PETROLOGICAL AND STRUCTURAL INVESTIGATION OF WILLYAMA COMPLEX ROCKS, WIPERAMINGA HILL AREA, SOUTH AUSTRALIA.

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CONTENTS

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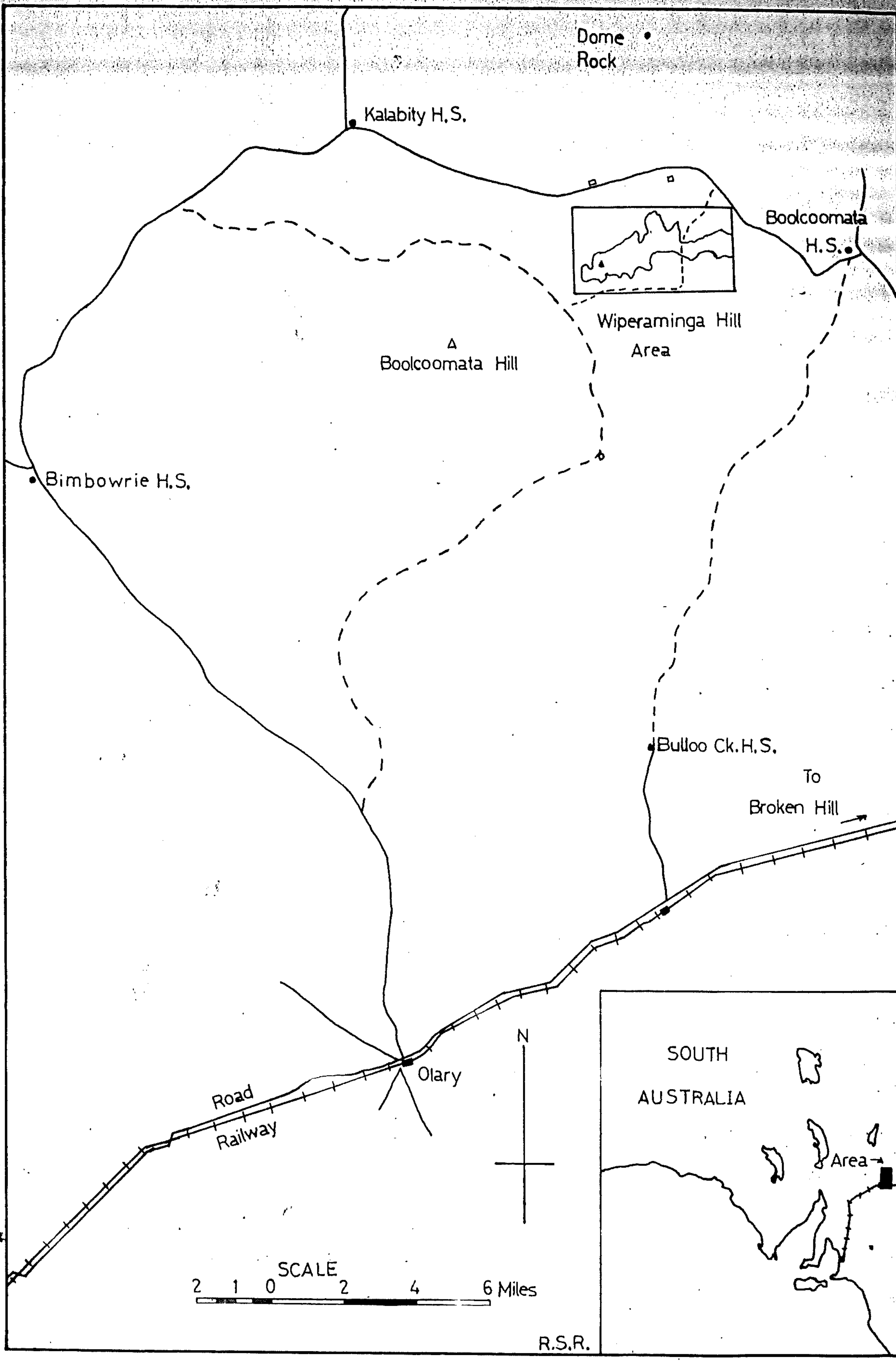
ABSTRACT

The rocks of the Wiperaminga Hill area are metasediments and granitic rocks of the Willyama Complex. They have undergone metamorphism to upper amphibolite grade. The rocks of the area are predominantly mica schists, calc-silicates and granite gneisses. Associated with the metamorphism was a phase of isoclinal folding (Group 1) which resulted in a schistosity (S_1) being developed mostly parallel to layering. No fold hinges of this phase were seen in the area (i.e. no occurrences of S_1 not parallel to layering).

The generally E.N.E. trending and steeply dipping S_1 and layering are deformed by a second more open phase of folding (Group 2). A second schistosity S_2 is developed axial plane to these folds. In some locations S_2 replaces S_1 as the dominant schistosity.

The area has undergone a later retrogressive phase of greenschist facies metamorphism. Also at a quite late stage albitization and related brecciation of some calc-silicate rocks took place.

LOCALITY MAP



INTRODUCTION

The area studied is situated about 20 miles N.N.E. of Olary in South Australia at about longtitude 140° 30' latitude 32° 00'. The area lies in Boolcoomata Station near the boundary with Binbowrie Station and is approximately 4 square miles in area.

The search for minerals in the Olary region began in the 1860's and reached its peak in the 1880's at the time of the discovery of the Broken Hill silver lead deposit. Geological work was done by Mawson including investigation of chiastolite occurrences at Binbowrie (1911)and of the Dome Rock Copper Mine. The search for uranium and the development of the Radium Hill uranium deposit in the early 1950's gave a further impetus to geological investigation and the Olary Province was mapped by Campana of the S.A. Department of Mines. The area is at present being remapped by the S.A. Department of Mines for the production of a 1:250,000 Olary sheet.

The rocks outcrop in a range of low hills running east-west in a flat alluvial plain. The climate in the area is semi-arid and the vegetation, except after good rains, consists of salt-bush, bluebush and sparse low scrub. The land is used for the grazing of sheep. The relief in the area is fully mature but the outcrop is generally good because of the harsh nature of the climate.

The project was originally intended to be primarily a study of the structure of the area. However, because of the nature of the area, emphasis on the petrology was increased. The work was carried out in co-operation with the S.A. Department of Mines with A.J. Parker mapping an adjacent area. Detailed mapping was done using Lands Dept. photographs enlarged to 1:16,000. Samples were taken in the area and about 70 thin sections were cut, 16 descriptions of which appear in this thesis.

REGIONAL GEOLOGICAL SETTING

The rocks in the area studied belong to the Precambrian (Metamorphic age 1700 m.y. (Pidgeon, 1967)) Willyama Complex which stretches from the Broken Hill region to west of Weekaroo. Also in the Olary region are the Proterozoic Adelaide System rocks which lie unconformably on the crystalline basement rocks of the Willyama Complex. (These do not occur in the area mapped). Mawson called the boundary between the two the "Grand Unconformity".

The basement rocks have undergone metamorphism to upper amphibolite grade and multiple deformation. Hobbs (1966) from work at Broken Hill suggested that the deformation involved a phase of isoclinal folding resulting in the layering being mostly parallel to the axial plane schistosity and later refolding of the layering and parallel schistosity. Talbot (1967) also proposed this kind of deformational history at Weekeroo. The rocks are overprinted by a later phase of greenschist facies metamorphism.

Large areas of granitic rocks occur in the basement rocks. Campana and King envisaged these areas as centres of "granitization" with anatectic granites in the centre grading outwards to migmatites, gneisses and feldspathized schists and then to "uncontaminated" metasediments. A large mass of granitic rocks occurs in the old Boolcoomata-Bimbowrie area which lies to the south-west of the area studied.

Talbot proposed a stratigraphic sequence for the basement rocks at Weekeroo. The sequence was leucogneiss, migmatitic schist, granitoid gneiss, layered gneiss, Ethindna calc-silicates group, mica schist, bedded mica schist.

Pitt (1971) of the S.A. Department of Mines generally agrees with this sequence.

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PETROLOGY

The rocks of the Willyama complex are considered to have undergone metamorphism to upper amphibolite grade, contemperaneous with the deformation and a later phase of retrograde greenschist facies metamorphism (Binns 1963, 1964). The rocks of the Wiperaminga Hill area conform to this view.

In the area continuity of lithologies along strike generally seems to be poor. The more massive rock types, quartzites and calc silicates, mostly occur as discreet outcrops (apparently as boudins) surrounded by schists.

Schists are the most abundant rock type in the area. Of the different varieties of schist only the chiastolite schist, which is easily recognized in the field, was mapped as a separate unit.

Quartz mica schists which are the most common variety of schists in the area generally have rather subdued outcrop. The quartz mica schists are usually fine grey fissile rock weathering to a brown colour. Sometimes they have a "silky" appearance (especially in the region of shears). Occasionally they are more coarsely crystalline with muscovite or rarely sillimanite visible. Lithological layering is commonly difficult to discern in the outcrop.

In this section these rocks are characterized by the amount of micaceous minerals usually with a fairly strong preferred orientation (sometimes with 2 preferred orientations). Biotite is abundant and is usually of a fairly even grain size. It is present as tabular crystals or as ragged shreds but only rarely as larger porphyroblasts. Occasionally the biotite is partly replaced by muscovite. Muscovite content is more variable than biotite, being minor or absent in some schists and as high as 50-60% in others. It occurs as very fine single grains, sericitic aggregates, tabular crystals of the same size as biotite or as porphyroblasts.

Muscovite crystals are sometimes found truncating tabular biotite crystals, suggesting a time relationship of muscovite later than biotite. The preferred orientation of muscovite crystals is usually weaker than that of biotite.

In some cases it is apparent that muscovite or sericitic or sericitic/

aggregates have replaced pre existing porphyroblasts. The large chiastolite crystals are usually partly replaced by sericite. Two occurences were found of roughly spherical crystals 1 - 2 c.m. in size, in schists. When thin sections were cut of these, they were found to be completely replaced by muscovite.

The quartz content of these schists is usually 40 - 50%. The anhedral quartz grains are often elongated parallel to the schistosity. Some quartz (and some feldspar) grains are polygonal indicating recrystallization. Some grains show undulose extinction. Occasionally very fine quartz and sericite is present as a matrix for the larger grains. In some schists there is minor subhedral to anhedral hornblende parallel to the mica preferred orientation. Other minor minerals present are tourmaline, as euhedral priamatic to rounded grains, fine opaques including graphite, anhedral epidote grains and enhedral to subhedral garnet of various grain sizes.

Up to 5 - 7% sillimanite was present in a few thin sections studied. It is present as find needles, as inclusion in quartz grains or as discreet masses. In some occurrence the needles are oriented parallel to the schistosity in the rock, in others they are arranged in radiating aggregates.

Chiastolite schists as shown on the map, occur in a band passing through Wiperaminga Hill and in a large irregularly shaped area in the east-central area of the map. The irregular shape of this area could in part be due to structural features, and in part to the lack of continuity of occurrence of the chiastolites along strike. The chiastolites are megacrysts of andalusite with a characteristic black cross of carbon concentration.in cross section. The chiastolite prisms are 1 - 3 c.m. in width and up to 15 c.m. in length. They generally have a good preferred orientation. The chiastolite schists often have bold outcrop with the concentration of large crystals giving them a rather spectacular appearance. (See Plate 1).

In this section the matrix for the chiastolite porphyroblasts is found to be biotite and muscovite (with a poor preferred orientation parallel to layering), sericite, well deformed quartz grain (elongated parallel to layering and with undulose extinction) and up to 10% of fine anhedral graphite. The graphite gives some gives some/

of the chiastolite schists a dark carbonaceous appearance in hand specimen. The layering which is defined by different concentrations of graphite is bent around the chiastolites. The chiastolites are found to be partly replaced by sericite.

Feldspathic schists occur extensively in the area. They usually occur in areas near granitee gneiss or pegmatite occurrence. This suggests that a process of feldspathization of the schists related to the magmatic acitivity is involved. Both K feldspar (microcline twinning) and plagioclase feldspar is found in the feldspathic schists. The plagioclase composition in one sample was determined as Ab 67 (by the Michael-Levy method). The feldspar concent of these schists varies from 50-80% with a quartz content of up to 10%. The feldspar grains are anhedral, have a fairly even grain size and are often elongated parallel to the foliation direction. The feldspar grains commonly contain numerous inclusions of quartz, epidote and opaques. This feature tends to support the idea of feldspathization of quartz-schists. The other features of the feldspathic schists, as regards micaceous minerals etc., are as described for quartz schists.

<u>Calc-Silicates</u>

Rocks broadly classified as cal-silicates occur in the south-west of the area, just north of Wiperamingа Hill, in a band in the west-central section of the area and also scattered along the south-eastern edge. They occur as large masses, isolated boudins within schists or in one area, as shown on the map, interlayered with schistose rocks. This last occurrence is apparent on aerial photographs as an area of very obvious layering.

The rock types involved are hornfels, epidote hornfels and epidote quartzites.

The changes between these different rock types are gradational and they may be difficult to distinguish in the field.

The calc-silicates are fine grained, fairly massive and boldly outcropping. They are most commonly dark green in colour, sometimes with good layering visible.

Along the south-eastern edge of the area and in a couple of couple of/

outcrops north of Wiperaminga Hill, a light coloured feldspathic rock with prominent dark bands of amphibole is found. In the outcrops to the north of Wiperaminga Hill, a couple of samples were found with apparent sedinnentary cross-bedding (giving a facing to the south). However, these samples could not be regarded as conclusive.

In thin section the rocks generally have granoblastic texture. They contain hornblende from 0 to 25% (average 10-15%). The horneblende is anhedral to subhedral prismatic, sometimes with a weak preferred orientation. Epidote content varies from 1-2% to 15-20%. It is present as very small anhedral grains or as poikilitic porphyroblasts. In a few samples clino-pyroxene grains were found associated with the hornblende grains or as reaction rims around the horneblende. In one thin section only clino-pyroxene (20% of rock) and no horneblende was present.

Equigranular feldspar makes up an average of about 80% of the rock. The feldspar is most commonly K feldspar with smaller amounts of plagioclase, both sometimes contain a number of inclusions.

Biotite and a small amount of muscovite is present in some samples. Minor minerals include tourmaline, opaques, sphene, and in two, cases, calcite crystals.

The layering in these rocks is defined by concentrations of horneblende and epidote. Weak preferred orientations of biotite and horneblende are sometimes observed.

A thin section of a sample from the large mass of fine grained hornfels outcropping south of Wiperaminga Hill showed it to consist of about 50-60% K feldspar with 20-25% epidote and about 20% biotite grains with no preferred orientation. Horneblende content was only minor. Also in this area is a rock with strong epidote layering with a profusion of minor folds. In this section this rock was found to contain about 50% anhedral epidote, 40% quartz and only a small amount of feldspar.

A calc-silicate rock with quite an unusal mineralogy also occurs in this area. It is a well layered rock with boudinaging

with boudinaging/
developed. The boudins consists of concentrations of piedmontite and garnet and the outer layers are finer grained epidote, feldspar, quartz and abundant opaques.

In the extreme south-east corner of the area an epidote garnet quartzite occurs. Like most of the other cal-silicates it occurs in large isolated outcrops rather than in continuous layers. The rock is massive in outcrop with a blotchy appearance given by the dark minerals it contains. In this section 25-30% each of coarse anhedral brown garnet and yellow-green epidote was observed. The rest of the rock was quartz as inclusions in and matrix for the epidote and garnet.

Albitized Rocks.

Along the southern edge of the are there are several occurrences of albitized rocks with a brecciated appearance. (See Plate 2). These rocks seem closely related to the light coloured feldspathic rock with amphibole layering already mentioned above. It seems reasonable to suggest that the layered feldspathic rock is the same rock type as that albitized. The two rock types alternate in a series of outcrops scattered along strike in the south-east corner of the area. There are mineralogical and textural similarities between the unalbitized rock and layered blocks in the brecciated albitized rock.

The unalbitized rock has prominent dark layering. In thin section it is found to consist of 75-85% feldspar, most of the twinned grains being K feldspar with a small amount of plagioclase present. There is about 10% anhedral to subhedral hornblende, 3-5% clino-pyroxene and minor epidote in the rock. The layering is defined by concentrations of hornblende, clino-pyroxene and epidote. Also present are a few grains of calcite.

The ~~stabi~~albitlized rocks are fairly massive in outcrop with a characteristic porcellaneous appearance on weathered surfaces. They have the appearance of a breccia with a matrix containing blocks of well layered rock, from a few cms. to a metre or so across. One block was seen with apparent sedimentary cross bedding in its layering. The identification of this feature must be regarded with caution in rocks which are so altered. If it is a sedimentary feature it of course supports the idea that these rocks are meta sediments which have suffered later metasomatism.

The matrix for the breccia is albite, amphibole and some epidote. Veins and "dykes" of albite or sometimes of pure amphibole cutting across the layered blocks. The layering is often bent around next to the dykes. Some blocks have kinking in their layering with veining developed along the kinks. This probably represents the initial stage of the brecciation process.

The amount of brecciation varies in different outcrops. In some the orientation of the layered blocks is completely random; this grades to partial orientation of the blocks and then to situations where the layering through the outcrop is intact with just some veining present. An open fold in the layering with a wavelength of about 2 metres was observed in one outcrop. Veining in this seemed to be partly parallel to the axial plane of the fold.

In thin section the albitized rocks are fine grained with a granoblastic texture. Theycontain 80-90% feldspar which is almost entirely plagioclase (with a few grains of microcline). The plagioclase was determined to be about Ab 98 by the Michel-Levy statistical method. The hornblende content averages about 10%, the hornblende being anhedral with inclusions of albite, giving it a poikilitic appearance. Clino-pyroxene is often associated with the hornblende, sometimes as a reaction rim around it. One sample has a clino-pyroxene content of 5% with only minor hornblende present. Fine anhedral epidote (1-5%) and opaques (1-3%) are also present.

The hornblende, clino pyroxene, epidote and opaques define a well developed layering in thin sections that are taken from a layered block. The layered hornblende has a constant optical orientation. Thin sections taken from the matrix material do not show a good layering.

The albitized rocks which occur to the south of Wiperaninga Hill are slightly different to those which occur in the east of the area. They have the same porcellaneous weathered surface but they have not got the same layered and brecciated appearance. In thin section the content of hornblende and epidote is less although there

although there/
is still some layering of these minerals.

The albitized rocks occur in areas where granite gneiss and pegmatite are present, but whether there is any genetic significance in this is problematical. The rocks are apparently the result of metasomatism with Na replacing K. A whole rock analysis of one of the albitized rocks gave the following results.

Sample 384/A7

Total	Fe_2O_3	MnO	TiO_2	CaO	K_2O	SiO_2	Al_2O_3	P_2O_5	MgO
99.79	3.961	.029	.616	4.645	1.153	61.175	14.986	.296	2.337
								Na_2O	Loss
								10.28	.310

The extremely large Na_2O content and low K_2O content emphasizes the almost complete conversion of the K feldspar in the rock to albite.

The author believes that the albitization was a fairly late stage process acting on calc-silicate rocks. Evidence that the albitization took place at least after the major deformational episode was seen in a schist adjacent to one of the outcrops of albitized rocks. In this schist were found veins of coarse albite presumably related to the albitization of the calc-silicates. The albite grains contained numerous inclusions of biotite, the biotite having a preferred orientation parallel to the preferred orientation in the rest of the schist. (See plate 7).

Other Rock Types

Quartzites occur in several parts of the area, as shown on the map. They are present as layers continuous over a distance or as small isolated outcrops due to faulting or boudinaging. The quartzite varies from a content of almost 100% granoblastic quartz to a rock with about 5% feldspar and 5% biotite with a preferred orientation. They then grade into quartzitic schists. The quartzites commonly have a content of secondary copper minerals, mostly malachite, possibly related to faulting. There are a large number of small Cu. diggings along the quartzite in the north-east of the area.

An abundant rock type on the northern side and in the east of the area is granite gneiss. It occurs as larger areas of boldly of boldly/

outcropping, massive granite gneiss and smaller pods of granite gneiss with a well developed foliation. The two types are found to be fairly similar in thin section. Their texture is coarse grained and granoblastic. They have a feldspar content of 65-75% mostly K feldspar (often microperthitic) with about 10% plagioclase. The feldspars are anhedral and often contain inclusions of biotite and other minerals. The quartz content is 25% to 35%. Mica is mostly equigranular anhedral biotite (3-5%) with a small amount of muscovite.

In the thin sections from the foliated granite gneiss the biotite was found to have a definite crystallographic preferred orientation. No layering was apparent in these rocks. The quartz grains in these showed undulose extinction. The foliation in these rocks (presumably resulting from the preferred orientation of biotite) was found in the field to be always parallel to the foliation in the nearby schists. It is suggested that these granite gneisses were implaced either before or during the major phases of deformation, which gave them the same foliation as the surrounding rocks.

Shown on the map are areas designated as migmatite. These are areas where pods of foliated granite gneiss with dimensions from a few metres to 100 or so metres are completely intermingled with coarse mica schists. A situation such as this suggests that a process of granitization or partial melting is forming the granitic rocks virtually in situ probably during the major deformation and high grade metamorphic event. The more massive granite gneisses possibly moved further and were implaced just after the deformation.

Prominently outcropping pegmatites are found both conformable to and cutting across the layering as shown on the map. The pegmatites are coarse grained with about 50-60% feldspar (mostly plagioclase), 40% quartz, and 5-10% muscovite (sometimes occurring as large mica "books"). Tourmaline and some garnet is also found in the pegmatites.

One occurrence of amphibolite was found in the area. This was in the area of and parallel to a major shear. The outcrop

The outcrop/
was quite well weathered; in some parts it had a foliation developed, in others it was more massive. In this section 30-40% hornblende was found. The hornblende was in tabular shreddy masses or as anhedral equidimensional grains. Other minerals are biotite 20-30%, quartz 10-15%, epidote 3-5% and albite 15-20%. The larger quartz grains show much undulose extinction. The albite is in very large grains containing a multitude of inclusions of epidote, hornblende, biotite and quartz. The albite may be related to the albitization which occurs in some nearby rocks. (see map).

Along the southern edge and in the far west of the area, there are patches of iron formation. These are fairly massive in outcrop and have a brecciated appearance. They consist of angular quartz grains and some muscovite with a content of 30-40% of opaque iron mineral (haematite) as irregular masses and infilling in cracks. The iron formations are almost certainly a secondary development and would have no stratigraphic significance.

Summary and Conclusions.

It seems reasonable to conclude that the rocks of the Wiperaninga Hill area were originally pelitic and quartzo-feldspathic sediments. They underwent metamorphism to upper amphibolite grade (indicated by presence of sillimanite) contemperaneous with the deformation which produced the major schistosity in the rock. The chiastolites were probably produced during this phase. In the more calcic rocks, hornblende and clino-pyroxene were formed. Also during this phase granite gneisses were produced perhaps by some anatectic process (as envisaged by Campana).

The area underwent a later retrogressive phase of metamorphism to greenschist facies. This resulted in the formation of chlorite, sericite (often replacing pre existing porphyroblasts) and probably also the epidote which is common in the area.

At a fairly late stage some calc-silicates underwent albitization involving brecciation and almost complete replacement of K with Na.

STRUCTURE

The structural features of the Wiperaminga Hill Area conform to the generally held concept of the Willyama Complex deformational history. This entails a phase of isoclinal folding (Group 1) with an axial plane schistosity developed mostly parallel to layering and a second phase of more open folding (Group 2) deforming this. (Hobbs 1966). However in the area mapped there is little actual evidence of Group 1 folding, apart from the development of the strong schistosity parallel to layering. Also found in the area is a second schistosity, in places quite strongly developed, related to the Group 2 folding.

Lithological layering is difficult to see in outcrop in some schists in the area. However in thin section most rocks are found to have some layering. The layering is defined by the concentration of micas, sillimanite or opaques in schists and by hornblende, clino-pyroxene, epidote, garnet and opaques in calc-silicates. Occasionally differences in grain-size also define the layering.

The layering in the rocks in the region is generally considered to represent the original sedimentary bedding. In the Wiperaminga Hill area there are only two examples of apparent sedimentary cross bedding in calc-silicates to support the idea of a sedimentary nature for the layering rather than just a metamorphic layering. The mica concentrations alternating with quartz rich layers and some concentrations of opaques may be indicative of bedding.

The most prominent structural feature in the area is the strongly developed schistosity (S_1) which is presumably the axial plane schistosity for the isoclinal Group 1 folds. In every case seen in the area both in outcrop and in thin section where a layering was visible, S_1 was parallel to it. This means, in effect, that no Group 1 fold hinges were seen. It is possible that some examples were missed because, as stated above, with a well developed schistosity in the rock, it is often very hard to discern a lithological layering in the mica schists.

In one locality in about the centre of the area, what was at first thought by the author to be an example of a Group 1 fold

Group 1 fold/

was found. The layering (defined here by the presence or absence of chiastolites in the schist) seemed to be folded with the major schistosity axial plane to the fold. However more detailed examination showed that there was a schistosity (S_1) folded around with the layering, but there was a second schistority (S_2) developed strongly across the area.

Features which may represent Group 1 folding were seen in an area where thin, pegmatitic type, migmatite layering was present in schist. The layers were generally parallel to the ordinary layering and schistosity present in the schist. However, in one case the migmatite layers were isoclinally folded back and forth along S_1. (See Plate 4). In another case the migmatite layers formed the hinge of a fold with S1 parallel to ordinary lithological layering axial plane to the fold in the migmatite.

From examination of thin sections (and of coarser hand specimens) it was found that the schistosity was the result predominantly of the referred orientation of tabular micaceous minerals. These were primarily biotite and muscovite but also some sericite and chlorite was oriented parallel to S_1. These latter minerals were almost certainly the result of replacement of pre-existing minerals in the same orientation. Sillimanite needles are generally parallel to S_1. In a number of cases, quartz and feldspar grains were elongated parallel to S_1. In the calc-silicates a poor schistosity was sometimes given by a preferred orientation of the small amount of biotite. Amphibole prisms often have a fairly poor preferred orientation parallel to S_1.

As shown on the map of structural elements there is a general trend through the area of S1 striking E.N.E. A contoured plot of poles of S_1 (and layering) (see Fig. 1) consequently gives a concentration at about 45° to 330°. Due to the Group 2 folding there is a distribution along the great circle approximately 55° to 262°.

Mineral lineations measured in the area where on chiastolite prisms, on elongated lathes of coarse mica and a few on sillimanite needles. They were all measured in S_1 surfaces. Hobbs

Hobbs/
at Broken Hill considered that mineral lineations were parallel to Group 1 fold axes, however, no conclusive evidence of this was seen in this area. A.J. Parker, working in an adjacent area, believes he has established that the mineral lineation is parallel to Group 1 fold axes.

The pre- or syn-tectonic nature of the chiastolites was shown by the deforming around them of S_1/and layering. The plot of mineral lineations shows a maximum concentration at about 30° to 100° but with a fair dispersal of points. This dispersal is as expected if the mineral lineations represent Group 1 fold axes redistrubuted by later folding.

All folding seen in the area has S_1 folded and therefore represents Group 2 deformation. This was confirmed by examining several thin sections from the hinge areas of folds; all had S_1 folded around with layering. The deformation was seen as folds or crenulations in schists. The folds are open to tight in nature.

The Group 2 fold axes (from minor folds and crenulations) are plotted in Figure 3. A distribution approximately along a great circle, vertical and striking 060°, is found. The great circle distribution is consistent with the Group 2 deformation being imposed on previously folded rocks.

A second schistosity (S_2) is developed axial plane to the Group 2 folds. (See Plates 5 and 6). In thin section S_2 is defined by a second preferred orientation of tabular biotite, muscovite, sericite and chlorite. In one case in a calc-silicate from the hinge of a fold, hornblende prisms were oriented parallel to S_2. In one section quartz grains were elongated apparently parallel to S_2. The minerals defining S_2 were often definitely re-crystallized in that orientation. They were surrounded by, and sometimes truncating minerals with an S_1 preferred orientation. (See Plate 8). S_2 is sometimes defined by an alignment of minerals due to crenulation of S_1. (See Plate 9).

In some outcrops and thin sections S_2 is the dominant schistosity. This is the case in the locality mentioned

locality mentioned/
before where the S_2 axial plane to a Group 2 fold was thought to be S_1 crossing the layering. The stereo plot of poles to S_2 (Fig.4) shows a good concentration of S_2 approximately vertical and striking 105° reflecting the reasonably constant orientation of S_2 through the area. The plot of S_1 and layering - S_2 intersections (Fig. 5) coincides fairly well with the Group 2 fold axes as might be expected if S_2 is the axial plane schistosity of the Group 2 folds.

Two major faults occur in the area, one just south of Wiperaminga Hill running approximately E-W, one to the north striking about 120°. An amphibolite occurs in the region of the southern fault. Both faults have fault breccia occurring along their length. The fault breccias have Cu minerals present in them which results in a number of small Cu diggings along the faults. The more northerly fault apparently displaces the chiastolite schists and the calc-silicates to the north-west on the south side of the fault. This and the dragging around of some of the schists near the fault suggest the movement on the fault is dextral. A few other small faults were mapped in the area, but generally faults are hard to discern in the area because of the lack of good marker horizons.

Boudinaging is another feature seen in the area. It is seen on the small scale, in one case with finer schists wrapped around coarser blocks, and on a larger scale with outcrops or more massive calc-silicates or quartzite as boudins within schists.

On the southern side of the fault south of Wiperaminga Hill there is an area of quite confused schistosity orientation (see map of structural elements). The general picture is of a synform plunging south-west, but complications are indicated by some schistosity orientations, and the confused pattern of occurrence of the calc-silicates in the area. (See geological map). In the area some "basin" structures with gently dipping sides were seen. These could be taken as indicating as indicating/

2 phases of non isoclinal folding. However, the complications in this area are quite possibly due to movement on the major fault just to the north deforming the nearby rocks.

Apart from this locality, the structural picture in the area is of S_1 generally trending E.N.E. but deformed in places by the Group 2 folding. North of Wiperaminga Hill a fold can be seen in S_1 with S_2 axial plane to it. In the central-west of the area the western end of the chiastolite schist is folded around in a Group 2 fold. The chiastolite schists and S_1 are deformed by a drag fold in about the centre of the area and S_2 is strongly developed axial plane to this feature.

Through this part of the area the vergences are S - type (with the S_1 - S_2 relationship in agreement with this). East of the chiastolite schist the vergences and, generally, the S_1 - S_2 relations change to Z type. This may indicate a structure of the nature of that sketched in Fig. 6 (b).

In the east of the area the calc-silicate rocks outline some Group 2 folds with S_2 developed in their hinge areas.

The occurrences of lithologies do not help much in determining the overall structure of the area. In many places there is not good continuity of lithologies along strike. Considering about the centre of the area a "stratigraphy" north to south could be suggested of migmatite and granite gneiss, mica schists, calc-silicates, mica schists and chiastolite schists. However, calc-silicates and albitized rocks (albitized calc-silicates?) also occur to the south and south east of the chiastolite schists. This apparent repetition of lithologies and the irregular lenticular outline of chiastolite occurrence (which may be simply due to impersistence of chiastolites along strike) could suggest that a large scale fold interference pattern is present, (perhaps Type 2 (Ramsay 1962)). This, however, is only speculation.

SUMMARY AND CONCLUSIONS

The rocks of the Wiperaminga Hill area conform to the general ideas held for the geology of the Willyama Complex. The rocks were probably originally pelitic and quartzo-felds-pathic sediments. These underwent metamorphism (at 1700 (at 1700/

million years) to upper amphibolite grade. This grade is indicated by the presence of sillimanite. Hornblende and clino-pyroxene formed in the more calcic rocks. Contemporaneous deformation into isoclinal folds (Group 1 folding) resulted in the formation of a strong mica schistosity, S_1 (mostly parallel to layering) in most of the rocks. No situations where S_1 was not parallel to layering (i.e. no Group 1 fold hinges) were found in the area. Also at this time there was implacement of granite gneiss and possibly feldspathization of some schist.

A second deformation (Group 2) deformed S_1 and layering and had a second schistosity S_2 developed axial plane to its folds. All folds seen in the area are of this generation. The schistosity relationships in these folds is shown in Fig. 6(a). The overallstructural pattern in the area is of S_1 and layering generally trending E.N.E. deformed to some extent by Group 2 folds and by 2 large faults in the west of the area.

At a later stage there was a retrogressive phase of greenschist facies metamorphism. This resulted in the presence in the area of chlorite, a large amount of epidote and sericite (some replacing pre-existing minerals). Also at a quite late stage albitization and related brecciation of some calc-silicate rocks took place.

Acknowledgments

I would like to thank Dr. Etheridge and Dr. Oliver for their supervision and assistance during the year. The project was done in cooperation with the South Australian Department of Mines. I gratefully acknowledge its help. In particular, I would like to thank Graham Pitt for his assistance in starting the project. Thanks go to fellow students for discussions and help during the years, in particular to J. Parker, who worked in an adjacent area to mine, also to D. Milton for carrying out a whole rock analysis for me.

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Plate 1. Location no. B 6. Chiastolite schist.

Plate 2. Location no. A 7. Brecciated albitized rock.

Plate 1

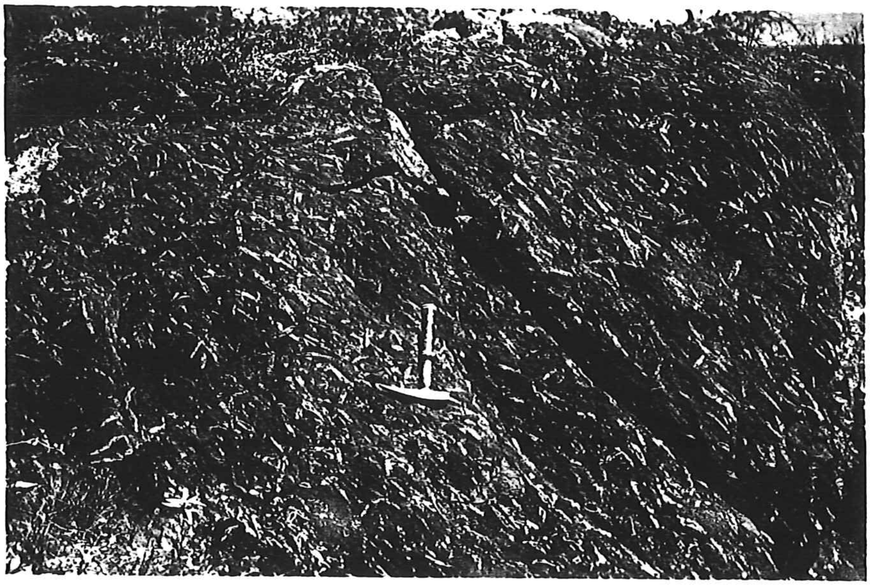


Plate 2

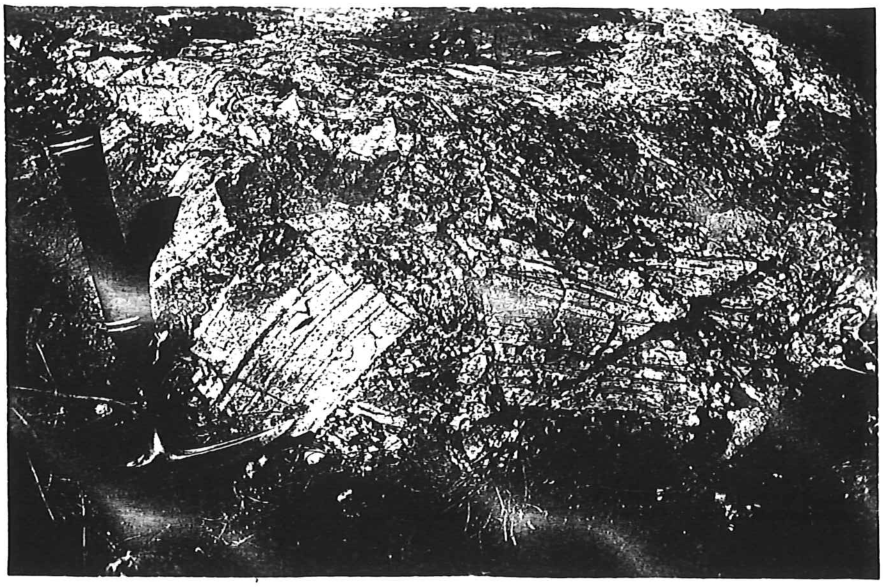


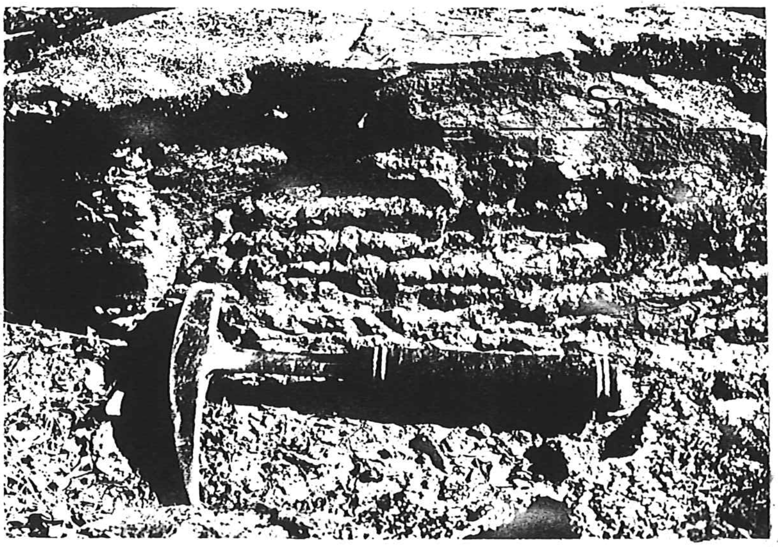
Plate 3. Location no. A 8. Folds in foliated granite gneiss.

Plate 4. Location no. K 24. Migmatite layering isoclinally folded along S_1.

Plate 5. Location no. A 5. Schist with two well developed schistosities.

Plate 3

Plate 4



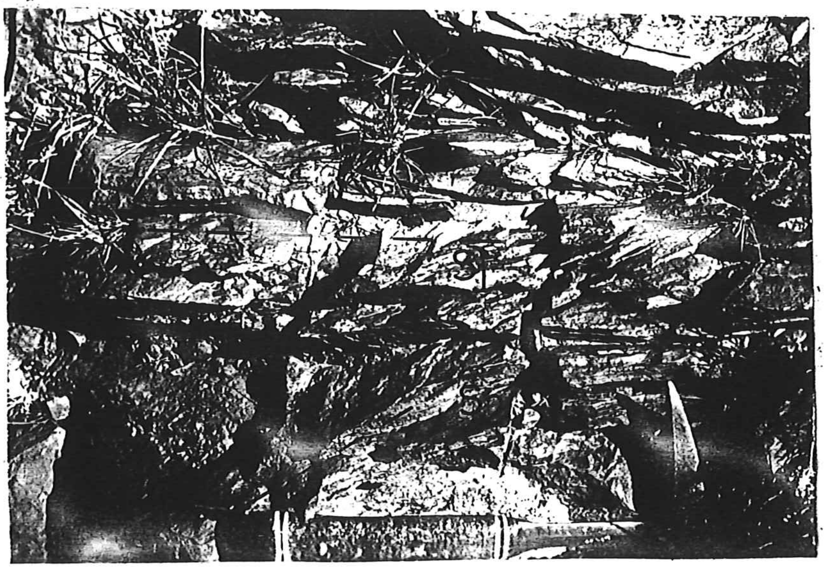


Plate 5

Plate 6. Location no. G.56. A fold hinge Layering and parallel S_1 folded and S_2 developed.

Plate 7. Sample G 47. Photomicrograph. Biotite with good preferred orientation as inclusions within coarse albite crystals.

Plate 6

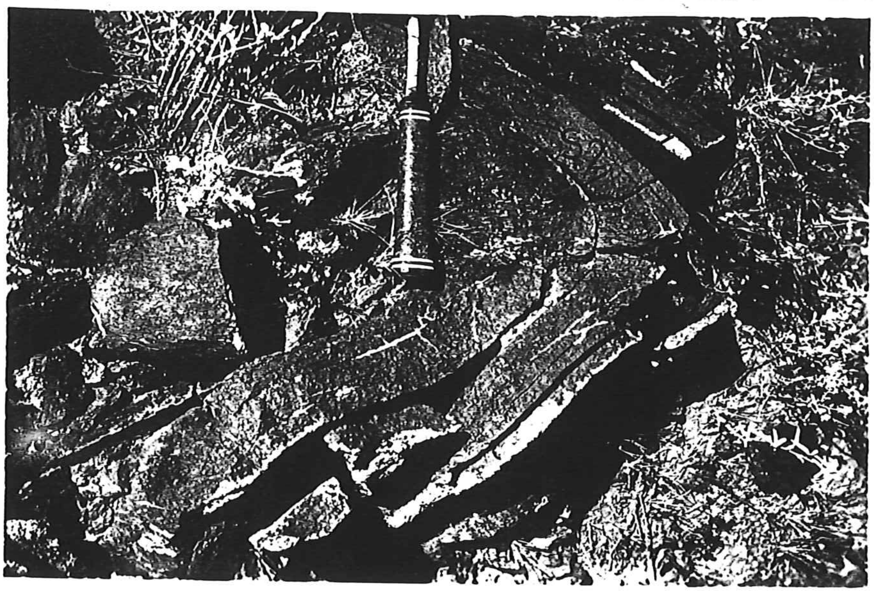


Plate 7

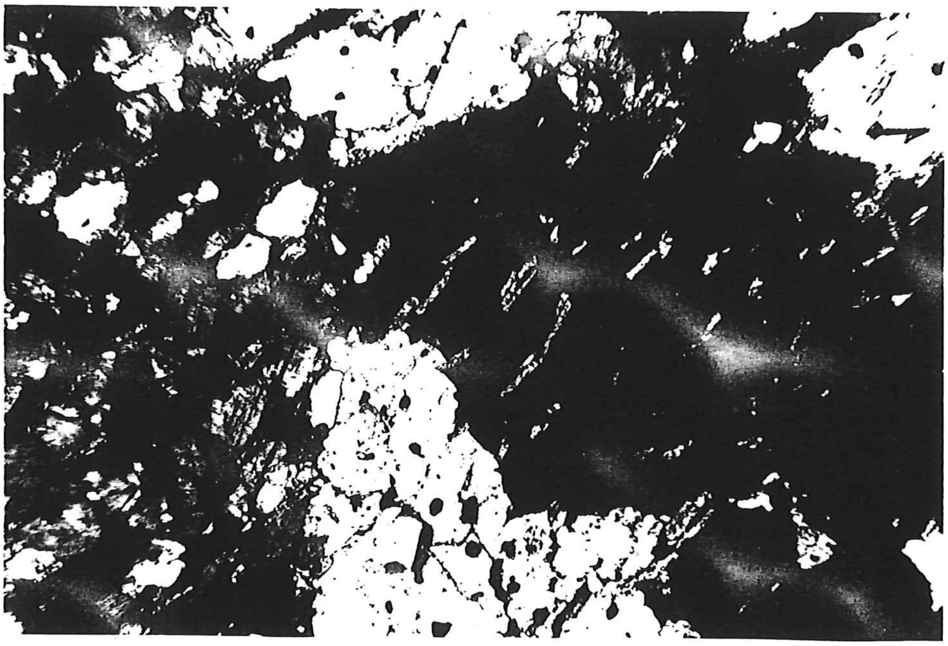


Plate 8. Sample F 7. Photo micrograph.
Biotite with 2 preferred orientations.
S1 parallel to layering. S_2
truncating other biotites and cross
cutting layering.

Plate 9. Sample K 71. Photomicrograph
Crenulated mica schist.

Plate 8

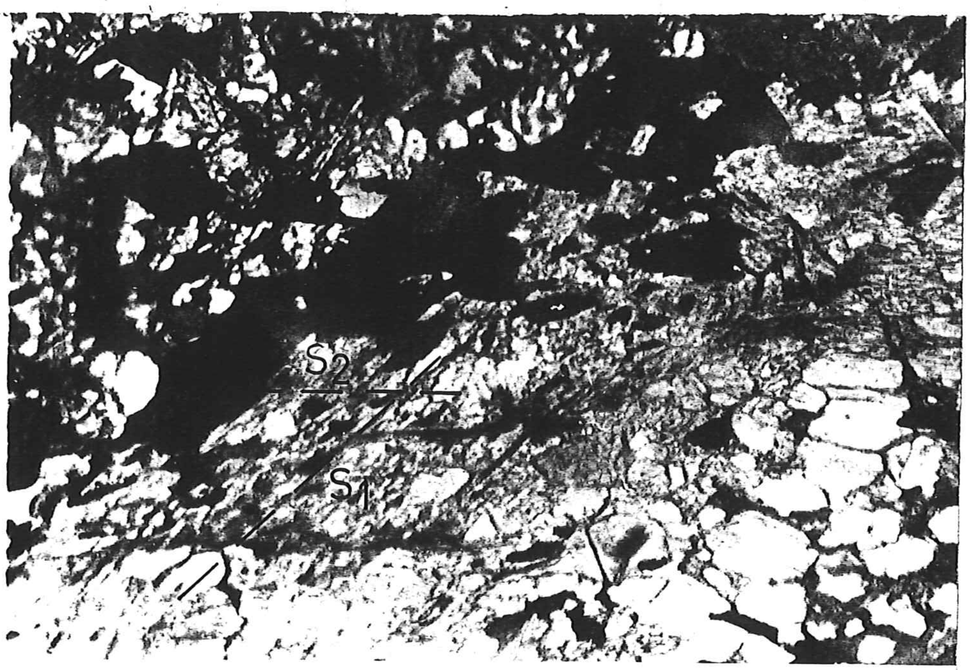
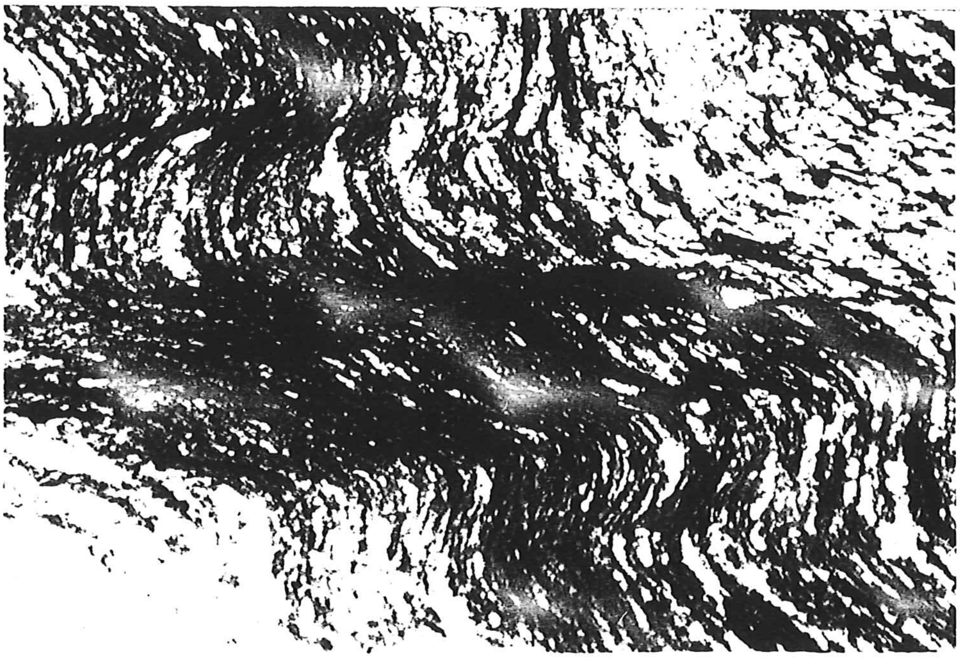


Plate 9



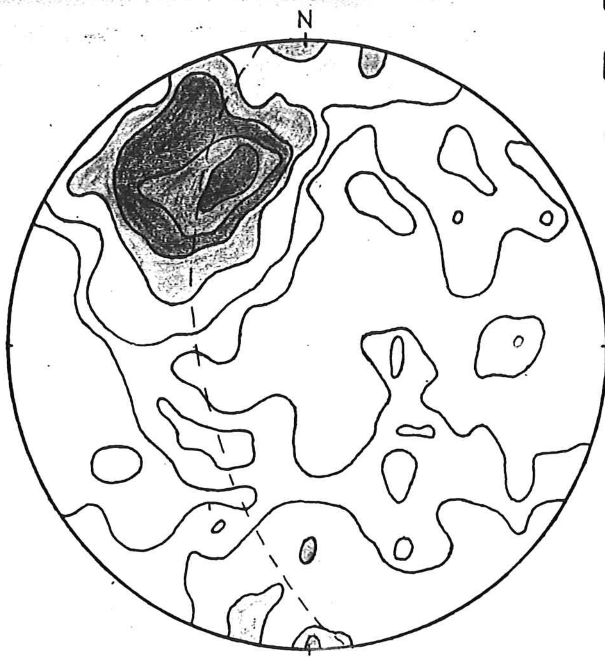


Fig. 1

Poles to layering and S_1

488 Poles
Contours at 0.5,1,2,3,4, and 5 %. per 1 %. total area.

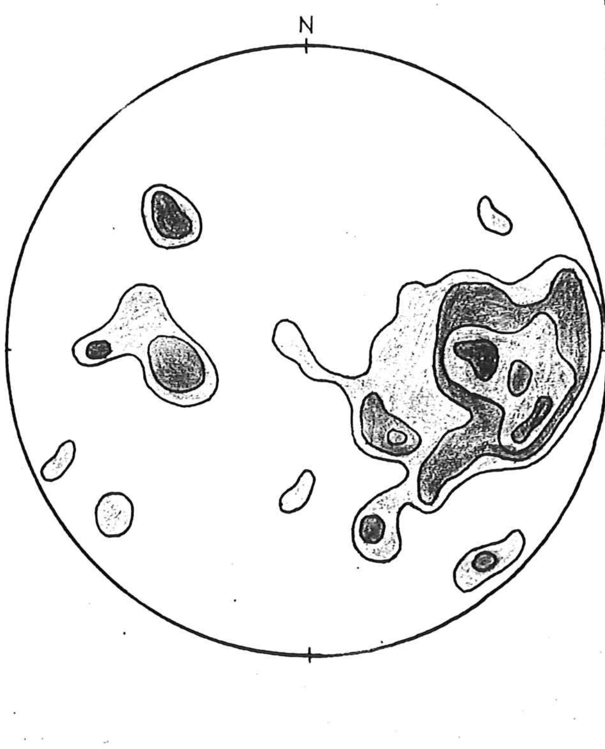


Fig. 2

Mineral lineation plots

52 Plots
Contours at 2,3,5, and 7 %. per 1 %. total area.

R.S.R.

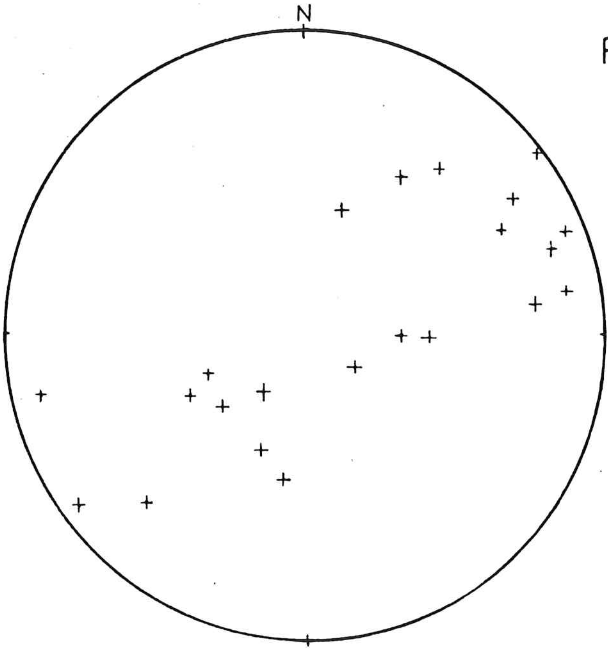


Fig. 3

Fold axes (group 2)

22 Plots

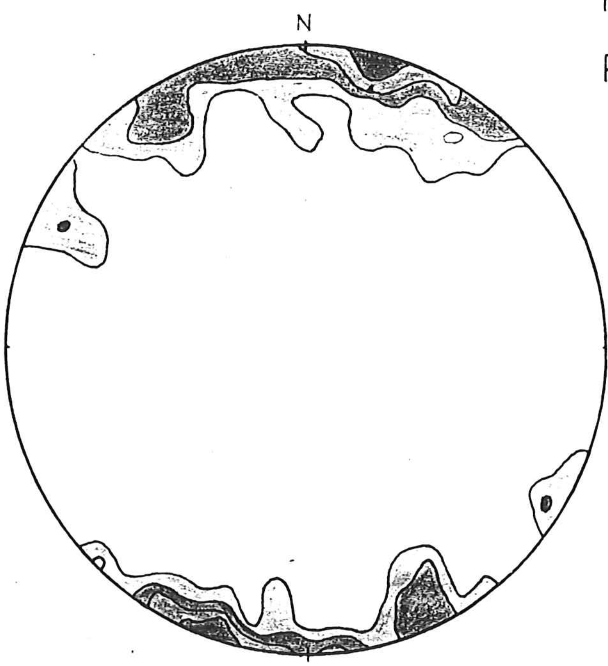


Fig. 4

Poles to S_2

72 Poles

Contours at 2,4,6 and 10% per 1% total area.

R.S.R.

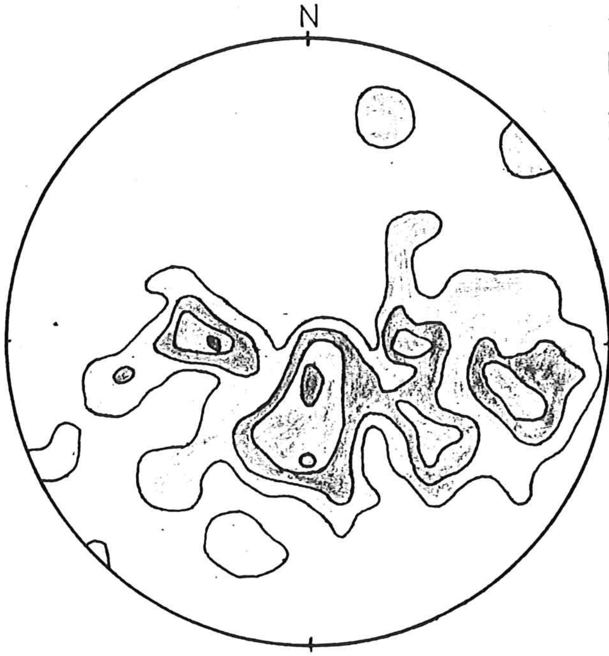


Fig. 5

Layering and S_2 intersections

59 Plots

Contours at 1, 3, 5 and 8 % per 1 % total area.

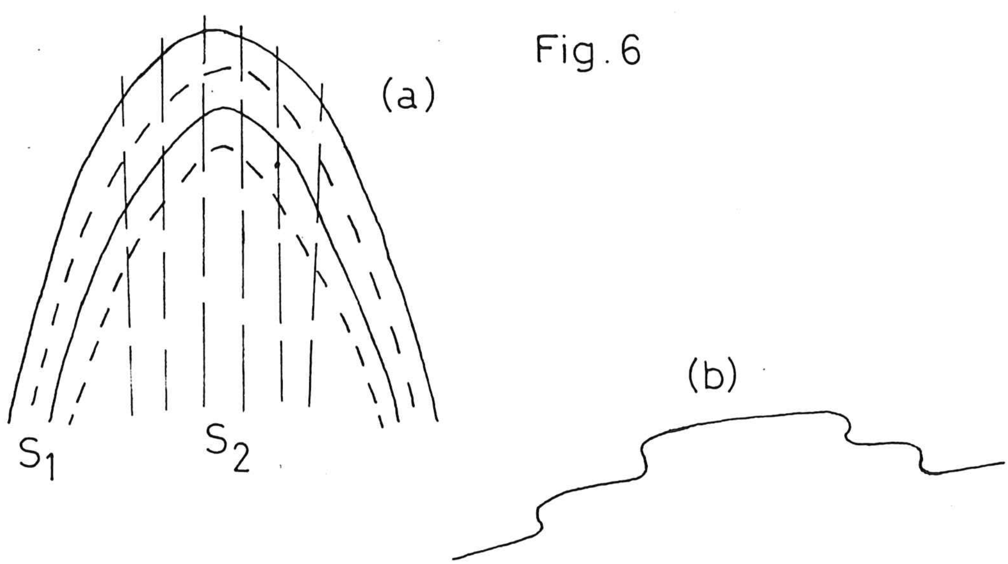


Fig. 6

R.S.R.

APPENDIX

Thin Section descriptions.

384/A.7. Macro. Feldspathic rock with layers of amphibole and epidote. Layered angular blocks within feldspar and amphibole matrix.

Micro. 10% Amphibole - hornblende, 0.5 - 1 m.m. grain size. Anhedral, poikilitic with albite about 0.1 m.m. within it. Layered.

75-85% Feldspar - mostly albite (Ab 98). Grain size 0.05 - 2 m.m. Anhedral grains in mosaic. Few grains of microcline.

3 - 5% Clino-pyroxene, mostly as rims around hornblende. 1 - 2% Epidote anhedral to poikilitic. Associated with hornblende grains.

Minor-Sphene
Opaques

Fabric. In part of the thin section layering hornblende epidote, and opaques is present. Hornblende in constant optical orientation.

Rock name - Albitized rock.

384/A 12. Macro. Dark rock with coarse garnet, epidote and quartz visible.

Micro. A coarse grained rock.

30% Garnet 0.3 - 3 m.m. grain size. Brown colour mostly anhedral.

25% Epidote. Grain size 0.3 - 3 m.m. Anhedral, green-yellow pleochroism.

45% Quartz. In between and inside masses of above minerals.

Rock name - Epidote, garnet quartzite.

384/C 7 Macro. Medium grained grey (weathered to brown) schist.

384/C 7

Micro. 5% Biotite - 0.2 m.m. grain size.
Tabular

5% Muscovite - 0.2 m.m. grain size.

15% Sericite. In large ragged masses, some around muscovite grains. Some replacing pre-existing porphyroblasts?

3 - 5% Chlorite. Light green to colourless. Needles or fibrous aggregate. Approx. 0.2 m.m. grain size.

70% Quartz, approx. 0.1 m.m. grain size.
Grains mostly equidimensional, some elongate.
Fabric: Lepidoblastic texture. Layering defined by concentrations of sericite. Preferred orientation of biotite, muscovite, chlorite (fairly poor) and some elongate quartz parallel to this layering. This layering and schistosity is folded. Some biotite and chlorite is aligned axial plane to these folds.
Rock name - Quartz, mica schist.

384/D1

Macro. Fine to medium grained grey crenulated schist.

Micro. 35-45% Quartz. 0.1 - 0.2 m.m. Some grains with undulose extinction.
40-45% Muscovite as large (0.5 m.m. length) tabular crystals.
5% Sericite, interstitial to larger grains .
5% Biotite. Approx. 0.5 m.m. grain size.
Truncated and ingrown by muscovite.
3 - 4% Amphibole - hornblende. Anhedral.
Minor opaques, concentrated in or near biotite patches.
Fabric. Layering of concentrations of micas.
Schistosity parallel to this layering - preferred orientation of micas, amphibole and some elongated

384/D1 (Cont.)
some elongated/

quartz grains. This foliation is folded and some muscovite and biotite is axial plane to these folds. Lepidoblastic texture .
Rock name - Crenulated quartz mica schist.

384/D 29. <u>Macro</u>. Medium to coarse grained amphibole rich rock.
<u>Micro</u>. 30 - 40% Amphibole - hornblende. In coarse tabular grains, shreddy masses or anhedral equidimensional grains.
20 - 30% biotite, tabular.
10 - 20% Albite, coarse crystals with many inclusions of epidote, hornblende, biotite; also quartz and K feldspar?
3 - 5% Epidote, as inclusions or larger crystals.
10-15% Quartz. Some polygonal grains. Some other larger grains with much undulose extinction.
5% K feldspar - microcline.
2% Opaques, as masses in centre of biotite and hornblende aggregate.
Lepidoblastic texture - orientation of tabular biotite and hornblende.
Rock name - Amphibolite.

384/E 10 <u>Macro</u>. Granite gneiss with foliation.

<u>Micro</u>. 25 - 35% Quartz. Equidimensional grains - 1 m.m. size. Well developed undulose extinction in most grains.
50 - 60% K. Feldspar - microcline. Coarse grained, contain some inclusions.
10 - 15% Plagioclase, contain a number of inclusions.
3 - 5% Biotite, anhedral crystals, equidimensional.
Granoblastic texture, but biotites have preferred

384/E 10 (Cont.)
have preferred/
optical orientation.

384/E 44. **Macro.** Fine grained, massive, grey-green rock.

Micro. 65 - 75% Feldspar. Grain size 0.1 - 0.05 m.m. Grains equidimensional. Mostly K - feldspar, small amount of plagioclase.
15 - 20% Hornblende. Grain size 0.1 m.m.
10 - 15% Epidote. Anhedral, colourless.
3 - 5% Quartz.
Fabric - Granoblastic texture. No preferred orientation or layering.
Rock name - Epidote Hornfels.

384/F 7 **Macro.** Medium grained schist with layering visible. From the limb of a minor fold.

Micro. 40 - 50% Quartz. Grain size 0.1 - 0.3 m.m. Many grains elongated.
10-15% Muscovite. Some 1 - 2 m.m. grain size. Some fine grained interstitial.
5% Sillimanite. Fine needles, mostly in quartz host. Weak preferred orientation.
30 - 35% Biotite.
Fabric - Layering defined by concentrations of biotite and sillimanite. Some biotite parallel to layering (S_1). Most biotite and some elongated quartz grains have a preferred orientation cross cutting layering.
Rock name - Sillimanite, quartz, schist.

384/G 14 **Macro.** Fine grained, well layered rock. Grey to reddish colour. Boudinaging of finer layers around coarser layers.

384/G 14 (cont.)

Micro. Outer layers.

70% Feldspar

2 - 3% Quartz

10 - 15% Opaques

10% Epidote. Needles.

5% Piedmontite. Anhedral, Pleochroic, bright red to pink.

Also layers with a large amount (up to 80%) of fine garnet.

Central boudins contain coarse piedmontite and garnet.

384/G 20. Macro. Fine grained layered, grey schist.. Folded.

Micro. 5 - 10% Biotite. Tabular 0.1 - 02 m.m. grain size.

3 - 5% Opaques. Anhedral.

1 - 2% Muscovite.

80 - 85% Feldspar. Very little twinning.

384/G 20 (cont.)

Very little twinning./

Where present mostly microcline. Some undulose extinction. Grain size 0.05 - 0.5 m.m.
Fabric - Layering defined by biotite and opaques. Biotite preferred orientations and some elongation of feldspar grains parallel to layering. This foliation is folded. In hinge zone of fold some biotite grains parallel to axial plane - S_2.
Lepidoblastic texture.
Rock name - Feldspathic schist.

384/G 47. <u>Macro</u>. Fine grey layered schist.

<u>Micro</u> 3 - 5% Quartz. Grain Size .05 m.m.
As inclusions in albite or as discreet grains.
Undulose extinction.
80% Feldspar. Smaller grains, $\frac{1}{2}$ microcline and $\frac{1}{2}$ plagioclase. Some inclusions. Also large amount of coarse albite crystals (Ab 95)
Grain size 0.5 - 2.00 m.m.
Large number of inclusions of biotite with a preferred orientation parallel to that in the rest of slide.
7 - 10% Biotite. Tabular with preferred orientation.
3 - 5% Opaques. Some hexagonal; graphite?
Rock name - Feldspathic schist.

384/H 38. <u>Macro</u>. Fine to medium grained schist.

<u>Micro</u>. 5 - 7% Biotite. Tabular. Grain size 1.00 m.m. - 0.1 m.m.

3 - 5% Muscovite 0.5 m.m. to fine sericite.

1 - 2% Chlorite. Associated with

384/H 38. (Cont.)

Associated with/

biotite grains. Grain size 0.05 - 1.00 m.m.

2 - 3% Garnet. Enhedral porphyroblasts. Schistosity bent around crystals

5% Sillimanite. Fine needles in masses or included in quartz grains.

70-80% Quartz. Grain size 0.05 - 1.00 m.m.

Fabric - Preferred orientation of micas (muscovite not as good as biotite) and sillimanite parallel to layering. A second cross cutting preferred orientation (S_2) is also developed in micas (and sillimanite?)
Lepidoblastic texture.
Rock name - Quartz schist.

384/I 39. Macro. Fine light coloured schist. Folded and crenulated.

Micro. 30 - 40% Quartz. Grains equidimensional, some polygonal grains. Few larger grains have undulose extinction.
40 - 45% Muscovite. Tabular. Grain size 0.1 - 0.5 m.m.
Also some sericite.

10 - 15% Biotite. Tabular, grain size 0.1 m.m.

3 - 5% Chlorite.

Minor Garnet - subhedral.
Fabric - Strong preferred orinetation of micas parallel to layering. Folded and crenulated.
Lepidoblastic texture.
Rock name - Quartz schist.

384/I.61.

Macro. Fine dark grey schist containing large chiastolite prisms.

Micro.

Approx. 25%. Chiastolite porphyroblasts. 10 m.m. across. Enhedral. Some fine sericite within the crystal.

15 - 20% Musocvite. Grain size 0.1 m.m.

15% Biotite. Shapeless grains, 0.05 - 0.1 m.m. grain size.

30 - 40% Quartz. Very fine quartz as a matrix. Also some coarser quartz with undulose extinction.

10% Opaque - probably graphite. Very fine. Anhedral.

Fabric - Layering defined by concentrations of graphite. Some biotite and muscovite parallel to layering. Foliation bent around porphyroblast.

Rock name - Chiastolite schist.

384/K 25

Macro. Medium grained, grey, layered schist

Micro. 10% Biotite. Tabular to prismatic 0.2 - 0.5 m.m.

85% Feldspar. Grain size 0.1 - 0.4 m.m. Mostly plagioclase. Ab 67. Some microcline.

2 - 3% opaques. Anhedral. 0.01 - 0.05 m.m.

Fabric - Layering given by amount of biotite. Biotite has 2 preferred orientations one parallel to layering the other cross cutting. Lepidoblastic texture.

Rock name - Feldspathic schist.

384/N 4.

Macro. Fine grained rock with light and dark layering.

Micro. 5 - 10% Amphibole - hornblende. Grain size 0.05 - 0.5 m.m. Anhedral to subhedral prismatic

75 - 85% Feldspar. Grain size 0.1 - 0.4 m.m.

Mostly microcline twinning, some plagioclase.

1 - 2% Epidote. Anhedral 0.05 - 0.1 m.m.

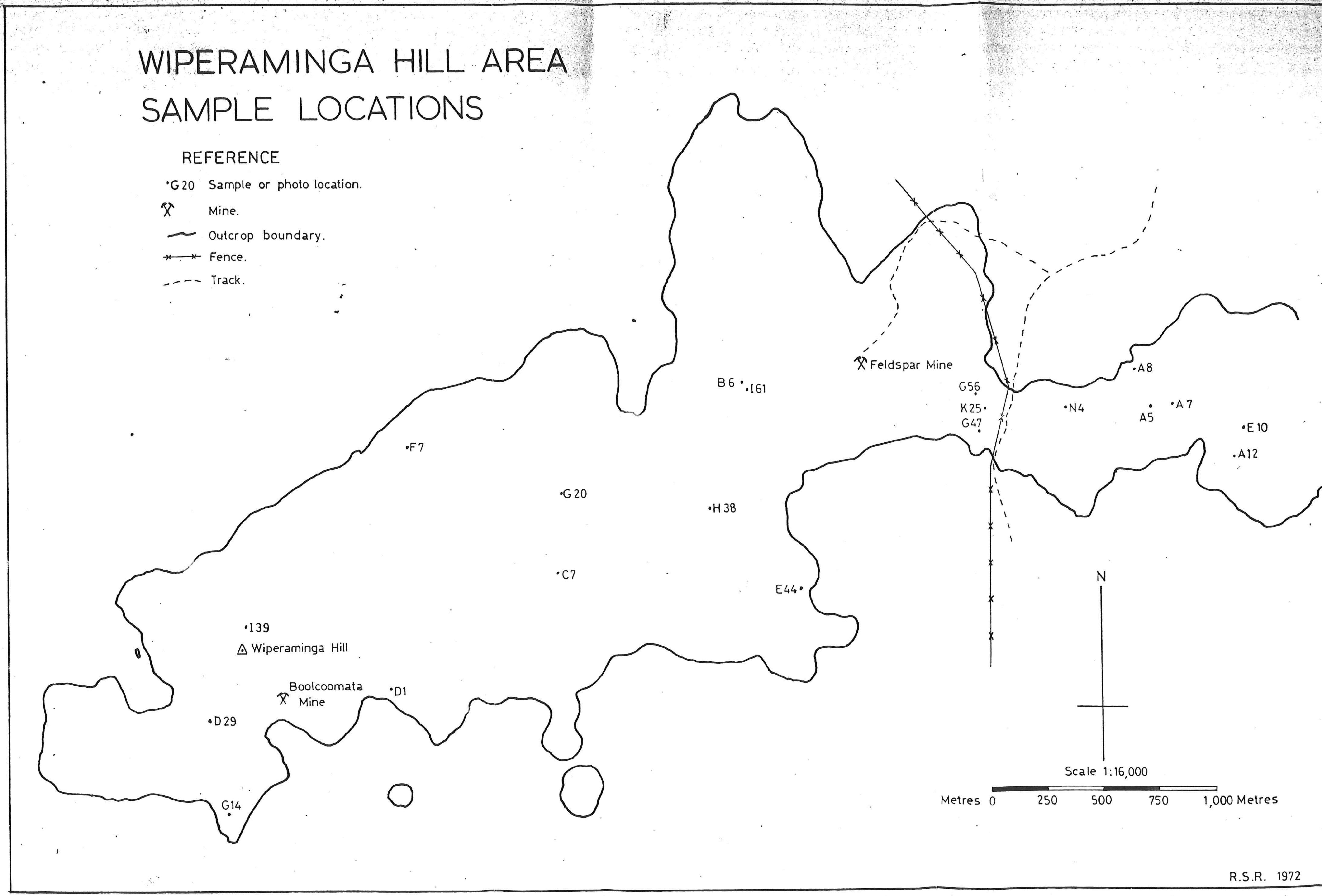
3 - 5% Clino pyroxene. Anhedral, 0.05 - 0.1 m.m. grain size.

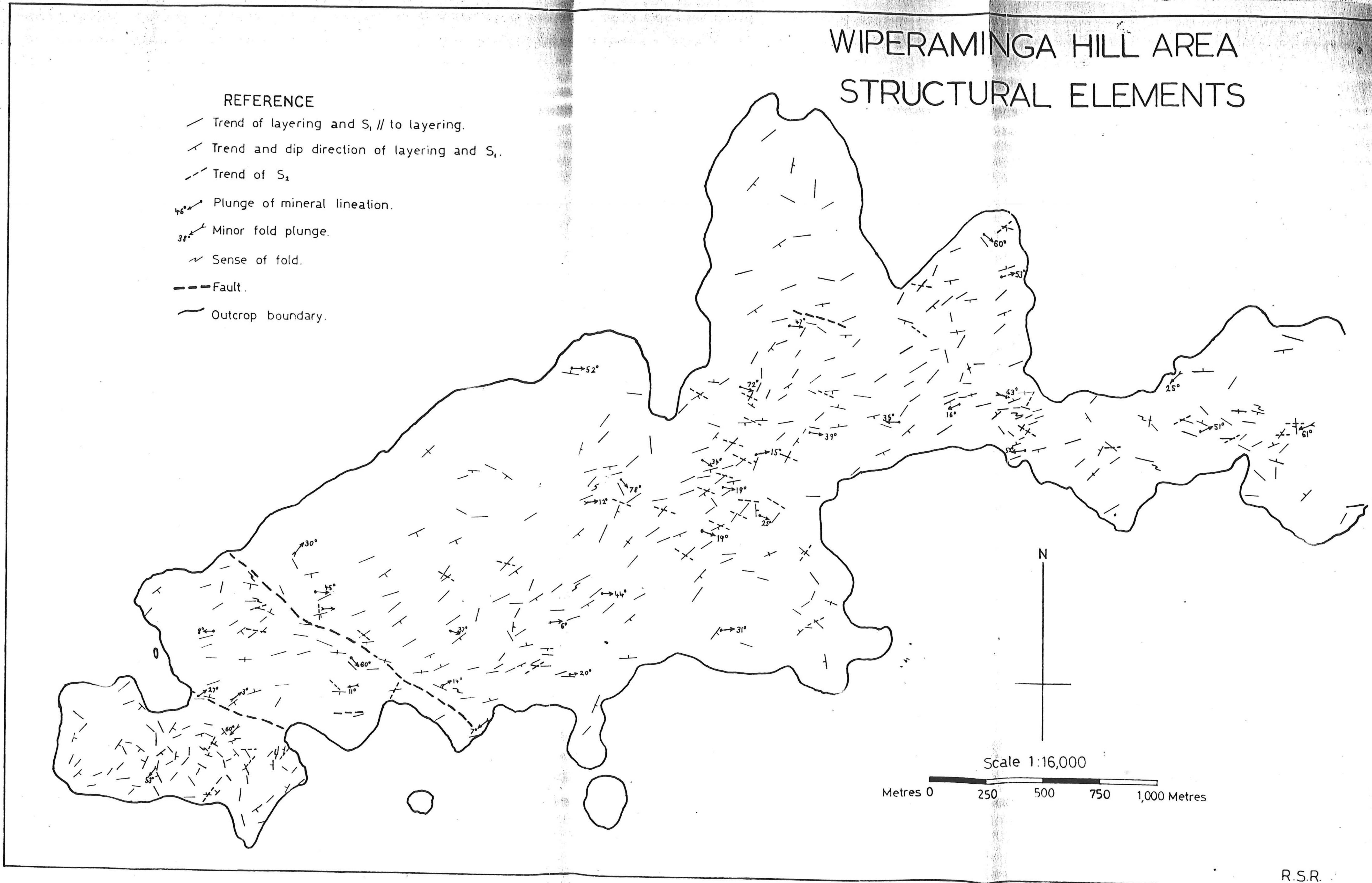
Minor. Calcite ?

Opaques.

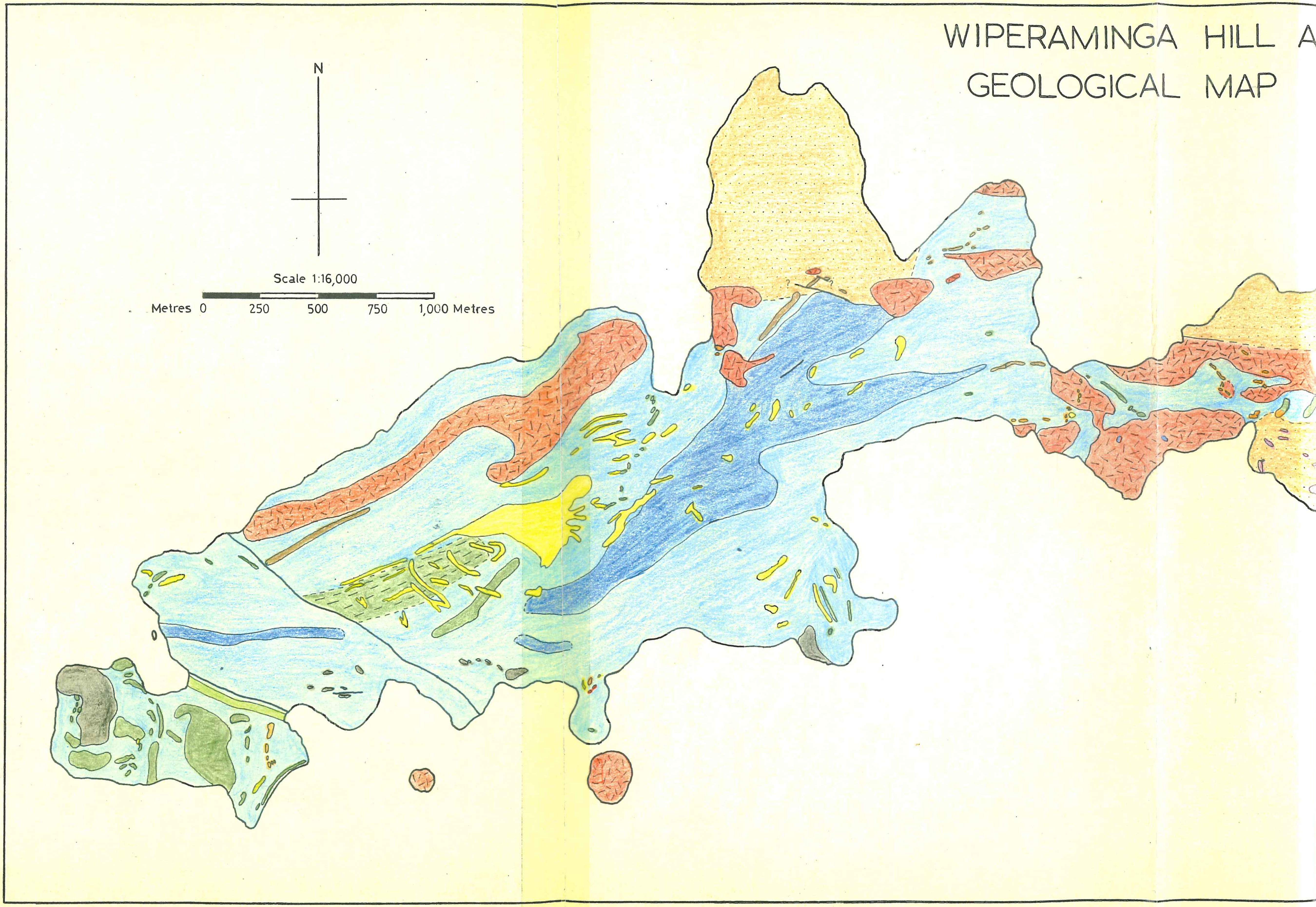
Fabric - Granoblastic texture. Layering defined by hornblende, clino pyroxene or epidote.

Rock name - Hornfels.


WIPERAMINGA HILL AREA
SAMPLE LOCATIONS
REFERENCE
•G 20 Sample or photo location.
Mine.
Outcrop boundary.
Fence.
Track.
Feldspar Mine
B 6
161
G56
K25
G47
N4
A8
A5
A7
E 10
A12
F7
G 20
H 38
C7
E44
I39
Wiperaminga Hill
Boolcoomata Mine
D1
D 29
G14
N
Scale 1:16,000
Metres 0 250 500 750 1,000 Metres
R.S.R. 1972


WIPERAMINGA HILL AREA
STRUCTURAL ELEMENTS
REFERENCE
Trend of layering and S1 // to layering.
Trend and dip direction of layering and S1.
Trend of S2
Plunge of mineral lineation.
Minor fold plunge.
Sense of fold.
Fault.
Outcrop boundary.
N
Scale 1:16,000
Metres 0
250
500
750
1,000 Metres
R.S.R.

WIPERAMINGA HILL A
GEOLOGICAL MAP



WIPERAMINGA HILL AREA
GEOLOGICAL MAP