grained (0.1mm or less) fine quartzo-felspathic rock with rare larger quartz grains (to 3mm), and several biotite rich layers, noticeably richer in opaques and coarser (0.3-0.4mm) than rest of rock. Grain boundaries are straight, with common triple point junctions. Alteration is between grains rather than in the grains.

Quartz: ?%. Larger grains very undulose, with sutured grain boundaries, and fractures. Some of the fine material is also quartz, not plagioclase, but it is very difficult to estimate the amount.

Felspar: 50%+. Ab_{95}, anhedral, simple grains.

Biotite: 5%. Green pleochroic in fractures, red-brown pleochroic where rimming opaques. Some lenticular biotite rich areas.

Opaques: 5%. Less than 0.1mm, black, some euhedral. Occur throughout rock. Rare larger red-brown concentrically banded opaques appear similar to features observed in chalcopyrite gossan.

Malachite: occurs as an infilling in fractures, with green biotite and red-brown irregular iron oxides.

362/W5 RS 596

Macro: Medium grained quartzo-felspathic rock with minor biotite.

Micro: Quartzo-felspathic rock, uneven grained (very fine to 0.2 mm) with minor biotite.

Quartz: 50%. Noticeable as the unaltered colourless grains. Anhedral, undulose, with some sutured boundaries and some fine inclusions.

Felspar: 40-50%. Anhedral, brown alteration well developed, with rarely observed cross-hatching. Probably microcline.

Biotite: 2%. Anhedral, irregular to 0.2mm. Some complex, chloritized grains to 1mm. Unevenly distributed in rock.

362/W5 (cont)

Muscovite: 2% Most grains irregular, to 0.2mm.

Opaques: Less than 1%. Very fine to 0.1mm. Rarely cubic outline, usually anhedral. Occurs as small patches rich in mafic grains. Rare, fine zircon.

362/W6 RS597

Macro: Fine grained, weathered felspathic rock with minor opaques.

Micro: Most grains less than 0.1mm, with smooth, simple boundaries. Apparently quartz and untwinned felspar with 1-2% fine, black opaque grains. Analysis suggests about 15% felspar, if all K is assumed to be in felspar.

362/W7 RS598

Macro: Transition between iron formation and quartzite. Highly magnetic opaques suggest magnetite.

Micro: Shows gradation between essentially opaque free quartz-muscovite to magnetite rich rock.

Felsic Portion:

Quartz: 60% Boundaries slightly sutured, some triple point junctions. Anhedral, slightly undulose.

Muscovite: 40% Anhedral to euhedral, with intergranular quartz.

Opaques: Minor, wide variation in grain size. Anhedral to euhedral.

Opaque Portion:

Black opaques show good form (cubic to hexagonal) up to 90% within the iron formation. Some quartz, highly sutured, undulose, to 2mm. One area shows a definite elongation fabric of quartz grains (up to 10 to 1 elongation) with parallel elongate muscovite, all parallel to the layer of ironstone. Similar but well curved effect prominent in the polished section of the same rock.

362/W8 RS599

Macro: Medium to fine grained white quartzo-felspathic rock with minor opaques and rare larger quartz grains, showing slight elongation parallel to the weakly developed layering.

Micro: Uneven grained (0.1-2mm) quartzo-felspathic rock. Large porphyroblasts (2mm) of quartz and aggregates of felspar

362/W8 (cont)

usually 0.5-1mm, within a finer (0.3-0.5mm) groundmass.

Quartz: Anhedral, generally sutured, undulose to 2mm.

Orthoclase: ?% Anhedral, unaltered, distinguished from quartz by low relief and biaxial -ve character.

Plagioclase: 30% Anhedral, Ab_{95}, slightly irregular grain boundaries.

Opaques: 1% Black, anhedral.

Rare muscovite to 0.5mm, subhedral to anhedral.

362/W9 RS 600

Macro: Medium grained mica rich rock, with folded coarse quartzo-felspathic vein.

Micro: Rock has a schistosity parallel to the vein, and folded with it, with a slight development of an axial plane schistosity in the tight hinges, although no kinking of the early schistosity is present.

Rock: Mainly quartz in a matrix of biotite and muscovite, with a well developed P.O.

Quartz: 40-50% Anhedral. Slight degree of elongation parallel to the schistosity. Fractured and rehealed grains commonly seen. Boundaries between the rarely touching quartz grains generally sutured. Undulose, fine to 1mm, average 0.5mm.

Mica: 50% Intergrowth of muscovite and biotite, commonly to 1mm. Some separate development of the two micas.

Plagioclase: Rare, anhedral, Ab_{90}.

Minor opaques.

Vein: Mainly coarse quartz and plagioclase, with minor mica.

Quartz: To 5mm, anhedral, fractured, undulose, smaller than the felspar grains, and as blebs within the felspar grains.

Plagioclase: To at least 2mm, anhedral with fine, continuous twins. Albitic, commonly sericitized within central part of grain, but not regular.

362/W10 RS 601

macro: Fine grained unlayered quartzo-felspathic rock with minor black opaques.

Micro: Moderately even grained (fine to 0.2mm) rock, mainly quartz, plagioclase and untwinned albite. No apparent layering. Simple polygonal grains, with minor fractures crossing the slide.

Quartz: About 20-30% Anhedral, slightly undulose. Some grains with curved boundaries, some straight but all smooth. Fine inclusions.

Plagioclase: 40-50% Ab_{95}, often simple boundaries. Anhedral, unaltered, rare bent multiple twins.

Albite: % hard to estimate, about 20%. Analysis shows 60% albite in rock. Untwinned, anhedral. Biaxial nature distinguishes it from quartz,

Opaques: 1% Anhedral, well embayed to subhedral (smaller grains). Fine to 1mm, black.

Biotite: Rare laths or complex grains to 0.5mm. Intergrown with muscovite, chlorite. No apparent P.O.

362/W11 RS 602

Macro: Fine to medium grained rock with weak layering of opaques to 2mm, magnetic.

Micro: Anhedral felsic grains of varying size, with biotite laths showing a P.O. approximately parallel to the lithological layering, which is defined by bands rich in opaques.

Quartz: 40-50% Anhedral, undulose. Fine to 0.5mm, average 0.25mm. Large size range with grains frequently separated by micas.

K-felspar: 15-20% Anhedral with fine brown alteration.

Biotite: 20% Some laths, anhedral in part.

Opaques: 10% Anhedral, some markedly coarser than the rest of the rock, often with biotite enclosed. Define a layering.

Plagioclase: Rare, anhedral, Ab_{95}.

362/W12 RS 603

Macro: Fine quartzo-felspathic rock with fine banding of opaques.

Micro: Interlocking, irregular grains with rare large (5mm) very undulose quartz. Banding is due to layers rich in irregular fine opaques, zircon and xenotime (possibly rutile).

362/W12 (cont)

Quartz: 40% Anhedral, undulose, sutured boundaries.

Felspar: 30% Anhedral, altered, untwinned, probably K-spar.

Opaques: 5%, fine, anhedral, black.

Plagioclase: 2%, anhedral, albitic.

Muscovite: Rare, to 1mm. Irregular with optical continuity between separate grains, suggesting replacement by quartz.

Xenotime: In bands with opaques. Rounded. Strong yellow colour, uniaxial +ve (could also be rutile).

362/W13a RS 604

Macro: Medium to fine grained layered calcareous quartzite.

Micro: Complex intergrowth of highly variable grains (very fine to 2mm) Layering due to extreme variation in grain sizes, coupled with varying proportions of constituent minerals (e.g. coarse carbonate layers, fine quartz rich layers).

Quartz: 20% Generally simple grains, noticeably smaller than the other minerals, with more simple, even grains. Some undulose and sutured.

Clinozoisite: 30% Recognized by opt. props. and abnormal interference blue ~~int~~ colours. Anhedral, irregular, poikiloblastic with quartz and carbonate inclusions. Appears almost relict in places. Grains usually smaller than cpx.

Clinopyroxene: 30% Fine to 2mm - coarser than other constituents. Virtually colourless. Anhedral, irregular grains, very poikiloblastic, with alteration to amphibole along cleavages.

Carbonate: 20% Enhedral to anhedral, frequently irregular inclusions within clinopyroxene and clinozoisite. Max 0.3mm.

Chlorite: 1% Subhedral, with minor biotite.

Sphene and apatite common accessories.

362/W13b RS 605

Macro: Medium grained laminated marble.

Micro: Rock shows a lithological layering of predominantly carbonate layers with fine grained quartz rich layers between (2-5mm)

Carbonate layers: Subhedral to anhedral carbonate to 2mm. Common

362/W13b (cont)

remnant tremolite, minor fine quartz.

Quartz rich layers: Less than 0.1mm quartz grains with some larger carbonate and relict tremolite, and minor clinozoisite.

362/W13c RS 606

Macro: Coarse tremolite-carbonate rock.

Micro: Unlayered intergrowth of relict tremolite-quartz-carbonate. Basically 75% subhedral carbonate, 10% irregular quartz with well defined relict tremolite grains to 5mm.

362/W14 RS 607

Macro: Medium grained, weakly layered quartz-felspar-biotite rock.

Micro: Weakly layered quartz-Kspar-bitite rock with opaques. Uneven grained.

Quartz: 30% Anhedral, slightly undulose, sutured boundaries.

K felspar: Anhedral. Host for fine sericite and numerous small biotite laths. Staining confirms identification.

Biotite: 30% Partly anhedral (relatively large grains) and partly subhedral laths confined to felspar grains.

Opaques: 10-15% Anhedral, define vague layering.

Accessory apatite, withminor opaque inclusions.

362/W15 RS 608

Macro: Fine to medium grained quartzo-felspathic rock.

Micro: Layers 1-2mm thick due to variations in the amount of biotite. Unevened grained (fine to 0.5mm) with rare patches of muscovite laths to 5mm.

Quartz: 10% Anhedral, slightly undulose.

Microcline: 60% Anhedral, some cross-hatching, altered mainly in the core of the grains.

Plagioclase: Minor, vague twinning, grains larger than the average.

Biotite: 30-40% Anhedral, corroded grains to laths. Defines the layering, but no apparent P.O.

Muscovite: Minor constituent, as patches of fine laths.

Common accessory apatite (rounded, fractured grains).

362/W16 RS 609

Macro: Medium grained quartzo-felspathic rock with magnetite and minor chalcopyrite. Analysis shows 79.2% albite.

Micro: Rock consists almost entirely of felspar with simple grain boundaries, and common triple point junctions.

Quartz: Less than 5%, anhedral, smaller grains than average.

Plagioclase: 40-50% Anhedral, multiple twins slightly kinked in places. Alteration seen as fine cloudiness. Ab_{95}.

Albite: 30-40% Untwinned, or very weakly twinned, anhedral

Muscovite: Less than 5%. Often surrounds opaques, some as isolated irregular grains and patches to 2mm, and as vein filling.

Biotite: Rare, green pleochroic and intergrown with chlorite.

Opaques: 10-15% Irregular distribution, with areas rich in biotite. Several quartz healed fractures cross the slide, with minor displaced felspar twins. One larger fracture has associated biotite and muscovite and contains the anhedral chalcopyrite.

362/W17 RS 610

Macro: Weakly layered, medium grained rock rich in mafics (60%)

Micro: Uneven grained, max 1mm most less than 0.5mm, mainly quartz-felspar-epidote-biotite. No layering or schistosity apparent.

Quartz: 10-20% Anhedral, undulose with fine inclusions. Large size variation, sutured boundaries. Some areas of small grain aggregates (secondary?) are developed, and myrmekitic intergroths in K felspar.

K felspar: 40% Anhedral, sutured boundaries, undulose. Sericitized. Some complex grains may be checkerboard albite.

Epidote: 40-50% Large variation in size of grains, with large grains more irregular. Inclusions of garnet, felspar.

Carbonate: 1% Anhedral, some associated with epidote.

Biotite: 5% Fine, green, some seen as laths.

Zircon common accessory.

362/W18 RS611

Macro: Massive medium to fine grained green (pyroxene or amphibole) rock, with quartz veins.

Micro: Uneven grained rock with fairly even boundaries between Cpx grains, irregular between quartz and Cpx.

362/W18 (cont)

Clinopyroxene: 70% Anhedral to subhedral. Irregular uneven grains (fine to greater than 1mm) with common alteration to amphibole along cleavage planes.

K felspar: Less than 10% Slightly altered, no cross hatching.

Quartz: Less than 10% Undulose, cuts across other grains, appears to have replaced amphibole in part.

Garnet: Rare, anhedral, pale pink.

Opaques: Rare, subhedral, reddish brown.

Sphene common accessory.

362/W19a RS 612

Macro: Fine grained, light grey, banded felspathic rock with minor pyrite. Well developed healed fractures.

Micro: Grains vary from less than 0.05-1mm (maximum in veins). Banding is due to fine layers of fine opaques. Fractures have some large muscovite laths parallel to them, and have slightly displaced the layering. Possibly minor quartz present, but amt. uncertain due to fine grain size.

Plagioclase: About 70% (analysis shows 67% Ab) Albitic in bulk of rock and in the veins. Very fine multiple twinning, anhedral, with very little alteration.

Muscovite: Associated with fractures, generally laths.

Opaques: 5-10% Very fine, euhedral. Black and highly magnetic suggests they are magnetite.

362/W19b RS 613

Macro: As W19a.

Micro: As 19a but fewer infilled veins, finer grains and one well developed microfault.

362/W20a RS 614

Macro: Weathered medium to coarse grained quartz- mica schist with conspicuous large biotites. Poor schistosity, but two separate schistosities appear present in the field.

Micro: Muscovite-sericite-biotite-chlorite intergrowths to 1.5mm in a sericite-muscovite matrix with about 10% anhedral, 362/W20a (cont)

undulose quartz. Biotite (30%) is red/brown. Two directions of P.O. of micas are present and marked on the thin section, and these presumably correspond with the two observed in the field.

362/W20b RS 615

Macro: As W20a.

Micro: Larger grains ofquartz, muscovite, biotite-chlorite in a finer muscovite-sericite matrix.

Biotite: 30% To 1,5mm. Subhedral to anhedral, irregular. Some is intergrown with very elongate muscovite laths. Pleochroic red/brown-black/brown-pale yellow/brown.

Chlorite: 5% Anhedral to subhedral to 0.5mm, and some apparently replacing biotite.

Quartz: 15% Anhedral, sutured, undulose to 5mm. Quartz grains rarely touching.

Sericite: 50-60% Grades to muscovite in places, generally as a matrix between the grains.

Opaques: Fine, often concentrated with the biotite.

Garnet: Rare, colourless, well fractured, often rimmed with biotite.

362/W21 RS616

Macro: Fine to medium grained felspar rich rock with biotite rich networks and some magnetite. Minor disseminated chalcopyrite.

Micro: Mainly fine (less than 0.1mm) anhedral grains of twinned Ab rich plagioclase, with some untwinned albite. Usually simple, straight grain boundaries. Some subhedral to anhedral muscovite to 0.1mm, and fine sericite between grains. Irregular distribution of patches and bands of green biotite with coarser albitic plagioclase constitutes about 5% of the slide. Rare colourless garnet present, and opaques to 0.3mm, which show a slight "preference" for the biotite rich areas.

362/W22a RS 617

Macro: Medium grained quartz- muscovite-biotite-garnet schist with a very well defined schistosity.

Micro: Strong schistosity is due to curved continuous trains of

362/W22a (cont)

muscovite with lenticles of quartz and garnet-quartz. Slight cross schistosity is developed at a high angle to the main schistosity.

Quartz: 40% Fine to 1mm, anhedral. Some elongate parallel to the main schistosity. Often fractured and healed with later quartz, seen as trains of fine inclusions. Some quartz has grown across the main schistosity.

Muscovite: 20% Most elongate in trains defining the main schistosity, but some as large porphyroblasts with an almost square outline, which suggests replacement (probably felspar or andalusite)

Biotite: 5% Intergrown with sericite, altered to chlorite. Some as laths parallel to the schistosity, some with garnet.

Chlorite: 20% Elongate parallel to the main schistosity, and some distinctly cutting across it.

Garnet: 1-2% Colourless to pale pink. Fractured, subhedral to anhedral. Max 0.7mm, associated with biotite often.

Opaques: Fine, black and brown. Quite common, and some are elongate parallel to the schistosity.

Rare checkerboard albite, tourmaline.

362/W22b RS 618

Macro: As W22a but a perpendicular section.

Micro: Shows essentially the same features, but the schistosity is less prominent, and the black opaques can be seen to be generally confined to the biotite grains.

362/W23 RS 619

Macro: Brecciated albitite rock. Felspar rich fragments with a black biotite-magnetite matrix. Chalcopyrite in the matrix mainly.

Micro: Finer and more even grained felspar rich fragments with an irregular coarser mafic matrix with some coarse checkerboard albite.

Felsic fragments: Simple, straight grain boundaries, about 80% Ab rich twinned plagioclase. Minor muscovite, colourless anhedral garnet, and apatite. 5-10% anhedral quartz, and minor fine black opaques.

362/W23 (cOnt)

Matrix: Includes some large grains of checkerboard albite to 2mm, which vary in appearance from complex grains of slightly disoriented Ab rich plag withinterstitial sericite to pethitic-like grains. Mainly black opaques (up to90% in parts). Anhedral to 1mm, but some form inplaces. Green biotite to 0.5mm, rare muscovite laths and garnets. Some complexly sutured quartz. Anhedral chalcopyrite is seen as a dark grey opaque. Plagioclase twins often slightly kinked.

362/W24 RS 620

Macro: Fine grained albiized metasilt with well developed cross bedding in fine dark bands.

Micro: Most of the rock is fine albitic plagioclase, with slight fracturing and biotite infilling. The banding is fine layers of fine magnetite, with definite truncation of layering as seen in the hand specimen.

362/W25 RS 621

Macro: Weakly layered fine grained felspar rich rock with diffuse quartz veining.

Micro: Bulk of rock is fine grained albitic pagioclase with a layering defined by fine bands of fine magnetite. The vein is well defined in the parts where it consists almost entirely of sututed, undulose quartz, but is less obvious where rich in plagioclase (also albitic). The rock shows an overall unevenness of grain size, withsimple, straight boundaries throughout.

APPENDIX "B"

Walparute Mine Area - Polished Section descriptions.

(Nos. W7,26a,26b,27a,27b,28)

W7

Macro: Iron formation - massive magnetite and silicate.

Micro: Opaque is mainly magnetite (VH 505) with minor oxidation to haematite, (VH 950). Small grains of haematite common in the silicates, generally in "trains" of parallel elongate grains, parallel to the curved deformation fabric in the silicates. Some magnetite deeply embayed by silicate.

W26a,b

Macro: Mainly chalcopyrite with a fine network of pale blue sulphide and rare pyritahedra to 2cm in field. The typical peacock blue colour associated with bornite is prominent in places.

Micro: Chalcopyrite 75% Massive, well fractured, yellow/blue aisotropism, VH 195.

Bornite 10-15% Blue massive in fractures and along grain boundaries. Apparently a product of secondary enrichment VH 102, prob too high for chalcocite.

Pyrite Less than 5% Euhedral, to 2-4mm

Note peacock blue is not bormite, but tarnished chalcopyrite.

W27a,b

Macro: Gossanous iron formation, with well developed boxworks. Very weakly magnetic in part. Apparently chalcopyrite boxworks.

Micro: Distinct cellular texture, mainly haematite and silicates, and minor chalcopyrite blebs. Vaguely rectangular boxworks in part.

W28

Macro: Iron formation, magnetite and quartz with Cu staining.

Micro: Anhedral magnetite (VH 510) and minor silicate. Common oxidation to haematite along fractures, grain boundaries, with fine radiating networks and thin lines apparently crystallographically controlled. Rare, fine chalcopyrite grains in magnetite and silicate, often adjacent to the Cu staining.

APPENDIX "C"

Walparuta Mine Area - Analysis results

Procedure:

Rocks that appeared felspar rich in hand specimen were crushed and passed through an 80 mesh sieve. Mafics were removed where possible by magnetic separation (and it was found essential to wash the samples for efficient separation). The samples were then pressed into mounts and analysed for Na, K and Ca by XRF techniques. Samples were then analysed for Cu using atomic absorbtion methods, to check for any relationship between Cu and felspar rich rocks.

APPENDIX "D"

Ethiudna Mine Area - Thin section Descriptions.

All sampes prefixed by 6833

362/E1 RS 82

Macro: Medium grained quartz-pyroxene-scapolite rock, with two distinct compositional layers.

Micro: Two predominant assemblages: (1) Quartz with minor scapolite and clinopyroxene and (2) Clinopyroxene and scapolite

Layer (1) Quartz: 80%, to 5mm, most greater than 1mm. Very undulose, highly sutured. Contains minor small, equidimensional grains of cpx and scapolite, and has a sharp contact with layer (2)

Layer (2) Clinopyroxene: 50% Probably diopside from opt props. max 3mm, from less than 0.5mm. Grain boundaries vary from quite sutured to very straight with triple point junctions. All anhedral, rarely elongate.

Scapolite: 50% Colourless, low relief, uniaxial -ve. Poikiloblastic with irregular carbonate and apparently relict epidote. Tneds to have straight boundaries where in contact with scapolite grains, but is sutured where enclosed by diopside.

Rare interstitial carbonate.

362/E2 RS 83

Macro: Fine to medium grained quartzite with some amphibole and diopside. Fine layering in places but often obliterated by coarser grains.

Micro: Uneven grained, complex appearance. Indistinct clinozoisite layering.

Quartz: 60% Highly sutured grains, some undulose, with a wide size range. Some apparently enclosed by clinozoisite. A few large complex grains .

Clinozoisite: 10% Anhedral to 1mm, from 0.1mm. Very distinct blue abnormal interference colours.

Clinopyroxene: 10-20% Anhedral to irregular grains. Intergrown with minor amphibole, and associated with minor amphibole on grain edges and cleavages. Poikiloblastic with quartz inclusions.

Garnet: 1-2% Average 0.3mm, max 1mm. Subhedral to euhedral.

Calcite: 1-2% Average 0.3mm, max 1mm, anhedral.

Amphibole: 1% Dark blue/green-green pleochroic. Hornblende, actinolite. Mainly associated with cpx but some isolated grains.

362/E3 RS 84

Macro: Coarse green pyroxene with minor garnet and quartz. Part of a larger scale lithological layer.

Micro: Intergrowth of clinopyroene-scapolite-garnet.

Diopside: 60% Commonly 5mm or larger, some grains less than 0.5mm. Anhedral, someslightly sutured boundaries, most straight. Rarely seen enclosing quabtz, minor amphibole.

Garnet: 15% Rounded, anhedral-euhedral. Most less than 1mm, some 2.5mm More often associated with scapolite than cpx. Minor inclusions, most grains fractured.

Scapolite: 35-40% Anhedral, poikiloblastic with epidote inclusions. Geerally finer grained than diopside, and intergrown with it. Some shows fine brown alteration. Simple boundaries between scapolites.

Amphibole: 1% Anhedral, fine, as intergrowths with pyroxene and as rare isolated grains.

Quartz: 1% Anhedral, interstitial, some secondary in fractures.

Minor sphene.

362/E4 RS 85

Macro: Medium to coarse grained quartz-felspar-biotite rock.

Micro: Appears to be mainly quartz, plag, Kspar, biotite and opaques. Average 0.5mm, from 0.1mm-1.5mm.

Quartz: 40% at least. Commonly as aggregates to 0.5mm, composed of different grains with undulose extinction and sutured boundaries. Some appears to have replaced plagioclase.

Plagioclase: 30-40% (includes Kspar) Highly sericitized in parts. Multiple twinning not always distinct, may confuse with Kfelspar.

K-felspar: Rare cross-hatching, % not certain.

Biotite: 10-15% Anhedral, some laths with a slight degree of P.O. Irregular in part, with a large size variation.

Opaques: 10-15% Anhedral, fine to 0.5mm, black. Often approx equidimensional, some blebby. Frequently rimmed with sphene (may be titaniferous.

362/E5 RS 86

Macro: Layered rock of quartz and diopside. Medium grained.

Micro: Layering due to alternation between layers rich in quartz and

362/E5 (cont)

clinopyroxene. Uneven grained form less than 0.2mm to greater than 2mm.

Quartz: 80% in the quartz rich bands. Highly sutured and undulose. Some composite grains, some irreglar grains fully enclosed by cpx.

Clinopyroxene: 80% in px rich bands. Anhedral, poikiloblastic with inclusions of quartz and yellow alteration along cleavage planes.

Vesuvianite: 10% Moderate relief, brown, with dark, mottled appearance with crossed polars. Irregular, interstitial grains of variable size.

362/E6 RS 87

Macro: Medium grained felspathic, unlayered rock.

Micro: Almost pure microcline, fairly even grained, simple grain boundaries. Gen 1-2mm, but some less than 0.2mm.

Microcline: 80-90% Appears slightly perthitic. Some slightly sutured boundaries, many triple point junctions. Anhedral, equidimensional.

Quartz: 10% Most fine blebs between and within microclines. Some as aggregates of fine grains.

Epidote: Less than 5% Anhedral, irregular grains with a chlorite rim.

Amphibole: Less than 5% Only 1 grain (4mm) Almost relict, very poikiloblastic appearance. Strong green-brown pleochroic colours.

Malachite: Less than 5% Anhedral, roundish grains.

Chlorite: 1% Anhedral.

Minor red/brown opaques.

362/E7 RS 88

Macro: Medium grained, layered diopside-quartz rock.

Micro: Composition layering present, due to differing relative amounts of principle constituents.

Diopside: 15-20% Anhedral, highly poikiloblastic grains to 5mm, and some composite grains. Inclusions of quartz and vesuvianite.

Vesuvianite: Dark mottled appearance, some seeming slightly twinned and associated with cordieritein this slide.

Cordierite: 15-20% Almost relict, replaced by vesuvianite and quartz. Max 3mm. Distinctive lameelar twinning.

Quartz: 10% Interstitial, absent from some layers, undulose.

Rare carbonate, anhedral.

362/E8 RS 128

Macro: Almost entirely dark brown, massive garnet.

Micro: As macro.

Garnet: 95% Well fractured, with quartz infilling.

Quartz: 2% Two grains, rounded, undulose with later quartz rims, and a fine band of carbonate like material.

Clinopyroxene: 5% Anhedral, as isolated grains.

362/E9 RS129

Macro: Medium to fine grained quartzitic rock with pale green mineral and a weak layering.

Micro: Generally irregular grains with layering due to varying proportions of constituent minerals.

Quartz: Anhedral, undulose, irregular, maximum 0.5mm generally finer.

Cordierite: Present with quartz, distinguished with difficulty by biaxial nature, cleavage. Relative amounts uncertain, but 60-70% combined. Some lamellar twins.

Vesuvianite: 20% Irregular. Rarely as skeletal tetragonal outlines. Replaced by quartz in part.

Clinopyroxene: 5% Large poikiloblastic anhedral grains to 5mm.

Garnet: Rare, equidimensional, colourless.

Sphene: 1% Anhedral to 0.5mm

Carbonate: 1% Irregular to 2mm.

362/E10 RS ~~129~~ 130

Macro: Banded epidote-quartzite

Micro: Mainly epidote-quartz-garnet, in distinct layers.

Garnet: Deeply embayed, coarsely poikiloblastic pink garnet to 5mm. A vitually contiuous band with fine quartz and minor epidote and some amphibole.

Quartz: Fine to coarse highly undulose, sutured grains.

Epidote: usually aggregates of smaller grains, deeply embayed. Rare sphene and anhedral red/brown opaques.

362/E11 RS131

macro: Medium to coarse graind guartz rich rock with minor epidote.

Micro: mainly quartz, fractured between grains with carbonates, some epidote, amphibole and red/brown opaques. unlayered

Quartz: 90% Fine to 5mm. Well sutured, anhedral, with the variation in size apparently random.

Amphibole: 5% Poikiloblastic with quartz inclusions, anhedral to subhedral, often associated with epidote.

Epidote: 5% Most less than 1mm. Anhedral, intergrown with quartz and amphibole.

Opaques: 1% Very messy, red/brown to 2mm.

Accessory apatite.

362/E12 RS132

Macro: Coarse grained epidote-quartzite with amphiboles to 10mm.

micro: Bandingdefined by areas rich in quartz, epidote, garnet and actinolite (hornblende?)

Quartz: 40-50% Highly sutured and undulose, with wide variationiin grain size (fine to 5mm) Rarely poikiloblastic with amphibole inclusions

Epidote: 30% Anhedral, pleochroic (pale green to vivid yellow/green) with mottled extinction. many composite grains. Associated with garnet and often surrounded by larger actinolite grains. Deeply embayed by quartz in places.

Actinolite: 5-10% Subhedral to anhedral.Grains generally larger than other constituents, and single, not aggregates. Irregular grain edges, poikiloblastic, with epidote inclusions.

Garnet: 10% Anhedral, embayed. Inclusions of quartz and epidote, and euhedral sphene.

Accessory sphene and apatite.

Possibility of actinolite replaced by epidote + quartz.

362/E13 RS 133

Macro: Medium grained felspathic rock with weak schistosity and a vein of malachite.

Micro: Large size variation in grains. Mainly microcline and plag with biotite, graphite and malachite. A weak layering is seen parallel to the schistosity.

362/E13 (cOnt)

Microcline: 40% Perthitic in part, with exsolved (?) material showing greater alteration. Fro less than 0.5mm to greater than 2mm. Sutured.

Plagioclase: 40% Highly sericitised, sometimes only in the core of the grains. Anhedral grains, generally finer than microcline. Grain boundaries may be somewhat vague. Albitic. Some grains contain subhedral biotite and muscovite, and the coarse sericitization may be seen quite often as fine muscovite between the felspars.

Biotite:10% Partly subhedral laths, apparently corroded. Some is in bands parallel to the schistosity, and some isolated groups of biotites show a kinking.

Graphite: 5% Some as plates, some as blebs with a spidery appearance with very finely sutured boundaries. Most is roughly parallel to the schistosity, and intergranular, but some is enclosed by microcline.

Malachite: Seen as a network of branching sub-parallel veins, which often cut across grains of felspar and biotite (parallel to the cleavage in the latter).

362/E14 RS 134

Macro: Medium grained epidote quartzite.

Micro: Fairly even grained, most 0.2-0.5mm, some to 2mm. Mainly quartz, epidote, amphibole.

Quartz: 50% Mainly roundish, equidimensional grains forming embayments and growths within epidoteand amphibole. Brown, fine inclusions. Undulose, sutured where grains are larger, but generally simple boundaries. Often contains minor inclusions of rounded epidote and quartz.

Epidote: 30% Generally integranular with respect to quartz, and seen as irregular grains and crescents etc. grading to poikiloblastic grains - virtually sieve structures. Many grains are composite.

Actinolite: 5% Embayed, apparently relict texture, seemingly replaced by epidote + quartz. Generally single grains, not composite.

Accessory sphene.

362/E15 RS 135

Macro: Medium to fine grained poorly layered rock, layers to 1-2mm, apparently defined by biotite.

Micro: Uneven grained layered rock. Layers are rich in chloritoid, generally forming a schistosity parallel to the layering, but not all platy minerals are parallel to the layering.

Quartz: Up to 70% in quartz rich bands, absent from some chloritoid rich bands. Sutured, undulose, anhedral, 0.1mm-0.5mm, generally separated by sericite matrix.

Chloritoid: Distinctive laths, high RI, low biref, colourless to grey non-pleochroic with multiple twinning. Occurs in distinctive layers with a P.O. parallel to the layering. Some grains have fine sillimanite inclusions at an angle to the twinning.

Biotite: 5% Some irregular, almost relict, parallel to the layering, and associated with fine black opaques. Some laths at a high angle to the layering.

Sericite: Up to 30% of rock as a fine intergranular matrix.

Muscovite: 2% Laths to 2mm, parallel to the layering, grades to sericite.

Sillimanite: Fine needles in small groups replaced by sericite in part, also in chloritoid grains.

362/E16 RS 136

Macro: Medium grained quartzo-felspathic rock with biotite and fine grained wavy bands.

Micro: Mainly quartz and untwinned felspar, fractured, with fine, intergranular sericite. Sericite also in many small curved bands parallel to the biotite schistosity, and in one marked band with relict fibrolite and complex swirl structures. Some sericite infilling fractures in grains, with little alteration within grains.

362/E17 RS 137

Macro: Medium grained quartz-felspar-biotite rock with a well developed layering and a parallel biotite schistosity.

Micro: Uneven grained rock with well developed schistosity and layers

362/E17 (cont) ⊠

of sericite parallel to it.

Biotite: 30% Laths, fine to 0.5mm, with a well developed preferred orientation. Some cross cutting micas, Intergrown with muscovite.

Sericite: 40% Bands to 2mm thick, branching but generally parallel to the schistosity and including grains of quartz and biotite.

Quartz: Anhedral, weakly undulose, rarely touching, with rare sillimanite needles.

362/E18 RS 138

Macro: Medium grained amphibole rich rock - metadolerite.

Micro: Intergrowth of amphiboles of varying sizes with interstitial felsics and minor opaques.

Amphibole: 90-95% Subhedral to 2.5mm. Strongly pleochroic in green-blue/green-brown, probably hornblende.

Opaques 2-5% Black, anhedral

Felspar: 2-5% Albitic plagioclase, anhedral, rounded, interstitial intergrowths with uncertain amounts of quartz. Brown irregular alteration.

Quartz: 2-5% Anhedral, undulose.

362/E19 RS 139

Macro: Coarse to fine micaceous, dark, weathered rock with weak schistosity and large white porphyroblasts, now entirely clay.

Micro: Rock is generally inhomogeneous with varying amounts of clay (fine sericite?), sericite, muscovite,and quartz to 0.3mm, and clumps of noticeably larger biotites. A schistosity is quite well developed in places, with trains of micas and a few larger cross-cutting micas. Some biotites appear kinked. Quartz grains commonly contain fine sillimanite needles. Rare euhedral garnets.

362/E20 RS- 140

Macro: Fine to medium grained biotite rich rock with a folded fine grained layering, and a crenulation at a large angle to the fold axis.

362/E20 (cont) RS140

Micro: Fairly even grained quartz and plagioclase, fine to0.5mm, in a sericite matrix with biotite. Well defined bands are folded rather than axial planar to folds, and contain common fibrolite

Quartz: 30% Fairly equidimensional grains, not very undulose, with simple grain boundaries. Well fractured. Some as rounded blebs within plagioclase grains.

Plagioclase: Approx 30%, albitic. Generally unaltered, with rare garns showing preferential alteration on one set of twin lamellae. Sometimes fractured.

Biotite: 30% Anhedral to subhedral, some as laths, some irregular. Fine to 2mm. Associated with sericite, and some definitely curves around the nose of the fold, i.e. a folded schistosity is present.

Fibrolite: Found within the well developed sericite bands, with good P.O. parallel to the bands, and folded.

362/E21 RS 141

Macro: As E19.

Micro: As E19.

362/E22 RS 142

Macro: Graphite rich rock. Layers of graphite plates, kinked, in a clay matrix.

Micro: 40-50% graphite as plates defining a schistosity, with well developed, complex kinking. The degree of development varies from a few small plates to almost massive graphite. The matrix is mainly clay with some muscovite and very fine graphite.

362/E23 RS 143

Macro: Fine to medium grained quartzo-felspathic rock with weak layering and minor graphite.

Micro: Graphite and biotite plates define a schistosity parallel to the layering in the microcline-quartz rock. Confused appearance due to large size variation in the constituents, and irregular grains.

Microcline: Anhedral, 0.2-0.4mm. Highly perthitic appearance. Tend to

362/E23 (cont)

be the coarsest grains. Very irregular grain boundaries, and some coarse irregular sericite in some grains. 70%

Plagioclase: 10% Anhedral, albitic, with poorly developed multiple twinning. Apparently replaced by microcline.

Quartz: 10% Anhedral, undulose. 0.1-0.5mm, generally as isolated, rounded aggregates of 5-10 grains, with rounded margin.

Graphite: 5% Well developed laths, most 0.5-1mm, rarely 4mm, with very finely sutured edges, some blebby. Often along the edges of biotite grains. Have a definite P.O. parallel to the biotite schistosity, with some cross-cutting grains.

Biotite: Less than 5% Laths to 1mm, forming a schistosity. Some fine and irregular between felspar grains, some inclusions in felspar.

362/E24 RS 144

Macro: Medium grained quartz-pyroxene rock with a layering 2-3mm thick disrupted by unlayered areas of quartz and pyroxene.

Micro: Quartz-clinopyroxene-veuvianite rock.

Quartz: 60% 0.1-1mm in the layered portion. Slightly sutured, undulose with a fairly even appearance. To 5mm in the massive area, and highly sutured, undulose, uneven grained.

Clinopyroxene: 20% 0.1-1mm in the layered portion. Yellow alteration along cleavages, grain boundaries, and fractures. Anhedral with some straight boundaries, some embayments. To 5mm in the unlayered area, with numerous blebby quartz inclusions, anhedral.

Vesuvianite: Anhedral, embayed, irregular. Encloses clinopyroxene and quartz and occurs as blebs in quartz.

362/E25 RS 145

Macro Brown and white layered (0.1-2mm) calcareous rock with wavy veins of calcite, some parallel to the layering, some not.

Micro Rock has isolated large grains of clinopyroxene and small grains of quartz in carbonate matrix with numerous veinlets of carbonate cutting the matrix and fractured grains.

Clinopyroxene: %? Highly altered (brown) especially along fractures.

Quartz: 10% Some 0.1mm, some to 2mm. Fractured with carbonate filling.

362/E25 (cont)

Carbonate: 90% Matrix and many veins, with individual grains at right angles to the vein, and which cut virtually all non-carbonate grains.

Garnet: Less than 5% Anhedral, fractured.

362/E26 RS 146

Macro: Medium grained quartzo-felspathic rock. Biotite schistosity.

Micro: Largely microcline of varying grain size with a poor P.O. of biotites. Layering parallel to schistosity due to coarser grain size of biotite and microcline.

Microcline: 80% Rounded, perthitic appearance, relatively unaltered with inclusions of biotite parallel to the schistosity.

Plagioclase: 10% Rare multiple twins, highly altered in parts. Albitic, enclosed by microcline.

Biotite: 10% Subhedral laths to 2mm. Define a weak schistosity, or a well developed but kinked schistosity, not recognized because biotites are isolated.

362/E27 RS 147

Macro: As E19

362/E28 RS 148

Macro: Fine to medium grained quartzo-felspathic rock with some biotite. A weak schistosity parallel to a layering (due to grain size variation) is apparent.

Micro:

Micrcline: Some with good cross-hatching, some untwinned K-felspar. Appears perthitic. Anhedral, equidimensional. Often sutured boundaries and appears to have replaced plagioclase. Most less than 1mm. 50%.

Plagioclase: Highly sericitized 30% Minor untwinned rims, albitic.

Quartz: 10-15% Rounded fine blebs within felspars often, and very irregular, undulose grains where interstitial.

Biotite: Slightly irregular laths, 0.1-0.8mm. Altered to fine green material in centres often (possibly malachite) Some associated graphite and brown opaques.

362/E29 RS 149

Macro: Unlayered medium to coarse grained quartz-pyroxene-carbonate rock.

Micro: Weak compositional layering of quartz + carbonate, quartz + garnet + clinopyroxene predominantly.

Quartz: 50% Sutured, undulose, generally less than 1mm, rarely 2.5mm.

Clinopyroxene: 20% Anhedral, yellow alteration along cleavage, max 3mm.

Garnet: 10% Anhedral, irregular, quite colourless, to 1.5mm.

Opaque: 1 only red/brown subhedral opaque with sphene rim.

362/E30 RS 150

Macro: Fine grained layered rock. Quartzo-felspathic with layers to 1-3mm thick, brown/white colour difference.

Micro: Rockis mainly felspar and biotite, with the layering due to varying amounts of biotite, which also has a P.O. parallel to the layering.

Felspar: 60-70% Micrcline replacing albitic plagioclase. Plag is highly sericitized.

Quartz: 20% Most less than 0.3mm Well rounded blebs within microcline.

Biotite: Seen as laths if section is perpendicular to the basal cleavage, otherwise somewhat ragged.

362/E31 RS 151

Macro: Coarse white felspar rich rock, with minor quartz, mica.

Micro: Appearance is dominated by large evenly twinned plagioclase with subordinate quartz and micas.

Plagioclase: 90% Less than 1mm to 5mm. Subhedral to anhedral, with fine even multiple twinning, with some slightly kinked twins. The grains are finely sericitized with coarser material between the grains, and the individual felspars are intergrown to a degree.

Quartz: 10% Max 3mm, anhedral, undulose. Both intergranular and as blebs within the plagioclase grains.

Biotite: 1 plumose complex grain (1.5mm) with associated muscovite.

Muscovite: Rare large irregular laths replaced by plagioclase. Finer grain aggregates between plag grains.

362/E32 RS152

Macro: Medium to coarse grained felspar rich rock with a weak biotite schistosity.

Micro: Mainly microcline, with minor quartz, plag, and a biotite schistosity.

Microcline: 85% Approx equidimensional, slightly sutured boundaries. Appears to replace plagioclase, contains small quartz blebs, and is slightly perthitic in appearance (relict plagioclase?) 0.3-3mm.

Quartz: 10% Anhedral, sutured, undulose with a generally interstitial relationship to the felspar. Max 0.5mm

Plagioclase: 2% Albitic, anhedral, generally within microclines, and apparently replaced by them.

Biotite: 2% Defines a weak schistosity, with trains of irregular laths.

Graphite: 1% Irregular, finely sutured grains.

362/E33 RS 153

Macro: Medium grained felspathic rock with finer biotite and fractures infilled with chrysocolla and malachite. Biotite rich weakly developed layers are apparent, with the veins at right angles to the layers.

Micro: Mainly microcline, with fractures cutting all minerals present.

Microcline: 60-70% 0.1-2mm, perthitic appearance, altered, with either quartz or alteration products between the grains.

Quartz: 10% Anhedral to 1.5mm, slightly undulose.

Plagioclase: less than 5% , albitic, anhedral with slightly kinked multiple twins.

Biotite: 5% Red/brown, laths and irregular grains with ragged grain edges. Weak P.O. parallel to the layering.

Copper minerals appear to be chrysocolla and malachite occurring with carbonate as a botryoidal infilling in the fractures. Some blebs of light green mineral in the rock, not the fractures, and is fully enclosed by biotite in places.

362/L34 RS154

macro: Massive wollastonite-diopside rock. Diopside grains to 6mm, some wollastonite to 2cm. The relative amounts of wo and di are highly variable in outcrop.

micro:

Diopside: 40% Anhedral, 0.3-5mm. Smooth, rounded grain boundaries, with the large grains poikiloblastic with rounded inclusions of quartz, carbonate and untwinned felspar.

Wollastonite: 40-50% Colourless, non-pleochroic, slightly cloudy, moderate relief, biaxial negative, 2V= 40, max biref 0.02. Anhedral to subhedral in T.S., with the blades seen in some outcrop not at all obvious. Minor round quartz inclusions, max 2mm

Quartz and Felspar: 10-15% Suspect K-felspar. Unsutured, simple boundaries, often as blebs within diopside.

List of Hand Specimens, Thin Sections and Polished Sections

(1) Walparuta Mine Area:

Hand Specimens: W1 to 28 inclusive

Thin Sections: W1 to 25 inclusive

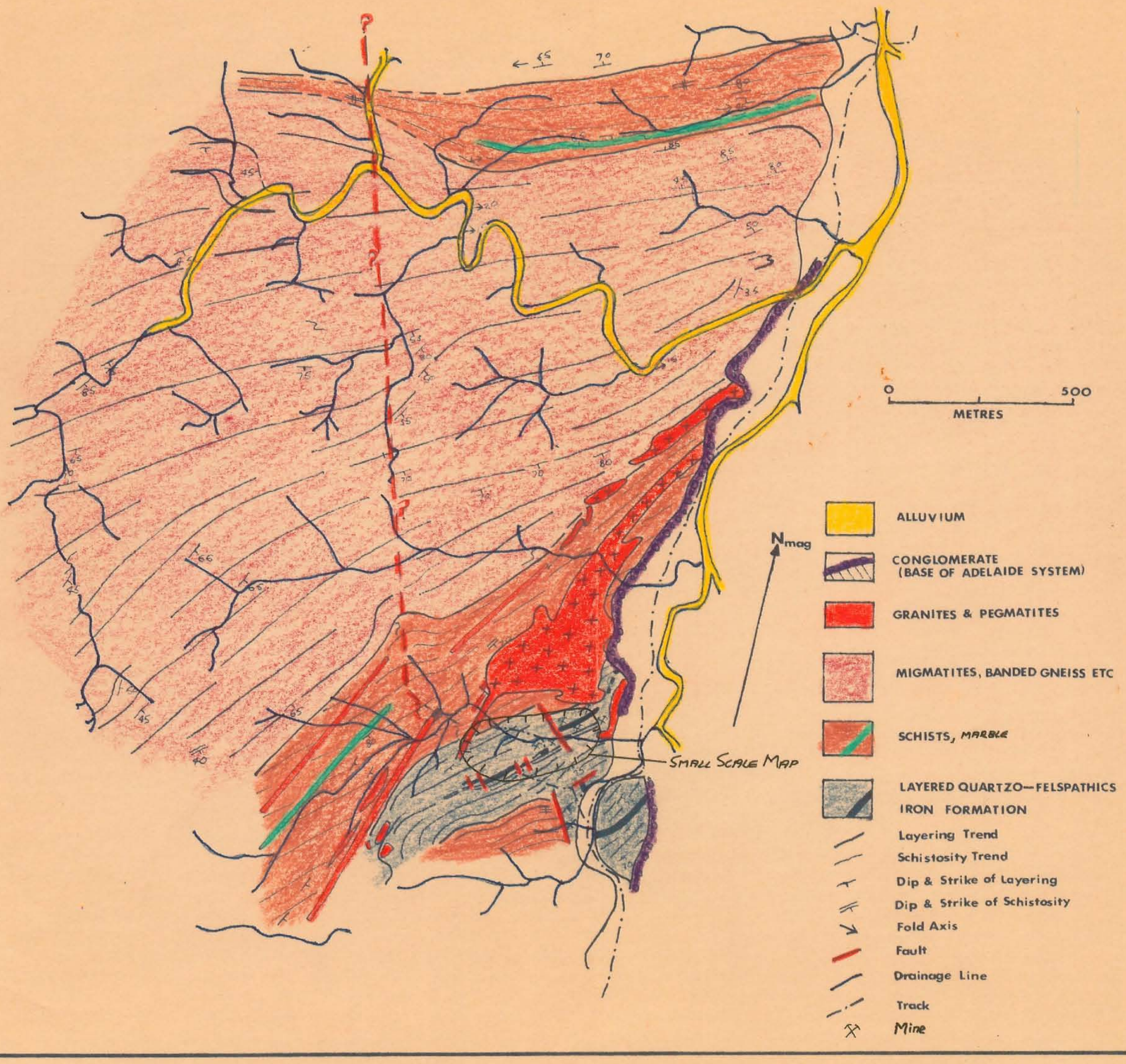
Polished Sections: W7,26a,26b,27a,27b,28.

Ethiudna Mine Area:

Hand Specimens: E1 to 36 inclusive

Thin Sections: E1 to 34 inclusive.

WALPARUTA MINE AREA



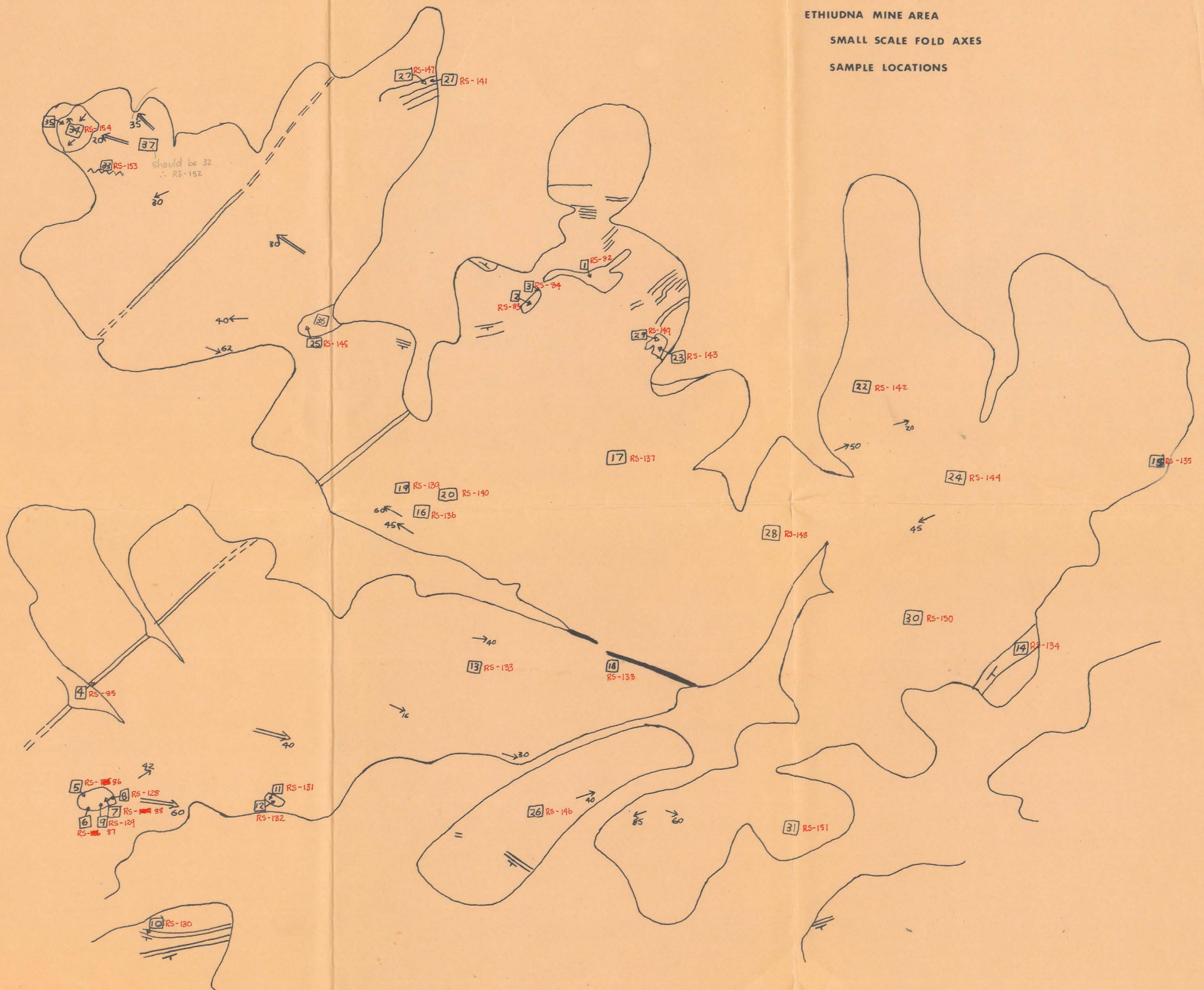
6833

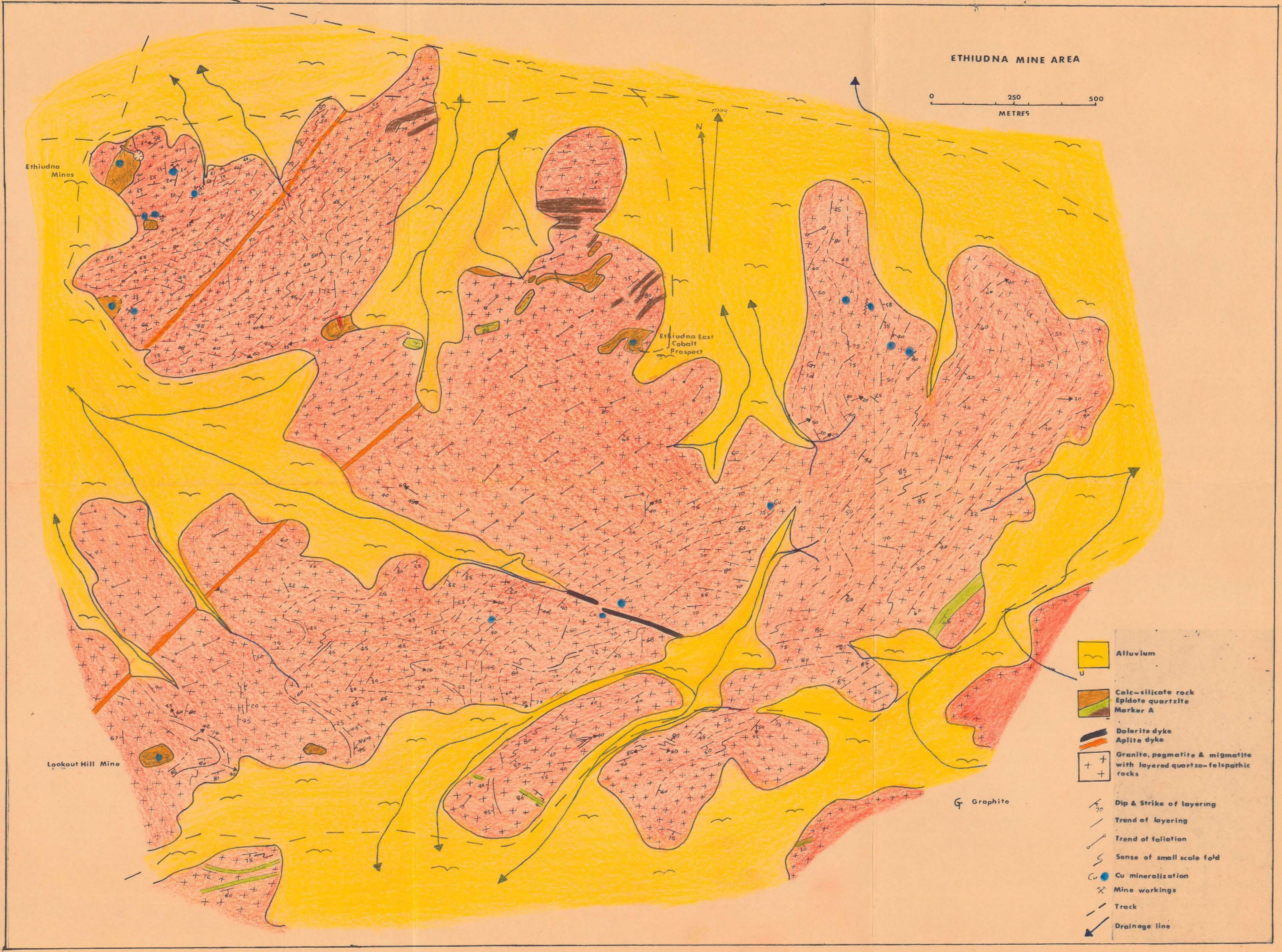
Please reduce x ½

ETHIUDNA MINE AREA

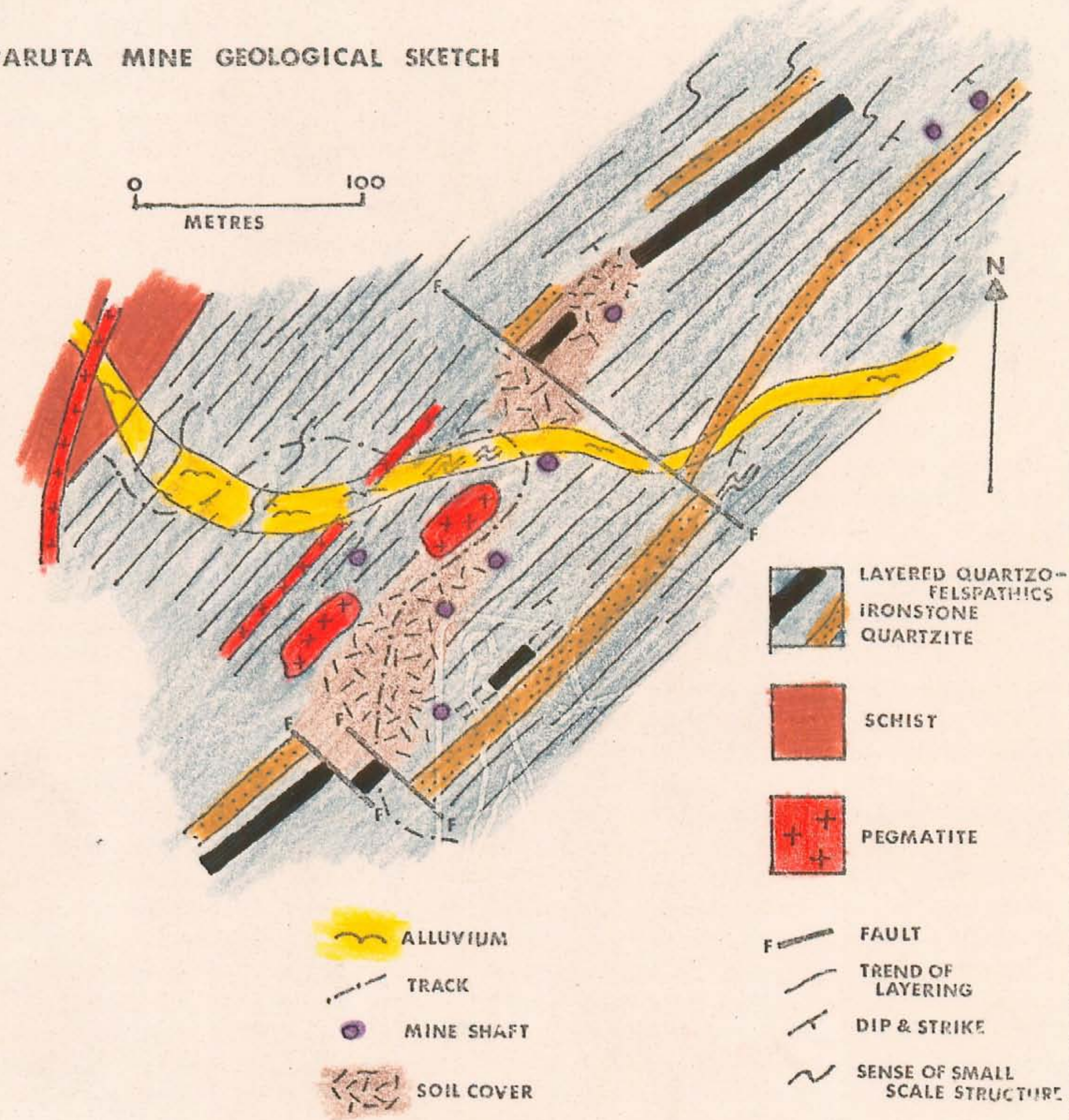
SMALL SCALE FOLD AXES

SAMPLE LOCATIONS




ETHIUDNA MINE AREA
0 250 500
METRES
N
mag
Ethiudna Mines
Ethiudna East Cobalt Prospect
Lookout Hill Mine
Graphite
Alluvium
Calc-silicate rock
Epidote quartzite
Marker A
Dolerite dyke
Aplite dyke
Granite, pegmatite & migmatite with layered quartzo-felspathic rocks
Dip & Strike of layering
Trend of layering
Trend of foliation
Sense of small scale fold
Cu mineralization
Mine workings
Track
Drainage line

WALPARUTA MINE GEOLOGICAL SKETCH



ETHIUDNA MINE - GEOLOGICAL SKETCH