

Honours B.Sc. Thesis

THE GEOLOGY OF THE MT. CRAWFORD GNEISSIC GRANITE  
AND ITS ENVIRONS.

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SUMMARY.

A description of the stratigraphy of the area is given, with associated petrographic notes on each unit of the sequence.

The petrology of the Mt. Crawford Gneissic Granite, its variation, the nature of the enclaves and contacts with the surrounding schists is discussed.

Descriptive notes on the petrology, mineralogy, and occurrence of various amphibolites and pegmatite dykes, have been added.

A study of the variation of minor minerals in the granite and its enclaves, and their relation to the surrounding sediments is presented.

The structural geology of the area with special reference to a statistical study of jointing and lineation in the granite, and micro-folding in the surrounding schists is summarized; and a possible theory to explain the evidence is given.

Conclusions on the possible origin of the granite, the amphibolites, and a discussion of the metamorphism and metasomatism in the area in the light of the petrological, mineralogical, and structural evidence concludes the paper.

## INTRODUCTION.

The area under consideration is situated some 30 miles north - east of Adelaide, extending south and west from the South Warren Reservoir, approximately 4 miles south - east of Williamstown on the Williamstown - Birdwood road.

The mapping programme, with its associated petrological, mineralogical and structural studies, was carried out to attempt to ascertain the nature and the origin of the Mt. Crawford Gneissic Granite and its relation to the country rocks.

The granite body is elongated parallel to the schistosity (and bedding) strike, and extends over a distance of 3 miles with a maximum width of one third of a mile. The total area mapped was some 9 square miles, bounded to the north by the South Para Creek (and the South Warren Reservoir), to the east by an area of alluvium, to the south by Dead Horse Gully and to the west by the Kitchener Fault line. The area adjacent to the granite was mapped in detail and the western part mapped in less detail for structural purposes.

The area is largely Crown Land; the eastern part being the western section of the Mt. Crawford Pine Plantations, the central part leased grazing land and the western part steep virgin scrub country.

The topography varies from the steep rugged country to the west, on the eroding fault scarp, to low rounded uplands and alluvial slopes to the east, grading out onto the Mt. Crawford plains to the south - east.

The highest point in the area is the central Warren Hill Lookout Tower, reaching over 1700' above sea - level. This hill is on a prominent north - south ridge marking the top of the Kitchener Fault scarp. The steep eroding scarp country to the west has a relief of some 800', with steep youthful watercourses running in deep channels with gorges and steep waterfalls. The South Para Gorge is distinctly antecedent, the river erosion almost keeping pace with the scarp development.



East of the Lookout Tower the uplands are gently undulating and often covered with original and reworked alluvium and weathering products of the old uplifted Tertiary peneplain. Here the topography has a semi-mature appearance.

The area has been regionally mapped by the south Australian Mines Department Geological Survey and the results recorded on the Gawler one mile Geological sheet. The metamorphic rocks have been correlated with the lower part of the Torrensian Series of the Adelaide System. The mapping also indicated that the area was a metamorphic high in the metamorphosed eastern part of the Mt. Lofty Ranges.

## HISTORICAL SUMMARY.

The area first became of geological interest when early in 1884 Watts discovered gold in a tributary of Dead Horse Gully. The following year the gold-rush to the Mt. Crawford Goldfields began, and in 1886 Harry P. Woodward <sup>1.</sup> produced the first geological report of the area. This report dealt largely with the gold drifts, but Woodward makes some interesting observations on the origin of quartz and granite dykes (pegmatites), and of the occurrence of opal in the area. He presents an interesting and surprizingly accurate topographic map of the area.

In 1926 Howchin <sup>2.</sup> reported that the stratigraphy could be correlated with the lower part of the Adelaide System, with the coarse cross-bedded pebbly sandstone as the basal bed.

Hossfeld in 1935 <sup>3.</sup> regarded the sequence as reversed; the metamorphic schists being Barossian (Archaean) and the cross-bedded Proterozoic sandstone being unconformable with the schists. He records the occurrence of talc, hydromica, muscovite, biotite, chlorite, kyanite, quartz, actinolite, magnetite, and pegmatized schists with local tourmaline, magnetite, garnet, rutile and ilmenite concentrations. He regards the granite as being the result of "pegmatization" and the opalization of the marbles as the consequence of this process.

In 1942 Alderman <sup>4.</sup> studied the area immediately north of the Warren Reservoir and presented evidence for the production of the massive sillimanite and kyanite rocks there, by alumina metasomatism. He showed that the zone was rather local and was surrounded by metamorphosed rocks of the biotite grade of progressive regional metamorphism.

The aluminosilicates were found to occur in various ways, and from these a well-defined series of phases of metasomatic activity based on temperature and alumina concentration could be worked out. The sequence of activity ranged from phases of Al, Si, Ti, (B) metasomatism to a late stage of pegmatization and a final hydrothermal stage which vastly affected the rocks

causing clays to be derived from sillimanite and damourite (sericite) from kyanite.

Campana and Whittle (1953) <sup>5.</sup> in an explanation of the Gawler one-mile Geological Sheet described the area under present consideration. They discuss the petrology of some of the rocks of the area as being of metasomatic origin, including local garnet, rutile and aluminosilicate concentrations. Campana claims that alumina metasomatism has converted the basal grit to the mica schists and discounts a purely stratigraphic variation.

DESCRIPTIVE PETROLOGY.

(a). GENERAL STRATIGRAPHY.

The sequence east of the central Lookout Tower Anticline has been studied in detail and is used as type area although reference to the western part will be made at appropriate places.

(1). The Basal Arkosic Sandstone Member.

This is the oldest bed represented in the area and outcrops in the core of the Lookout Tower Anticline. The anticline plunges slightly north, the sandstone core ending in Sailors Gully. The core reappears as a double anticline just south of the reservoir. Outcrops are rare in this double anticline, but several outcrops at the edge of the reservoir consist of a medium to coarse grained banded feldspathic sandstone, cross-bedded in part, with titaniferous haematite granules outlining some of the bedding planes; and sometimes occurring in bands of almost pure iron ore several inches thick. Muscovite is an accessory constituent. Pebbles are sometimes found in these outcrops and have been strongly flattened during metamorphism, into circular plates up to 10" in diameter and averaging 1" thick. The circular plates are oriented parallel to the bedding planes. The pebbles are generally smooth, waterworn, massive, quartzites, some showing their own bedding planes outlined with titaniferous haematite. In the eastern part of the northern core the soft sandstone contains stumpy tourmaline granules thought to be introduced; possibly being related to the pegmatization on the eastern edge of the core.

South of the Lookout Tower the anticlinal core is isoclinally folded, and the sandstone of the crest of the fold in Sailors Gully has been strongly recrystallized to a tough coarse grained quartz, muscovite rock. The quartz is a milky white variety which seems to characterise the basal sandstone. The muscovite is a pale green variety which occurs as small aggregates of stumpy flakes in decussate arrangement throughout the rock. The quartz is strongly lineated. White semi-opaque quartz and quartz - muscovite veins are also commonly developed

here.

In the south, a fault with a large vertical displacement has exposed a steep scarp of the basal sandstone. Here outcrop is well-exposed, and the cross-bedded nature of the rock is clearly indicated. Boulders are common in the bedding planes, these being lineated into ellipsoids rather than flattened into plates. A typical assemblage is quartz 60%, felspar 35%, titaniferous haematite 3%, and muscovite 2%. The stratigraphic thickness is unknown.

(2). The Lower Tremolite Bed.

A thin transition zone of muscovite rich haematitic sandstones, grading to sandy mica schists, marks the lower boundary of a thick sequence of variable coarse mica rich schists. The schists immediately above the sandstone (slide 2/ 418) are rich in mica, especially muscovite. A typical assemblage is muscovite 80%, biotite 5%, quartz 10%, and felspar 5%, although some varieties are richer in quartz and felspar, and others show small sericite bands and pseudomorphs of sericite after kyanite. These schists are always strongly crenulated; with folding on a variable scale from micro-folding to folds several feet across. The folds are generally very irregular; micro en echelon folding being very common.

The schists are sometimes banded; the quartz - felspar rich bands, commonly showing rounded parallel folding, while the mica rich bands are strongly shear folded. Folding and recrystallisation appear to have been contemporaneous. The quartz - felspar bands of the schists vary from a fraction of an inch to several feet thick, and are best seen on the fresh artificial outcrop at the reservoir weir. Here all gradations from bedded bands to mobilized cross-cutting pegmatoidal segregations, can be seen.

Some 200' above the top of the basal sandstone a thin tremolite - actinolite bed often replaced by opal, may be traced intermittently along the eastern flanks of the Lookout Tower



Anticline. It apparently disappears from the sequence to the south, and has not been found in the western flank (although an amphibolitic bed at the weir may represent a calcic bed in the schists corresponding to this bed). According to Hossfeld 1935<sup>3</sup> the bed may be traced from Williamstown to the Warren Reservoir.

A small shaft near Sailors Gully provided the only fresh specimen of the rock ( slide <sup>2</sup>/ 410 ). It is a pale green tough rock, with green stumpy xenoblastic actinolite crystals of variable size set in decussate structure, in a fine grained cream coloured matrix. The specimen shows a strong ion by ion alteration along sharp boundaries to pale green porous asbestos, retaining silky pseudomorphs of actinolite crystals. The slide shows that the rock is made up entirely of tremolite-actinolite crystals; the fine grained matrix being made up of small, radiate, interlocking fibres, which explains the extreme toughness of the rock.

Elsewhere this bed may be traced by means of relict opaline replacement products, which appear to represent a surface effect only.

Immediately above this bed, a thin fine grained slightly haematitic sandstone may be traced intermittently on the eastern flank of the anticline, and has been recognised at one point on the western flank.

### (3). The Thick Lower Schist Sequence.

To the east of the central anticline, above the thin sandstone bed a thick sequence of predominant quartz, felspar, mica, sericite schists occur. This sequence may be more than 2000' thick and although the schists may be divided into several varieties, no subdivision into smaller stratigraphic units is possible. Subdivision into varieties is apparently based on metamorphic and metasomatic rather than stratigraphic grounds.

The schists are strongly recrystallized and show a prominent





PHOTOGRAPH 1. Massive exposures of the main schist sequence in the South Para Creek Gorge one mile down-stream from the weir. Photograph facing east and looking up-stream.

schistosity. Crenulation folding is strongly developed throughout the whole sequence, although becoming less intense away from the anticlinal core. Knots of fine grained sericite are common throughout the sequence, but are more abundant in certain beds, especially those near the top of the sequence (near the granite). The recrystallization and the intense folding have obliterated the original bedding of the schists and the abundance of sericite knots in some schists tends to distort the mica orientation, and obscure the schistosity of the rocks as well. Deep hydrothermal alteration has apparently permeated the whole sequence, and fresh specimens showing the original nature of the sericite are difficult to obtain.

The schists vary from quartz, felspar, mica schists with rare sericite to schists containing up to 80% sericite.

A typical specimen of a large bulk of the schist (slide <sup>2</sup>/653) has chlorite 30% (after biotite), muscovite 3%, sericite 15%, ilmenite 1%, quartz 50% and no felspar, with accessory haematite and zircon. The chlorite occurs as ragged and splintery sheafs of flakes with abundant inclusions of quartz, muscovite and ilmenite. The chlorite is pleochroic from pale to mid green and is almost isotropic, although showing some anomalous purple interference colours. The mineral often extends into the sericite knots as thin feathers. The chlorite and ilmenite have resulted from the alteration of original biotite. Sericite is present as fibrous knots recrystallizing to muscovite. Adjacent to these knots quartz grains bear unaltered sillimanite spindles indicating that the original rock was a quartz, sillimanite, biotite, muscovite schist.

This type of schist grades to tough varieties richer in quartz (slide <sup>1</sup>/325). This variety often occurs as thin discontinuous beds which can be traced parallel to the schistosity for short distances. A typical assemblage is quartz 65%, sericite 25%, chlorite 5%, muscovite 3%, with accessory haematite and

zircon. Felspar is generally absent. The rock is rather massive and with a poorly developed schistosity.

Another prominent variation is a felspar rich schist (slides <sup>2</sup>/270 and <sup>1</sup>/328) which occurs only near the granite contacts. A strong tendency for gneissic banding exists in this type and an average mineral assemblage is quartz 50%, felspar 30%, sericite 10%, biotite 5 - 10%, muscovite 2 - 10%. The quartz is generally clear and sometimes shows strain shadows. The felspar is andesine varying between An 30 - An 35, and is often zoned. No microcline or orthoclase were detected. The biotite is only slightly altered to chlorite in these rocks, and the presence of felspar may have had some stabilizing effect on the biotite.

A prominent variety near the top of the schist sequence is a mica poor, sericite rich knotted schist (slide <sup>1</sup>/186), with a very irregular structure governed largely by the presence of irregular sericite knots. These knots appear to be relicts after sillimanite. An average composition is sericite 45%, quartz 35%, felspar 5%, muscovite 5%, chlorite 5%, with accessory haematite, pyrite, zircon and monazite. The sericite occurs as fibrous knots with spindles penetrating nearby quartz grains. The felspar is largely andesine and is often zoned. The original biotite is generally completely converted to chlorite, and this is often well mixed with the sericite knots.

A rarer variety is one rich in mica and sericite but very poor in quartz (slide <sup>2</sup>/237). An average composition is sericite 70%, muscovite 20%, chlorite 5% and quartz 5% with accessory ilmenite, haematite and zircon. The original biotite is completely converted to chlorite, and felspar is absent. In these rocks the sericite is more compact, and lacks the fibrous structure present in the above types. The original aluminosilicate may have been kyanite.

Several of the freshest specimens showed the occurrence of sillimanite relicts which had escaped sericitization. The sericite in these cases has a fibrous structure. However no specimens were found sufficiently unaltered to show the presence of kyanite, although mica rich schists, with small bladed sericite pseudomorphs after kyanite, were sometimes found.

The sericite rich schists often showed the presence of thick bands (to one inch, and rarely more) of solid compact sericite, which varied in colour from white to grey, to green, to pink. The origin of these bands is unknown, as in no case were relicts of any original minerals found in them. These bands are often strongly folded and suggest that the crystallization of the original aluminosilicate mineral, and the folding, were contemporaneous.

It must be concluded that sillimanite was the major aluminosilicate in these schists prior to hydrothermal alteration which converted the original aluminosilicate to sericite, and biotite to chlorite. Kyanite may have had a subordinate role, but its presence is not established.

The origin of the sericite from aluminosilicates is definite, but the origin of the aluminosilicates is a problem which cannot be answered definitely in this area, because of the extent of hydrothermal alteration of almost all the schist outcrops.

However, one peculiar quartzo-felspathic rock with an unusual composition was collected, which, because of its impermeability escaped hydrothermal alteration, and shows clearly the origin of the sillimanite. The rock (slide 1/247) is composed of quartz 50%, felspar 25%, biotite 10%, muscovite 5%, sillimanite 5 - 10%, garnet 3%, staurolite 1%, apatite 1% and iron ore 1%, with accessory chlorite, tourmaline and monazite. The felspar is partly plagioclase but is largely untwinned. Both the biotite and the muscovite show strong replacement by sillimanite. During the replacement the brown biotite is leached and iron ore is



released. This process is analogous to that described by Tozer (1955) from the Dalradian of Glen, Co. Donegal (see Francis 1956 <sup>6</sup>). Relicts of twisted and leached biotite extend among the sillimanite spindles, and this explains the peculiar chlorite - sericite mixtures of the altered specimens. The garnets are very small (1mm) and of irregular shape. The staurolite occurs as small rounded grains (.2mm) included in quartz.

Another unusual rock from the centre of the schist sequence, (slide <sup>2</sup>/337) composed of quartz 50%, feldspar 30%, sillimanite 5%, biotite 5%, muscovite 5%, tourmaline 5%, magnetite 2% and ilmenite 1%, has also escaped late stage diaphoresis; sillimanite here is clearly developing from muscovite. The feldspar is zoned and has some albite twinning. The biotite shows a certain amount of alteration to chlorite and ilmenite.

Several unusual rocks occur in this schist sequence. Two locations of rocks bearing abundant staurolite have been found north of the granite (e.g. slide <sup>1</sup>/427). These rocks contain closely packed staurolites up to 12 mm. long, in a matrix of biotite, and accessory muscovite and quartz. The mineral has suffered strong alteration to sericite with the release of iron ore. The original composition was approximately staurolite 80%, biotite 10%, muscovite 5%, quartz 3%, with accessory zircon. The biotite has been partially altered to chlorite crowded with rutile spindles. There is little doubt that the staurolite is of a metamorphic origin, especially since the plagioclase of the associated schists is in the range An 30 - An 35, the normal associate of staurolite bearing rocks. This would place the metamorphic grade near the lower boundary of the amphibolite facies of regional metamorphism.

Small discontinuous beds of biotite rich schists are sometimes seen in the schist sequence. These generally contain large biotite crystals, abundant quartz, lesser

muscovite and accessory apatite. Several enclaves of biotite schist in the granite ( v.i. ) contain large garnet porphyroblasts. The beginnings of garnet formation in these schists may be illustrated by a specimen from a location north of the granite. (slide 1/209) This specimen showed rotating porphyroblastic knots of pale green chlorite (pennine), quartz, magnetite and accessory rutile in a matrix of quartz and biotite, with accessory magnetite and apatite. These knots may represent retrograde garnets, although no relicts of garnet were seen.

West of the reservoir weir biotite schist bands are common and sometimes show green - yellow apatite porphyroblasts up to one inch in diameter near quartz and pegmatoidal segregations in the schists. The association biotite - apatite is a normal one and these schists appear to be of metamorphic origin.

Quartzo-felspathic beds are rare in this sequence, but one thin bed immediately north of the granite has a markedly arkosic appearance. (slide 1/420). The composition is feldspar 90%, biotite 5%, quartz 2-3%, and muscovite 2%, with rutile and zircon accessories. About 50% of the feldspar is twinned on the albite law and has a composition near An  $\frac{34}{66}$ . No microcline twinning was detected.

#### (4) The Upper Crossbedded Arkose.

At the northern end of the granite the schists extend to the upper tremolite rock bed, but to the south of the granite a marked facies change has occurred; for here the upper part of the schist sequence is replaced by a microcline rich arkose, which thickens rapidly and becomes a major stratigraphic unit further south. The rock outcrops well in the south-east plunging anticline at the lower end of the granite. In this anticline the outer edges of the arkose bed are strongly sheared and recrystallized, first to a granulite, and then to a gneissic granulite, which grades to the granite. However the centre of the competent arkose bed is poorly recrystallized; the original



shapes and size of the microcline and quartz grains being still clearly visible.

Petrologically the arkose is almost identical to the basal arkosic sandstone of the Lookout Tower Anticline, being made up of about 60% feldspar (largely microcline) showing excellent cross-hatched twinning, and 40% quartz, with accessory titaniferous haematite outlining the bedding planes. The rock is commonly cross-bedded. Some parts of the arkose have accessory talc.

The granite covers the area which would show the facies change from the arkose to the schists to the north of the granite. However it is certain that the arkose thins out rapidly to the north, and near Talc Gully where the granite is displaced westwards, the arkose is represented by a thin feldspar rich rock, sometimes having heavy mineral laminations. Here the arkose appears to be rich in plagioclase An 36. (slide 3/14). Small float in this vicinity indicates that the upper part of the arkose has been replaced by a fine-grained quartz - mica schist similar to those schists above the Upper Tremolite Bed (v.i.). A minor (tremolite ?) opal bed, just below the major one is also present in these schists. Both this minor opal bed and the fine-grained schists are replaced by the granite northwards. The upper arkose has an important stratigraphic role west of the Lookout Tower Anticline, where a thick cross-bedded arkose parallels the Kitchener Fault on the western side of the map, while two synclinal bodies of this rock occur in the centre. The stratigraphic position of this bed in relation to the underlying schists is well established from cross-bedding relations.

In the western area the underlying schist sequence grades upwards from a thick sequence of banded quartz, feldspar, mica schists, often pegmatized, above the basal sandstone, to sandy mica schists, to micaceous sandstones with coarser gritty layers. These latter are sometimes rich in titaniferous



PHOTOGRAPH 2 View looking east along a gorge cut through the synclinal core of the upper arkose  $\frac{1}{2}$  mile west of the Lookout Tower. The upper arkose of the synclinal core is well exposed on the steep hills in the foreground. In the background is the high Lookout Tower ridge.

haematite. The sequence culminates in the coarse cross-bedded sandstone.

This arkosic sandstone is in many ways identical with the basal sandstone, having not only a similar cross-bedded structure and composition, but also possesses, in some beds, abundant water worn pebbles and boulders to several inches in diameter. These pebbles are mostly massive quartzite and quartz, although some quartz-tourmaline and pegmatite pebbles may be found. Hossfeld<sup>3</sup>. claimed that the "cross-bedded basal sandstone overlies the schists" and this claim is not completely unjustified.

The thickness of the upper arkose may reach over 1000' near the Kitchener Fault where the dip of the bed is almost vertical. Here the top of the arkose grades into fine-grained silicified quartzites, which in turn grade into a fine-grained grey-blue, impure, dolomitic limestone, often showing a bedded appearance, and with small grey flinty particles of silica prominent on the weathered surfaces. This dolomite is correlated with the Upper Tremolite Bed east of the granite.

#### (5). The Upper Tremolite Bed.

Between the Upper Tremolite Bed and the granite, a thin strongly recrystallized quartz, muscovite, sericite, (sillimanite) schist occurs. This may be traced around the shallow anticline in the south, between the Upper Tremolite Bed and the Upper Arkose; thus indicating that the granite has, to some extent, replaced a facies equivalent of the arkose. Glassy quartz veins, parallel to the schistosity, are common in this bed adjacent to the granite.

Above this, the Upper Tremolite Opal Bed is a prominent stratigraphic horizon. The actual thickness of this bed is unknown, but it is doubtful whether it would exceed 100'.

Fresh outcrops of this rock show massive white tremolite

rock, with opaline replacement at the surface. This opal is far more prevalent near weathered outcrops, and appears to be a purely surface effect.

The rock is composed of a variable amount of tremolite, which is replaced first along grain boundaries, and then along the cleavages by opal (slide <sup>2</sup>/168). The opal is isotropic and X-ray identification has shown it to have a  $\beta$  - cristobalite pattern; a structure which is probably kept stable by impurities in the lattice holding it open.

The tremolite is nearly always a pure white colour, although slight greenish tints occur, probably due to solid solution with actinolite. The crystals range from several inches in length, to a microscopic matrix. Some varieties are uniformly fine-grained (slide <sup>4</sup>/90). Deep weathering converts the tremolite to talc, and in some places to meerschaum.

The Tremolite Bed is often part replaced by thin calc-silicate sandstones ( quartz, microcline, plagioclase, and actinolite, with accessory pyrite, zircon and rutile ) (slide <sup>1</sup>/69).

Immediately above the Tremolite Bed are a few thin beds of fine-grained mica - quartz schists, followed by a thin pink quartzite, which may be traced over long distances adjacent to the tremolite bed. This quartzite is a fine-grained (.5mm.) rock (slide <sup>2</sup>/170) with quartz 80%, feldspar 20%, (largely microcline), pores 2% and having accessory muscovite zircon and rutile.

#### (6). The Fine-grained Mica Schist Group.

Above the thin pink sandstone occur a series of fine-grained schists some 200 - 300' thick. These grade from medium grained (.5mm.) near the base to fine-grained phyllites at the top of the group. Minor silty sandstones and arkoses also occur, and near the top of the sequence the phyllites become finely knotted and begin to grade into the Calc-silicate



Group.

The medium grained schists near the base are uniform in general appearance, but vary in composition (slide <sup>1</sup>/6b). They generally carry biotite 20%, muscovite 5%, quartz 50%, feldspar 20%, with accessory tourmaline, zircon and apatite. The feldspar is sometimes oligoclase and sometimes microcline. Bedding lamination is common in these schists.

These schists grade upwards to finer grained varieties (slide <sup>1</sup>/3), which have 1-2% pyrite but otherwise similar to the above type in composition. The feldspar again is either oligoclase, or microcline, or both.

One small arkosic siltstone bed had 85% microcline (slide <sup>1</sup>/15).

Near the top of the schist sequence, the rocks become fine-grained, knotted phyllites, which continue upward interbedded with beds of calc-silicates. These phyllites have 20% biotite, 45% sericite, 35% quartz and feldspar, with accessory muscovite and zircon. The sericite occurs as small knots to 3mm. long, lensed out parallel to the cleavages. One of the freshest specimens (slide <sup>2</sup>/94) showed relict grains with the properties of kyanite in these knots.

#### (7). The Calc-silicate Group.

The rocks of the uppermost stratigraphic unit in the area vary from coarse to fine-grained calc-silicate rocks interbedded with phyllitic finely knotted schists.

Near the base of the formation a bed of coarsely knotted phyllitic schist is prominent. It has 35% biotite, 40% quartz, 15% feldspar and 10% sericite occurring as lensoid knots up to 1cm. x  $\frac{1}{2}$ cm.

The calc-silicate rocks contain various combinations of actinolite, (diopside), scapolite, oligoclase, quartz, zoizite, tremolite, sphene, and accessory iron ore (slide <sup>1</sup>/562, <sup>1</sup>/18, <sup>1</sup>/167, <sup>2</sup>/135).

The textures vary from coarsely pegmatoidal, to massive closely felted, actinolitic varieties, to mottled varieties rich in scapolite and plagioclase. Some varieties are sharply banded, with laminations of fine-grained plagioclase and scapolite in an actinolite rich matrix. These laminations are somewhat discontinuous but appear to be of a sedimentary origin.

The calc-silicate rocks grade upwards into fine-grained phyllitic schists.

## (b). THE GRANITE.

### (1). Petrology of the Granite.

The granite forms a single body some three miles in length and up to one third of a mile in width. Its contacts are relatively sharp, and the texture of the rock makes it easily distinguishable from the country rocks. Outcrops are prominent and abundant in the north, but south of Blood and Thunder Gully no further outcrop exists; the granite boundaries being traced by means of strongly laterized and weathered float and soil types. The granite, when viewed generally, has a uniform composition and texture throughout. However in detail numerous minor variations may be found, both in composition and in texture.

A fresh sample of the granite was analysed. The sample chosen may be considered as an average sample from its mineralogical composition. The analysis, norm calculation, and the modes are presented in Table 1.

In texture the granite varies from more massive varieties poor in mica, to strongly schistose varieties rich in mica. The schistosity is always constant in direction, and is never folded (except when distorted near boudinaged quartz veins). Gneissic foliation is a dominant feature in most specimens; the gneissic bands of quartz and feldspar, outlined by the micas being very thin (3mm. thick) and discontinuous. A strong lineation



Norm Calculation of Granite A177 3/95.				
	Weight %	Equivalent M.W.	Cation Proportion x 1000	Cation %
SiO <sub>2</sub>	72.85	60	1214	69.2
TiO <sub>2</sub>	.38	80	5	.3
Al <sub>2</sub> O <sub>3</sub>	12.73	51	250	14.2
Fe <sub>2</sub> O <sub>3</sub>	1.29	80	16	.9
FeO	2.13	72	30	1.7
MnO	.04	71	1	.1
MgO	.63	40	16	.9
CaO	1.32	56	24	1.4
Na <sub>2</sub> O	2.91	31	94	5.4
K <sub>2</sub> O	4.80	47	102	5.8
P <sub>2</sub> O <sub>5</sub>	.15	71	2	.1
H <sub>2</sub> O +	.46			
H <sub>2</sub> O -	.07			
CO <sub>2</sub>	Nil.			
	99.76%		1754	100.0%
Apatite	.1	1.67 x .1	=	.3
Ilmenite	.3	.3	=	.6
Orthoclase	5.8	5.8	3 x 5.8	= 29.0
Albite	5.4	5.4	3 x 5.4	= 27.0
Anorthite	1.2	2.4	2.4	= 6.0
Corundum			=	.6
Magnetite	.9	.5	=	1.4
Enstatite	.9	.9	=	1.8
Ferrosilite	1.0	1.0	=	2.0
Quartz			=	31.3
				100.0%
<u>Salics.</u>			<u>Femics</u>	
Or	29.0		En	1.8
Ab	27.0		Fs	2.0
An	6.0		Ap	.3
Q	31.3		Il	.6
C	.6		Mt	1.4
	93.9%			6.1%

### Modal Compositions

	Volume.	Weight	
Quartz.	39.5	39.3	
Untwinned felspar	22.4	22.0	Untwinned Plagioclase
Plagioclase	10.0	10.0	Composition Ab70.
			Reversed zoning.
Microcline	21.6	21.0	Strongly twinned.
			No exsolution.
Biotite	5.7	6.4	Well lineated.
Muscovite	.4	.5	
Haematite	.4	.8	
Zircon, apatite trace.			

Analyst : K.J.Mills. 24/9/59.

TABLE 1.



PHOTOGRAPH 3 Showing the general nature of the granite outcrop. The hammer handle rests in the schistosity plane. Numerous longitudinal joints are visible on the prominent cross - joint face.

produced by mica orientation is also noticeable. The rock is almost invariably very crumbly, though generally fresh. Some of the freshest specimens from watercoarces are solid and massive.

The granite is variable in mineralogical composition within certain limits (slides <sup>3</sup>/95, 1/572, 2/45, 1/648, 1/468, 1/578<sup>27</sup>). In general the rock consists of quartz, microcline, plagioclase, biotite, muscovite and accessory iron ore, zircon and apatite.

The quartz varies between 20% and 60% of the rock. It is always clear, xenoblastic, relatively free of inclusions (except for occasional apatite or mica grains), and generally free of prominent strain shadows. However undulose extinction is important in some specimens. There is a tendency for the quartz grains to be larger than the feldspars (averaging .75mm.). Some quartz grains may reach 4mm. in diameter. The quartz grains vary in size in all specimens and there is little tendency for gneissic banding of the quartz, although large quartz grains sometimes tend to aggregate together with the exclusion of feldspars. The quartz has little tendency to occur interstitial to the feldspar.

Microcline showing cross-hatched twinning is conspicuous in all specimens, although ranging in amount from 5 - 60% of the rock. The grains are generally clear, and seldom sericitized or weathered. Inclusions are rare.

Plagioclase varies in amount from an accessory to 50% of the rock. In many specimens untwinned feldspar is in excess of twinned plagioclase. Simple twinning on the Albite Law is common in some specimens but Pericline twinning is completely absent microscopically. The composition of the plagioclase is very constant (An<sub>30</sub> - An<sub>37</sub>), and is comparable to that found in the surrounding schists. Zoning of the plagioclase is rare and negligible ( zoning is often seen in the plagioclase of

surrounding schists).

The feldspars average .5mm in diameter and are rather constant in size. They always have sharp straight boundaries with the surrounding grains, and this explains the soft crumbly nature of most specimens. The feldspars are remarkably fresh in all specimens.

The feldspars (especially microcline) tend to segregate into gneissic bands, these being in general complementary to bands containing biotite. No exsolution features were visible in the feldspars.

Biotite occurs in all specimens in amounts varying from 2 - 15%. It is always strongly pleochroic from pale yellow to dark green - black, and is never altered to chlorite. It occurs in well defined flakes and in discontinuous gneissic bands evenly developed throughout the rock. The biotite generally occurs in flat elongate patches of flakes arranged parallel to the schistosity. Pleochroic haloes about small rounded zircon and monazite grains characterize all specimens.

Muscovite is a lesser constituent ranging to 5% in the rock. It is associated with the biotite, and generally forms larger, but thinner, flakes than that mineral. Large grains are sometimes isolated in the quartz and feldspar matrix. The mineral is always clear and colourless.

Iron ore (haematite and magnetite) is an important accessory in some rocks. It generally occurs in close association with the biotite and the zircon. Both zircon and apatite are common accessories.

Weathered specimens of granite float from the southern end of the granite body (slides 3/76, 3/193) indicate that the rock attains a more sheared appearance, and quartz and microcline become dominant constituents here.



PHOTOGRAPH 4 General view of the nature of the granite outcrop. Looking north along the strike or the schistosity (dipping to the right) across Sailors Gully (foreground).



## (2). Minor Variations in the Granite.

Several minor structures are of interest in the granite. One of these is the variation from a coarse grained to a fine grained texture. There is often a sharp boundary delineating the fine and coarse grained phases. In some cases it is certain that the fine grained phase occurs in a minor shear zone in the granite, but in other cases the fine grained phase has an occurrence which cannot be attributed to shear. In places a fine grained type occurs as ellipsoidal blebs up to 2' in length having sharp contacts with the coarser phase. In another case the fine and coarse phases had a cross-bedded appearance. In another case the fine grained variety showed a sharp "facies change" with the coarser phase. In one place two thin parallel "veins" of the finer phase cut the coarser (slide 1/617.). In most cases the compositions of both phases are similar, although the finer phase may be poorer in mica.

In several places the granite had a markedly arkosic appearance (e.g. slide 2/ 478), having an abundance of quartz, felspar and iron ore and negligible mica. Beds of stretched pebbles (?) (e.g. slide 1 /630) were occasionally found. These beds were generally narrow and the "pebbles", although partly granitized, were certainly not of normal granitic composition.

## (3). The Enclaves.

A number of definite schist enclaves were found in the granite, and in all cases (except the amphibolites), the enclave contacts graded from schist to granite. The enclaves are often large and indefinite in shape, and apparently represent tracts of schists which escaped conversion to granite.

In the granite north of Sailors Gully, a series of enclaves show a variable mineralogy. Some are quartz, mica schists, others possess sericite knots showing alteration from sillimanite while another has unaltered sillimanite in a quartz, mica, plagioclase matrix (slide 2/38). Microcline felspar has not



been found in these enclaves. The change to granite appears to involve the replacement of sericite by feldspar (some muscovite is also replaced) and a subsequent recrystallization.

Also present in this area are biotite schists, which in one place show the development of coarse porphyroblasts of garnets (slide <sup>2</sup>/56). The garnet appears to be developing from quartz, biotite and iron ore in the rock. A similar rock occurs in the granite on a ridge south of Sailors Gully; here the garnets are well crystallized icositetrahedra up to 1" in diameter. They are strongly altered to chlorite.

Another garnet biotite rock on a ridge north of Baynes Gully shows small idioblastic staurolite crystals included in large rounded garnets to 2" in diameter, thickly clustered in the coarse biotite. This garnet has a cell size of  $11.517 \text{ \AA} \pm .001 \text{ \AA}$ , a density of  $4.13 \pm .01 \text{ grms / cc.}$ , and a refractive index of  $1.802 \pm .001$ .

On the ridge south of Baynes Gully another prominent biotite schist bed cuts the granite but this contains no garnet. In this vicinity also, schists and partly granitized schists, are common in the granite (e.g. slide <sup>2</sup>/626). These illustrate the conversion of sericite knots and muscovite to feldspar, and some possess small staurolite crystals showing replacement by sericite (slides <sup>2</sup>/622, <sup>2</sup>/224).

Plagioclase is the major feldspar in these enclaves, its composition being in the range An 34 - 35 (which is the normal composition for an association with staurolite).

#### (4). The Contacts.

The shape of the granite body has been accurately mapped although outcrop at the granite contacts with the country rocks, is rare, and the relation of the granite to the country rock at the contact is a little obscure. Where the contacts can be observed, they appear to be rather sharp when parallel with the schistosity, but gradational and intertonguing with the

schists when transversing the schistosity. To represent this intertonguing the granite is given a serrated edge on the map.

Because of the lack of outcrop little can be said of the petrological nature of the contact. The eastern (upper) contacts are nowhere visible, and the southern half of the granite is obscured by deep weathering and laterization.

Several float blocks at the northern tip of the granite, indicate that the contacts here consist of a "muscovite granodiorite" with 10% muscovite, 60% quartz, and 30% felspar. The felspar is largely oligoclase - andesine, with microcline being rare. There are no exsolution features in the feldspars. The rock is strongly schistose and resembles the normal granite in texture.

An almost identical rock (slide 3/89) occurs along part of the western contact as a thin band separating the granite from the schists, north of Blood and Thunder Gully. This rock has a plagioclase composition near An<sub>33</sub> and has 30% total felspar. The contact schist here has 20% andesine and 50% quartz, with muscovite and biotite, and is similar to the other plagioclase bearing schists adjacent to the granite.

The first outcrops of granite at the northern tip are rather fine-grained, and are rich in quartz and felspar (slide 1/434). The composition is quartz 50%, pink microcline 40%, plagioclase 5%, biotite 2%, muscovite 1%, iron ore 2%. The rock has a "normal" composition, but is notably poor in biotite. This rock soon grades to granite of the normal texture southwards.

On a hill  $\frac{1}{4}$  mile south of the northern tip of the granite, a good contact with the schist occurs. The quartz, plagioclase, muscovite, biotite, sericite schist is seen to recrystallize, and develop a strong schistosity near the contact. Nearer the contact the sericite knots are absent, and the rock becomes a quartz, mica, felspar schist (slide 1/341(a)). Microcline becomes the dominant felspar. Mica is still abundant (20%). A

further stage in the conversion to granite (slide  $1/341(b)$ ) involves a reduction of the amount of mica to 10% (largely a reduction of muscovite). The rock develops a definite gneissic appearance due to banding of the micas, and the rock develops the granite texture. This specimen contains predominant plagioclase feldspar ( $An_{35}$ ), and the reason why microcline is absent is not clear.

Several yards south of the contact a biotite schist borders the granite. There is little tendency for this rock to be converted to one of a granitic composition.

Immediately south of this location the granite broadens by intertonguing with the sediments. Although still relatively sharp, the contacts indicate a gradation of the schists to granite, both in texture and composition.

A specimen from a tongue of schist penetrating into granite in Sailors Gully (slide  $2/319$ ) indicates little change to a rock of a granitic texture or composition, although the rock is only 10 yards from the granite contact. The rock has the composition biotite-chlorite 10%, muscovite 15%, sericite 35%, quartz 40%, with accessory garnet - no feldspar was detected.

There are several places where amphibolite dykes cut the granite. These are little different from similar rocks outside the granite. One contact between granite and amphibolite was found and was a hybrid contact (slides  $1/487(a), (b), (c)$ ).

The amphibolite has the composition hornblende 60%, quartz 5 - 10%, labradorite 25 - 30%, sphene 3%, with a trace of biotite and iron ore. The hornblende occurs as small spindles which are strongly lineated. The feldspar is solely plagioclase of a composition  $An_{40}$  (this basic feldspar is normal for the amphibolites).

The granite is of the usual type consisting of quartz 50%, microcline 35%, plagioclase 5%, biotite 5 - 10% and muscovite 1%. The plagioclase is of the composition  $An_{33}$ , and is

notably zoned; the outer zones being more basic (reversed zoning). This zoning is not usual in the plagioclase of the granite, and it may be related to the proximity of the amphibolite.

The hybrid rock is a compact massive hornblende "granite" with a slightly gneissic appearance. The composition is hornblende 15%, microcline 5%, plagioclase 20%, quartz 45%, sphene 1%, biotite 1%, and accessory apatite. The plagioclase is of a basic composition (An<sub>50</sub>) and is strongly zoned. The feldspars are very poeciloblastic. The rock appears on compositional grounds to be amphibolite diluted with quartz, microcline and possibly plagioclase.

### (c). The Amphibolites.

Dark amphibole rich rocks are common on the eastern flank of the Lookout Tower Anticline ( although several locations have also been found on the western flank). They are most abundantly developed just south of the reservoir. The most southerly occurrence is at the southern tip of the granite. The dykes range up to 30 yards in width, though in general being much narrower. They cut both the schists and the granite, and although outcrops are rare, some dykes may be over one mile in length. Based on their composition (see later) ( Edwards 6.) and environment they are regarded as igneous, and the "beds" as near vertical dykes or sills parallel with the schistosity.

They may be divided into two main types :-

- (a). a fine-grained strongly lineated schistose variety.
- (b). a more massive variety showing only weak schistosity.

The former type is by far the most abundant. The southernmost occurrence, being very fresh and a normal composition and texture was analysed (slide 3/202). The analysis, with normal calculation and the modal analysis are presented ( Table 2).



## Norm Calculation of Amphibolite A177 3/202.

	Weight %	Equivalent M.W.	Cation Proportion x 1000	Cation %
SiO <sub>2</sub>	48.67	60	811	46.1
TiO <sub>2</sub>	1.66	80	21	1.2
Al <sub>2</sub> O <sub>3</sub>	15.05	51	295	16.8
Fe <sub>2</sub> O <sub>3</sub>	3.12	80	39	2.2
FeO	8.70	72	121	6.9
MnO	.17	71	2	.1
MgO	6.63	40	166	9.4
CaO	11.49	56	212	12.1
Na <sub>2</sub> O	2.42	31	79	4.5
K <sub>2</sub> O	.42	47	9	.5
P <sub>2</sub> O <sub>5</sub>	.26	71	4	.2
H <sub>2</sub> O +	1.59			
H <sub>2</sub> O -	.09			
CO <sub>2</sub>	.10			
	<u>100.37%</u>		<u>1759</u>	<u>100.0</u>

Apatite	.2	1.67 x .2	=	.5		
Ilmenite	1.2	1.2	=	2.4		
Orthoclase	.5	.5	3 x .5	=	2.5	
Albite	4.5	4.5	3 x 4.5	=	22.5	
Anorthite	5.9	11.8	11.8	=	29.5	
Magnetite	2.2	1.1		=	3.3	
Wollastonite	5.9	5.9		=	11.8	Diopside 23.6
Enstatite	9.4	9.4		=	18.8	Hypersthene 14.2
Ferrosilite	4.6	4.6		=	9.2	Olivine 1.5
					100.5%	100.0%

## Modal Compositions.

	Volume.	Weight.
Quartz	6.6	5.7
Hornblende	64.2	67.5
Plagioclase	25.3	22.2 (Ab <sub>45</sub> An <sub>55</sub> )
Sphene	3.3	3.8
Magnetite	.3	.5
Apatite.	.2	.3
	100.0%	100.0%

## Normal Compositions.

## Salics.

Or	2.5	
Ab	22.5	(Ab <sub>43</sub> )
An	29.5	
	54.5%	

## Femics.

Ap	.5
Il	2.4
Mt	3.3
Di	23.6
Hy	14.2
Ol	1.5

45.5%

Analyst : E.J.Mills. 24/9/59.

TABLE 2.



The mode is typical of most of the other amphibolites of the area. The hornblende occurs as spindles, pleochroic pale yellow to dark green and is slightly diablastic, having quartz and feldspar inclusions. The plagioclase is notably basic (An 54-55) and is very different from the plagioclase compositions of either the schists, the calc-silicate rocks, or the granite. The plagioclase is often zoned, but the grains are always very small (.4mm.) and the nature of the zoning is unknown. The quartz occurs in small grains throughout the rock. Sphene is a common accessory, occurring as small, exceptionally clear, rounded grains, with small black (ilmenite) inclusions in their centres. Apatite is also a common accessory.

The texture is strongly schistose; the quartz and the feldspar occurring in ellipsoidal aggregates through the well lineated hornblende matrix.

The fine-grained amphibolites vary little from this description. Some have accessory ilmenite and pyrite, and in some, octahedra of magnetite are commonly developed. One specimen (slide 1/245) had a plagioclase near An 58.

The texture is identical in almost all fine-grained, schistose varieties, although some variation in the degree of lineation and schistosity is noticeable. The lineation of the hornblende spindles is parallel to the lineation found in the granite.

In only two cases did the amphibolites show signs of internal folding. In one case small folds up to 2" across folded the schistosity about steeply north plunging axes. In another case joint planes containing films of quartz, feldspar and epidote, and has been shear folded by the imposed schistosity, thus indicating that the jointing had developed prior to the schistosity, and again suggests an igneous origin for these rocks.

The coarser grained amphibolites have an identical composition to the finer grained ones. These occur in rare dykes

either alone, or with the fine-grained type. The mineralogy is no different, but the hornblendes are strongly decussate in structure, and stumpy in form (slides 1/326, 1/276). In one slide pale coloured pyroxene was recognised as relicts in the hornblende, and iron ore was commonly present as an exsolution product of the hornblende, the exsolution planes apparently corresponding with the original pyroxene cleavages.

The contacts of the amphibolites were invariably sharp. Except for the granite contact described above the only other hybrid rock (slide 1/192<sub>(a)</sub>) was adjacent to a schist contact. The rock consisted of 70% labradorite, 20% quartz, and 10% hornblende. The hornblende occurred as large flat, lenticular, diablastic phenocrysts up to 2 cm. long. The plagioclase had a composition near An 60 and was reversed zoned.

An interesting "hornblende pegmatite" stringer 2" wide was found cutting an amphibolite in one place. The rock has large hornblende crystals (slide 1/301) to 2 cm. in length, and has the composition quartz 20%, basic plagioclase 5%, chlorite 30%, hornblende 20% and diopside 20%, with accessory sphene, ilmenite, pyrite and tourmaline. The diopside is a bright green colour and occurs in subhedral crystals to 1mm. and resembling epidote in the hand specimen. The quartz, felspar and hornblende are in large interlocking crystals.

#### (d). The Pegmatites.

Numerous pegmatites occur in the area. These may be grouped into several types.

##### (1). The Country Rock Type.

These occur throughout the area mapped, but are most abundant north and south of the reservoir. They develop parallel to the schistosity and bedding in most places as dykes up to several yards in width. Their composition is variable but microcline and plagioclase are the commonest constituents. The plagioclase is constant in composition (An 10-12). Quartz is another major

constituent and often occurs in graphic intergrowth with the feldspars. Muscovite is a rare constituent, but in places concentrations occur, and sheets up to 1' in diameter may be found. Beryl, tourmaline and apatite are rarer constituents. Minor off-shoots and some thinner pegmatites, have a concentration of these constituents. Beryl occurs in various colours. These seldom exceed 2" in diameter. Tourmaline is invariably black and is sometimes altered to a felted mass of sericite and chlorite (ripidolite). This mass may retain a basal parting and a prismatic parting reflecting the original hexagonal structure of the tourmaline. Apatite occurs in pale green crystals, and is generally rare although widespread. At one location monazite crystals to one centimetre in length were found in a pegmatite, and in another case small stumpy zircons to 3 mm. in diameter were obtained embedded in the sides of small beryls from a garnet bearing pegmatite. Garnet has been found in several pegmatites occurring as well formed rhombohedra up to 1" in diameter.

It is interesting to note that the pegmatites by-pass the granite and seem to have no connection with it. They are apparently of a regional origin. Enclaves of schists are common in these pegmatites and indicate that their mode of origin was largely by replacement.

#### (2). The Granite Pegmatites.

These pegmatites occur in various sizes in the granite, ranging from stringers 1" wide, to large pegmatites and "plugs" several feet in diameter. They may be distinguished from the country rock type by their abundance of well twinned microcline occurring as subhedral to euhedral crystals of a variable size. Graphic intergrowths of quartz and feldspar are rare or absent. At the northern end of the granite the pegmatites contain beryl and tourmaline.

These pegmatites occur generally in cross joints or flat lying longitudinal joints. Irregular pods also occur. The irregular pods often grade into the granite, whereas the veins show sharp contacts. The stringers generally end by "diffusing" into the granite. This indicates that these pegmatites originated by late stage solutions being carried along late stage joint planes from local sources adjacent to the ends of the joint. The pegmatites show a variable grain size which is strictly dependant on their thickness; the contacts being fine-grained and the central part coarse, and often having a central core of quartz. The microclines and the beryls grow inwards from the sides of the pegmatites.

Both the country rock type and the granite type are completely unstrained by the imposed schistosity of the rocks in which they occur and both types are of a late origin. Both types cut the granite and their relative ages are unknown. It is possible that all pegmatites of the area are of the same age and their mineralogical differences may be attributed to the rock type from which they have originated ( there is a marked correlation between the mineralogy of the pegmatites and the rocks in which they occur).

### (3). Pegmatoidal Segregations in the Schists.

These are common in the main schist sequence, and have a variable mineralogy apparently depending on the rocks in which they occur. In most cases they appear to be of local origin, having minerals common to the host rock, but being richer in the more "active" quartz and felspar. They are generally surrounded by, or have as schlieren, a basic front rich in biotite, which represents the relict mafic constituents left behind when the felsic minerals migrated to form the "pegmatite". Since these "pegmatites" occur in association with strongly folded beds of schists with alternating competent quartzo-felspathic bands, it is suggested that these pegmatoidal



segregations represent local low pressure regions produced during the folding; metamorphic differentiation was a natural consequence.

#### (4). Quartz Veins.

Various types of quartz veins occur but were not studied in great detail. In the granite lenticular veins and pods were sometimes developed up to several feet thick and 50 feet long. In most cases they were barren, but some carried haematite often in large masses of irregular shape, and lacking crystalline form. Some veins carried large isolated feldspars and sometimes muscovite crystals. They appear to represent "diluted" pegmatites.

The veins in the granite occurred mostly in flat lying joints, although cross-joint veins also occurred. One outcrop showed a boudinaged quartz vein, with the schistosity of the granite distorted to fill the boudin cavities.

In the country rock quartz veins were very common (except in the calc-silicate group). Their character indicates that in most cases they are derived from the rock in which they occur. Veins at the head of Dead Horse Gully carry a little gold, and pyrite crystals in abundance. Numerous shafts have been sunk on quartz veins in the area.

#### (5). Pegmatitic Mylonites. (slide 2/327).

These represent pegmatized shear zones, which run parallel to the schistosity, and are sometimes several feet in width. They are not common, and occur as bladed outcrops. They vary in composition from schistose to felspathic varieties. The feldspar is largely plagioclase of a composition comparable with that in the schists (An 30 - 35). In some cases strain shadows are strong in the quartz, but are absent in others (especially feldspar rich varieties). Muscovite seldom exceeds 5%, and the biotite, although rare, is apparently stable as minute grains. Zircons are a common



accessory.

The texture varies from schistose to augen gneissic, with small eyes of quartz and feldspar.

(g). Sillimanite Pods.

Several pods of sillimanite-quartz occur immediately north of the granite. These are massive non-schistose rocks, with an abundance of sillimanite (slide 1/34). The average composition is sillimanite 80%, quartz 20%, with a trace of muscovite. Rutile may also occur in small golden yellow grains. The quartz is free of strain shadows and is strongly penetrated by sillimanite fibres.

Thin sheared sillimanite - quartz veins are often found in the eastern (upper) side of the granite to the north, where they permeate the quartz mica schist just below the Upper Tremolite Bed.

Sillimanite pods also occur in a zone of strong metasomatic activity somewhat west of the granite. The sillimanite rocks here have quartz and rutile associated with them.

In this zone also are prominent quartz - rutile veins which were once mined economically. Thick bands of massive sericite are common in this zone, and strong hydrothermal activity has leached the surrounding schists with biotite being reduced to chlorite. Rutile is released in this reaction in sufficient quantities to explain the origin of the rutile concentrations in the area.

(h). Kyanite Pegmatites.

One location of a thin kyanite sillimanite pegmatite (slide 1/180) was found north of the granite. The composition was oligoclase (An<sub>17</sub>) 65%, quartz 20%, sericite 10%, muscovite 3%, sillimanite 2%, kyanite 1%. The sillimanite and the kyanite were strongly altered to sericite.

In the same area two locations of quartz kyanite rocks were found (e.g. slide 1/89) The kyanite was being replaced first by gibbsite and later by sericite.

(i). Tourmalinization.

Tourmalinization is commonly seen near pegmatites carrying that mineral, and a prominent zone of tourmalinization occurs parallel to the schistosity in Sailors Gully, somewhat west of the granite

(j). Tertiary Deposits.

Some of the ridges in the vicinity of the granite are covered in thin deposits of conglomerates, sands, clays and laterite of the old Tertiary peneplain; and reworked material covers the slopes and gullies. Deep weathering and laterization is apparently still in process in the southern area of the granite, where shafts up to 80' deep barely penetrate the zone of leaching.

### MINERALOGY.

Most of the mineral occurrences of interest have been plotted on the accompanying map. Pegmatites carry apatite, beryl, garnet, monazite, muscovite, tourmaline and zircon. Strongly metasomatized rocks carry sillimanite and kyanite and rutile. Massive pale green-yellow opal replaces the tremolite rock horizon in many places. Staurolite and garnet are commonly found in the schists and in the enclaves of the granite.

To ascertain the variation of minor minerals of the rocks of the area 15 heavy mineral analyses were completed. Seventeen separate minerals were identified, and these mineral fractions are summarized in the accompanying map, along with the specimen locations. A description of each specimen and the minerals contained will be found in appendix A. Apatite was generally removed by acid during the extraction process. The occurrence of well formed graphite crystals in one specimen indicates that the crushing process did not affect the shape of the minerals extracted.

It is noteworthy that the amphibolites ( 1/245 and 1/623) only had sphene, iron ore and apatite in their heavy mineral fractions.

The basal sandstone ( 1/446) had zircon in excess of monazite, and accessory garnet, hypersthene and rutile.

Specimens 2/560 and 1/622 of the granite contain almost identical heavy minerals, monazite being in excess of zircon, and the total iron ore being less than either of these constituents.

Specimen 2/57 has a similar relation. This rock is an enclave of schist in the granite.

Specimen 1/186 ( a schist) also has monazite in excess of zircon. These four locations fall roughly on the same stratigraphic horizon and it is suggested that a correlation of these assemblages may be possible.

Specimens 1/461 and 1/573 of normal granite show contrasts in their assemblages, sphene being prominent in one and zircon in the other.

Specimens 1/620 and 2/478 are specimens of "granite" with an arkosic appearance and an abundance of iron ore. Their major minerals agree in their degree of importance.

One striking feature is the presence of hypersthene and garnet both in the granite, the enclaves and the basal sandstone member. Epidote is present in at least one granite sample. Blue green anatase was identified ( X-ray) from sample 2/478 ("arkosic granite"), and well-formed hexagonal, barrel shaped graphite crystals were found in the schist enclave 1/57.

Zircons in the granite were less rounded than the zircons of the basal sandstone, but were generally far from euhedral. The zircons in the granite were similar to those in the schist enclaves. Some specimens of the granite showed three varieties of zircons:-

(a). small, clear, weakly magnetic grains.

(b). small, slightly altered, rounded to subhedral, elongate grains and fragments.

(c), large, opaque, stumpy, prismatic, euhedral to subhedral pitted malacoons.

Samples of creek sand ( 2/320, 2/125, 1/85 and 1/142) reflect directly the minerals which have been found in the rocks of the area. The abundance of staurolite in sample 1/85 indicates that this mineral is important in the schists of the main schist sequence.

## STRUCTURAL GEOLOGY.

The stratigraphic mapping indicates that the granite body exists on the eastern limb of a strongly folded anticlinal structure ( the Lookout Tower Anticline), whose axial plane trends north-south and dips approximately  $70^{\circ}$  east. The western limb of the anticline is overturned to the west. The anticline is easily traced in the field by means of the basal felspathic sandstone of its core. To the south a complexity arises from an apparent cross fold, with a fold axis trending north-west -south-east and plunging south. To the north the central anticlinal core of the sandstone plunges out due to a low north plunge, but reappears as a double anticline of sandstone immediately south of the reservoir. This indicates a further complexity produced by either a pitch reversal or en echelon folding.

In order to establish the nature and the effect of these fold forms on the surrounding rocks, especially the granite, a structural analysis was undertaken. Outcrop was sufficient in some of the critical areas , and penetrative deformations in the form of microfolds, mineral elongations, and joints were so commonly seen, that a detailed analysis was possible.

The method of attack was primarily to divide the area into that occupied by the granite, and that surrounding the granite. To test the homogeneity of the deformation these two areas were further subdivided into smaller ones, and separate structure diagrams prepared. These were found to be slightly inhomogeneous with respect to each other (See Plates I. and II.)

The structure of the granite was relatively simple, being made up of a prominent single schistosity or foliation containing a strong lineation, shown as the elongation of patches of biotite and muscovite. Four separate foliation-lineation diagrams were plotted for the granite, and these were found to be homogeneous; the schistosity dipping in every case  $50-60^{\circ}$  east and striking at  $340^{\circ}$ . The lineation





PHOTOGRAPH 5. Showing the fold style at the reservoir weir. The hammer handle rests on a central mobilized core of coarse amphibolite (This amphibolite appears sedimentary, and may be equivalent to the lower tremolite - opal bed discussed in the text). The lighter bands are quartzo-felspathic sediments and the darker rocks are richer in mica. The dark bed, lower left (arrow), also contains considerable biotite and amphibole.

plunged constantly at  $25^{\circ}$  south on a direction of  $150^{\circ}$ . Joints were also common and will be discussed later.

Amphibolites adjacent to, and cutting the granite, are often strongly lineated due to the preferred orientation of hornblende spindles, and this lineation plunges in a direction parallel to that in the granite.

The area around the granite (and especially those schists to the west) were found to have a more complex structure than that of the granite. To the east of the granite the sedimentary rocks are weakly recrystallized and often show prominent bedding parallel to the schistosity of the granite (diagram 18.). To the west of the granite the schists are strongly recrystallized, and show in some places several microfold axial directions, as well as a weak mineral elongation (not always present) which is parallel to that in the granite.

The small folds in the schists whose axial directions were measured, show a variable size from small microfolds to folds many feet across. On the southern side of the Warren Reservoir weir, fresh artificial outcrop shows well the fold style, with fold forms varying from sharply pointed shear folds, to gently folded parallel types.

Nearer the granite many outcrops contain sharp accordian folds produced by axial plane shear. Other folds here are of a more concentric form.

Diagram 15. is a foliation - lineation diagram for the outcrop at the reservoir weir. A single slightly south plunging fold axis is shown, and a large area south of the weir and west of the central Lookout Tower Anticline is homogeneous with this deformation direction.

To the south near Watts Gully, microfold axes correspond to the south-east plunge of the lineations in the granite and of the weir (diagram 14).

Diagram 11. is a plot of poles of lineations (largely



PHOTOGRAPH 6. Showing the general fold style at the reservoir weir. The photograph was taken looking south along the lineation. Photograph 5. was taken in the central right region of this photograph. Pegmatized schists occur in the centre, and mobilized pegmatites are present in the foreground.

microfold axes) in the central area. The diagram is taken from a large single outcrop of strongly folded schists just west of the granite. It shows two maxima; the larger corresponds with the general south-east plunge referred to above, and the smaller to a low plunge to the north. A slight spread of poles on a girdle containing the two maxima is noticeable. These two axial directions are taken to correspond with the fold traces seen on the stratigraphic map (one plunging south-east and the other to the north).

Diagram 12. represents 100 lineations measured at the edge of the reservoir to the north of the granite. A prominent spread of the poles along a north-west - south-east girdle is evident.

Diagrams 13, 16, 17, 19 and 20 show smaller sections of this area and indicate a pronounced inhomogeneity.

The above evidence indicates the existence of at least two deformation directions and possibly two periods of folding.

The presence of only one lineation in the granite but of two in the enclaves and surrounding rocks indicates that the NW - SE trending deformation axis is the later one, and corresponds with the fold axes recognised by other workers in the Adelaide region ( notably Kleeman and White <sup>8.</sup>). The low north plunge of the schists appears to belong to an earlier deformation.

Although still present in the schists and the schist enclaves this earlier fold direction was obliterated during the process of granitization which produced the granite. However the later deformation did affect the granite, and produced the structures observed.

Defining the first deformation as giving the statistical fold axis  $\beta$ , and the second deformation as giving rise to an axial plane (the schistosity)  $S'$ , we may consider how the second deformation plane  $S'$ , would deform the already folded bedding planes  $S$  about  $\beta'$ , the statistical fold axis of the second deformation.



Figure 1 indicates that the schistosity plane in the area would introduce lineations such as  $B_1, B_2, B_3, B_4$  etc, in the original folded bedding directions  $S_1, S_2, S_3, S_4$ , etc. This seems to adequately explain the spread of fold axes in Diagram 12.

We might also consider how  $\beta$  would vary under this scheme. If the variation was due to flexural slip we would expect  $\beta$  to vary in a small circle about  $b'$  as the centre (figure 2).

If the second deformation was predominantly one of axial plane slip, we would expect  $\beta$  to vary on a plane containing  $\beta$  and  $a'$  (figure 3) (Weiss 1958<sup>9</sup>).

The difference in axial trends of the statistical fold axes  $\beta$  and  $\beta'$  is insufficient to establish which of these processes has occurred, although some tendency for flexural slip is evident in diagram 11 and for axial plane slip in diagrams 11 and 12.

We may consider the effect of the introduced fold axes  $B_1, B_2, B_3, B_4$ , etc. on the axial plane of the second deformation  $S'$ . Each fold axis  $B_1, B_2, B_3, B_4$ , etc would tend to rotate  $S'$  to produce a tendency for a spread of the poles of  $S'$  along a north-south girdle (as shown in figure 1). This may explain some of the variation in poles of  $S'$ .

#### Joints.

Although joints are very rare in the schists (and are very irregular when found), jointing is common in the granite and in the sandstones of the area. To test the relation of joints in the granite to the folding in the area some 1390 joints were measured, and four diagrams of poles of joints have been plotted from various parts of the granite (Diagrams 1, 2, 4, 5, and 8 being equivalent to areas represented by diagrams 6, 7, 9, 10, and 3).

The most prominent joints are cross joints, with subordinate longitudinal joints and occasional flat joints.



The rarity of the flat joints is probably related to the round, bladed outcrop shape of the granite, and its rapid mechanical weathering, which rapidly obliterates the flat joints, but enables the steeper to survive.

The maxima of the poles of the cross joints appear to reflect the  $\beta$  maxima of the folding.

An interesting movement picture is conveyed by diagrams 1, 2, 4, 5, (i.e. from the middle to the north end of the granite). The striking similarities of diagrams 2 and 12 illustrate the close relation of joints to the folding.

It may be noted that although only the second deformation is indicated by the foliation - lineation structure of the granite, both deformations are reflected by the joints. This is further evidence that, although the delicate fold structures of the first deformation were obliterated during the granite formation, the strain effects of the first deformation were preserved, and are reflected in the joints.

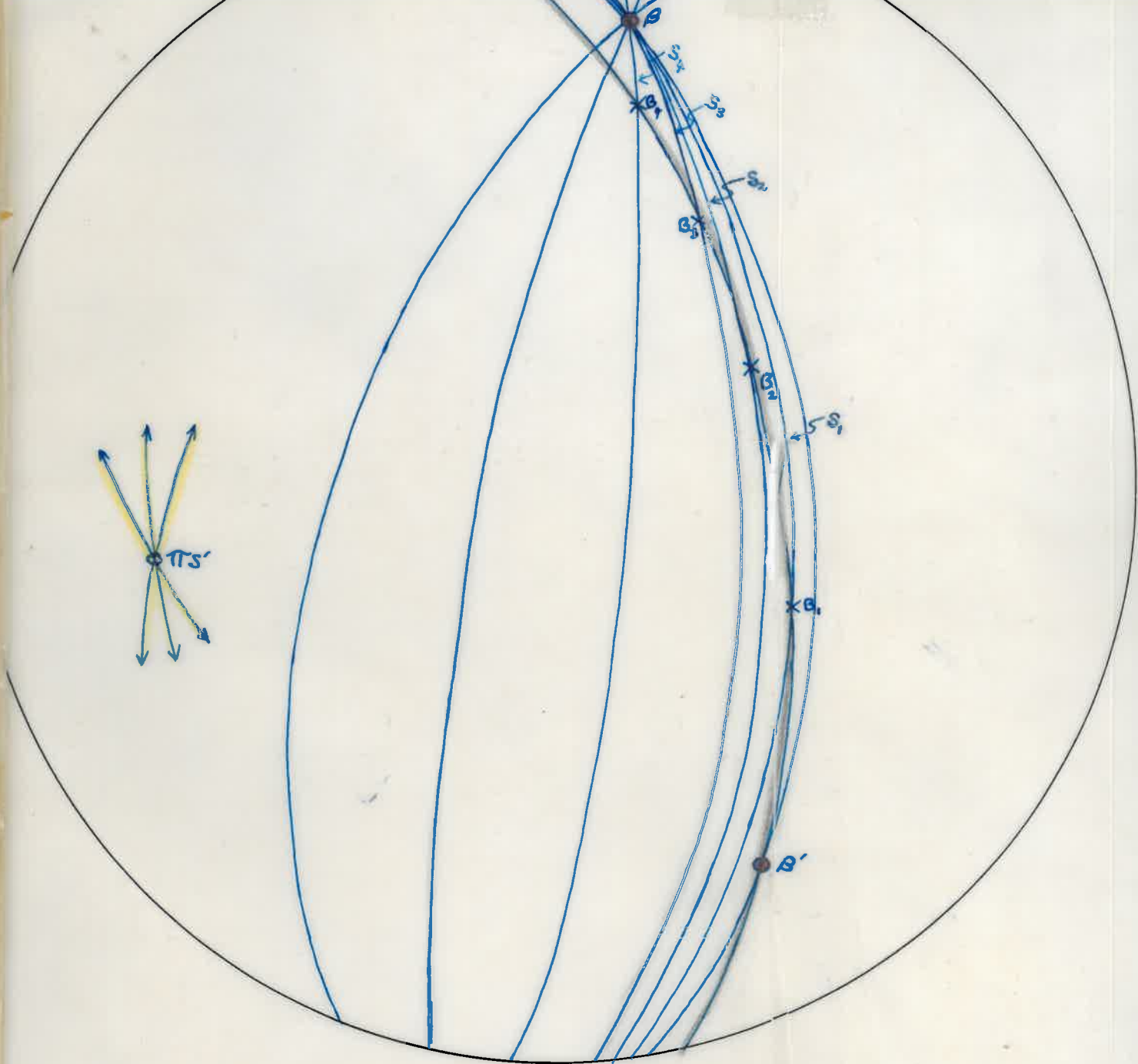


Fig. 1.

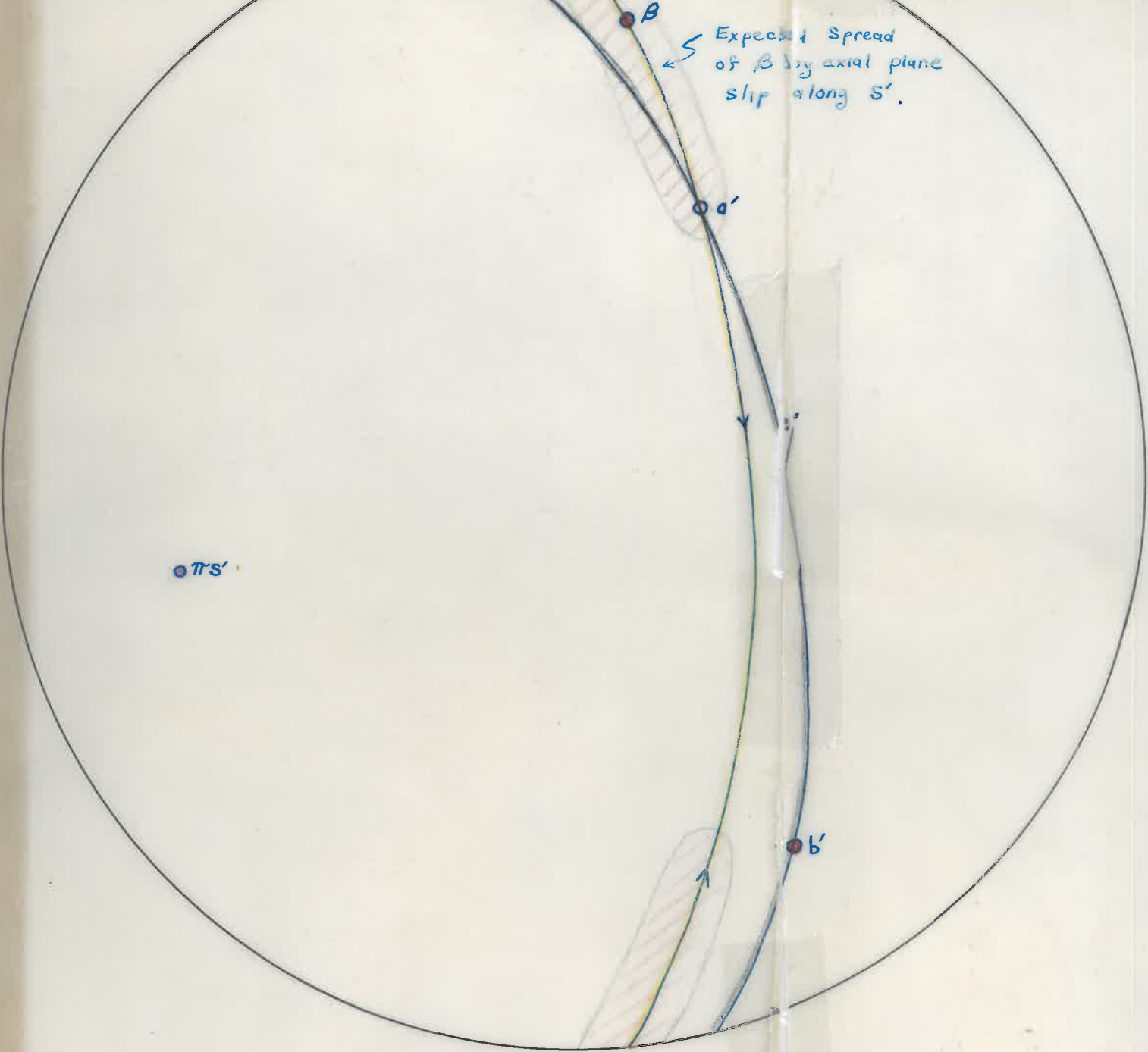


Fig. 3.

Expected  
Spread of  $\beta$   
about  $b'$  as axis  
caused by  
Flexural Slip.

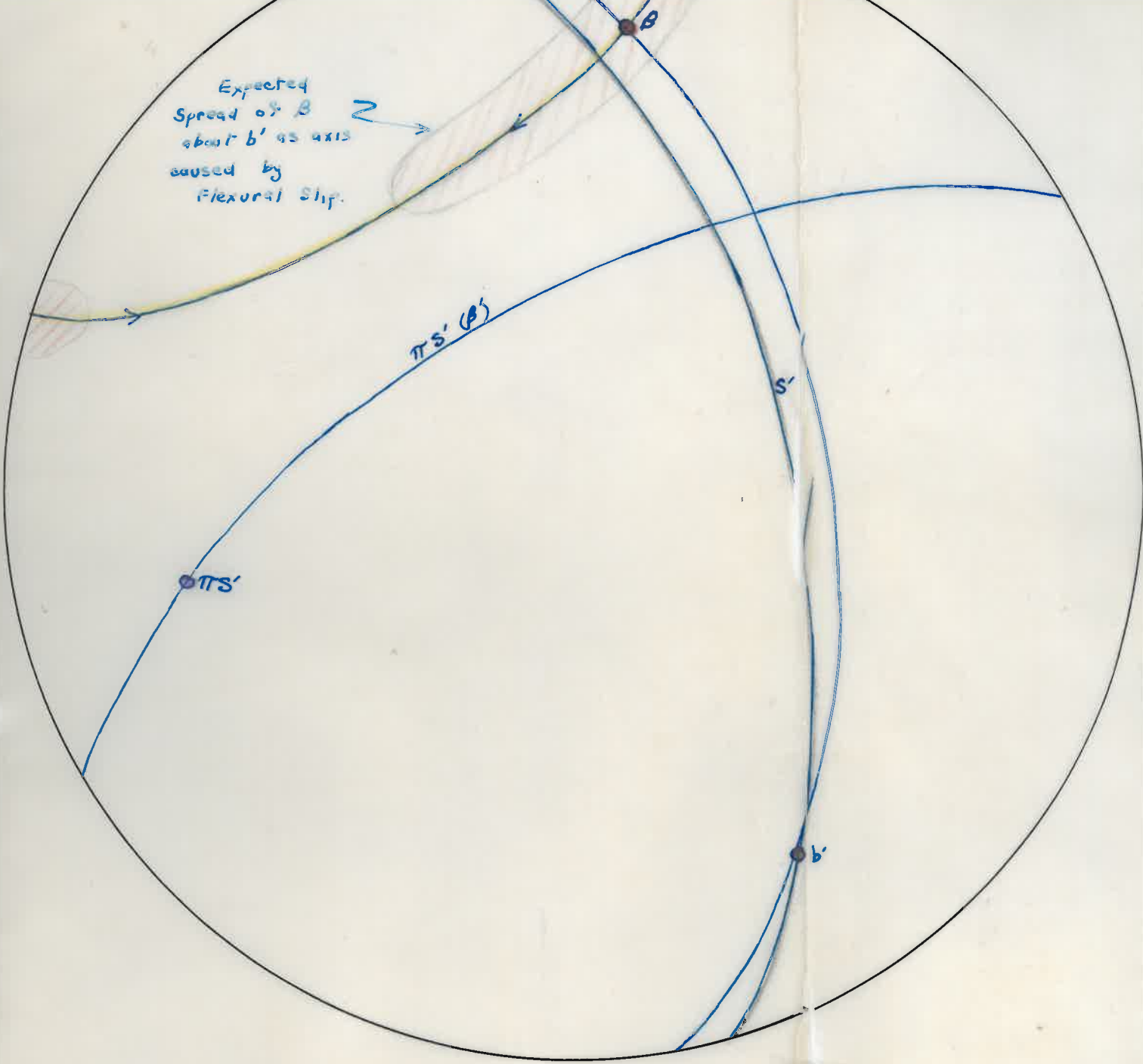
$\pi s'(\beta)$

$\pi s'$

$s'$

$b'$

Fig. 2.





## CONCLUSIONS.

In the light of the above evidence several conclusions regarding the petrogenesis of the rocks of the area may be made.

### (1). The Granite.

Evidence with a strong bearing on the origin of the granite is as follows:-

(a). The granite forms a single body with relatively sharp contacts.

(b). In detail the contacts appear to be gradational.

(c). The existence of a number of enclaves of granitized schist.

(d). The predominance of microcline feldspar in the granite and its absence in the surrounding schists (microcline occurs in schists above the Upper Tremolite bed).

(e). The predominance of plagioclase feldspar in the enclaves and the feldspathized schists near the contacts.

(f). The greater plagioclase content of schists nearer the granite contact.

(g). The plagioclases of the granite, enclaves, and the schists have the same composition (An 30-37).

(h). The absence of exsolution features in the feldspars

(i). The metamorphosed granoblastic texture, with the feldspar and quartz forming separate rounded grains with sharp contacts.

(j). The biotite of the granite is identical with that of the schists.

(k). The single schistosity plane and lineation which correspond exactly with a regional axial fold direction.

(l). The presence of an earlier fold axis in the schists and enclaves but not in the granite.

(m). The existence of joints in the granite corresponding with both fold axes.

(n). The occurrence of minor unstrained granite pegmatites.

(o). The gradation of the granite into a microcline arkose in the south.

(p). The hydrothermal alteration has altered the schists but not the granite.

(q). The occurrence of hypersthene and garnet both in the country rock, the enclaves, and in the granite, and the occurrence of several types of zircon in the one specimen of granite.

(r). The variation in heavy mineral assemblages in the granite.

(s). The existence of similar heavy mineral assemblages traceable along stratigraphic horizons from the schists into the granite.

There is little evidence to support an igneous origin and many factors suggest a metamorphic - metasomatic origin. The field evidence clearly indicates that the granite was formed between two periods of folding, and post dates the growth of sillimanite knots in the country rock, although possibly contemporaneous with the hydrothermal alteration in the area. Plagioclase in the enclaves and contacts indicates an early phase of soda introduction ( the sericite may be soda rich - see Segnit <sup>10</sup> ). This was followed by extensive microclinization, with a second phase of potash introduction. This scheme is in accordance with the expected time relations of alkali metasomatism based on atomic size (  $Na < K$  ). The metasomatizing solutions probably moved along the schistosity from the south to the north, and originated in the core of the south-east plunging anticline to the south. The occurrence of a microcline rich arkose here, indicates a ready source of alkalies, especially potash. The microcline molecule may have migrated as such

## (2). The Amphibolites.

These are characterised by:-

(1). The occurrence of numerous dykes roughly parallel

to the schistosity but sometimes deviating from this.

(b). They have basic plagioclase An 40 - 60

(c). They have rare relicts of pyroxene in the hornblende, and have iron ore and sphene exsolving from the hornblende.

(d). They have sharp contacts with the country rocks.

(e). The occurrence of two textures, one massive and one schistose.

(f). Some joints have been axial plane folded along the induced second schistosity.

(g). Both the earlier and the later deformations are represented in the structure.

(h). The dykes have a uniform petrology.

The amphibolites appear to be of an igneous origin, and nothing in the analysis or norm calculation opposes this conclusion. The original magma would have been an olivine basalt type. On structural grounds the amphibolites may predate the granite; the dykes cutting the granite being ungranitized enclaves.

### (3). The Country Rocks.

There is no evidence to support the extensive metasomatic interplay which Campana has envisaged, the basal sandstone and the schists being of purely stratigraphic origin. The alumina metasomatism which has been active in producing the sillimanite and kyanite rich rocks in the area is a local effect. The sillimanite originated prior to the granite (possibly during the first deformation). Its origin is not solved but some evidence for a metamorphic origin from mica is indicated. Kyanite appears to be of minor importance in the schists. Sillimanite-quartz pods and kyanite veins occurring north of the granite appear to be of a later origin, probably originating during the granitization, excess alumina being driven northwards along the schistosity to produce the highly metasomatic rocks to the north.

The rutile deposits of the hydrothermal zone west of the granite, seem to have originated from the breakdown of biotite to chlorite in the surrounding schists, with subsequent hydrothermal concentration.

The grade of metamorphism based on the plagioclase composition and the occurrence of staurolite and garnet is in the lower amphibolite facies. Although if sillimanite is originating from mica an upper amphibolite facies is indicated ( Francis 6. )



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DISCUSSION

During the preparation of the Mt. Crawford Gneissic Granite it was decided that some use should be made of heavy minerals. Although it was not possible to carry out a full-scale statistical analysis of the heavy mineral content of the granite, the heavy mineral content has been studied in the granite. The heavy mineral content of the granite was found to be lower than the heavy mineral content of the granite and the surrounding gneiss. This relationship may be due to the fact that the granite is a younger intrusion than the surrounding gneiss.

Honours B.Sc, Thesis

A brief mention of the method of extraction of the heavy minerals may be appropriate at this stage.

" THE GEOLOGY OF THE MT. CRAWFORD GNEISSIC GRANITE AND ITS ENVIRONS.

The purpose of this study was to determine the position of the heavy mineral content of the granite. Although the heavy mineral content of the granite was found to be lower than the heavy mineral content of the surrounding gneiss, it was believed that this could be due to the fact that the granite is a younger intrusion than the surrounding gneiss. The heavy mineral content of the granite was found to be lower than the heavy mineral content of the surrounding gneiss.

APPENDIX A.

HEAVY MINERAL ANALYSES.

The heavy mineral content of the granite was determined by "panning" to separate the heavy minerals from the surrounding gneiss. The heavy mineral content of the granite was found to be lower than the heavy mineral content of the surrounding gneiss. The heavy mineral content of the granite was found to be lower than the heavy mineral content of the surrounding gneiss.

What follows is a brief summary of results of the analyses and it is hoped that they will prove well interesting and useful.

Kingsley J Mills.

1959.

AMPHIBOLITES.A177 1/245.

THE SAMPLE. The rock was a fine-grained schistose and lineated, dark, green-black amphibolite. The major minerals present were hornblende, labradorite, and quartz. The sample was fresh and may be considered typical of the amphibolites which cut the schists.

THE ANALYSIS.

Sphene	98%	Ilmenite	1%	Magnetite	1%
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THE MINERALS.

Sphene : The grains are rounded, clear and show many liquid and dark (ilmenite?) inclusions. Extinction is imperfect and the dispersion is strong. (  $r > v$  ).

Ilmenite : Minute inclusions in sphene.

Magnetite : Few grains present.

A177 1/623.

THE SAMPLE. The rock was a fine-grained, schistose and lineated, dark, green-black amphibolite. The major minerals present were hornblende, labradorite and quartz. The sample may be considered as typical of the amphibolites cutting the granite

THE ANALYSIS.

Sphene	96%	Ilmenite	1%	Apatite	1%.
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THE MINERALS.

Sphene : Even-grained (.075 mm), clear, rounded to fragmental grains with adamantine lustre in reflected light. Bubble and ilmenite inclusions are common.

Apatite : Prismatic milky grains of dull lustre and low birefringence.

Ilmenite : Inclusions in sphene.

THE COUNTRY ROCKS.

A177 2/446

THE SAMPLE. The rock was a haematite rich sample of the basal sandstone member. The major minerals were quartz, haematite (20%), and muscovite.

THE ANALYSIS.

Zircon	92.1%	Garnet	2.1%	Rutile	1.0%
Monazite	2.1%	Hypersthene	2.1%		

(Iron Ore and Apatite removed.)

THE MINERALS.

Zircon : Clear to partly clouded rounded grains with an adamantine lustre. The roundness of the grains was a little greater than those of the granite.

Monazite : Pale yellow-green grains.

Garnet : Orange-pink magnetic fragments.

Hypersthene : Pale green-grey fragments with a dull lustre, slightly pleochroic from pale pink to a very pale green.

Rutile : Orange-brown adamantine, nonmagnetic grains; often showing a good crystal form.

A177 1/186

THE SAMPLE. The sample was a hydrothermally altered sericite quartz, mica, chlorite schist from north of the granite.

THE ANALYSIS.

Monazite	50%	Staurolite	5%	Tourmaline	2%
Zircon	40%	Others	3%		

(Iron ore, Apatite and carbonates removed).

THE MINERALS.

Monazite : Rounded yellow grains.

Zircon : <sup>u</sup>Rounded stumpy grains.

Staurolite : Small rounded fragments pleochroic in the yellows.

Tourmaline : Prisms to .1mm long.



THE GRANITE

A177 1/573.

THE SAMPLE. The rock is a typical specimen of the granite. The specimen was taken 10 - 20 yards from the granite contact at the north end of the granite body. The major minerals were quartz, microcline, andesine, biotite and muscovite.

THE ANALYSIS.

	Iron ore	88.4%		
	Others	11.6%		
Others.				
Zircon	50.9%	Hypersthene	1.1%	Garnet .5%
Monazite	46.2%	Apatite	1.0%	Epidote .1%

THE MINERALS.

Iron ore : Small well crystallized magnetite and haematite (martite) grains and fragments with a bright metallic lustre are common.

Zircon : Two types of zircon may be distinguished :-

- (a). Small (ave. .05mm) grains, milky white to colourless and even-grained. Grains elongate (elongation averages 2:1) and rounded and show pitted surfaces. Very good crystal faces and terminations are very rare. Inclusions of biotite at the grain boundaries are common. Most grains have an adamantine lustre.
- (b). Grey-brown opaque to translucent grains generally showing good crystal form (but pitted and somewhat worn). These grow to a somewhat larger size (to .3mm) and average .075mm. They are characteristically stumpy in crystal form.

Monazite : Variable grain size to .2mm (ave. .05mm). The grains are colourless to pale yellow to yellow-green and often have biotite inclusions. The grains are generally clear and unweathered. Some show good crystal faces but others are rounded. Some crystal forms are also visible. The grains are optically positive, with a very low optic axial angle and a high birefringence.

Hypersthene : Pale green-grey fragments having a fine fibrous cleavage structure and a dull glassy lustre.

Apatite : Small colourless prisms.

Garnet : Clear grains of orange-pink and pale pink colours.

Epidote : Green-yellow grains.

A177 1/461.

THE SAMPLE. The rock was a specimen of granite rich in iron ore from the northern end of the granite body. The major minerals were quartz, microcline, andesine, biotite, muscovite and iron ore.

THE ANALYSIS.

		Total heavy mineral excluding iron ore	.01%
Sphene	72.6%	Garnet	3.7%
Hypersthene	22.4%	Zircon	1.2%
		Rutile	.1%

THE MINERALS.

Sphene : Rounded clear colourless grains with an adamantine lustre. Small dark round inclusions are common. The sphene is similar to that of the amphibolites.

Hypersthene : Pale grey-green transparent grains often showing bladed fragments with a weak cleavage. Refractive index is near 1.722. Pleochroic pale pink to pale green-grey; however, some grains are less pleochroic palegreen to green-grey. Extinction is parallel to the cleavage and the mineral is length slow. The optic axial angle is near  $90^\circ$  and axial bisectrix and optic axial figures are hard to obtain. The birefringence is moderate.

Garnet : Pale pink isotropic fragments.

Zircon : Very rounded elongate grains, some being much altered and stained yellow.

Rutile : Golden orange grains.

A177 2/560.

THE SAMPLE. The rock was a soft specimen of granite of a normal composition. The major minerals were quartz, microcline, andesine, biotite and muscovite.

THE ANALYSIS.

Total heavy mineral (excluding Apatite and including iron ore .05%.

Monazite	56.2%	Iron ore	1.7%	Hypersthene	.03%
Zircon	41.1%	Garnet	.5%	Others	.5%

THE MINERALS.

Monazite : Rounded pale yellow transparent grains. The mineral is even-grained (ave. .05mm). Inclusions are rare but some variation in colour from yellow to colourless may be due to weathering.

Zircon : Two types :-

- Clear colourless rounded magnetic grains free of inclusions. *Xenotime*
- Clear colourless, rounded, non-magnetic grains with an even size (ave. .05mm). Crystal faces are rare and the grains lack any marked elongation, having a high degree of roundness. Inclusions of iron ore and biotite occur in a few grains.

Iron ore : Fine grained.

Garnet : Pink-orange isotropic, magnetic grains.

Hypersthene : Pale green-grey fragments.

A177 1/622.

THE SAMPLE. The rock was a typical sample of the granite with major quartz, micro cline, andesine, biotite and muscovite.

THE ANALYSIS.

Total heavy minerals (excluding Apatite but including iron ore .053%

Monazite	52.7%	Rutile	.4%	Garnet	.06%
Zircon	46.7%	Iron ore	.14%		

THE MINERALS.

Monazite.: Glassy pale yellow grains with a high relief. The grains are even in size (ave. .05mm), rounded, but with a few crystal faces visible; these faces being very smooth and unpitted. The grains are clear, although a little oxidized and some have biotite inclusions on their edges.

Zircons : Three types:-

- (a). Clear, colourless, very rounded, magnetic grains; structureless and mostly free of inclusions. Uniaxial positive with a high relief. Few crystal faces are shown. Most grains are about .025mm in diameter. Xenotime
- (b). Common, clear to milky-white (slightly grey), non-magnetic grains showing rudiments of crystal form with some rarer grains showing well developed crystal faces and terminations. The grains have an adamantine lustre, and an even grain size (ave. .05mm).
- (c). Rare, grey-brown, opaque, nonmagnetic malacoons showing large stumpy well developed but pitted crystal form.

Rutile : A few orange, non-magnetic grains.

Iron ore : Small grains averaging .025mm.

Garnets : Isotropic pale orange-pink fragments.

NOTE the striking similarities between samples A177 <sup>1</sup>/522 and A177 <sup>2</sup>/560.

THE ENCLAVES.

A177 2/57

THE SAMPLE. The rock was a strongly schistose quartz, mica schist occurring as a sedimentary inclusion in the granite. The major minerals were quartz, biotite and muscovite.

THE ANALYSIS.

Total heavy mineral in the rock (including iron ore but excluding Apatite) .076%.

Monazite	66.4%	Iron ore	.6%	Garnet	.05%
Zircon	32.1%	Graphite	.05%	Others	.05%
Tourmaline	.7%	Hypersthene	.05%		

THE MINERALS.

**Monazite :** Pale yellow grains varying from very pale yellow to orange-brown. Some grains are very rounded whereas others are rather fragmental. No crystal forms are visible. The grains are of an even size, averaging .05mm to .075mm but some range up to .3mm. The grains are not evenly coloured and the inclusions of gas bubbles are common. The grains are rather rounded and pitted. Inclusions of biotite are common on the grain edges.

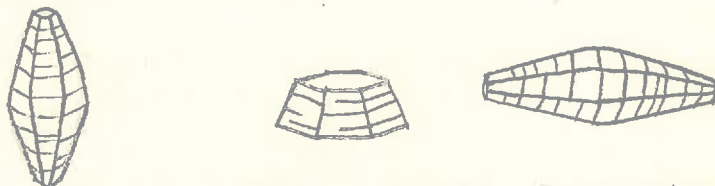
**Zircon :** Four types:-

- Clear, rounded, even-grained ( .075mm to .01mm), magnetic grains. Gas bubble inclusions are common. Zones are absent. Uniaxial positive with a high birefringence.
- Small, (.075mm), translucent, pale grey-brown grains with a greasy lustre in reflected light. The grains often show a few crystal faces and small biotite and monazite inclusions are common on their surfaces.
- Small (.05mm), clear, colourless to yellow brown, rounded, non-magnetic grains.
- Large (to .3mm), translucent, pale grey-brown grains showing good prism and tetrahedral terminations and small biotite inclusions on their surfaces. The crystals have a pitted and worn appearance.

**Tourmaline :** Prisms and broken fragments; clear, transparent and pleochroic from pink to grey.

**Iron ore :** Rare.

**Graphite :** Non-magnetic well-formed hexagonal barrel shaped crystals to .075mm long. Silvery lustre in reflected light. Platy basal parting. The mineral is soft and has a pitch black streak.



**Hypersthene :** Pale green-grey, magnetic fragments showing a slight cleavage. The grains have a length slow character, high relief, very high optic axial angle (positive or negative biaxial sign).

**Garnet :** Non pleochroic, pink, isotropic grains with a high relief and conchoidal fracture.



A177 2/478.

THE SAMPLE. The rock was a haematite rich specimen of arkose like "granite", with major quartz, microcline, andesine, haematite and minor muscovite. The specimen was taken from the centre of the granite body.

THE ANALYSIS.

Heavy mineral excluding iron ore and Apatite. .02%					
Zircon	71.5%	Anatase	11.4%	Others	.3%
Monazite	13.9%	Rutile	.9%		

THE MINERALS.

**Zircon :** Transparent to translucent grains averaging .05mm (but ranging up to .4mm). Some grains are well-formed crystals but most are pitted and worn in appearance. Vitreous lustre is a characteristic. Inclusions are rare.

**Monazite :** Cloudy pale yellow rounded to angular grains showing some crystal faces but generally having a pitted appearance. Even grain size at .05mm.

**Anatase :** (X-ray verification). Dark green to blue-green grains with an adamantine lustre and often showing a good crystal form. The grains are transparent to translucent.

**Rutile :** Pale orange fragments with an adamantine lustre.

A177 1/617.

THE SAMPLE. The rock was a haematite rich specimen of an arkose like "granite", with major quartz, microcline, andesine, haematite and minor muscovite. The specimen was taken from the northern part of the granite body.

THE ANALYSIS.

Total heavy mineral extracted from the rock		10.3%
	Iron ore	10.3%
	Others	.014%

Others	Zircon	97.0%	Rutile	1.0%	Garnet	.1%
	Monazite	1.7%	Hypersthene	.1%	Others	.1%

THE MINERALS.

**Zircon :** Two types:-

(a). Common, clear, lustrous grains averaging .05mm x .10mm. The grains are rounded and pitted but show a few prism faces and terminations with strongly pitted surfaces. Zoning was not detected. The grains are commonly fractured and have gas bubble inclusions.

(b). Rarer, opaque, grey-brown crystals showing common prism faces and terminations with strongly pitted surfaces. The grains average .2mm and some reach .3mm in length. The crystals are characteristically stumpy in form (prism faces equal the length of the pyramidal edge. A few of these grains are more irregular. In transmitted light the grains appear to be full of very minute impurities.

**Monazite :** Rounded fresh pale yellow to yellow-green grains averaging .05mm in diameter and having a high relief.

Rutile : Non-magnetic opaque grains, black in colour and with an adamantine lustre.

Hypersthene : Pale green magnetic fragments with a high relief, moderate birefringence and a very large optic axial angle. Slight traces of cleavage and a slight pleochroism from pale pink to pale green are characteristic

Garnet : Small orange-pink fragments; isotropic and clear.

CREEK SANDS.A177 <sup>2</sup>/125.

THE SAMPLE. The sample was a well washed, fine-grained, clean, quartz rich sand from a small watercourse in the central part of the area east of the granite. Minor heavy mineral was visible in the sand.

THE ANALYSIS.

(including iron ore but excluding apatite).

Hornblende	46.8%	Epidote	4.3%	Garnet	.80%
Iron ore	13.3%	Sillimanite	3.3%	Tremolite	.37%
Rutile	8.9%	Monazite	3.2%	Sphene	.32%
Tourmaline	8.1%	Zircon	2.7%	Kyanite	.28%
Hypersthene	4.9%	Staurolite	1.4%	Others	.27%

THE MINERALS.

Hornblende : Dark green prismatic fragments.

Iron ore : Black grains of magnetite and ilmenite.

Rutile : Deep orange coloured grains with an adamantine lustre, and often showing crystal form.

Tourmaline : Transparent smoky grey-brown, prismatic grains.

Hypersthene : Pale green to grey-green fragments.

Epidote : Irregular, transparent, lime-green to green-yellow pitted grains.

Sillimanite : Colourless spindles and bladed fragments.

Monazite : Pale yellow, mildly magnetic grains.

Zircon : Very rounded, waterworn grains. Most grains are clear but some have a greasy white colour.

Staurolite.: Deep yellow glassy grains and fragments.

Garnet : Pale pink fragments.

Tremolite : Pale green to colourless bladed fragments.

Sphene : Clear colourless grains.

Kyanite : Bladed blue fragments.

A177 <sup>1</sup>/85.

THE SAMPLE. The sample was a mixed sand of variable grain size, from a watercourse just east of the northern tip of the granite. The sand was partly derived from a nearby remnant of lateritic peneplane. Iron ore, garnet and hornblende were visible.

The ANALYSIS.

(excluding iron ore and apatite)

Hornblende	50%	Sillimanite	5%	Epidote	5%
Staurolite	15%	Rutile	5%	Others	5%
Monazite	10%	Zircon	5%		

THE MINERALS.

The minerals were not described in detail.

A177 2/320.

THE SAMPLE. The sample was a solid, boulder clay derived from the base of a creek bank in a watercourse at the western edge of the granite.

THE ANALYSIS.

(including iron ore but excluding apatite).

Iron ore	57.0%	Garnet	3.0%	Sphene	.16%
Epidote	13.4%	Tourmaline	2.1%	Sillimanite	.12%
Hornblende	12.7%	Hypersthene	.60%	Kyanite	.11%
Rutile	5.5%	Staurolite	.60%	Anatase	.02%
Monazite	4.4%	Zircon	.24%	Others	.05%

THE MINERALS.

Iron ore : Shiny black grains often rounded but sometimes showing crystal form. There is a mixture of magnetite, haematite and ilmenite (leucogene coatings).

Epidote : Green to yellow-green grains of irregular shape. They are generally clear but sometimes clouded.

Hornblende : Dark green, glassy grains showing cleavage.

Rutile : Clear to clouded, rounded to prismatic grains of a deep orange colour.

Monazite : Pale yellow grains of rounded habit.

Garnet : Clear fragments of pale pink and pale orange colours.

Tourmaline : Small, clear, smoky brown to grey-brown prisms with a glassy lustre and often showing a good crystal form.

Hypersthene : Grey green grains.

Staurolite : Pale orange weakly magnetic grains.

Zircon : Average grain size .05mm. Rounded oval eye shaped grains which appear to be more rounded than zircons from the rocks of the area. The zircons are mostly clear and colourless but some are slightly rounded, clouded grains. Zoning is rare or absent. A few prismatic grains with rounded ends occur.

Sphene : Clear rounded grains.

Sillimanite : Small colourless transparent spindles and prisms.

Kyanite : Several blue prisms seen.

Anatase : A few blue-green grains were seen.

A177 1/142.

THE SAMPLE. The sample was a sand from a minor watercourse east of the northern tip of the granite. Rutile was a prominent visible component.

The ANALYSIS.

(including iron ore but excluding apatite.)

Iron ore	47%	Monazite	5%	Tourmaline	2%
Rutile	36%	Garnet	1%	Sphene	1%
Zircon	5%	Staurolite	1%	Others	2%

THE MINERALS.

Iron ore : Black opaque grains.

Rutile : Very rounded fragments of variable colour from pale orange to deep blood red.

Zircon : Colourless small rounded grains.

Monazite : Pale yellow rounded grains.

Garnet : Pale pink fragments.

Staurolite.: Deep yellow grains.

Tourmaline : Smoky grey-brown prisms.

Sphene : Colourless to grey with small inclusions.



Honours B.Sc. Thesis

THE GEOLOGY OF THE MT. CRAWFORD GNEISSIC GRANITE  
AND ITS ENVIRONS.

APPENDIX B.

SELECTED SLIDE DESCRIPTIONS.

Kingsley J Mills.  
1959.

INDEX TO THE SELECTED SLIDE DESCRIPTIONS.

During the course of the work in the Mt. Crawford area about 140 slides were cut. Of these 60 have been selected to illustrate the petrology of the area.

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SCHISTS ABOVE THE BASAL SANDSTONE.

A177 2/418.

MACRO. The rock is a strongly crenulated, quartz, bimica schist with visible muscovite, biotite, quartz and a few sericite pseudomorphs of kyanite crystals. These pseudomorphs are up to 5 mm. long and 1 mm. wide and occur parallel to the foliation plane of the mica flakes. A thin grey band of fine grained quartz probably represents a sedimentary lamination. This band is 4 mm. wide and is parallel to the mica foliation which has been folded along irregular axes, which show a general direction of plunge.

MICRO. The slide is cut perpendicular to the fold axes.

The rock has a crystalloblastic texture, with strong micro-folding.

Biotite : The biotite occurs as small flakes isomorphously intergrown with the muscovite flakes, muscovite being the major mineral in the rock. The biotite is pleochroic from very pale yellow-green to dark green-grey. The mineral is rather fresh and occurs in flakes averaging 1 mm. long. Pleochroic haloes are absent. 5%.

Muscovite : 85% : This mineral occurs as thin flakes averaging 1 mm. long, closely packed and interlocked. The flakes are almost totally oriented parallel to the foliation, this being folded into shallow crenulations. Mica in the axial regions of these folds is sometimes broken and sometimes bent. The folding was probably contemporaneous with the crystallization.

Quartz : 10% : Occasional grains averaging 1 mm. occur throughout the mica bands. Strain shadows and undulose extinction is common. Finer grained quartz (.3 mm.) occurs in the band of quartzose material seen in the hand specimen.

Felspar : None recognised.

Tourmaline : 1-2% : The mineral is very abundant throughout the rock as small grains, and also appear to be concentrated into certain bands. In the fine-grained quartzose band, tourmaline occurs as abundant small rounded grains. Certain small bands in the micaceous parts of the rock are also rich in tourmaline. The grains have a uniform character throughout being pleochroic from dark grey to very pale gray-brown. Crystal faces are not present.

Pyrite? : One or two limonitic replacements after pyrite? were noted.

DISCUSSION. The rock is a bimica quartz schist. Muscovite is the major mica. Tourmaline is an abundant accessory. The rounded nature of this accessory suggests that a sedimentary origin might be considered. The rock has been strongly crenulated and folding appears to have been contemporaneous with the crystallization.

THE LOWER TREMOLITE BED.

A177 2/410.

MACRO. The specimen is a weathered nodule of the tremolite rock obtained from a small mine shaft on the ridge north of Sailors Gully. The nodule shows the presence of an unweathered central portion of pale green tremolite-actinolite, having an irregularly grained matrix of matted crystals, giving a very tough, massive rock. The decussate structured central core is surrounded by a weathered zone (with a sharp boundary) of a whiter, soft asbestos like material, with silky pseudomorphs after tremolite still visible and retaining their pale green tinge. The lack of oxidation of the iron present indicates that weathering has occurred under reducing conditions.

MICRO. The slide has a random orientation.

The rock has a decussate crystalloblastic structure.

The slide shows that the rock is made up entirely of tremolite-actinolite in fine matted fibrous crystals, which show the characteristic elongation and relief of tremolite. The crystals range greatly in size and consist of two types:-

(a). A fine-grained matrix of irregularly radiating fibrous crystals. The radiating fibrous crystals are often elongated in two directions at about  $100^{\circ}$ . These may either represent two lineations, or have some relation to the crystal structure of tremolite.

(b). Larger fibrous crystals of optical continuity.

Although some grains were of a deeper green colour in the hand specimen, no difference was noted in the grains of the slide.

DISCUSSION. The rock is most probably of a sedimentary origin, being originally a dolomite, which has been raised by metamorphism, to the status of a tremolite rock. There was no evidence in the specimen for the possible origin of the opaline silica so commonly seen in the upper weathering zone of this formation.



NORMAL ROCKS OF THE MAIN SCHIST SEQUENCE.

A177 2/653.

MACRO. The rock is a light coloured, fresh, muscovite, quartz, chlorite, sillimanite, (sericite); magnetite schists. The schistosity is a marked feature of the hand specimen. The schistosity planes are rather knobby in appearance due to the presence of sillimanite clots distributed throughout the rock. The rock has an irregular lineation in the form of minute, closely spaced, isoclinal shear folds up to 2 mm. across, in the micaceous bands. These have probably obliterated the original bedding of the rock. The visible minerals are quartz, sillimanite, chlorite and muscovite. Magnetite specks can be seen embedded in the chlorite.

MICRO. The slide is cut parallel to the lineation and perpendicular to the schistosity.

The texture is a purely crystalloblastic one.

Chlorite : 30% : (Pennine). The chlorite occurs in very ragged and splintery, ill-defined sheafs of flakes, up to, 6mm. in length. Abundant inclusions of quartz, muscovite and iron ore occur. The flakes are pleochroic from very pale green to mid green, and the birefringence is very low, being almost isotropic, although a faint anomalous purple can be seen in some flakes. The flakes are well oriented and elongated parallel to the schistosity but some flakes of a more stumpy, and better formed habit, lie across the schistosity. The individual flakes of a sheaf generally intersect at low angles, giving a V shaped folded appearance. Crowds of thin anastomosing feathers of chlorite also occur throughout the sillimanite-sericite rich parts of the slide. The chlorite feathers thin out in the more sillimanite rich parts.

Muscovite : Two types :-

(a). Original muscovite : 3% : Occurs as well developed flakes intergrown with the chlorite

(b). Secondary muscovite : 15% : This is recrystallizing from sericite. There is a complete gradation to sericite. The sericite has resulted from the hydrothermal alteration of sillimanite. The first stage of this alteration is the ultramicroscopic development of sericite flakes, which in later stages further from the unaltered sillimanite recrystallize to larger microscopic flakes, which grow and eventually become recognisable muscovite. Feathers of chlorite often extend into the sericite patches.

Sillimanite : Small, thin, clear, colourless sillimanite prisms occur embedded in quartz grains, where they have escaped alteration. Their bulk is negligible and they represent unstable relicts in the present assemblage.

Iron ore : 1% : Iron ore is a constant associate of the chlorite. The greater bulk of this mineral occurs disseminated throughout the chlorite as fine grains. The grains are seldom greater than 3 mm. in diameter. A few remnants of biotite in the chlorite indicate that the chlorite and the iron ore have resulted from biotite alteration.

Zircon : Several minute zircons were noted in the chlorite surrounded by dark green pleochroic haloes. The grains were clear, rounded and seldom exceeded .05 mm. in diameter.

Quartz : 50% : Forming a "background" to the sillimanite and sericite are large, closely packed quartz grains. The grains, which average 1 mm. in diameter are clear, show sharp extinction and are completely free of strain shadows. Sillimanite spindles are often found penetrating the quartz grains.

NORMAL ROCKS OF THE MAIN SCHIST SEQUENCE (cont.)

DISCUSSION. The rock is composed of chlorite, sericite, muscovite, quartz, iron ore and minor sillimanite (relicts). Sillimanite, quartz, biotite and muscovite appear to represent the original minerals. Later retrograde metamorphism ( or hydrothermal alteration ) has converted sillimanite to sericite, and biotite to chlorite and iron ore. The quartz is clear and unstrained. Felspar is absent.

A177 1/325.

MACRO. The rock is a green-red lineated, quartzose, sericite, chlorite, muscovite schist. The rock is even grained at about 1 mm.

MICRO. The slide was cut perpendicular to the lineation and the schistosity.

The texture is a purely crystalloblastic one.

Biotite : 2% : This mineral occurs in irregular iron stained flakes averaging .4 mm. in length. These flakes are poorly oriented and often show retrogression to chlorite. The biotite is pleochroic from light to dark brown.

Chlorite : 5% : The ragged and iron-stained flakes result from the alteration of biotite. The mineral is pleochroic from pale yellow to mid green, and has anomalous interference colours. Inclusions of minute zircons occasionally occur producing pleochroic haloes.

Muscovite : 3% : Clear, mildly oriented flakes of muscovite up to .5 mm. in length, occur associated with the chlorite and biotite.

Sericite : 25% : This mineral occurs as streaks and blebs along the grain boundaries, and especially near the mica flakes. The sericite is structureless, and there is no sign of sillimanite relicts or fibrous structures. The mineral may be an alteration product of the mica.

Haematite : 1% : Several haematite and limonite pseudomorphs after magnetite occur.

Zircon : One or two rounded grains were seen associated with the iron ore.

Quartz : 65% : The quartz occurs as even grains averaging .5 mm. in diameter. The grains are clear, free of inclusions, and have no strain shadows.

Felspar : Appears to absent.

DISCUSSION . The rock was originally a quartz, muscovite, biotite schist, which by diaphoresis has become a quartz, muscovite, biotite-chlorite, sericite schist. Felspar is notably absent.

A177 2/270.

MACRO. The rock is quartz - felspar - sericite - muscovite - biotite schist, with a strong schistosity and a weak lineation. The rock is even, medium grained, and gneissic. Accessory haematite is also visible in the hand specimen. A slight lineation occurs.

MICRO. The slide is cut perpendicular to the lineation and the schistosity.

NORMAL ROCKS OF THE MAIN SCHIST SEQUENCE. (cont.)

The texture is a gneissic crystalloblastic one.

**Biotite : 10% :** When fresh the grains are pleochroic from pale yellow to deep green black, but some grains show stages of alteration to chlorite, losing their colour in the process.

**Chlorite :** Traces of chlorite with anomalous interference colours are the result of biotite alteration.

**Muscovite : 2% :** Clear grains associated with the biotite and often reaching 1 mm. in diameter.

**Sericite : 10% :** Ultrafine, fibrous knots and strings, which are often mixed with chloritic material. The sericite masses often show micro-folding. The mineral probably represents original sillimanite.

**Iron ore :** One large, irregular grain of haematite, 4 mm. in diameter, with a small magnetite inclusion in the centre. Small grains of iron ore are exsolved from the altering biotite as well as abundant limonite along the grain boundaries.

**Quartz : 50% :** The grains have a variable size up to 6 mm. but average .75 mm. in diameter. The grains are generally clear and free of inclusions, but show strong strain effects under crossed nicols.

**Felspar : 30% :** No microcline twinning was observed, although plagioclase twinning was common, both albite and pericline twins occurring. The xenoblastic grains averaged .5 mm. and were fairly even grained. No zoning was observed. Some untwinned felspar was present.

Extinction angles on albite twins :-

11°, 10°, 11°, 6°, 16°, 7°, 3°, 9°, 11°, 10°.

This indicates a composition  $An_{34}$ . (Andesine).

**DISCUSSION.** The rock is a quartz - plagioclase - sericite - biotite - muscovite schist with signs that the sericite was originally sillimanite. The quartz is strongly strained and the felspar is largely plagioclase.

A177 1/328.

**MACRO.** The rock is a slightly weathered, schistose gneiss of a granitic aspect. Biotite and muscovite give a marked schistosity to the specimen. Quartz and felspar is of an even grain size ranging from .5 - 1 mm. and occur in bands between the mica bands. Accessory limonite pseudomorphs after pyrite? are also visible.

**MICRO.** The slide was cut perpendicular to the schistosity.

The texture is a gneissic crystalloblastic one.

**Biotite : 3-4% :** This mineral occurs in irregular flakes averaging .75 mm. in length and often well oriented parallel to the schistosity. Alteration and weathering of these flakes is a common feature. The fresh flakes show a pleochroism from pale yellow to black-green. The more oxidized flakes are of a lighter redder colour. Some of the biotite is altered to chlorite and other flakes have altered to sericite and limonite.

Secondary biotite is also present in some parts of the slide occurring as radiate disoriented crystals.

**Chlorite :** This is sometimes present as an alteration product of biotite. It is pleochroic from very pale green-yellow



NORMAL SCHISTS OF THE MAIN SCHIST SEQUENCE.(cont.)

to mid green.

**Muscovite : 5-8% :** The muscovite flakes are generally strongly oriented, and show a much greater grain elongation than the associated biotite flakes. The flakes average 1 mm. in length, and generally occur in gneissic bands. The grains show little alteration.

**Iron ore : 1% :** Iron ore in the form of small grains and elongate streaks occurs in association with the biotite. The mineral (probably magnetite) often occurs in the biotite cleavages. Several limonitic pseudomorphs also occur, and show concentric replacement structures.

**Zircon :** Very small rounded grains of zircon are sometimes present in the mica flakes, and cause pleochroic haloes in the biotite.

**Quartz : 50% :** The grain boundaries are often coated with limonitic material. The grain size of the quartz is relatively uniform, averaging .5 mm. in diameter. Strain shadows and inclusions are rare in the quartz.

**Felspar : 35% :** No microcline twinning was observed in the felspar, although plagioclase twinning was common. Some of the smaller grains show a little zoning. The grains average .5 mm. and is fairly uniform in size. Many grains are untwinned.

Extinction angles on albite twins :-

$3^{\circ}$ ,  $6\frac{1}{2}^{\circ}$ ,  $9^{\circ}$ ,  $11^{\circ}$ ,  $12^{\circ}$ ,  $5^{\circ}$ ,  $12^{\circ}$ ,  $12^{\circ}$ ,  $11^{\circ}$ ,  $13^{\circ}$ .

These indicate a composition near  $An_{31}$  (Andesine-oligoclase). The felspars are generally slightly fractured and weathered.

**DISCUSSION.** The rock has apparently suffered some alteration and weathering. However the original assemblage of biotite, muscovite, quartz, plagioclase, and iron ore seems to be well established. The rock apparently lack significant potash felspar.

A177 1/186.

**MACRO.** The rock is a coarse grained irregularly crumpled schist. The visible minerals are sericite, quartz (large, pale milky grains with an irregular distribution), chlorite (pale green feathery crystals), felspar (creamy, translucent to opaque, fine-grained aggregates associated with the quartz), and traces of small iron ore crystals. The sericite occurs as irregular, feathery and radiate knots, of irregular shape and size, which tend to crumple the schistosity. The quartz and felspar occur in minute aggregations of pegmatoidal aspect. Muscovite and chlorite (probably original biotite) are distributed throughout, sometimes occurring in gneissic bands. The rock is not very schistose, and the gneissic banding is slight. Microfolding is masked by alteration.

**MICRO.** The slide is cut perpendicular to the slight lineation.

The texture is purely crystalloblastic one.

**Chlorite : 5% :** The chlorite is very strongly pleochroic from pale yellow green to a deep green. The grains reach 1 mm. in diameter but are generally smaller. They are typically ragged and irregular in shape, and not well oriented. Straight

NORMAL ROCKS OF THE MAIN SCHIST SEQUENCE (CONT.).

extinction and anomalous blue interference colours are characteristic and possibly indicate pennine. Abundant ilmenite inclusions occur in the chlorite and indicates original biotite, although this mineral is not present, even as relicts. The chlorite shows all stages of alteration to sericite and iron ore.

**Muscovite : 5% :** The original metamorphic muscovite flakes have remained stable during the late stage alteration. The muscovite occurs as isolated crystal aggregates and as crystals intergrown with the chlorite in bands. The grains average 1 mm. in diameter.

**Sericite : 45% :** Ultrafine sericite is the major mineral of the slide, occurring as relicts after sillimanite (relict spindle shapes in the quartz grains), and after chlorite, although sillimanite is the main source. Feathery and fibrous structures are common and only slight recrystallization to muscovite is evidenced.

**Iron ore : 1% :** The major iron ore is ilmenite developed as (.1 mm.) small irregular and elongate specks in the chlorite. Here the mineral is an alteration product of biotite. A few larger grains of limonitized haematite, representing original iron ore was also noted in the slide.

**Zircon :** Small grains of rounded aspect are occasionally seen, causing pleochroic haloes in the chlorite. One notable grain was .2 mm. in length and was included in muscovite.

**Monazite :** Minute crystals of monazite less than .1 mm. in diameter, with a rusty rounded appearance, and surrounded by very dark, strongly pleochroic haloes (pleochroic from pale yellow to black), are common in the chlorite flakes. The birefringence was strong to extreme. The grains had a weathered, ragged and rusty appearance.

**Quartz : 35% :** The quartz occurred as irregular, interlocking, xenoblastic crystals, averaging 1 mm. in diameter. The grains often contained rounded inclusions of the other major minerals. The mineral had a uniform grain size throughout the rock. Undulose extinction was a common feature.

**Felspar : 5% :** The felspar seemed to be mainly plagioclase as no microcline twinning was seen, and albite twinning was very common. The grains were xenoblastic, and smaller than the associated quartz, averaging .3 mm. in diameter. The felspar occurred in groups of grains often surrounded with quartz, and having quartz grains interlocking with their edges. There was a slight sericitization of the felspars. The plagioclase composition was near Andesine (few good twin angles could be measured).

**DISCUSSION.** The rock is a typical metamorphite, having a good crystalloblastic texture. The rock was originally a quartz - sillimanite - biotite - muscovite - felspar schist. During diaphoresis the biotite was completely converted to chlorite, and the sillimanite to sericite.

A177 2/237.

**MACRO.** The rock was a tough, irregularly microfolded schist with visible muscovite, chlorite, sericite and quartz and iron ore. The rock had a pale green appearance and showed an irregular schistosity, with no uniform lineation.



NORMAL ROCKS OF THE MAIN SCHIST SEQUENCE (cont.)

MICRO. The slide was cut perpendicular to the schistosity.

The texture was a strongly crystalloblastic one.

**Chlorite : 5% :** Chlorite occurs as irregular grains of variable size throughout the rock. The mineral is pleochroic from pale yellow to pale green. It occurs as an alteration product of biotite, this mineral having been completely reduced to chlorite. The chlorite is often stained by limonite and anomalous blue interference colours are common.

**Muscovite : 20% :** Muscovite occurs as well oriented flakes and bands of flakes. The mineral is generally clear but is sometimes coated with limonite.

**Sericite : 70% :** This mineral occurs as rounded, <sup>blebs</sup> closely packed throughout the rock. The mineral is ultrafine in grain size, and has an irregular structure, with no sign of the nature of the original mineral. A compact mineral (e.g. kyanite) may be indicated.

**Iron ore : 3% :** Iron ore grains of rounded habit, up to .5 mm. in diameter, are sometimes edged with ilmenite granules. Ilmenite commonly occurs as small, irregular grains included in chlorite, being an alteration product of biotite. Limonite is common along the grain boundaries and occurs as pseudomorphs after pyrite.

**Zircon :** Accessory zircons of a rounded habit are common.

**Quartz : 5% :** This mineral occurs as groups of grains. It lacks strain effects.

**Felspar :** Apparently absent.

**DISCUSSION.** The rock is a sericite - muscovite - chlorite - quartz schist, with indications of the alteration of original biotite, but no evidence for the origin of the sericite.

## UNUSUAL ROCKS OF THE MAIN SCHIST SEQUENCE.

A177 1/247.

**MACRO.** The rock is a fine-grained, tough, slightly iron-stained schist rock. Visible minerals are biotite, muscovite, quartz and feldspar, with minute pink garnets. The schistosity is weak, gneissic banding is visible and lineation is prominent. The constituent minerals are spread evenly throughout the rock.

**MICRO.** The slide was cut perpendicular to the lineation and the gneissic banding.

**Biotite : 10% :** The biotite is pleochroic from pale yellow to mustard green. Monazite inclusions with a rounded form are sometimes seen, surrounded by thick black haloes. Iron ore inclusions also occur. The flakes are well oriented, although some do traverse the schistosity, and they average .5 mm. in length. The flakes show all stages in the replacement of the biotite by sillimanite, especially in certain of the gneissic bands. The first stage in the reaction is seen in some flakes where a few spindles of sillimanite are found penetrating the mica. These fibres of sillimanite intensify until the biotite flakes begin to breakup into twisted streaks between the sillimanite fibres. The biotite decolorizes during the replacement.

**Muscovite : 5% :** This mica also shows strong replacement by sillimanite.

**Chlorite :** One small flake was recognised as an alteration product of biotite.

**Iron ore : 1% :** Irregular grains of ilmenite and haematite up to .3 mm. in diameter, are developed near sillimanite fibres.

**Sillimanite : 5-10% :** Sillimanite occurs fine, clear, unaltered, oriented fibres. These fibres occur in flat lensoid groups. The fibres extend into the surrounding quartz grains. The sillimanite may be seen in all stages of development from biotite and muscovite. This adequately explains the occurrence of feathery chlorite flakes extending into the sericite knots of the altered specimens. The production of sillimanite from biotite probably demands shear, along with incoming solutions to remove the potash released. There is a concomitant release of iron ore.

**Staurolite : 1% :** Small (.2 mm.) rounded grains of staurolite, showing no crystal faces, occur as inclusions in quartz. The mineral is pleochroic from very pale yellow to yellow.

**Garnet : 3% :** Clear colourless, unaltered, but slightly shattered, isotropic garnets are common. The grains show no sign of their method of growth.

**Apatite : 1% :** Apatite occurs as rounded to subhedral grains with a high relief and low birefringence, up to .2 mm. in diameter.

**Tourmaline :** Zoned grey crystals of tourmaline are often seen. They are pleochroic from pale pink to grey.

**Quartz : 50% :** The quartz occurs as xenoblastic grains, averaging .4 mm. in diameter, and showing some strain shadow effects.

**Feldspar : 25% :** This mineral is largely untwinned, but is often strongly zoned (may be produced by K<sub>2</sub>O release). Some

UNUSUAL ROCKS OF THE MAIN SCHIST SEQUENCE (cont.)

albite twinning was seen but not sufficient for a composition determination.

DISCUSSION. The rock appears to be an arkosic schist, having quartz, plagioclase, biotite and muscovite, and showing the development of garnet, staurolite and sillimanite. The sillimanite is being produced from the micas. The released potash may be causing the zoning in the plagioclase. Accessory zircon, apatite, tourmaline and iron ore are common.

A177 2/337.

MACRO. A tough, medium grained rock, having an heterogeneous, structureless mixture of quartz, feldspar, tourmaline, muscovite, sillimanite, biotite and magnetite. The magnetite occurs in crystals up to 4 mm. in diameter.

MICRO. The slide was cut perpendicular to a slight lineation.

Biotite : 5% : Flakes of biotite were pleochroic from pale yellow to a dark green black. The mineral shows some alteration to chlorite and ilmenite. Pleochroic haloes were common.

Muscovite : 5% : This mineral occurs in broad flakes which are often replaced strongly by sillimanite.

Sillimanite : 5% : The mineral has developed from the micas, and is now part altered to sericite.

Iron ore : 3% : Magnetite occurs in large well formed crystal shapes up to 4 mm. in diameter. Ilmenite occurs as smaller irregular crystals due to biotite replacement by sillimanite.

Zircon : Zircon is an abundant accessory as small rounded grains.

Tourmaline : 5% : This mineral is pleochroic from dark green to pale grey green. Some crystals appear to have fibrous ?sillimanite inclusions. The tourmaline apparently developed at a late stage as it tends to force the adjacent grains away.

Quartz : 50% : Quartz occurs as large xenoblastic grains averaging .5 mm. in diameter, and showing strain shadows.

Feldspar : 30% : Feldspar grains average .5 mm., and are strongly zoned. They are often untwinned although some very thin albite twins were shown.

DISCUSSION. A medium grained, non-schistose, quartz, feldspar, muscovite, biotite, sillimanite rock, showing the development of sillimanite from mica (largely muscovite). Accessory magnetite and tourmaline are notable.

A177 4/427.

MACRO. The specimen is a tough, knobby rock with a weathered appearance. Staurolite knots are etched out on the erosion surface of the rock. Mica is also visible, but in a lesser amount.

MICRO. The slide is cut at random.

Biotite : 10% : The biotite is pleochroic from pale yellow



UNUSUAL ROCKS OF THE MAIN SCHIST SEQUENCE (cont.).

to pale mustard green. The crystals are altering to sericite, the crystals being very ragged, and showing strong replacement by sericite. The cleavages are irregular due to limonite precipitating in them. Two patches of concentrated biotite occur in the slide, and these seem to have developed in the interstices of the originally close packed staurolite crystals. In the centre of these biotite rich patches are a few quartz grains radially surrounded by biotite flakes.

**Chlorite :** This mineral occurs as traces only, and diaphthoric alteration does not seem to have been as active in altering the biotite as the recent weathering of the biotite to sericite and iron ore. A little chlorite does occur as an alteration product of the biotite however, and is often filled with minute rutile spindles. The optical character of the chlorite is not obvious, but a biaxial negative figure was obtained on one fragment.

**Muscovite :** Although most of the muscovite recognisable in the slide has recrystallized from sericite, a little associated with the biotite rich patches as well formed flakes, may represent original metamorphic muscovite.

**Sericite : 85% :** Most of the rock is sericite, which has partly recrystallized to muscovite along cracks and fractures. The regular structure of the sericite near the staurolite relicts indicates the original size of the staurolite crystals. Sericite has also been formed by the alteration of biotite, and limonite appears to be the mafic product of this weathering reaction. No intermediate alteration products between the staurolite and the sericite were found. However a few staurolite fragments were edged by a thin band of material of a low birefringence, containing very small spindles of a clear, high relief mineral, growing perpendicular to the staurolite edges.

**Staurolite : 3-5% :** The mineral is of a high relief, the grains being length slow, and optically positive with a high optic axial angle. The crystals were originally large porphyroblasts averaging .5 - 1 cm. long, but are now mostly altered to sericite. The ragged fragmental relicts are pieochroic from very pale yellow to yellow. The cleavage of the mineral has been made conspicuous by alteration. No inclusions were seen. A simple twin occurred in one group of fragments.

**Iron ore :** Ilmenite occurs as small grains showing alteration to leucoxene. Limonite is a common alteration product of the biotite and the staurolite, and tends to migrate to the biotite flakes where it lodges in the cleavages.

**Zircon :** Several minute rounded grains were seen in one quartz grain.

**Quartz :** A few grains to .5 mm. were seen surrounded by biotite flakes and rimmed with limonite.

**DISCUSSION.** The texture is one of closely packed staurolite crystals, which have been extensively altered to sericite. Biotite flakes occur in the interstices of the packed staurolite crystals, and have also suffered alteration to sericite. Rare patches of chlorite carry abundant rutile spindles. The iron released during the sericitization has accumulated as limonite in the biotite cleavages, and in certain fractures in the rock. Quartz is a rarity in the rock and occurs surrounded by biotite flakes. The extent to which surface alteration has changed the rock is not accessible from the slide.



## UNUSUAL ROCKS OF THE MAIN SCHIST SEQUENCE (cont.).

A177 1/209.

MACRO. The rock is a medium grained dark green biotite - quartz schist, containing irregular knobby porphyroblasts of a chloritic appearance. Foliation is evident but is poorly developed. The visible minerals are quartz - biotite - chlorite - iron ore.

MICRO. The slide was cut perpendicular to the schistosity

The texture is a porphyroblastic one.

The rock may be described in two parts :-

(a). The Groundmass.

Biotite : 50% : The average grain size is .4-.5 cm. in diam. The pleochroism is from pale yellow green to pale orange green to dark mustard green. Some edges show a pleochroism from pale yellow to orange, and this may reflect weathering at the grain boundaries. Some grains show a stronger pleochroism to dark green black. A few minute inclusions of zircons cause pleochroic haloes in the biotite. Iron ore inclusions are also common. Alteration to chlorite (pennine) is noticeable, especially near the edge of porphyroblastic aggregates. The reaction appears to involve the release of some iron ore. The freshest biotite grains are those occurring as inclusions of small size, up to 1 mm., in the quartz rich matrix. These show a pleochroism from pale green yellow to dark green. The micas have a general tendency for parallel alignment, but this not strong. Most of the mica appears to have collected into foliae up to 2 mm. across, consisting of closely packed biotite flakes. These foliae have been the focal points of the accession of oxidizing agents and ground water.

Muscovite : Absent.

Iron ore : 1% : Small grains of magnetite are numerous throughout the slide. The grains occur mostly in the biotite where they tend to grow elongated parallel to the biotite cleavages. Small patches of iron ore inclusions in the quartzose matrix, show a general roundness and lack of orientation.

Zircon : Small grains of zircon, up to .05 mm., occur in the biotite flakes. They appear to be well rounded.

Apatite : .5% : Apatite occurs as small inclusions in quartz grains where they are always rounded and average .1-.2 mm. in diameter. They have a grain elongation of 2:1 to 3:1. Other crystals at the grain boundaries show a better crystal form, and grow up to 1 mm. in length. When growing in the biotite the mineral has a good crystal form.

Quartz : 50% : The quartz grains average 1 mm. in diameter and commonly have inclusions of apatite and iron ore. The grains are even in size and xenoblastic in form.

Felspar : Absent.

(b). The Porphyroblastic Knots.

These often show a rolled form with rotation through 90°.

Biotite : A few irregular fragments of biotite occur near the edge of the knots.

Chlorite (Pennine) : 45% : The pleochroism of this mineral varies from pale yellow to deep green. A few small zircon inclusions cause an irregularity of colour. The interference

UNUSUAL ROCKS OF THE MAIN SCHIST SEQUENCE. (cont.)

colours are slightly anomalous, there being a very weak birefringence. The grain size averages .4 mm. and the grains in cross section have an elongation of 4-5:1. The chlorite tends to have a decussate structure, the flakes being rather curved and the cleavage not as regular as that of the biotite.

Iron ore : 2% : The iron ore occurred as large ragged grains upto 1 mm. in diameter, and as hosts of small elongate grains swarming through the porphyroblastic knots, being oriented into the S shaped rotary form of the porphyroblast. The average length of these grains is .2 mm. and their grain elongation is 3:1.

Rutile : Small irregular grains and feathers are spread throughout the aggregate.

Quartz : 50% : The quartz grains average .2 mm. in diameter. Thus they are much smaller than those of the matrix. Very small rounded apatite inclusions were common.

DISCUSSION. Large porphyroblastic aggregates up to 2 cm. in diameter occur throughout the biotite - quartz schist. The knots consist of chlorite, well oriented ilmenite grains and quartz, with accessory rutile. The ilmenite traces out strong S bends in the knots, the axis of the twist lying in the schistosity plane. Accessory zircons and apatite occur throughout the rock. Apatite near the grain boundaries has grown to a larger size. The knots appear to be in a position to produce garnet, but this mineral was not detected.

A177 1/420.

MACRO. The specimen is a quartzofelspathic rock with a pink appearance. Irregular "slumped" structures of quartz and feldspar, with accessory biotite and muscovite, are partially sheathed in muscovite. The average grain size is .5 mm. in diameter, and the rock is even grained. The rock is essentially structureless, although a partial orientation of the mica is noticeable.

MICRO. The section was cut at random across the arkosic part of the specimen. The rock is very even grained at about .5 mm.

Biotite : 5% : Biotite occurs as small flakes up to 1 mm. in length, and with a grain elongation of 2-4:1 in section. The pleochroism ranges from pale green yellow to deep red-brown. A little weathering to green chlorite is noticeable. The flakes are only slightly oriented. Lamella twinning occurred in a few flakes. Small zircon inclusions produced pleochroic haloes.

Muscovite : 2% : Several flakes occur associated with the biotite, but were not abundant.

Iron ore : Several grains .05 - 1 mm. in diameter occurred in the rock but were partly weathered. Limonite and an iron oxidation mineral of an orange-red colour, and subtransparent, was commonly developed throughout the slide, especially along the grain boundaries.

Rutile : A few rounded grains .05 mm. in diameter, were present in the quartz - feldspar matrix. They appear sedimentary in origin.

Zircon : Zircon grains to .1 mm. in diameter were commonly seen as inclusions in biotite. A few grains also occur in the

UNUSUAL ROCKS OF THE MAIN SCHIST SEQUENCE (cont.)

quartz - feldspar matrix. These are always rounded.

Quartz : 2-3% : This mineral occurs as small grains to .2-.3 mm. in diameter. Strain shadows were rare.

Feldspar : 90% : Most of the feldspar showed albite twinning but many grains were untwinned. No microcline twinning was detected.

Extinction angles on albite twins :-

$13\frac{1}{2}^{\circ}$ ,  $14\frac{1}{2}^{\circ}$ ,  $14\frac{1}{2}^{\circ}$ ,  $13^{\circ}$ ,  $11\frac{1}{2}^{\circ}$ ,  $11\frac{1}{2}^{\circ}$ ,  $15^{\circ}$ ,  $14^{\circ}$ ,  $16^{\circ}$ .

This indicates a composition near An<sub>34</sub> (Andesine-oligoclase)

DISCUSSION. The rock may be a sedimentary rock of an arkosic composition. The rarity of quartz and mica and the high proportion of plagioclase are notable features. Biotite appears to be the major mica in the arkosic parts, but in the mica rich parts, muscovite is the major constituent. Zircon, rutile and iron ore are common accessories.

FACIES EQUIVALENT OF THE UPPER ARKOSE BED.

A177 3/14.

**MACRO.** The specimen is a light coloured, fine, even grained, tough, felspar rich rock, with accessory muscovite, biotite, and limonite pseudomorphs after pyrite. The micas are well oriented into the schistosity plane. Frequent small pores may indicate a sedimentary origin. The rock has a compact granular appearance. The grain size averages 1 mm.

**MICRO.** The slide was cut perpendicular to the schistosity and the slight lineation.

**Biotite : 1-2% :** The flakes average .3 mm. in length, are stumpy and ragged in form, and are often iron stained. They are pleochroic from pale yellow to deep yellow. The flakes are strongly oriented into the schistosity plane.

**Muscovite : 3% :** Small non-oriented flakes occur throughout the slide, probably occurring as a late alteration product of the felspar.

**Rutile-Leucoxene :** Minute blebs of golden yellow rutile may result from the alteration of biotite.

**Quartz :** Appears to be absent.

**Felspar : 95% :** Plagioclase twinning was a common feature. No microcline twinning was seen. Untwinned felspar was also common. All felspars were slightly weathered to sericite.

**Extinction angles on albite twins :-**

15°, 13°, 16°, 7°, 7°, 6°, 17°, 18°, 10°, 8°, .

These indicate a composition near An 36 (Andesine).

**DISCUSSION.** The rock appears to be a sedimentary one. It consists almost entirely of andesine felspar. Quartz appears to be absent. Accessory biotite and muscovite also occur.



THE UPPER TREMOLITE BED.

A177 2/168.

MACRO. The rock is tough, dense white rock having elongate tremolite crystals set in a decussate arrangement in an opaline matrix. Accessory pyrite is a common constituent.

MICRO. The slide was cut at random.

The texture is one of subhedral tremolites set in a chalcedonic matrix which has replaced the tremolites near their edges giving them a fractured appearance.

Tremolite : 80%: Tremolite occurs as colourless subhedral grains having a high relief and good cleavages. The mineral is glassy in reflected light. Most grains appear fractured. Cross-sections of the mineral show symmetrical extinction. The crystals are optically negative, with a high optical axial angle and a moderate birefringence. Some grains show a fine polysynthetic twinning. The grains are often ragged and show chalcedonic replacement along the fractures and cleavages.

Chalcedony : 20% : This mineral occurs as spherulitic cryptocrystalline blebs and irregular crack fillings in the tremolite. The spherules have a rotating-cross extinction.

Muscovite : A few rare flakes of small size were seen.

DISCUSSION. The rock appears to have been a pure dolomite silica rock which has been raised to the status of a tremolite rock by metamorphism. Chalcedony is replacing the rock first along the grain boundaries and then along the cleavages in the tremolite.

A177 1/90.

MACRO. The specimen is a fine grained tremolite rock. The tremolite is white and very fine spindles, with complete disorientation, constitutes most of the rock. Isolated veinlets of opal and small iron ore crystals are also visible. The hand specimen has a general bedded structure.

MICRO. The slide was cut perpendicular to the bedding.

Tremolite : 70% : The tremolite is colourless, biaxial negative with a high 2V, and has symmetrical extinction in cross-sections. The elongate sections are length slow. The cleavages make an angle of 56°. The optical axial plane is parallel to the cleavage. The mineral is clear and colourless. The crystals are well formed and occur in all orientations in the rock. The grains are very irregular in size and range up to 2 mm. in length and 1 mm. in width. The tremolite crystals are set in an opaline matrix.

Opal : 30% : This mineral is isotropic and has irregular structures and fractures throughout. Some of the opal rich part have talcy alteration products of the tremolite.

Iron ore.: A few isolated crystals of haematite reach  $\frac{1}{2}$  mm. in diameter and stain their surroundings yellow.

DISCUSSION. The rock is a pure tremolite rock which shows strong replacement by opal.

ARKOSIC BEDS NEAR THE UPPER TREMOLITE ROCK.

A177 4/69.

MACRO. A weathered porous felspathic sandstone, with visible rounded quartz grains set in a felspathic matrix. The pores have limonite coatings. Parts of the rock are silicified.

MICRO. The texture is rather irregular, consisting of large irregular quartz grains set in a granoblastic matrix.

Muscovite : A few small flakes of muscovite, with a ragged and bent appearance occurred throughout the slide.

Zircon : Small, rare, rounded grains.

Rutile : A few small rounded grains occur throughout the rock.

Quartz : 60-70% : The quartz grains are very irregular both in size and shape. They average  $\frac{1}{2}$  mm. in diameter, but reach 2 mm. The grain boundaries are generally smooth. The grains are free of inclusions, and are unstrained.

Microcline : 25% : These grains were recognised by their microcline twinning. The twinning was not well developed. The microcline occurred in association with the plagioclase as a finer matrix between the larger quartz grains.

Plagioclase : 5% : Some polysynthetic twinning occurred but the twin laminae were not well developed. Twin measurements indicated an oligoclase-andesine composition. Some grains appeared to have been crushed.

DISCUSSION. The rock appears to be a sedimentary arkose with quartz, plagioclase and microcline as the main constituents.

THE PINK SANDSTONE BED.

A177 2/170.

MACRO. The specimen is a tough, pink, fine to medium grained feldspathic sandstone. The grain size averages .5 mm. The rock is very compact but has a small number of pores.. Accessory iron ore is visible, and stains some of the pores.

MICRO. The slide is cut at random. The grain size averages .25 mm. The texture is an interlocking mosaic of quartz and feldspar grains of an even size.

Muscovite : Flakes of this mica are rare.

Iron ore : Some unweathered iron ore and limonite occur throughout the rock.

Zircon : A few very small grains of zircon were noted. They are rounded although some elongate grains included in quartz have an elongation up to 4:1.

Rutile : A few rounded grains occurred as inclusions in the quartz.

Tourmaline : Several small spindular crystals occurred as inclusions in the quartz.

Quartz : 78% : The quartz grains average .5 mm. in diameter and often have spindular inclusions.

Feldspar : This mineral was easily distinguished from the quartz by its lower refringence. The grains were often sericitized and clouded. Cross-hatched twinning was common and most of the feldspar was probably microcline. No albite twinning was seen. Spindular inclusions were common.

DISCUSSION. The rock is an arkosic sandstone in which the major feldspar was microcline. This is in marked contrast to feldspars of the main schist sequence.

THE FINE GRAINED SCHIST SEQUENCE.

A177 1/6b.

MACRO. The rock was a greenish grey, medium grained, laminated mica schist. The visible minerals were biotite, muscovite, quartz and felspar. The schistosity is well developed parallel to the bedding lamination.

MICRO. The slide was cut perpendicular to the bedding.

Biotite : 20% : The biotite is pleochroic from greenish yellow to a dark red-brown. The flakes are strongly oriented parallel to the schistosity. The flakes, which are fresh and unaltered, are even grained with a length of .5 mm.

Muscovite : 5% : The flakes showed an average size of 1 mm. in length, although some flakes reached 2 mm. The flakes had a lesser degree of orientation than the biotites, and some traversed the schistosity. The flakes had an irregular distribution, many being intergrown with the biotite flakes in the mica foliae.

Iron ore : Absent.

Zircon : Zircon occurred as very small grains producing pleochroic haloes in the biotite flakes.

Sphene : Rare accessory grains.

Apatite : This mineral was a fairly common accessory.

Tourmaline : Tourmaline was a common accessory as small rounded well formed grains, pleochroic from pale yellow to deep grey and often showing a slight zoning.

Quartz : 45% : This mineral was easily distinguished from the felspar by a higher refringence, lack of twinning and lack of alteration.

Microcline : clear, unweathered grains showing strong cross-hatching. The grains were even in size and regularly distributed throughout the rock in a decussate texture. The grains averaged .25 mm. in diameter. 25%.

Plagioclase : 2% : Unweathered plagioclase is distinguished readily from the quartz by its higher degree of cloudiness and from the microcline by its albite twinning. The twinning indicated an oligoclase composition. The grain size averaged .25 mm. in diameter.

DISCUSSION. The rock is intermediate in grain size between the schists of the main schist sequence to the west, and the the finer grained schists to the east. The abundance of microcline was notable.

A177 1/3.

MACRO. The rock was a fine grained hard pyritic silt schist. The grey unweathered rock has thin laminations of pyrite giving a bedded appearance. The average grain size was .1 mm.

MICRO. The section was cut perpendicular to the bedded laminations.

Muscovite : 10% : This was the only mica present and occurred as small well oriented, elongate flakes. They average .4 mm. in length and .05 mm. in width.



THE FINE GRAINED SCHIST SEQUENCE. (cont.)

Rutile : .5% : This was an abundant accessory as small rounded yellow grains often showing a cleavage. The relief of the mineral was very high.

Pyrite : 1% : This mineral occurred as small opaque specks which averaged .05 mm. in diameter. These specks consisted of aggregates of fine crystals. The grains were characteristically golden in colour in reflected light. The pyrite occurred evenly throughout the slide.

Quartz : 50% : Quartz occurred as even sized grains (.1 mm.) throughout the rock. Some rarer grains reach .3 mm. in diameter.

Felspar : 40% : This may be distinguished from the quartz by its lower relief. Most of the felspar is untwinned although microcline and albite twinning were sometimes seen.

Discussion. The rock was an even grained quartz, felspar, muscovite schist with accessory pyrite. The rock had a slight schistosity due to the mica orientation. In the hand specimen the pyrite occurred in bands, but this was not obvious in the slide.

A177 1/15.

MACRO. The specimen was a fine-grained, hard, uniform, light coloured arkosic siltstone. The grains were barely visible to the naked eye. The rock had a bedded structure. Occasional talc crystals to 1 mm. in diameter occurred embedded in the fine-grained feldspathic matrix.

MICRO. The slide was cut perpendicular to the bedding.

Talc? : 1% : A yellow, limonite stained, talcose mineral resembling chlorite, occurred throughout the rock as small grains up to .4 mm. in diameter. The mineral was pale green in colour and slightly pleochroic when fresh.

Leucoxene-limonite : 1% : Traces of leucoxene-limonite blebs occurred and often outlined the bedding lamination.

Quartz.: 10-15% : Quartz occurred as angular grains filling cavities between the felspar grains. The grains average about .1 mm. in diameter, but there are grains ranging to .4 mm. The grains were far from strained and showed few inclusions.

Felspar : 85% : The major mineral was microcline, with grains averaging .1 mm. in diameter, although some reached .5 mm. Excellent cross-hatched twinning was shown by most of the felspar grains, but some were untwinned. No plagioclase was detected.

DISCUSSION. The rock was originally a fine-grained microcline siltstone, with a small percent of quartz and minor impurities, which later gave talc, limonite and leucoxene. The rarity of plagioclase is very notable. This rock indicates that some rocks near the granite are very microcline rich.

A177 2/94.

MACRO. The rock was a hard, fine-grained, porphyroblastic schist. The grain size was such that the individual minerals could not be distinguished by eye. The schistosity is phyllitic and the schistosity appeared parallel to the bedding, which

THE FINE GRAINED SCHIST SEQUENCE (cont.)

was indicated by flattened porphyroblastic knots of sericitic material. The rock was a light brownish-grey colour and had a tough texture.

MICRO. The slide was cut perpendicular to the bedding.

The rock was a fine-grained phyllitic schist, with oriented mica and sericitic knots. The average grain size was less than .05 mm.

**Biotite : 20% :** The biotite was pleochroic from very pale yellow to a pale red-brown. Small pleochroic haloes occurred about microscopic zircons, but were not common. The flakes were of an irregular shape and most of them anastomose together. They by-pass sericite rich knots, leaving them as eyes averaging 1-4 mm. in length. The grain size of the biotite was from .05-.1 mm.

**Sericite : 45% :** Sericite was an abundant mineral throughout the slide as aggregates of ultramicroscopic grains, which showed some recrystallization to muscovite.

**Iron ore :** Small irregular flecks of iron ore or limonitic material occurred throughout the slide in accessory amounts.

**Kyanite, : 1-2% :** Although difficult to identify because of the small grain size, small strings of grains in less weathered sericite knots, were thought to be kyanite based on their high relief, lack of colour, low birefringence (up to first order red), and the existence of at least two prominent cleavage directions. The slow ray was found to parallel the more prominent cleavage. The grains were small, relicts of larger crystals, and show alteration to sericite.

**Zircon :** Submicroscopic grains cause pleochroic haloes in the biotite.

**Apatite :** A few apatite crystals were seen. These were pale yellow green in colour and showed hexagonal cross-sections.

**Quartz - Felspar : 35% :** Because of the fine grain of this rock these minerals could not be separated. The grains averaged .05 mm. in diameter and they occurred spread evenly throughout the slide.

**DISCUSSION.** The rock is a fine-grained, slightly schistose rock with sericite rich knots (sometimes containing kyanite relicts) in a uniform mixture of sericite, quartz, felspar, biotite and muscovite.

ROCKS OF THE CALC-SILICATE GROUP.

A177 1/562.

MACRO. The specimen was a pale green well crystallized calc-silicate rock, with visible actinolite, diopside and scapolite. The grain size was very irregular. A bedded appearance is well shown in the specimen.

MICRO. The slide was cut perpendicular to the bedding.

Diopside - Actinolite : 50% : Actinolite was recognised by its slight pleochroism and its characteristic cleavage. The diopside was optically positive with a 2V near 60°, and non-pleochroic. Haloes were common about small sphene inclusions and these were often pleochroic from pale yellow to pale brown. The crystals were clear, except for a few inclusions of sphene and scapolite, and were subhedral to anhedral. The grain size was variable but averaged 2 mm. When the crystals were grouped closely together they tended to be xenoblastic, but when isolated and embedded in the scapolite they tended to be idioblastic. Diopside often showed the characteristic near perpendicular cleavages, and its birefringence was strong. In the diopside the extinction direction that made the smaller angle with the cleavage traces in the longitudinal sections was the slower ray. Twinning was rare and when present was simple.

Scapolite : 45% : This mineral occurred in a mosaic patchwork of low relief grains, showing a moderate cleavage. The grain size averaged .2 mm. In the coarser parts of the rock the patches tended to orient themselves into larger crystals, which still showed a slight mosaic texture (mottled extinction). In the larger crystals the diopside occurred as poeciloblasts. The extinction of the grains of scapolite was generally rather ragged and diffuse.

Sphene : 2% : This was a common accessory mineral distinguished as small grains distributed throughout the rock. The grains varied in size up to 2 mm., many being much smaller. When included in the diopside and actinolite the grains were often surrounded by small pleochroic haloes. The birefringence was high and the interference figures were hard to obtain due to the cloudiness of the grains. The grains were almost wholly xenoblastic.

Plagioclase : 3% : Clear grains of plagioclase averaging .2-.3 mm. in diameter were commonly encountered but were difficult to distinguish from the scapolite. A few grains had a vague albite twinning. The plagioclase showed a clearer and sharper extinction than the scapolite.

DISCUSSION. The rock was originally an impure dolomitic shale, which has now been recrystallized to a diopside - actinolite - scapolite - plagioclase rock with accessory sphene. The average grain size was .2 mm. and the texture was an interlocking mosaic of grains.

A177 1/18.

MACRO. The specimen was a pale irregularly crystallized calc-silicate rock, with visible greenish diopside and white scapolite. The grain size was rather small but coarser bands occurred.

MICRO. The slide was cut at random.

The texture was one of interlocking xenoblastic fine and coarse grains, forming an irregular patchwork mosaic of diopside



ROCKS OF THE CALC-SILICATE GROUP (cont.)

scapolite and tremolite. The slide shows that the rock had a slightly bedded appearance.

**Diopside : 40% :** This mineral occurred as grains averaging .3-.4 mm. in diameter, of a very pale green colour. The grains were not pleochroic, had a high relief and showed a good cleavage. The crystals were xenoblastic to sub-idioblastic. The mineral was optically positive with a high 2V, and a strong birefringence. Twinning was rare. When closely packed the grains formed an interlocking mosaic, but many of the grains showed isolated round forms in the scapolite matrix. Polysynthetic twinning was occasionally seen.

**Tremolite : 15% :** A tremolite rich band occurred on one side of the specimen. This mineral was distinguished from the diopside by its lower refringence. It was of a pale green colour resembling the diopside. The grains were clear, had an obvious cleavage and bright interference colours. 2V was high. The grains were slightly pleochroic from yellow to green. The grain size was even at .2-.4 mm.

**Scapolite : 40% :** This mineral occurred as a low relief matrix between the higher relief diopside and tremolite. The cleavage was often well shown and had a parallel extinction.. The birefringence was low to moderate and uniaxial figures with a negative sign were characteristic. The grains averaged .2 mm. in diameter. The scapolite commonly had inclusions of sphene and diopside.

**Iron ore :** Several well formed limonite pseudomorphs after pyrite were seen.

**Sphene : 1% :** This mineral was an abundant accessory as small neutral grains of high relief and extreme birefringence. The irregular and rounded xenoblastic grains occur in groups and strings. They average .1 mm. in diameter. The clouded nature of the grains prevented the occurrence of good interference figures.

**DISCUSSION.** The rock was a calc-silicate rock made up largely of diopside, tremolite and scapolite. Accessory sphene was prominent.

A177 4/167.

**MACRO.** The specimen was a massive, dark green grey, calc-silicate rock, with visible and abundant actinolite crystals in an interlocking mosaic. The rock had an average grain size of 2-3 mm. Small flecks of feldspar? were visible as a minor constituent, and small pyrite grains were occasionally seen. The rock was essentially structureless although the actinolite crystals may have been slightly oriented.

**MICRO.** The slide was cut at random.

**Actinolite : 90% :** The pale green actinolite was pleochroic from pale yellow green to pale green. Slightly pleochroic green haloes about abundant sphene inclusions was a constant feature. Individual crystals averaged 2-3 mm. in length, and were made up of unusual fanlike aggregates of small irregular actinolite crystals. This feature gave the grains an undulose or wavy extinction. The individual patches making up each crystal were elongate in shape but were very diffuse. This structure appears to be a type of crystal growth rather than a mechanical aggregate of smaller actinolite grains. The actinolite fans were closely packed and interlocking, and enclose small patches of fine grained feldspar matrix.



ROCKS OF THE CALC-SILICATE GROUP (cont.)

**Sphene : 1% :** This common accessory mineral occurred as small grains of irregular shape, with the characteristic extreme birefringence, neutral colour and cloudiness due to roughened surfaces during grinding. Some grains are the loci of formation of zoizite.

**Zoizite : 1% :** This mineral occurred as xenoblastic grains up to .4 mm. in diameter, growing about small sphene nuclei in the quartz - feldspar matrix. Cleavage was seen in some grains and anomalous blue interference colours were usual. The relief was between that of the sphene and the actinolite. The outer edges of the grains were often clouded and did not show the anomalous blue of the clear inner parts of the grains.

**Scapolite : 1% :** One large poeciloblastic crystal of scapolite (3 mm. in diameter), showing a low relief, low to moderate birefringence and cleavages with parallel extinction was seen.

**Feldspar and/or Quartz : 7% :** A very fine-grained matrix (.05 mm. ) existed between the large actinolite crystals, consisting of quartz or feldspar. Some of these small grains show a weak twinning on the albite law and a cleavage, but others of a higher birefringence may be quartz.

**DISCUSSION.** Large fan-like actinolite crystals are set in a fine-grained matrix of quartz and feldspar. The texture was an interlocking intergrowth of crystals, with abundant inclusions in the larger grains. Zoizite and sphene were subordinate constituents in the rock.

A177 2/135.

**MACRO.** The rock was a fine to medium grained calc-silicate. The visible minerals were actinolite and feldspar and small flecks of a yellow-orange mineral. Sedimentary banding was visible because of assorted bands of variable grain size.

**MICRO.** The slide was cut perpendicular to the bedding.

**Actinolite : 20% :** This mineral occurred as pale green crystals of moderate relief, showing the characteristic amphibole cleavage and a slight pleochroism from pale yellow-green to pale green. The grains were of a variable size ranging up to 2 mm. but averaged .5 mm. They tended to be subidioblastic to idioblastic in form, the smaller grains having a greater tendency for a euhedral shape.

**Sphene :** This was a rare accessory. A yellow orange alteration product may be leucoxene.

**Quartz : 5% :** This mineral generally occurred as rounded inclusions in the feldspar grains.

**Plagioclase : 75% :** Albite twinning was common and the twin extinctions would indicate that the plagioclase was near oligoclase. A lot of the feldspar was not twinned. The grains averaged .5 mm. in diameter, and were commonly crowded with small inclusions of quartz and feldspar. The grains were often sericitized.

Extinction angles on the albite twins :-  
 $3\frac{1}{2}^{\circ}$ ,  $5^{\circ}$ ,  $10^{\circ}$ ,  $7\frac{1}{2}^{\circ}$ ,  $12^{\circ}$ ,  $16^{\circ}$ ,  $12^{\circ}$ .

**DISCUSSION.** The rock was an even grained mosaic of feldspar grains bearing patches and individual crystals of actinolite, and having abundant inclusions of quartz and feldspar granules.

THE GRANITE.

A177 3/95. (Analysed).

MACRO. The rock was a yellow coloured, hard, compact, even grained granite. The visible minerals were quartz, felspar, biotite and haematite. The average grain size was 1 mm. The biotite flakes were oriented into the schistosity plane and aggregated into patched mosaics, which were elongated along the lineation. The rock had a slightly gneissic appearance.

MICRO. The slide was cut perpendicular to the lineation and the schistosity.

Biotite : 6.4% : This mineral was pleochroic from pale yellow to dark green black. The flakes showed a well defined stumpy shape, and were irregular in distribution and size throughout the slide. Slightly pleochroic haloes were sometimes encountered about included zircons.

Muscovite : Very rare.

Haematite : 1% : Rounded grains of haematite up to 1 mm. in diameter were associated with small zircons. The zircons were often seen embedded in the surface of the iron ore. One small haematite grain with a cubic outline was probably a pseudomorph after magnetite.

Zircon : These occurred as rare accessories associated with the biotite and the iron ore. They had a rounded irregular shape and averaged .1 mm. in diameter.

Quartz : 40% : Quartz occurred often in grains reaching 2 mm. in diameter, but the average was about .5 mm. . The grains were of an irregular shape and occurred throughout the slide. The extinction was slightly undulose. Biotite, felspar and quartz inclusions were common.

Felspar : 54% : Microcline (22%) was readily recognised by its cross-hatched twinning and low relief. This felspar was slightly weathered. Plagioclase (10%) was recognised by its albite twinning.

Extinction angles on albite twins :-

$5\frac{1}{2}^{\circ}$ ,  $5\frac{1}{2}^{\circ}$ ,  $6\frac{1}{2}^{\circ}$ ,  $3\frac{1}{2}^{\circ}$ ,  $12\frac{1}{2}^{\circ}$ .

This indicated a composition near An<sub>30</sub>. Oligoclase. Untwinned felspar also occurred. The felspars were all slightly sericitized. No exsolution features were noted.

DISCUSSION. The rock was a gneiss with a granitic composition. The major minerals were quartz, plagioclase, microcline, biotite, and iron ore. Muscovite was notably rare.

A177 4/572.

MACRO. The specimen was a pale pink, hard, schistose and lineated, medium grained granite. The visible minerals were quartz, felspar, biotite and muscovite. The micas occurred in thin patchy aggregates parallel to the schistosity. A lineation was produced by the elongate nature of these mica patches.

MICRO. The slide was cut perpendicular to the lineation and the schistosity.

Biotite : 5-8% : This mineral occurred as well formed unaltered flakes pleochroic from pale yellow green to dark green black. Most flakes occurred in large well-oriented flakes occurring in gneissic bands, but some smaller grains

THE GRANITE (cont).

also occur in the quartz - felspar matrix. The flakes averaged .5 mm. in length.

Muscovite : 1% : Muscovite occurs as small flakes occurring between and around biotite flakes.

Iron ore : This was rare, occurring as small flecks in association with the micas.

Zircon : This was a common accessory and was evenly distributed throughout the slide, but generally associated with or included in the biotite flakes.

Apatite : This was a rarer constituent occurring as crystals included in the quartz grains.

Quartz.: 40% : This constituent averaged .75 mm. in diameter but some grains reached 3 mm. In general the quartz was of a larger size than the surrounding felspars. The grains were xenoblastic in shape and were closely edged with felspar. Undulose extinction was not strong. The grains were clear of inclusions except for a few felspar and apatite grains.

Microcline : 30% : The microcline was clear and unaltered and had very good cross-hatching. The grains averaged .5 mm. in diameter.

Plagioclase : 20% : Albite twinning was sometimes shown although many untwinned grains occurred. Zoning was rare.

Extinction angles on albite twins :-

$7\frac{1}{2}^{\circ}$ ,  $11^{\circ}$ ,  $2^{\circ}$ ,  $10^{\circ}$ ,  $13^{\circ}$ ,  $10^{\circ}$ ,  $5^{\circ}$ ,  $10\frac{1}{2}^{\circ}$ ,  $10^{\circ}$ ,  $8^{\circ}$ ,  $11^{\circ}$ .

This indicated a composition near An 31.

DISCUSSION. The rock was a medium grained normal granite. Microcline was in slight excess over the plagioclase and biotite was the dominant mica. The micas were strongly oriented into gneissic bands. The quartz grains were generally larger than the associated felspar grains. Muscovite, zircon and apatite were accessories.

A177 2/45.

MACRO. The rock was a medium grained, crumbly, pink, schistose granite. The visible minerals were biotite, muscovite, quartz and felspar. The biotite and the muscovite are arranged into platy patches flattened parallel to the schistosity. These mica patches also defined a strong lineation in the rock. The specimen was slightly weathered and the outer layers of felspar were stained pink.

MICRO. The slide was cut perpendicular to the lineation and the schistosity. The rock had a crystalloblastic, slightly gneissic texture.

Biotite : 3% : This mineral occurred as short strings of closely packed crystals and as short stumpy, isolated flakes. The pleochroism was strong from pale yellow green to dark green black. The average grain was .4 mm. but some reach 3 mm. in length. The grain elongation in cross-section was 2:1 to 10:1 (average 3:1). Some flakes had zircon inclusions up to .2 mm. in diameter, surrounded by slightly pleochroic haloes.

Muscovite : 3% : This mineral occurred in a similar amount and habit to the biotite. The flakes had the same dimensions and the same well developed form. Much of the muscovite occurred isomorphously intergrown with the biotite.



THE GRANITE (cont).

Iron ore : Rare or absent.

Zircon : Small, clear, colourless, rounded, fractured, and unzoned grains of zircon often occurred as inclusions in and in association with the mica flakes.

Apatite : This was a rare accessory occurring as minute, wellformed crystals inclosed in quartz grains.

Quartz 50% : Grains of this mineral averaged .5 mm. in diameter although some grains reached 3-4 mm. The grains had the typical xenoblastic form. One grain showed sharp twinning. The larger grains were often surrounded by crowds of smaller quartz and felspar grains in a granoblastic texture. Strain shadows occurred in the quartz but were not well developed. The grains were clear and colourless, although showing some biotite inclusions.

Felspar : 45% : Microcline (20%) showed well developed cross-hatched twinning. The grains were xenoblastic, clear, and weathering features were absent. The microcline had no visible exsolution structures. Plagioclase (25%) sometimes showed well developed albite twinning. Untwinned plagioclase was also present. The plagioclase showed slight weathering and zoning was not seen.

Extinction angles on albite twins :-

$100^\circ$ ,  $10\frac{1}{2}^\circ$ ,  $5\frac{1}{2}^\circ$ ,  $11^\circ$ ,  $12^\circ$ ,  $2^\circ$ ,  $11^\circ$ ,  $11\frac{1}{2}^\circ$ ,  $11\frac{1}{2}^\circ$ ,.

This indicates a composition near An 31 (Oligoclase-Andesine).

DISCUSSION. The rock showed the characteristic crystalloblastic slightly gneissic texture of most of the other granite specimens. The grain size was small. Biotite and muscovite were present in equal amount, as slightly oriented flakes gathered into gneissic bands. Some large xenoblastic quartz grains occurred in an equigranular quartz felspar matrix. The plagioclase showed the usual oligoclase-andesine composition.

A177 2/648.

MACRO. The rock was a crumbly, medium grained schistose granite. The schistosity was well shown by the flattened mica patches which are well oriented in this plane. The visible minerals were muscovite, biotite, quartz and felspar.

MICRO. The slide was cut at random. The texture was the normal crystalloblastic gneissic one.

Biotite : 5% : The biotites were of an irregular size ranging up to 2 mm. in length, and having a grain elongation in cross-section of 5-6:1. The grains had a strong pleochroism from yellow green to dark green black. The grains were rather clear, but some showed a little limonite weathering along the cleavages and the grain boundaries. Most flakes were well oriented crystallographically. Pleochroic haloes about zircon inclusions were commonly seen. The grains were generally smooth edged.

Muscovite : 5% : The muscovite occurred as short irregular strings of closely packed, well oriented, flakes associated with the biotite, although many flakes were isolated. Both micas occurred in equal amounts, the muscovite flakes being similar in shape and size to the biotite flakes.

Haematite : Rare, ragged haematite grains occurred in association with the patches of mica. Weathering was common.



THE GRANITE (cont.)

**Zircon** : Rounded zircons reaching .1 mm. in diameter were common as inclusions in the biotite flakes, giving pleochroic haloes, and in the quartz.

**Apatite** : Small inclusions of apatite in the quartz were sometimes seen .

**Quartz** : 30% : The quartz grains averaged .75 mm. in diameter and were generally larger in size than the associated felspar. Twinning was sometimes seen but strain shadows were rare. Small rounded inclusions of biotite and apatite were common.

**Felspar** : 60% : Good cross-hatched twinning was rare, but some grains of felspar showing a diffuse lamina twins may be microcline with poorly developed twinning. Plagioclase was the major felspar, albite twinning being very common. Zoning was absent. Some twinned plagioclase was probably present.

Extinction angles on albite twins :-

8°, 5½°, 11½°, 12°, 7°, 0°, 9°, 10½°, 9½°, 6½°, 16°, .

This indicates a plagioclase near An 34. (Andesine).

**DISCUSSION.** A striking feature of this specimen was the rarity of well twinned microcline, although some poorly twinned microcline could be present. Plagioclase of an andesine composition was the major felspar, and showed good albite twinning. Biotite and muscovite were present in equal amount. Iron ore and zircon were accessories. A marked schistosity was present but gneissic banding was poorly developed. The felspar and quartz were unstrained and apparently disoriented, while the micas showed the usual strong orientation.

A177 4/468.

**MACRO.** The rock was a fine to medium grained, white, crumbly, schistose, slightly gneissic granite. The average grain size was 1 mm. The visible minerals were biotite, muscovite, quartz and felspar. The rock was even in composition and texture throughout. The micas occurred in patches of small flakes, which were flattened parallel to the schistosity. Lineation was also a marked feature.

**MICRO.** The slide was cut perpendicular to the lineation and the schistosity. The rock had an even grained crystalloblastic structure.

**Biotite** : 6% : The flakes averaged .5 mm. in length and in cross-section had an elongation of 2:1 to 4:1. The biotite was arranged into strings or platy aggregates of well oriented flakes. The flakes were pleochroic from pale yellow to dark green black. Clear rounded zircons were often found as inclusions giving rise to pleochroic haloes.

**Muscovite** : 1% : A small amount of muscovite occurred throughout the slide, generally intergrown with the biotite.

**Iron ore** : No original iron ore grains were seen but a few patches of limonitic material in the crystal interspaces could represent altered iron ore.

**Zircon** : Zircon was a common accessory generally occurring as inclusions in the biotite flakes. The grains were clear, rounded, and lacked zoning. Some biotite patches were rather rich in zircon.

**Quartz** : 30% : Quartz occurred as irregular xenoblastic grains averaging .75 mm. in diameter. The grains were clear, free of inclusions, and lacked strain effects. The quartz grains were generally larger than the associated felspar grains.

THE GRANITE (cont.)

**Microcline : 35%** : The microcline, recognised by its cross-hatched twinning, had an average grain size of .5 mm., although some grains reached .75 mm. The grains were generally clear and unaltered. Some grains showed a very slight exsolution? along the cleavages. Some of the larger grains had quartz inclusions.

**Plagioclase : 25%** : The average grain size was .5 mm. Some grains showed albite twinning but many grains appeared untwinned. Slight zoning was sometimes seen.

Extinction angles on albite twins :-  
90°, 6½°, 5½°, 7°, 9°.

**DISCUSSION.** The granite was a fine-grained to medium-grained type, having well oriented patches of mica showing a slight tendency for gneissic banding. The feldspars had a smaller average size than the quartz. Both the quartz and the feldspar were xenoblastic. Some albite twinning was shown by the plagioclase and slight zoning was sometimes seen. The microcline was well twinned and sometimes enclosed small quartz grains.

A177 1/587.

**MACRO.** The rock was a massive "non-schistose" granite. The visible minerals were biotite, muscovite, quartz, and feldspar. The micas were grouped into small irregular patches, and although slightly oriented, did not show the strong schistosity of the normal granite. The grain size was fairly uniform at .5 mm., however some feldspars had grown to 2 mm.

**MICRO.** The slide was cut at random. The texture was very irregular.

**Biotite : 3%** : The grains averaged .2 mm. in diameter, but a great range of grain size was present. The pleochroism was strong from yellow green to dark green black. The flakes were not well oriented. No alteration or weathering of the biotite was noted. A notable feature was the close packed grouping of the larger flakes.

**Muscovite : 3%** : This mineral was similar in habit to the biotite, and was likewise disoriented to a large extent.

**Zircon :** Some very rough and irregular zircon grains were noted as inclusions in the biotite. These ranged to .3 mm. in length, and caused pleochroic haloes in the biotite.

**Iron ore :** Appears to be absent.

**Quartz : 40%** : The quartz appeared in general to be of a smaller size than the associated feldspars. A few grains showed strain shadows. The grains were of a rather irregular size, ranging from .2 mm. to 1 mm. in diameter. This range in grain size gave the rock an arkosic appearance. Small inclusions of muscovite were common in some grains, but most were free of inclusions.

**Feldspar : 50%** : The feldspar, like the quartz, had a large grain size range, all sizes up to .3 mm. being present. Twinning was common in most grains. Twinned plagioclase (20%) was readily recognised by its albite twinning. Pericline twinning, as in the other granite samples, was absent.

Extinction angles on albite twins :-  
9½°, 20°, 14°, 9°, 5°, 13°, 6°.

This indicates a composition near An 33 (Andesine-Oligoclase).

Untwinned feldspar (10%) was also common.

THE GRANITE (cont.)

Microcline : 10-15% : Microcline twinning was present in some grains, but was very poorly developed, and in many cases the twinning in one direction was appeared to be more strongly developed than twinning in the direction perpendicular to it.

DISCUSSION. The rock appeared to have the normal granite composition and was generally unaltered. The texture, however, was very irregular and resembled a recrystallized arkose. Both the quartz and the felspar were of an irregular grain size, but the felspar grains were generally larger than the quartz. The plagioclase had the usual andesine-oligoclase composition.

A177 3/76.

MACRO. The specimen was a rather weathered, hard, siliceous granitic rock. The visible minerals were quartz, felspar, muscovite and iron ore. The muscovite was very altered in appearance and of a greenish colour. The average grain size of the rock was .5 - 1 mm. The schistosity was slightly developed by the orientation of the mica flakes. Lamination was good.

MICRO. The slide was cut perpendicular to the schistosity and the lamination.

Muscovite : 15-20% : The flakes were very irregular, ragged, and pitted. They ranged to 1 mm. in length. Much of the mica appeared to be recrystallized sericite.

Zircon : Several grains up to .2 mm. in length were noted, but few showed good crystal outlines. Zoning was sometimes seen parallel to the prism. The grains were always associated with the iron ores.

Haematite : 1.5% : This mineral occurred as crystalline to rounded grains probably representing pseudomorphs after magnetite.

Ilmenite : .5% : This was common as black grains altering along the cleavages to leucoxene.

Leucoxene : As well as occurring as an alteration product of the ilmenite, leucoxene occurred as small, irregular, yellow white, stellate blebs, and as orange flecks, distributed throughout the muscovite. Much of this material may represent an alteration product of the rutile.

Rutile : Blebs of rutile partly replaced by leucoxene occurred throughout the muscovite flakes. The rutile and the ilmenite may have been released during the alteration of original biotite.

Quartz : 55% : Quartz was the most common silic mineral and occurred as xenoblastic grains of variable size up to 5 mm. Strain shadows were prominent in most grains. The grains interlocked with each other in an irregular crystalloblastic texture. Inclusions were rare, but occasional small biotites which had escaped the alteration episode were found in the quartz grains. They were pleochroic from pale yellow green to dark green black.

Felspar : 20% : All felspar grains were very weathered and were in part dissolved and transported. Microcline was readily recognised by its twinning, the grains being much altered. Plagioclase twinning was seen in some grains but alteration prevented a composition determination.



THE GRANITE (cont.)

DISCUSSION. The rock had a definite granitic texture, and has the normal granite minerals developed, but alteration, probably by deep weathering, has caused alteration of the original biotite and the feldspar. There were relicts of biotite hidden in the quartz grains. Rutile, ilmenite and leucoxene probably represent alteration products of the biotite.

A177 3/ 193.

MACRO. The rock was a light pinkish granitic gneiss. The tough rock showed a good foliation and a slight lineation. The visible minerals were quartz, feldspar, muscovite-chlorite and iron ore. The quartz occurred in grains of various sizes, generally larger than the feldspar. The micas had a green, weathered and leached appearance, and occurred as aggregates of small flakes throughout the rock. The iron ore occurred in small grains.

MICRO. The slide was cut perpendicular to the schistosity.

Iron ore : 1% : The iron ore was largely haematite, which occurred in ragged grains, some showing good crystal faces. The grains ranged to .5 mm. in diameter. Limonite pseudomorphs also occurred.

Zircon : Several grains of zircon up to .2 mm. in diameter occurred in association with the iron ore. The grains were generally rounded and had common inclusions.

Muscovite-Chlorite : 9% : This mineral occurred as disoriented aggregates as if recrystallized from sericite. The association of iron staining, iron ore, leucoxene and zircon with these aggregates suggests the original presence of biotite. The individual grains seldom reach 1 mm. in diameter, the average grain being .1-.2 mm.

Leucoxene : This mineral occurred as irregular blebs in the rock and as a grain boundary precipitate. It probably results from the break-down of biotite.

Quartz : 30% : Quartz occurred as ragged xenoblasts to 3 mm. in diameter, and averaging .75 mm. Strain shadows were common and inclusions of feldspar and mica occurred.

Microcline : 60% : This feldspar occurred as clear, unaltered xenoblastic grains showing good cross-hatching. The grains average .5 mm. in diameter, but some reach 2 mm.

Plagioclase : Rare or absent. A few untwinned feldspars could be plagioclase.

DISCUSSION. The rock was originally a quartz - microcline - muscovite - biotite - iron ore rock. It has now been reduced to a quartz - microcline - muscovite - sericite - iron ore rock. Plagioclase was a rare constituent.



VARIATIONS IN THE GRANITE.

A177 +/817.

**MACRO.** The hand specimen consisted of a normal gneissic muscovite biotite granite with two small fine-grained, parallel, aplitic veinlets cutting the specimen at a slight angle to the schistosity. The visible minerals were quartz, felspar, biotite and muscovite. The micas were well oriented giving the rock a rather schistose appearance. The average grain size of the rock was .5-1 mm. The larger veinlet was 1.5 cm. in width and the smaller .2 cm. wide. Both were identical in appearance being made up quartz and felspar in a fine grained (.2 mm.) matrix. Accessory biotite and muscovite in the veinlets was also of a small size. The angle between the veinlets and the schistosity of the rock (parallel to the schistosity of the veinlets) was  $5-10^\circ$ , and indicates that the veins were probably formed before the gneissosity developed, for example in a joint plane, or the structures may represent some original sedimentary banding.

**MICRO.** The slide was cut perpendicular to the veins and showed a complete section of the larger vein.

(a). The granite adjacent to the vein.

**Biotite : 5% :** The strongly oriented flakes average .5 mm. in length, and in section show a grain elongation of 2-4:1. The pleochroism was strong from pale yellow green to dark green black. The flakes are nearly always intergrown with muscovite. The grains contain small zircons with pleochroic haloes about them. The micas generally occurred in bands and were seldom altered.

**Muscovite : 5% :** This mineral was common as flakes associated with the biotite. The flakes were strongly oriented, and had an elongation in cross-section of 5-6:1

**Zircon :** Rounded zircons occurred as inclusions in biotite.

**Quartz : 50% :** The clear grains showed an undulose extinction and often contained inclusions of felspar and biotite. The grains averaged .75 mm. in diameter.

**Microcline 35% :** The clear, xenoblastic grains, with sharp cross-hatched twinning, averaged .4 mm. in diameter. They were often clustered around quartz grains.

**Plagioclase : 5% :** Some grains were twinned and some untwinned. Some twin measurements were  $20^\circ$ ,  $14^\circ$ ,  $16^\circ$ .

(b). The vein.

**Biotite : 3% :** This mica occurred as small flakes averaging .2 mm. in length and having an elongation in cross-section of 2-4:1. The flakes were smooth edged and isolated. The pleochroism was from pale green yellow to dark green black. The grains were fresh and lacked inclusions, except for several minute zircons which caused pleochroic haloes. The flakes were well oriented parallel to the schistosity.

**Muscovite : 2% :** The clear, elongate, colourless flakes averaged .4 mm. in length. The grain elongation in section was 4-6:1. The flakes were well formed, strongly oriented, angular and unweathered. The muscovite occurred largely on one side of the vein.

**Quartz : 45% :** The quartz occurred as xenoblastic grains averaging .2 mm. in diameter. The grains were sometimes twinned, and strain shadows were weak.

VARIATIONS IN THE GRANITE (cont.)

Microcline : 30% : Strongly cross-hatched, xenoblastic grains were evenly spread throughout the slide. The twinning was often diffuse. The grains averaged .2 mm. in diameter.

Plagioclase : 20% : The xenoblastic grains were sometimes twinned, but many were untwinned. The grains were slightly sericitized.

Extinction angles on albite twins :-  
6°, 10°, 19°, 16°, 7°, 15°.

This indicates a composition near An<sub>37</sub> (Andesine).

DISCUSSION. The granite was of the normal type with the usual minerals and structure. The veins notably finer grained and less micaceous. The contacts of the veins were microgradational. Muscovite was the major mineral one side of the vein, and biotite the other. In the vein the micas were small and stumpy, but well formed and isolated. The schistosity was at a slight angle to the vein and this indicated a pre-tectonic origin. Whether the veins represented intruded aplitic material later metamorphosed, or original sedimentary banding, could not be determined.

A177 2/478.

MACRO. The rock was a hard, compact, strongly lineated, quartzofelspathic rock. The visible minerals were quartz, felspar, iron ore and muscovite. The quartz occurred in strings and bands of grains parallel to the schistosity and lineation. The iron ore occurred in strings of grains parallel to the lineation. The rock was rather even grained at about 1 mm.

MICRO. The slide was cut perpendicular to the lineation.

Muscovite : 2% : The flakes averaged .5 mm. in diameter. They were not well oriented in the rock. Inclusions were rare in the flakes. One grain was twinned parallel the cleavage.

Haematite : 3% : Some grains were cubic in outline and may have represented pseudomorphs after magnetite. Other grains were rounded to irregular in form.

Ilmenite : 1% : Black ilmenite grains of elongate to irregular shape were commonly found. They ranged to 1 mm. in diameter. The grains were generally rounded and part altered to leucoxene.

Anatase : A few grains of very high relief anatase were noted. They had a transparent to translucent blue green colour.

Zircon : Rounded to irregular zircons were common in association with the iron ores, being commonly embedded in their surfaces.

Chlorite : 2% : Ill-defined, weathered, pleochroic yellow flakes were common throughout the slide. They probably represented an oxidized chlorite mineral .

Quartz : 25% : Quartz grains were common in strings and bands throughout the slide.

Felspar : 70% : The felspar was readily recognised by its alteration products and general cloudiness. Small muscovite grains were sometimes seen as inclusions. Most of the grains were untwinned, but some grains showed well developed albite twinning. No microcline twinning was seen. The untwinned felspar (50%) was structureless except for occasional zoning and incipient alteration. No exsolution features were seen in any grains. Much of the twinned felspar showed broad, diffuse twin lamellae.

VARIATIONS IN THE GRANITE (cont.)

Extinction angles on albite twins :-  
 $15^{\circ}$ ,  $8\frac{1}{2}^{\circ}$ ,  $5^{\circ}$ ,  $10\frac{1}{2}^{\circ}$ ,  $11\frac{1}{2}^{\circ}$ ,  $14^{\circ}$ ,  $15^{\circ}$ ,  $12^{\circ}$ ,  $5^{\circ}$ ,  $6\frac{1}{2}^{\circ}$ ,  $9\frac{1}{2}^{\circ}$ ,  $16^{\circ}$ ,  
 $13\frac{1}{2}^{\circ}$ ,  $5\frac{1}{2}^{\circ}$ ,  $16\frac{1}{2}^{\circ}$ , .

These indicate a composition near An  $35$  (Andesine.).

DISCUSSION. The rock does not appear to have ever been of granitic composition. It is rich in both ilmenite and haematite and very poor in mica. Although microcline twinning was absent some of the untwinned feldspar may well be potash rich. The yellow orange chloritic material present may have once been biotite.

A177 1/630.

MACRO. The specimen was a fine to medium grained aplitic rock of light colour. The rock has the outward form of a stretched pebble and was found, along with several others, in a large granite outcrop of uniform lithology. The visible minerals were quartz, feldspar and muscovite, with rare iron ore and biotite flecks. The rock has a slight lineation parallel to the length of the "pebble".

MICRO. The slide was cut perpendicular to the long axis of the pebble.

Muscovite : 5-7% : This appeared to be the only mica present. It occurred as irregular stumpy grains of an average grain size of .5 mm. in diameter. The flakes were random in orientation and patchy in distribution.

Iron ore : .5% : Haematite was a common accessory in the rock occurring as irregular to well formed grains. The grains were not evenly distributed and there was a close association of the iron ore muscovite and the zircon.

Zircon : Several small grains of zircon were seen but none showed appreciable crystal faces.

Quartz : 40% : Quartz occurred as clear, xenoblastic grains, free of inclusions. The grain size varied from .2-2 mm. in diameter. Strain shadows were strong in some grains, but were absent in others.

Feldspar : 50% : The feldspar was made up of microcline (35%) and plagioclase (15%). The microcline averaged .5 mm. in diameter and showed very good cross-hatched twinning. The grains were clear and showed no exsolution features. Albite twins were common in the plagioclase, but were often poorly developed. Untwinned feldspar was also present.

Extinction angles on albite twins :-  
 $9^{\circ}$ ,  $11^{\circ}$ ,  $12^{\circ}$ ,  $15^{\circ}$ ,  $13\frac{1}{2}^{\circ}$ ,  $9^{\circ}$ ,  $10^{\circ}$ ,  $19^{\circ}$ , .

This indicates a composition near An  $37$ . (Andesine)

DISCUSSION. The rock was composed essentially of quartz and feldspar, with accessory muscovite, iron ore and zircon. The feldspar was made up of microcline with subordinate andesine. The absence of biotite and a strong schistosity are features that distinguish this rock from the usual granite texture and composition. No conclusion can be reached concerning the origin of the rock.



THE ENCLAVES.A177<sup>2</sup>/38

MACRO. The rock was a crenulated mica schist with thin bands of quartz and feldspar irregularly developed. Knots of quartz and sillimanite were spasmodically developed throughout. The small folds, which have a wavelength of about 1 mm. are not regular in form and have a variable pitch in detail. However a general fold axis may be defined for the outcrop. The visible minerals were muscovite, biotite, quartz and feldspar.

MICRO. The slide was cut perpendicular to the lineation.

Biotite : 5-7% : Biotite occurred in flakes to 3 mm. in length and was pleochroic from very pale yellow to yellow brown. Very small zircons often caused pleochroic haloes in the mica. The biotite had suffered no alteration.

Muscovite : 5-7% : This mineral was closely intergrown with the biotite.

Sillimanite : 2-3% : Sillimanite occurred as irregular bunches of fibres. It was relatively fresh and free of sericitization. It appeared to replace the micas.

Quartz : 50-60% : The quartz occurred in fairly uniform grains averaging 1 mm. in diameter. Strain shadows were present in some grains.

Feldspar : 15% : No microcline twinning was seen but some albite twinning was present. Insufficient twins were present to indicate the composition of the plagioclase. Some plagioclase grains reached 6 mm. in diameter, and often contained flat rounded tablets of quartz, strongly oriented along one direction in the plagioclase. Several grains of feldspar showed this relation and the quartz tablets from the various grains had an overall elongation. No zoning was seen in the plagioclase.

DISCUSSION. The rock consisted of a quartz - plagioclase matrix containing small sillimanite knots and fibrous aggregates and with mica showing the existence of small crenulations. The micas showed post tectonic crystallization. The folds were not regularly developed although a general fold plunge was present. No microcline was detected.

A177 2/56.

MACRO. The specimen was a dense, dark, biotite - quartz - garnet rock with a knobby appearance and a poorly developed schistosity. The biotite flakes defined a slight lineation. Irregular garnets up to 2 cm. in diameter were developing from the biotite and the quartz. The specimen also showed a garnet - quartz vein  $\frac{3}{4}$ " in width, apparently mobilized from the rock.

Micro. The slide was cut sub-parallel to the lineation.

Biotite : 15% : Much of the biotite occurred in bands and foliae in the rock, the bands of flakes being distorted around the growing garnet porphyroblasts. The foliae consisted of interlocking strings of closely packed biotites. The grains averaged 1 mm. in length and .1 mm. in width. The flakes were pleochroic from pale yellow to dark green. The flakes sometimes showed a slight alteration to limonite at the grain edges. One small pennine flake was noted in the slide and was probably an alteration product of the biotite. Inclusions of iron ore and zircons, surrounded by dark haloes up to .05 mm. thick, were sometimes seen. Near and in the garnet porphyroblasts the biotite flakes were less oriented, highly altered, and showed



THE ENCLAVES (cont.)

replacement by garnet. Near the garnets the biotite was altered to pennine and limonite. This may have been a pre-requisite to garnet formation or may have been the result of incoming solutions travelling along the garnet - biotite interfaces.

**Muscovite :** Only one small muscovite flake was detected in the rock but sericitic material occurred in the altered garnet fractures.

**Garnet : 30% :** The pale pink garnets were isotropic and contained many cross-cutting fractures. The garnets occurred as large feathery porphyroblasts, which grew by the replacement of the quartz and biotite along the grain boundaries, these minerals being included as relicts in the garnet as the reaction proceeded. The grains of quartz included in the garnet were often quite large. Magnetite was another common inclusion in the garnet, where it occurred largely in the fractures. The fractures were generally 2 mm. apart. Minute isotropic gas or liquid inclusions were common in the garnet. A few zircon inclusions were also seen but these were small and rare. Pennine and limonite were common alteration products occurring in the fractures. However only a few fractures were opened out and filled with alteration products in this way. The pennine was pale green in colour and very slightly pleochroic. It was often yellowed by the limonite.

**Tourmaline :** A few small zoned tourmalines, with light brown cores and green-grey exteriors were included as well formed trigonal prisms in the garnet.

**Quartz : 50% :** Quartz averaged .75 mm. in diameter, although some reached 2 mm. The grains were clear and had few inclusions.

**DISCUSSION.** The matrix of quartz contains biotite foliae which have been folded about centres of garnet crystallization. The garnets appear to be the direct result of a reaction between the quartz, biotite and a little iron ore. The reaction occurred along the grain boundaries and then spread across the enclosed grains of quartz and biotite as these were replaced. Inclusions were common in the garnet and alteration along certain fractures to pennine, sericite and limonite was marked. Felspar and muscovite were rare to absent in this rock.

Al77 2/626.

**MACRO.** The specimen was a granitized crumpled schist from the western granite contact. The rock was a slightly weathered, knotted and partly recrystallized; having a granitic textured matrix of quartz, felspar, muscovite and biotite, with large knots of quartz and sillimanite (largely sericitized). The knots of sillimanite reached 1 cm. in diameter and were elongated parallel to the lineation, which was the strongest structural feature of the rock, schistosity being poorly developed. No original sedimentary banding could be seen, the rock being strongly recrystallized. The knots make up about 10% of the rock.

**MICRO.** The rock was cut at random.

**Biotite 10% :** The flakes average .75 mm. in length. Most flakes have been strongly weathered. The fresh grains showed a pleochroism from very pale yellow green to green grey. The more weathered grains showed a redder colour. A slight alteration to sericite was noted about some grains.

**Muscovite : 1-2% :** This mica occurred as small stable flakes associated with the biotite.

THE ENCLAVES (cont.)

Sericite : 10% : This had largely resulted from the alteration of sillimanite, no remnants of which remained in the rock. The sericite is of a fine grain and showed relict fibrous structures.

Iron ore : Granular iron ore was absent, but limonite resulting from the weathering of biotite was often found deposited on grain boundaries and cleavages.

Zircon : Zircon occurred as rounded grains included in biotite flakes where they produce pleochroic haloes.

Quartz : 60% : The grains vary from .2 - 2 mm. The grains were clear of inclusions but have strain shadows.

Felspar : 15% : This was apparently the only felspar present, although rare grains of untwinned potash felspar could be present. Albite twinning was common.

Extinction angles on albite twins :-

$10\frac{1}{2}^\circ$ ,  $10^\circ$ ,  $3^\circ$ ,  $4^\circ$ ,  $8^\circ$ ,  $15\frac{1}{2}^\circ$ ,  $15^\circ$ ,  $6^\circ$ ,  $8^\circ$ ,  $9\frac{1}{2}^\circ$ , .

These indicate a composition near An  $_{34}$  (Andesine).

DISCUSSION. The rock was a normal schist of the thick lower schist sequence which has shown some recrystallization to a granitic texture. The sillimanite has suffered sericitization. Microcline appeared to be absent.

A177 2/622.

MACRO. The rock was a light coloured, slightly weathered, crumbly, granitized schist. The crumbly nature of the rock was probably due to alteration along the grain boundaries. The visible minerals were biotite, chlorite, sillimanite-sericite, quartz and felspar. The average grain size was about 1 mm. The schistosity was poor but the lineation was marked.

MICRO. The slide was cut at random. The rock had an irregular crystalloblastic texture.

Biotite ; 5% : The flakes were not well oriented, occurred in irregular patches throughout the slide and the flakes were generally altered to chlorite, sericite, limonite etc. The flakes averaged 1 mm. in length, with an elongation of 2-3:1 in crosssection. The fresher grains showed a pleochroism from pale yellow green to mid green brown. Small zircon inclusions were sometimes present giving rise to pleochroic haloes in the biotite.

Chlorite : 5% : The chlorite was a common alteration product of the biotite. All stages of the alteration were visible. The chlorite showed anomalous blue interference colours and was pleochroic from very pale green yellow to mid green. The small flakes (averaging .2 mm. ) were generally disoriented. Some larger flakes reached 1.5 mm. in length.

Muscovite : This mica was rare or absent.

Sericite : 5% : Sericite was a common alteration product of the sillimanite, staurolite and biotite. Whirly fibrous aggregates probably represented sillimanite knots originally. Small staurolite crystals showed alteration to sericite along their edges. The chlorite may also be altering to iron ore, sericite and talc.

Staurolite : Several small grains of this mineral were present in the quartz grains where they escaped sericitization. They had the usual pleochroism, high relief and low birefringence.

Zircon : Several small grains were noted as inclusions in the biotite.

THE ENCLAVES (cont.)

**Iron ore** : This mineral occurred largely as minute grains, an alteration product of the biotite. A few larger ragged aggregates of haematite also occurred.

**Quartz** : 50% : The average grain size was .5 mm. in diameter but grains ranged from .2 - 3 mm. Strain shadows were prominent in the larger grains. The grains were generally free of inclusions.

**Felspar** : 40% : Plagioclase was the only felspar recognised. It occurred in crystals from .2 to 4 mm. in diameter. Good albite twinning was common. The grains were slightly sericitized. Some grains showed abundant inclusions of small biotites. No zoning was detected. Pericline was seen in a few grains. Dislocated albite twinning was present in some grains giving them a unidirectional cross-hatched effect.

Extinction angles on albite twins :-

10°, 17°, 12°, 4°, 12°, 3°, 13°, 9½°, .

This indicates a composition near An 35 (Andesine.)

**DISCUSSION.** The rock originally had the assemblage quartz - biotite - sillimanite - staurolite - plagioclase, but later alteration has altered the sillimanite to sericite, the biotite to chlorite, sericite and iron ore, and staurolite to sericite and limonite. The presence of staurolite was significant.

A 177 2/224.

**MACRO.** The specimen was a granitized schist of an irregular texture. The schistosity was poorly developed although lineation was strong. The irregularity of texture was caused by the presence of sericitic and chloritic knots. The matrix around these knots was relatively even grained. The visible minerals were quartz, felspar, biotite, chlorite and iron ore.

**MICRO.** The rock was cut perpendicular to the lineation.

**Biotite** : 5% : The biotite averaged .5 mm. in length; and were not well oriented. The fresh flakes showed a pleochroism from pale yellow green to a deep green black. The grains were commonly ragged and altered to chlorite along the cleavages. Sericite and limonite may be further stages of this alteration. Pleochroic haloes were sometimes present about small zircons.

**Chlorite** : 5% : Chlorite, which occurred in small disoriented flakes was pleochroic from very pale yellow green to mid green.

**Muscovite** : This mineral was either rare or absent in the original assemblage.

**Sericite** ; 10% : Sericite was the result of alteration of the staurolite. A relict cleavage in some of the sericite aggregates may represent an original staurolite cleavage. A small amount of limonite often colours the sericite giving it a false relief.

**Staurolite** : Staurolite occurred as small relict grains surrounded by sericite alteration products. It showed a pleochroism from colourless to pale yellow.

**Iron ore** : 1% : This was an abundant accessory with grains reaching .2 mm. in diameter.

**Zircon** : Small rounded zircons were common throughout the slide, giving rise to pleochroic haloes in the biotite.

**Quartz** : 40% : The grains were generally clear. Strain shadows were present in the larger grains. The grains averaged



THE ENCLAVES (cont.)

.75 mm. in diameter, but some variation from .2 to 3 mm. was present.

Felspar : 40% : Plagioclase was the major felspar and may be the only felspar present. Albite twinning was well shown in most grains, and some grains showed both albite and pericline twins. No zoning was noted. Some grains showed a strongly disjointed albite twinning reminiscent of albite twinning. combined with pericline twinning to give a cross-hatched effect. The average grain was 1 mm. in diameter but some reached 3 mm. The grains were relatively fresh and free of inclusions. They were slightly weathered. Some untwinned felspar was also present.

Extinction angles on albite twins :-

14°, 15°, 14½°, 16°, 5°, 12°, 15°, 2°, 14°, 10°, 8°.

These indicate a composition near An 34.

DISCUSSION. The rock had an original assemblage of quartz, biotite, plagioclase and staurolite. Subsequent alteration has changed biotite to chlorite and staurolite to sericite. There was no evidence for the presence of microcline, and the plagioclase had the usual composition of andesine.



THE CONTACTS.

A177 3/89.

**MACRO.** The rock was a schistose muscovite rich granite. The visible minerals were muscovite, biotite, quartz, and feldspar. The average grains were from .5 to 1 mm. in diameter. The micas were well oriented parallel to the schistosity. Lamination was a marked feature. The rock had a soft crumbly texture.

**MICRO.** The slide was cut perpendicular to the schistosity. The texture was a crystalloblastic lepidoblastic one.

**Biotite : 1% :** The biotite occurred as small flakes in the quartzose matrix and a flakes in the muscovite rich bands. This mineral was pleochroic from pale yellow brown to red brown.

**Muscovite 10% :** The muscovite occurred in well oriented flakes with an average length of 1 mm. and an elongation in cross-section of 6:1. Many of the cleavages contain limonitic material.

**Iron ore :** A few traces of ilmenite occurred throughout the slide.

**Zircon :** One rounded zircon grain was noted.

**Quartz : 60% :** The grains averaged .75 mm. in diameter and were distributed evenly throughout the slide. The grains were xenoblastic and interlocking. The grains were variable both in size and shape, and they often showed strain shadows. Except for occasional biotites, inclusions were uncommon.

**Feldspar 30% :** No microcline twinning was seen although albite twinning was common. The grains averaged .5 mm. in diameter and were smaller than the quartz in general. They often formed a matrix for the larger quartz grains. No zoning was noted in the feldspars. Many feldspar grains were not twinned.

Extinction angles on albite twins :-

30°, 70°, 15°, 51°, 70°, 131°, 40°, 121°, 150°, 120°.

This indicates a composition near An 33 (Andesine-Oligoclase).

**DISCUSSION.** The rock was a relatively even grained mica rich granitic rock with a strong preferred orientation of the muscovites. As usual, exsolution structures were absent in the feldspars, which were largely plagioclase of an andesine-oligoclase composition. The presence of limonitic material in the cleavages suggests that the muscovite might be considered, in part, to be produced from the biotite, but this is very doubtful.

A177 4/434.

**MACRO.** The rock was a crumbly, fine to medium grained, pinkish, mica poor granite. The visible minerals were quartz, feldspar, biotite, muscovite and iron ore. The gneissic banding was poor and the schistosity weak. The micas occurred in patches.

**MICRO.** The slide was cut at random. The rock had an even grained granoblastic texture.

**Biotite : 2% :** This mineral occurred in small flakes less than .5 mm. in length. The flakes were pleochroic from pale yellow green to grey black.

**Muscovite : 1% :** Muscovite flakes reached 1 mm. in length and were associated with the biotite.

THE CONTACTS (cont.)

Iron ore : 2% : Haematite was common as irregular grains, but some showed crystal faces. The mineral was associated with the mica and zircon grains. Zircon grains were commonly included in the iron ore.

Zircon : Small grains of this accessory were often found in association with the iron ore. The grains were generally rather angular and clouded with inclusions.

Quartz : 50% : The grains averaged 1 mm. in diameter; they were generally rather clear but had some inclusions.

Felspar : 45% : Almost all of the felspar was well twinned microcline. The grains averaged .75 mm. in diameter. The mineral was sometimes clouded and had inclusions of quartz, muscovite and iron ore. A few crystals of plagioclase showing albite twinning were noted.

DISCUSSION. The rock had a fine even grain size. Compared with other specimens of the granite this rock was richer in iron ore and very poor in micas. Microcline was abundant. Accessory zircon occurred in close association with the micas and iron ores.

A 177 1/341(a).

MACRO. The rock was a fine to medium grained, quartz - felspar - muscovite - biotite schist. The rock had a strong schistosity and lineation. The grain size was variable, some quartz grains being large. The rock showed a slight gneissic banding.

MICRO. The slide was cut perpendicular to the lineation and schistosity.

Biotite : 3-5% : This mineral was strongly pleochroic from pale yellow green to a green-red-brown. It was a little iron stained due to weathering. Inclusions of zircons giving pleochroic haloes were common. The flakes averaged .5 mm. in length, and were well oriented parallel to the schistosity. Some tendency for gneissic banding was also observed.

Muscovite : 15% : Muscovite was common as strongly oriented bands of flakes. The flakes in section had an elongation of 6:1 (c.f. biotite 4:1). Limonite was commonly precipitated along the grain boundaries.

Limonite : This was commonly seen along the grain boundaries where it probably occurred as a weathering product.

Quartz : 50% : The quartz was variable in grain size, averaging .3 mm., although some grains reached 4 mm. in diameter. The grains, although clear, showed slight strain effects. The grain boundaries were often outlined by limonite. Occasional inclusions of biotite and felspar occurred.

Felspar : 30% : Microcline twinning was commonly seen, the grains being generally smaller than quartz. Some grains had albite twinning. Much of the felspar was untwinned.

DISCUSSION. The rock is a quartz - microcline - plagioclase - muscovite - biotite schist showing slight weathering effects. Microcline notably abundant. The rock had a granitic composition except for the abundance of mica.

THE CONTACTS (cont.)

A177 1/341(b).

MACRO. The rock was a crumbly quartz - felspar - biotite - muscovite schist, showing a strong lineation and a slight gneissic streaking of the biotite flakes.

MICRO. The slide was cut perpendicular to the schistosity.

Biotite : 5% : The biotite was fresh, and showed a pleochroic colour range from pale yellow green to deep green black. The biotites showed a moderate preferred orientation and a tendency for gneissic banding with the muscovite. The flakes were variable in grain size up to 2 mm. in length. Zircon inclusions and associated pleochroic haloes were common.

Muscovite : 5% : Muscovite occurred intergrown with the biotite. The flakes were clear, and were strongly oriented parallel to the schistosity of the rock.

Iron ore : Rare.

Zircon : Rounded zircons were common in association with the biotite.

Quartz : 60% : The quartz was clear and generally free of inclusions. The larger grains showed frequent strain effects. The grain size averaged .3 mm., although some grains ranged to 3 mm. The grains were always xenoblastic and generally larger than the associated felspars.

Felspar : There was little tendency for the banding or orientation of the felspar grains. No microcline twinning was observed. Albite twins were common and untwinned felspar was also present. The grains were generally clear, although the grain boundaries were sometimes slightly altered. The grains averaged .3 mm. in diameter, but some reached 1.5 mm.

Extinction angles on albite twins :-

15°, 14°, 4°, 16°, 16°, 14°, 10°, 12°, 8½°, .

These indicate a composition near An 35. (Andesine).

DISCUSSION. The rock is a quartz - felspar - muscovite - biotite schist. The grain size of the quartz and felspar varied greatly. The rock was fresh and unaltered. The absence of microcline was a notable feature.

A177 2/319.

MACRO. The rock was a rather fresh, knotted, sillimanitic, schistose rock, with visible sillimanite, sericite, felspar, quartz, muscovite, biotite, chlorite and small pink garnets. The garnets range to 1 mm. in diameter and are rare. Iron ore (probably limonite pseudomorphs after pyrite) was also present as an accessory. The rock had a very irregular texture.

MICRO. The slide was cut perpendicular to the lineation.

Biotite - Chlorite : 10% : The biotite showed all stages in the alteration to chlorite and iron ore. The flakes averaged 1 mm. in diameter, and were rather stumpy and disoriented. The original biotite showed a pleochroism from pale yellow orange to dark red black. Extreme alteration along the cleavages to pale green chlorite was common. The chlorite was pleochroic from pale yellow green to mid green. Some of the biotite had completely recrystallized to chlorite and iron ore. The recrystallized chlorite was present as very closely packed disoriented flakes averaging .2 mm. in length. The iron ore was distributed through the flakes as small flecks. The chlorite had anomalous blue interference colours and a



THE CONTACTS (cont.)

straight extinction. Irregular feathers of chlorite were often closely interwoven with the sericite rich knots.

**Muscovite : 15% :** Disoriented muscovite flakes were distributed throughout the slide. The flakes averaged 1 mm. in length and were fairly equidimensional.

**Garnet :** One small aggregate, diameter 1 mm. , of several small, irregular, isotropic, slightly pink, garnet fragments were seen. The fragments were xenoblastic and appeared to have suffered sericite alteration at the edges. Fractures were absent and the fragments themselves were clear.

**Zircon :** Small rounded zircons, averaging .05 mm. in diameter were sometimes seen included in the biotite and chlorite where they produced small pleochroic haloes.

**Sericite : 35% :** Irregular ragged clots of fine grained sericite, up to 5 mm. in diameter, were abundant in the rock. The knots appeared to anastomose into one another. Relicts of finely fibrous sillimanite can be seen in one of the larger sericite knots. Splinters of sericite pseudomorphs after sillimanite could be seen penetrating most of the adjacent quartz grains.

**Quartz : 40% :** The quartz grains averaged .75 mm. in diameter. The grains were fairly even grained and lacked strain shadows. The grains were clear, except for occasional inclusions of sillimanite (sericite) and muscovite.

**Felspar :** No felspar was identified in the slide.

**DISCUSSION.** The rock, although unweathered, has been altered by retrograde (or hydrothermal) metamorphism. The original assemblage of quartz - biotite - muscovite - sillimanite - and garnet has been altered to an assemblage with stable sericite and chlorite. All stages in the alteration were visible in the slide. The alteration of the biotite to chlorite had undoubtedly supplied some of the potash for the sericitization of the sillimanite.

A177 1/487 (a).

**MACRO.** The rock was a grey-black, fine grained, schistose and lineated amphibolite. The small hornblende spindles were well oriented parallel to the lineation, and partially gathered into strings along the lineation. Quartz and felspar were visible but very finegrained. The average grain size of the rock was .5 mm. The rock was rather even grained. On the weathered surface the hornblende weathered out preferentially leaving small knobs of quartz - felspar.

**MICRO.** The rock was cut parallel to the lineation and perpendicular to the schistosity.

**Hornblende : 60% :** The average grain length was .5 mm. Some grains reached 2 mm. in length and .3 mm. in width. The grain size was rather uneven. The pleochroism was strong from pale yellow green to deep olive green. Twinning was not seen. Many of the crystals were bundled together due to a slight development of a foliation. Small inclusions of quartz and felspar were common in the larger grains.

**Biotite :** A few sparse flakes of biotite were noted associated with the hornblende. The flakes were pleochroic from pale yellow to deep yellow brown.

**Sphene : 3% :** This mineral was readily recognised by its



THE CONTACTS (cont.)

high relief and extreme birefringence. It occurred as aggregates of small rounded grains oriented parallel to the lineation in the rock. These sphene aggregates are closely associated with the hornblende, occurring generally between the hornblende spindles.

Iron ore ; Rare fine grains associated with the sphene and the hornblende.

Quartz - Felspar : 35% : Plagioclase was the only felspar recognised. It was twinned on the albite and Carlsbad twin laws. Untwinned felspar was also present. Quartz was present but was not differentiated from the felspar.

Extinction angles on albite twins :-

13°, 0°, 8°, 13°, 18°, 18°, 13°, 20°, 15°, 20°, .

These indicate a composition near An<sub>40</sub> (Andesine).

DISCUSSION. The amphibolite appeared to be of the normal fine grained type. The plagioclase appeared to be a little more acidic than the plagioclase of most amphibolites. The sphene occurred in elongate aggregates of small grains. The hornblende was strongly lineated and showed a tendency for gneissic banding.

Al77 1/487 (b)

MACRO. The rock was a light coloured hornblende granite. The rock was hard, compact and massive, but having a slight schistose tendency. Hornblende occurred as small aggregates of minute crystals of irregular shape distributed unevenly throughout the slide. The quartz was common and occurred as flattened aggregates upto 2 mm. in thickness and several mm. in length. White felspar occurred as a fine grained matrix.

MICRO. The slide was cut perpendicular to the schistosity.

Hornblende : 15% : This mineral occurred as ragged crystals unevenly developed throughout the slide. Some patches showed a crowding of better formed hornblende. The pleochroism and cleavage were distinct. The pleochroism ranged from pale yellow green to deep green. Pleochroic haloes were common in most of the hornblende grains. These haloes, pleochroic from yellow brown to brown black, were caused by small inclusions of sphene. The grains of hornblende .3 - .5 mm. in diameter. A major feature was the irregular distribution of this mineral.

Biotite : 1% : This was a common accessory occurring as irregular grains and aggregates of grains. It appears to result from the alteration of the hornblende. Chlorite also occurred with the biotite. Only a few of the hornblendes showed this replacement by biotite.

Sphene : 1% : This was a common accessory. Isolated grains and aggregates of grains occurred throughout the slide. Some recrystallization to larger grains (.3 mm.) had occurred.

Iron ore : Absent.

Apatite : A few crystals of apatite of a very small size were noted.

Quartzo - feldspathic matrix : This matrix was extremely variable in grain size, with grains varying from .02 - 4 mm. in diameter. The average grain size was .2 mm. The larger grains were predominantly quartz and the remainder felspar. Poeciloblastic grains were common.

Felspar : 25% : A few crosshatched microclines were seen. They were invariably full of rounded inclusions of quartz and

THE CONTACTS (cont.)

felspar. Inclusions of a similar type were also common in the plagioclase where they permeated both the twinned and zoned grains. Zoning was often strongly shown in the plagioclase. Albite twinning was common although some grains showed no twins.

Extinction angles on albite twins :-

17°, 7°, 22°, 17°, 13°, 14°, 18°, 27°, 10°, .

This indicates a composition near Ab<sub>50</sub>. (Andesine-Labradorite)

Quartz : 50% : The quartz grains were generally large (up to 4 mm. ) compared with the felspar and was relatively free of inclusions compared with the inclusion loaded smaller felspars, squeezed into the interstices of the quartz grains. Undulose extinction was absent. The quartz tended to be lineated into bands parallel to the lineation of the hornblendes.

DISCUSSION. Irregular hornblende crystals, often having pleochroic haloes about sphene inclusions, were distributed irregularly throughout the slide. Some alteration to biotite had begun but this was local. Quartz occurred as large grains in ill-defined bands and was unstrained. The felspars were strongly poeciloblastic in structure. Plagioclase was common as twinned and untwinned grains. Zoning was a feature. The plagioclase was basic in composition. A few microclines were noted, and were generally crowded with inclusions of quartz and felspar.

A177 1/487 (c).

MACRO. The rock was a medium grained crumbly granite. The texture was uniform and somewhat schistose. The micas produced a slight lineation. The visible minerals were quartz, felspar, biotite and muscovite. The micas occurred in patches parallel to the schistosity and showed a slight lineation.

MICRO. The slide was cut perpendicular to the schistosity.

Biotite : 5-10% : The average grain was 1 mm. in length and .3 mm. in width. The grains were pleochroic from pale yellow brown to dark green black. The mica is well aligned along the schistosity and is segregated into gneissic bands. Pleochroic haloes about small zircon inclusions were common. The edges of the biotite grains were generally rather ragged in appearance.

Muscovite : 1% : The muscovite occurred as small crystals associated with the biotite.

Zircon : The grains were generally .1 mm. in diameter or less and were common throughout the rock. They generally occurred as inclusions in the biotite flakes, but an aggregate of some twenty grains were noted in the quartz - felspar matrix in one part of the slide.

Quartz : 50% : The grains were readily distinguished from the felspar by their higher relief. Strain shadows were absent. The average grain size was .5 mm. in diameter, although some grains reached 2 mm. This mineral generally even grained.

Felspar : 40% : Microcline was the predominant felspar in the rock and was readily distinguished by its well developed cross-hatched twinning. The average grain size was .3 mm. Plagioclase was recognised by its albite twinning. The plagioclase may make up 5% of the felspar. Untwinned felspar was also present but was minor in amount. Some of the plagioclase showed reversed zoning. Some plagioclase grains contained small quartz inclusions.

Extinction angles on albite twins :-

12½°, 13°, 2°, 15°, 7°, 13°, 7½°, .

These indicate a composition near An 33 (Andesine).

THE CONTACTS (cont.)

DISCUSSION . The rock was fairly even grained. The biotite well oriented into bands and linear streaks. Microcline was the major feldspar, plagioclase of an andesine composition was subordinate in amount. Zoning was present in some feldspar grains but was of the reversed type. No strain shadows were visible in the quartz grains.



MACRO. The rock was fine grained, schistose, lineated amphibolite. Hornblende, quartz and felspar were visible. The hornblende was well lineated. The quartz and the felspar occurred as lineated aggregates throughout the rock. The rock had a very uniform structure and composition throughout.

## Slide A.

MICRO. The slide was cut parallel to the lineation and perpendicular to the schistosity.

Hornblende : 65% : The grains averaged .4 mm. in length and .2 mm. in width. Some grains reached 1 mm. in length. The grain size was rather irregular. The mineral was pleochroic from pale yellow green to dark green. The relief was moderately high and the cleavage distinct. The grains were generally very clear, but some grains had abundant quartz and felspar inclusions of small size. The small grains were clear, but the larger ones were predominantly poeciloblastic. Twinning was a rare feature.

Sphene : 3-4% : Sphene was a very common accessory. The mineral occurred as groups of small grains. The relief was characteristically high and the birefringence extreme.

Magnetite : 1% : Small grains occurred occasionally in association with the quartz and sphene. Iron ore was rarely found outside clots of sphene grains.

Apatite : This was a rare accessory.

Quartz : 5-10% : Clear, equidimensional grains averaging .4 mm. in diameter.

Felspar : 25% : Plagioclase was the only felspar seen. It was commonly twinned on the albite and pericline laws. Untwinned felspar was also present and appeared to have the same relief as the twinned plagioclase.

Extinction angles on albite twins :-  
12°, 27°, 30°, 18°.

These indicate a composition near An 55.

DISCUSSION. The hornblende is notably elongated and a clustering of the hornblende spindles into rough foliae is evident. Elongate, ovoid clusters of sphene and magnetite grains were a feature. The quartz and the felspar had a uniform grain size and an equigranular texture.

## Slide B.

MICRO. The slide was cut perpendicular to the lineation and the schistosity.

The slide was rather structureless.

Hornblende : 65% : The grains were pleochroic from pale yellow to dark green. The average cross-section of the spindles was .2 mm. No twinning was seen. Poeciloblastic crystals were common.

Sphene : 3-4% : The sphene occurred in lineated ellipsoidal aggregates of fine grains, one circular cross-section of which occurred in this slide. Sphene grains also occurred as abundant inclusions in the edge of the hornblende crystals.

Apatite : This mineral was not a common accessory.

Quartz : 5-10% : Small grains of quartz, .3 mm. in diameter were spread throughout the slide.

Felspar : 20% : The only felspar recognised was plagioclase with an average grain size of .4 mm. Both albite and pericline



THE AMPHIBOLITES. (cont.)

twinning was commonly seen. The twinning was sharp in most grains but some showed diffuse twins, probably representing combinations of albite and pericline twins. Untwinned feldspar was distinguished from the quartz by its cleavage and its high relief. Several grains were strongly zoned from the centre.

Extinction angles on albite twins :-  
 $13\frac{1}{2}^{\circ}$ ,  $29^{\circ}$ ,  $28^{\circ}$ ,  $23^{\circ}$ ,  $26^{\circ}$ ,  $28^{\circ}$ ,  $20^{\circ}$ ,  $23^{\circ}$ ,  $24^{\circ}$ ,  $12^{\circ}$ ,  $20^{\circ}$ ,  $23^{\circ}$ .  
 These suggest a composition near An<sub>54</sub> (Labradorite).

DISCUSSION. The hornblende was strongly oriented and of a variable grain size. The plagioclase was of a labradorite composition, was commonly twinned, and sometimes zoned. Quartz occurred sparingly. Spinel and iron ore were common accessories.

A177 1/245.

MACRO. The rock was a strongly lineated amphibolite, with visible hornblende, feldspar and quartz. The rock showed a strong schistosity and a fine grain ( averaging .5 mm. ). The hornblende was a dark green black colour. Epidote was seen coating some of the joint planes in the rock.

MICRO. The slide was cut perpendicular to the lineation and the schistosity.

Hornblende : 60% : This mineral was pleochroic from pale yellow green to dark green to blue green. The grains were generally idioblastic and often closely packed. The crystals were strongly oriented with their lengths parallel to the lineation direction, and their flatter faces parallel to the schistosity. Cross-sections averaged .25 mm. in diameter. Rare feldspar or spinel inclusions occurred. The grains were generally clear and unweathered. Cleavage was a prominent structural element in the crystals. Fractures were rare.

Ilmenite : 1% : Grains of ilmenite of an even size ( .2 mm. ) occurred sparingly throughout the rock in association with the hornblende. The grains were generally idioblastic.

Spinel : This was common throughout the rock as aggregates of small rounded grains with a high relief, and often associated with the hornblende and the ilmenite. This mineral sometimes caused pleochroic haloes in the hornblende.

Apatite : This was a common accessory.

Limonite : This may be replacing pyrite. It occurred as rare pseudomorphs.

Quartz : 10% : Grains of quartz averaged .3 mm. in diameter. They showed few strain effects and were sometimes twinned.

Plagioclase : 20% : The plagioclase was very often zoned. Twinning was not common, much of the feldspar being untwinned.

Extinction angles on albite twins :-  
 $22^{\circ}$ ,  $18^{\circ}$ ,  $19^{\circ}$ ,  $32^{\circ}$ , .

These suggest a composition near An<sub>58</sub> (Labradorite).

DISCUSSION. The rock appears to have the usual composition and texture of the more schistose type of amphibolite. The plagioclase appears to be strongly basic in this specimen.

THE AMPHIBOLITES (cont.)

A177 1/326.

**MACRO.** The rock was a non-schistose amphibolite with visible hornblende, quartz and felspar. The hornblendes were large (up to 3-4 mm. in length), and of a roughly equidimensional shape. The quartz and felspar occurred as a fine grained matrix between the large stumpy, disoriented, hornblende crystals. Except for a direction easy splitting the rock was essentially massive.

**MICRO.** The slide was cut perpendicular to the easy direction of spitting.

**Hornblende : 70% :** The hornblende occurred as large irregular and partially intergrown crystals up to 4 mm. in diameter, but averaging 2 mm. The pleochroism was strong from pale yellow green to mid green to dark olive green. One of the striking features was the presence of exsolved iron ore in small black granules. These grains often occurred in well defined strings which cut across the hornblende with no apparent relation to geometry of their lattice. Of special significance was the occurrence in several crystals of two sets of strings of iron ore granules perpendicular to each other, and superimposed upon the hornblende structure. The exsolved nature of the iron ore grains was suggested by the extreme population in some hornblende crystals where the iron ore had not gathered into larger grains. The presence of original pyroxene was thus suggested by these granules.

**Diopside : 1% :** A few optically positive, colourless and non-pleochroic diopside grains showing perpendicular cleavages were noticed. They occurred as small individual crystals in the quartz - felspar matrix, and as relicts in the hornblende crystals.

Sphene appeared to be absent from this specimen (perhaps it is still held in solid solution in the hornblende).

**Zircon :** One small rounded zircon mineral occurred in a hornblende crystal where it was surrounded by a pleochroic haloe.

**Iron ore :** A few large original grains of iron ore were noted in the slide, but these were subordinate to the granules exsolved from the hornblende.

**Quartz - felspar : 30% :** Quartz could not be distinguished from the felspar except by interference figures. Much of the felspar showed good albite twinning. Zoning was sometimes seen.

Extinction angles on albite twins :-

25°, 20°, 13°, 19°, 24½°, 14°, 8°, 14½°, .

These suggest a composition near AN 47 (Andesine-Labrad.)

**DISCUSSION.** The absence of a schistosity is a notable feature of the rock. The presence of exsolved iron ore in the hornblende may indicate that pyroxene was originally the major mafic mineral in the rock. The small amount of pyroxene present in the rock may be relicts of this original pyroxene. Plagioclase had a composition near labradorite and was often zoned. Potash felspar was not identified.

A177 1/276.

**MACRO.** The rock was a dark, medium to coarse grained amphibolite with visible hornblende, quartz and felspar. The rock was essentially massive and structureless, but possessed an easy direction of splitting. The hornblendes averaged .2 mm. in diameter, but the quartz - felspar was finer grained than this.



THE AMPHIBOLITES (cont.)

MICRO. The slide was cut perpendicular to the direction of easy splitting.

Hornblende : 70% : This mineral occurred in grains of a variable shape and size. The average grain size around 1-2 mm. Some of the large grains were relatively free of inclusions but others were very poeciloblastic, enclosing large numbers of quartz and felspar granules averaging .1 - .2 mm. in diameter. The mineral was pleochroic from pale yellow green to mid green to olive green. The larger grains contained small inclusions of exsolved iron ore granules and dust. This effect may be indicative of converted pyroxenes. The hornblende crystals which contained abundant quartz and felspar inclusions were free of iron ore inclusions and may represent hornblendes growing along the grain boundaries in the quartz - felspar matrix. Some of the larger crystals were rich in stumpy grains sphene which showed marked orientation along directions not related to the amphibole structures, but probably related to the original pyroxene structure. Some inclusions do occur in the hornblende cleavages, and indicates that the exsolution of sphene was still active in the hornblende stage.

Sphene : A few grains of sphene also occurred outside the hornblende crystals.

Iron ore : Associated with the sphene.

Diopside : A few fragments of suspected diopside were present.

Quartz - Felspar : 30% : Plagioclase was in great excess of quartz, and the grains reached 1 mm. in diameter. The plagioclase was of a labradorite composition. It was almost invariably poeciloblastic, having small rounded quartz inclusions. These inclusions ranged from .1 - .2 mm. in diameter.

DISCUSSION. The rock was a massive amphibolite with 70% hornblende, some of which showed exsolution structures after pyroxene. Iron ore and sphene were common as inclusions in the hornblende. Some of the hornblende had crystallized along the grain boundaries and contained inclusions of quartz and felspar. The plagioclase was again notably basic, and in this case was full of inclusions. These inclusions were mainly quartz.

A177 <sup>1</sup>/192(a).

MACRO. The specimen was a predominantly light coloured rock, having about 10% hornblende occurring as large, black, spindle shaped, pointed, poeciloblastic porphyroblasts up to 2 cm. in length. These crystals averaged .5 cm. in length and 2 mm. in width. Most of the rock was made up of quartz and felspar in a rather even grained texture, with grains averaging .3 - .5 mm. in diameter. The rock possessed a roughly bedded appearance, with bands of a slightly variable composition and grain size. The hornblendes were often flattened parallel to the "bedding" planes, and showed different concentrations and grain sizes in different bands.

MICRO. The rock was cut perpendicular to the bands.

Hornblende : 10% : This mineral occurred as optically continuous crystals up to 2 cm. in length growing along the grain boundaries of the quartz and felspar grains. The pleochroism was from pale yellow green to mid green to deep olive green. Minute sphene granules were common in the hornblende crystals where they caused pleochroic haloes of a brown colour.

Iron ore : 1% : Iron ore occurred as small elongate granules averaging .2 mm. in length. They were evenly distributed throughout the slide, both in the hornblende and the matrix.

THE AMPHIBOLITES (cont.)

The Quartz - Felspar Matrix : This matrix had a fairly even grain size, averaging .3 - .5 mm. , and a uniform granoblastic texture. The quartz grains tended to be smaller than the associated feldspars. The distribution of the quartz and feldspar appeared to be related to the presence of bands. These bands could be distinguished by the amount of quartz in each, and the grain size. The coarser bands were richer in feldspar, and the finer bands richer in quartz. The banding appeared to be of a sedimentary origin.

Quartz : 20% : The quartz grains averaged .3 mm. in diameter, were always clear, lacked strain shadows and had sharp contacts.

Feldspar 70% : The feldspar appeared to be predominantly plagioclase. No microcline twinning was present, but untwinned feldspar may be partly potassic. Very fine albite twinning was common although not well developed and often diffuse. Most of the feldspar showed strong zoning throughout the grains. The zoning was diffuse and not often associated with the albite twins. The zoning appeared to be reversed.

Extinction angles on albite twins :-

$33\frac{1}{2}^{\circ}$ ,  $23\frac{1}{2}^{\circ}$ ,  $17\frac{1}{2}^{\circ}$ ,  $20\frac{1}{2}^{\circ}$ ,  $22^{\circ}$ .

These suggest a composition near An 60.

DISCUSSION . The rock appeared to be definitely sedimentary in structure but much recrystallization had occurred, giving rise to a granoblastic texture, reversed zoning of the plagioclase etc. The hornblende appeared to be growing by the infiltration of material along the grain boundaries. The plagioclase was very basic and strongly zoned. Its origin is obscure.

A177 1/301.

MACRO. The rock was an amphibolitic pegmatite veinlet. The hand specimen showed coarse glassy quartz (20%), in grains up to 1 cm. in diameter, feldspar (10%) in smaller grains, diopside (1-2%) as small yellow green crystals enclosed in the amphibole, ilmenite (1%) as small platy crystals to 6 mm. in length between the quartz and hornblende, and hornblende (65%) occurring as well formed crystals up to 2 cm. in length, but of a variable size. There were no apparent directional properties in the rock.

MICRO. The slide was cut at random.

Hornblende : 20% : The hornblende was common throughout the rock, and was identified readily by its cleavages and strong pleochroism from pale yellow green to a very deep green. The crystals were sometimes bent and fractured near the growing quartz grains (as is ilmenite). Alteration to chlorite was evident, but it was uncertain whether the diopside was forming from the hornblende or vice versa. The hornblende was more altered than the diopside. Some of the hornblende was poeciloblastic in structure, having quartz inclusions. Diopside was free of such a structure. A few isolated pleochroic haloes were seen but these were rare.

Chlorite : 30% : The chlorite was abundant and appeared to represent an alteration or retrograde product of the hornblende. Diopside did not appear to be altering to this mineral. The chlorite was of a rather unusual type. It occurred as extremely equigranular flakes ( averaging .3 mm.) which had a radiate structure. The overall structure was a strongly decussate "cart-wheel" effect. Inclusions were rare in these flakes and weathering products were absent. The pleochroism was from a pale yellow to a deep green. The birefringence was very low being made up of deep anomalous lavenders, blues and browns. The mineral had a parallel extinction. The chlorite had a uniform character throughout the slide.



THE AMPHIBOLITES (cont.)

Ilmenite : 1% : Strongly elongate, tabloid crystals to 5 mm. in length, showing good crystal form, but sometimes bent and fractured, were common in the slide. Minor irregular grains also occurred scattered in the diopside grains.

As well as limonitic staining along the grain boundaries, goethitic ring growths in cavities formerly occupied by pyrite? were common in the slide.

Sphene : 1% : Sphene was a common accessory in some parts of the slide, occurring as irregular grains and aggregates of grains. Small sphene overgrowths on ilmenite crystals were also seen. Slight alteration to leucoxene was seen about some grains.

Diopside : 20% : Abundant clear, high relief diopside crystals with extremely bright first order interference colours were easily detected. They possessed a slight yellow to colourless pleochroism and resembled epidote, but did not possess the parallel extinction of that mineral and have at least two well developed cleavages. The crystals averaged 1 mm. in diameter and were irregularly developed throughout the slide. When isolated the crystals had an idioblastic shape, but interlocking and fan-like aggregates of tabloid crystals were also a feature. Some grains showed a fine grained mosaic structure. Quartz and feldspar inclusions were common. The relation of the diopside to the hornblende and the chlorite was not clear. The diopside was often separated from the hornblende crystals by the chlorite. However some of the diopside appeared to have grown at the expense of the hornblende.

Unknown : A small development of a very ragged mineral of a dark grey blue colour occurred as an inclusion in a diopside grain in one part of the slide. The mineral was slightly pleochroic and had a similar relief to the diopside. The birefringence was very low. The mineral may be tourmaline.

Quartz : 20% : Large, clear quartz grains up to 8 mm. in width were common in the slide. Strain shadow effects were strong in these grains.

Feldspar : 5% : The relief of this mineral was greater than that of the quartz and indicates a basic plagioclase. Graphic intergrowths with the quartz were a feature.

DISCUSSION. The rock was undoubtedly a pegmatoidal variation of an amphibolite. The major minerals were quartz, plagioclase, hornblende, chlorite and diopside with minor sphene, ilmenite and limonite. The interrelations of the diopside, hornblende and chlorite are puzzling. The original rock may have contained hornblende, quartz and plagioclase (and perhaps diopside). Later retrograde effects could have converted some of the hornblende to chlorite, ilmenite and sphene. However where diopside fits into this scheme is not known. The diopside at present occurs in well formed clear crystals and is apparently stable in its present environment.

PEGMATITIC MYLONITES.

A177 2/327.

MACRO. The rock was a light coloured schistose, arkose from outcrops resembling a shear zone or mylonite in the field. The rock was tough, fresh, and slightly gneissic. The visible minerals were quartz, feldspar, muscovite and biotite. The grain size averaged .5 mm. in diameter.

MICRO. The slide was cut perpendicular to the schistosity.

Biotite : 1% : Intermittant, streaky bands of biotite occurred throughout the rock. The flakes were strongly pleochroic from a pale yellow to a deep green brown. The larger flakes showed some alteration to chlorite. The chlorite was pleochroic from pale green to pale yellow, and anomalous interference colours were common. The biotite flakes reached 2 mm. in length. Small well formed biotite flakes were common throughout the slide. Some of the muscovite was interlocked with the biotite. The biotite had a strong preferred orientation.

Muscovite : 4% : Strongly oriented, elongate, muscovite flakes occurred throughout the slide in broken gneissic streaks. This mica was associated with the biotite. One feldspar had minute dis-oriented muscovite crystals throughout.

Iron ore : Magnetite was a common accessory associated with the biotite.

Zircon and Monazite : Monazite was sometimes seen as inclusions in the biotite. The largest zircon seen (.1 mm. in length) was strongly zoned.

Apatite : This was rather common as sub-rounded grains to .2 mm. in diameter.

Quartz : 50% : The grains were xenoblastic and showed a variation in size from .1 - 5 mm. ( average .5 mm.). Strain shadows were prominent. The grains were clear except for occasional inclusions of muscovite and apatite.

Feldspar : 45% : Good albite twinning was commonly seen, but most of the feldspar was untwinned. Potash feldspar may be present as untwinned feldspar. The grains were clear and free of inclusions. The average grain was .5 mm.

Extinction angles on albite twins :-

11°, 9°, 10°, 10°, 2°, 3½°, 10°, 8°, 6°, 6°, 7°,.

These suggest a composition near An 29. ( Oligoclase ).  
The feldspar was optically negative.

DISCUSSION. The rock appeared to be a sheared, gneissic, quartzofeldspathic having accessory muscovite, biotite, apatite etc. The quartz was notably sheared, and the feldspar rather more sodic than others in the area. The rock may have been an arkose bed which has suffered strong shearing due to incompetence during folding.

SILLIMANITE PODS.

A177 1/34.

MACRO. The rock was very tough and medium grained, being made up of large quartzose areas surrounded by masses of fine, curved sillimanite fibres. These fibres also strongly impregnate the quartz. Traces of rutile and muscovite was also visible in the hand specimen. The rock was rather fresh, and alteration of sillimanite to sericite or clay was not strong.

MICRO. The slide was cut at random.

Sillimanite : 80% : This mineral occurred as sheafs of minute fibres. Some of the larger fragments of sillimanite were fractured across their fibres. Individual sheafs were made up of countless numbers of fibres reaching 4 mm. in length and 2 mm. in width. The mineral showed a first order birefringence and a high relief. The fibres showed a straight extinction and were length slow.

Quartz : 18% : The quartz occurred as interlocking grains up to 2 mm. in width (average 1 mm. ). Sillimanite spindles penetrated well into the quartz grains. The grains of quartz were strongly interlocking , this accounting for the toughness of the rock. Strain shadows were notably absent, the grains in general having a very sharp extinction.

Muscovite : 2% : Small muscovite flakes were often found enclosed in the quartz matrix. They were generally small ( .3 -, .4 mm. in length), and occurred in patches of several flakes closely associated.

Rutile : No rutile was seen in the slide.

DISCUSSION. The specimen was a massive sillimanite -, quartz rock with accessory muscovite. The sillimanite occurred as sheafs of minute fibres of a radiate structure. The quartz occurred in patches of interlocking unstrained grains and was strongly interpenetrated by sillimanite splinters. The rock was rather fresh and no sericitization or clay was seen in the slide.



KYANITE PEGMATITES .

A177 1/180.

MACRO. The specimen was a tough light coloured rock showing a slight foliation. The visible minerals were quartz, felspar, sericite, kyanite, sillimanite and rutile. Large bladed crystals of a pale green mineral were prominent in the rock. These were sericitized kyanite crystals. Irregular microfolding was a feature of the hand specimen.

Micro. The rock was cut perpendicular to the lineation and the schistosity.

Biotite : Minute flakes to .2 mm. in diameter were sparsely developed throughout the slide. They were pleochroic from pale yellow to orange.

Kyanite : 1% : Relict fragments of kyanite crystals were often seen. They were length slow and showed a low birefringence and the characteristic cleavage. The fragments were altered to sericite around the edges.

Sillimanite : 2% : This mineral was largely weathered to sericite but a few relict fibrous aggregates were present. The mineral was distinguished from the kyanite by its lower relief and its more spindular form. The mineral was altered to fibrous sericite aggregates.

Sericite : 10% : Elongate blotches of sericite with a fibrous pattern resulted from the alteration of the sillimanite.

Muscovite : 3% : Small oblong crystals to .1 mm. in length were common in some felspar crystals where they were often oriented and showed helicitic twisting in some crystals. This structure probably reflected the microfolding.

Rutile : 1% : This mineral occurred as clear rounded grains with an orange colour. The grains averaged .1 mm. in diameter and ranged up to .3 mm.

Zircon : Several rounded, fractured, clear, minute zircons were noted embedded in the quartz and felspar.

Quartz : 20% : Rounded xenoblastic grains of various sizes ranging to 1.5 mm. in diameter were developed irregularly.

Felspar : 65% : Much of the felspar was untwinned, but some grains showed both pericline and albite twins.

Extinction angles on albite twins :-

6°, 4°, 9°, 8°, 5°, 6°, 4°.

These suggest a composition near An 17. (Oligoclase).

DISCUSSION. The rock appeared to be an arkosic rock which had been pegmatized and metasomatized. The sillimanite and kyanite may have originally been present in equilibrium. The felspar of the rock was albite rich. Rutile was a notable accessory.

A177 1/89.

MACRO. The rock was a decussate aggregate of blue grey kyanite blades embedded in a glassy quartz matrix. The kyanite crystals reached 2 cm. in length and were strongly altered to sericite and muscovite.

MICRO. The slide was cut at random.

The rock consisted of even intergrowths of kyanite and its alteration products in quartz.



KYANITE PEGMATITES (cont.)

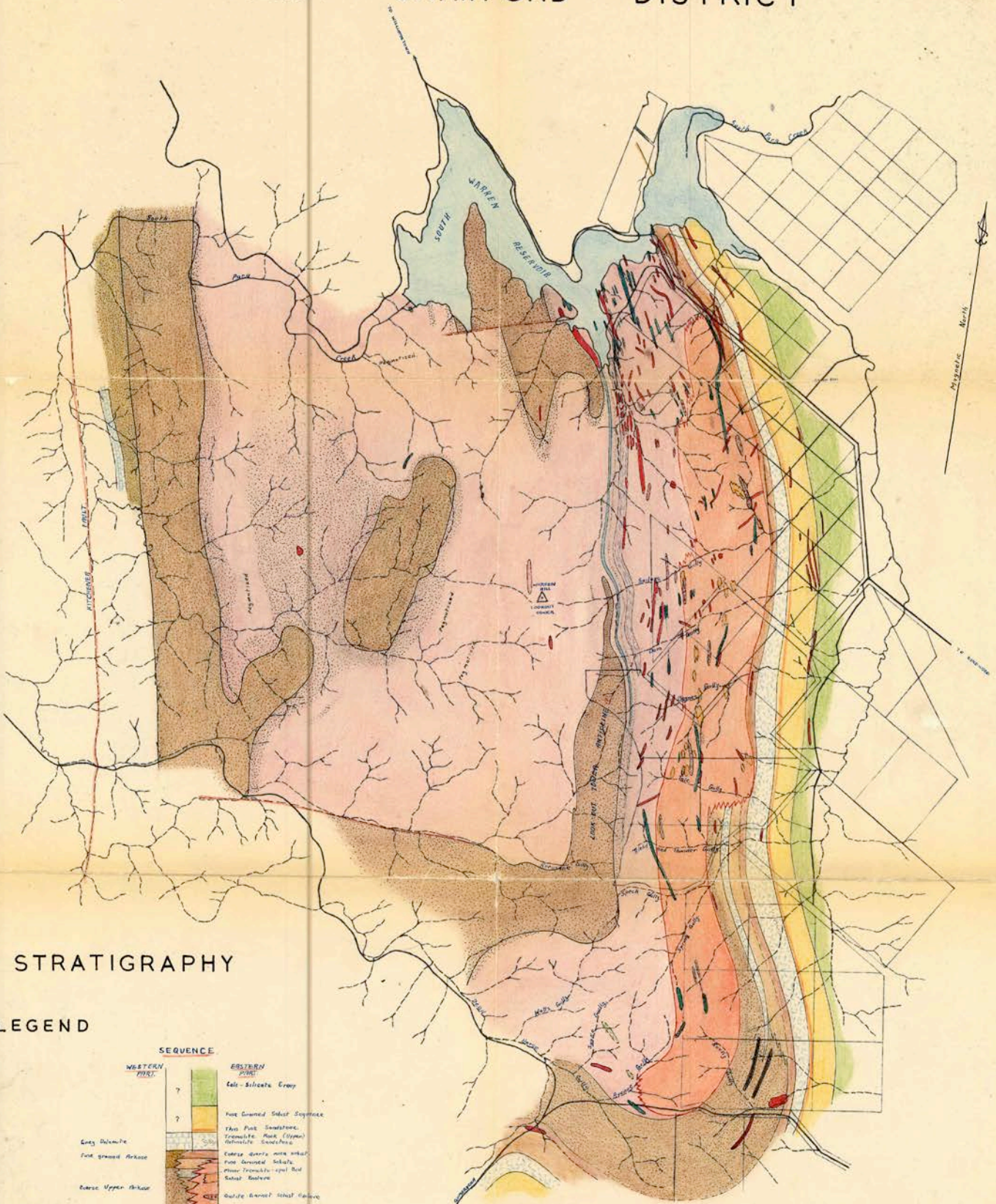
Quartz : 50% : The quartz occurred as large clear crystals with sericite intruding as spindles from the edges of the grains. Adjacent quartz grains showed interlocking saw-tooth edges. Some grains showed a wavy extinction. The grain size ranged to 1 cm. in diameter, but averaged 5 mm.

Kyanite : 50% : The crystals were colourless, optically negative, with a high optic axial angle. Cleavage was strong. The grains showed a moderate birefringence. The mineral was highly altered along the cleavages to sericite. Sericite rims completely surrounded the kyanite fragments and nowhere were quartz - kyanite contacts seen. The kyanite showed two stages of alteration. The kyanite was rimmed by a thin band of gibbsite occurring in fine fibres of low relief (less than the sericite) developed perpendicular to the kyanite borders. Further from the kyanite this mineral gave rise to sericite which recrystallized to muscovite further from the contact.

DISCUSSION. The rock was a kyanite quartz pegmatite. The kyanite showed alteration first to gibbsite and then to sericite

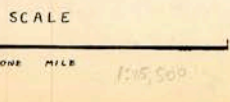
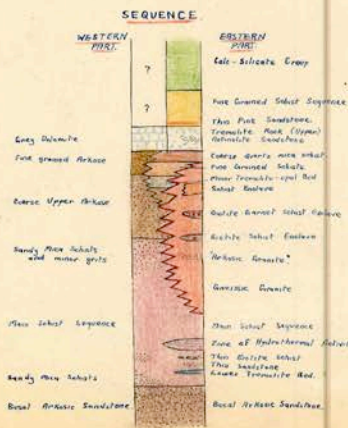


# GEOLOGY OF PORTION OF THE MOUNT CRAWFORD DISTRICT



## STRATIGRAPHY

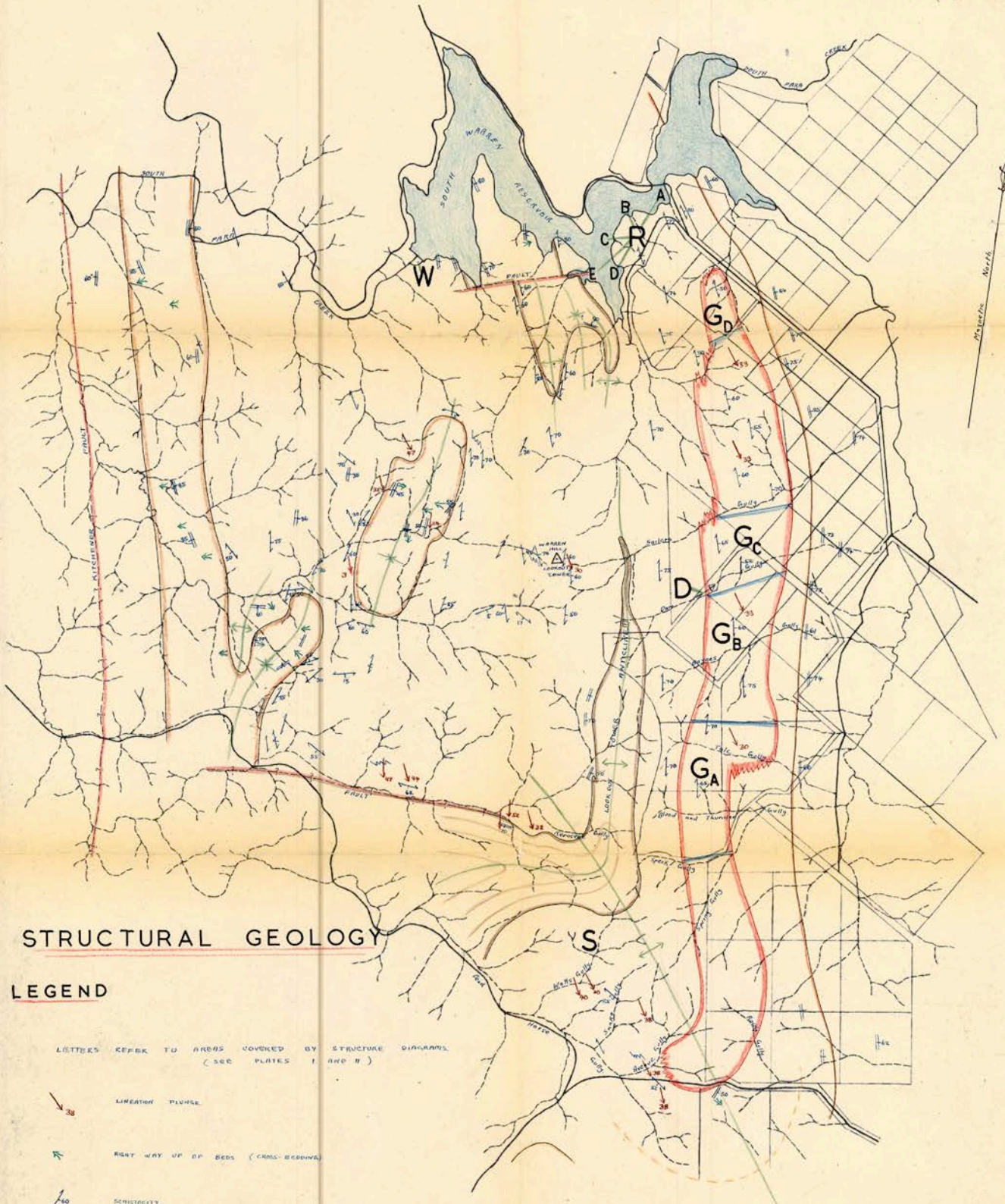
### LEGEND



Mississippi J. 1908  
Geo. Henry Texas 1909



# GEOLOGY OF PORTION OF THE MOUNT CRAWFORD DISTRICT

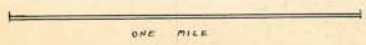


## STRUCTURAL GEOLOGY

### LEGEND

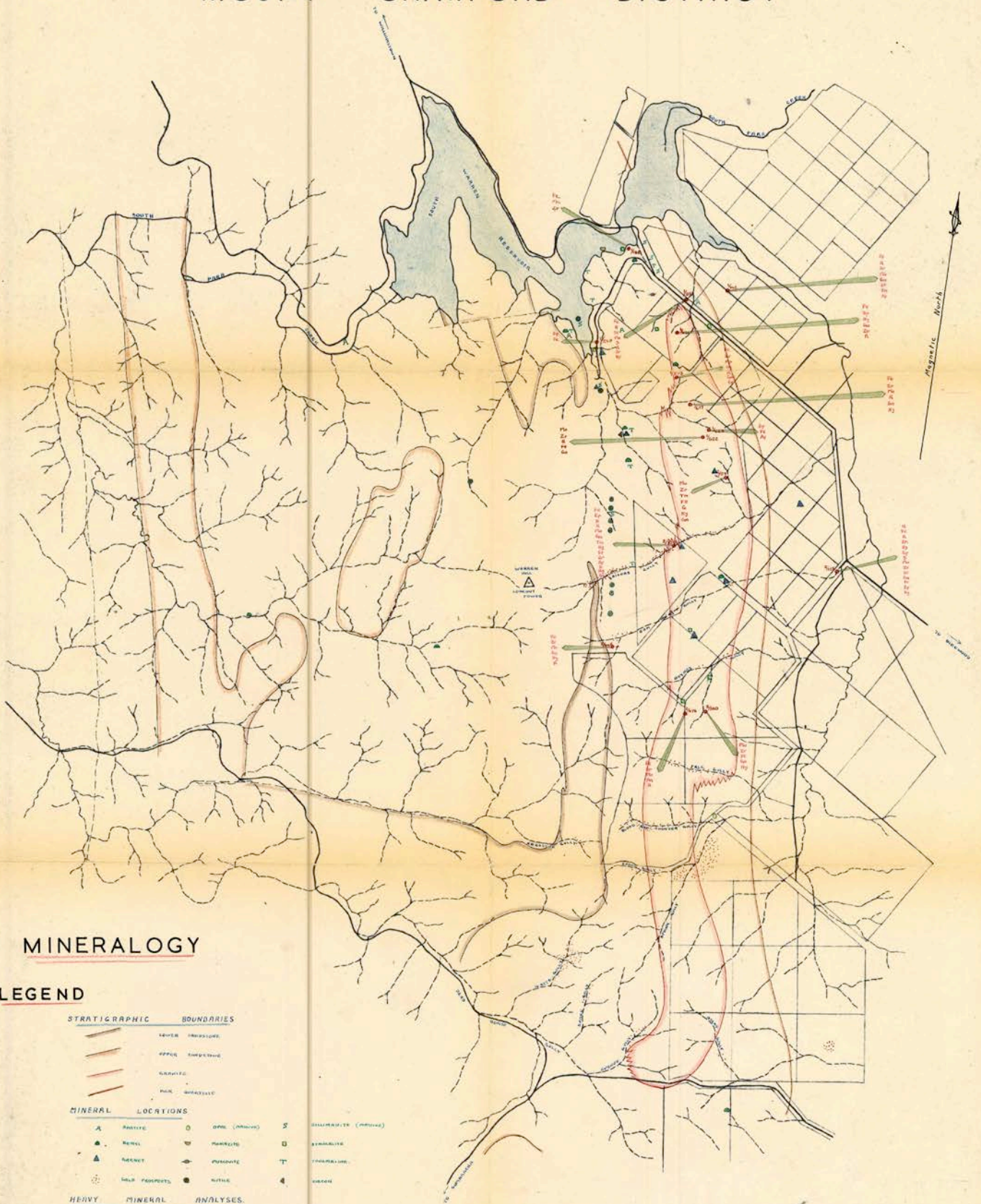
- LETTERS REFER TO AREAS COVERED BY STRUCTURE DIAGRAMS (SEE PLATES I AND II)
- DIRECTION PLUNGE
- RIGHT WAY UP OF BEDS (CROSS-BEDDING)
- SCHISTOSITY
- BEDDING

SCALE





# GEOLOGY OF PORTION OF THE MOUNT CRAWFORD DISTRICT



## MINERALOGY

### LEGEND

#### STRATIGRAPHIC BOUNDARIES

- LOWER TRIASSIC
- UPPER TRIASSIC
- GRANITE
- PALEOZOIC

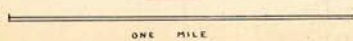
#### MINERAL LOCATIONS

- |          |                 |                       |
|----------|-----------------|-----------------------|
| ANATITE  | OPALE (ANATITE) | SILLIMANITE (ANATITE) |
| BERYL    | MANGANESE       | GARNET                |
| TANTALUM | PYROPHOSPHATE   | FELDSPAR              |
| CARBON   | KALITE          | LITHIUM               |

#### HEAVY MINERAL ANALYSES

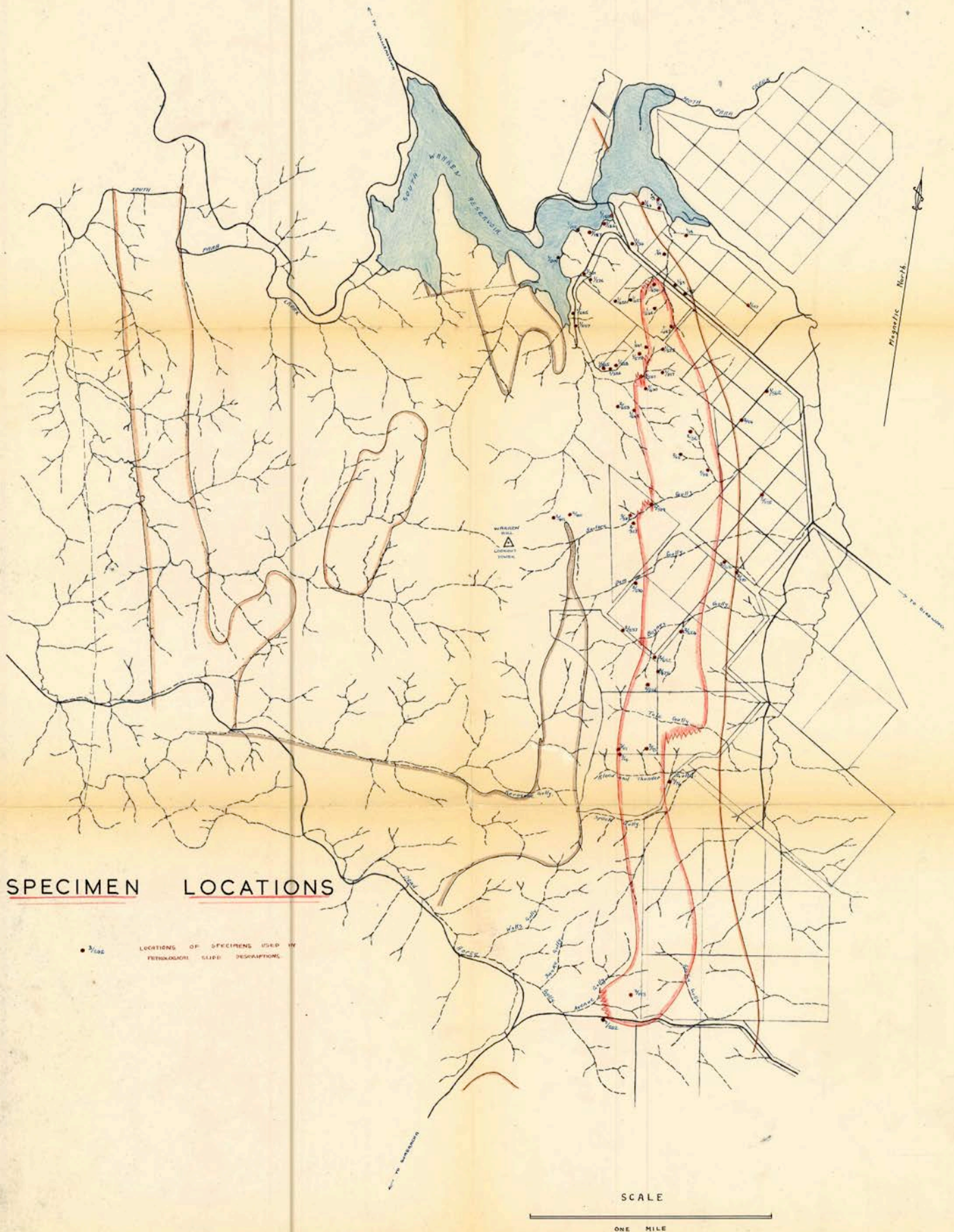
- |          |             |            |
|----------|-------------|------------|
| Anatite  | Hornblende  | Spinel     |
| Apatite  | Hydroxide   | Staurolite |
| Epidote  | Rhyolite    | Tronolite  |
| Felspar  | Plagioclase | Tremolite  |
| Garnet   | Kalsilite   | Zircon     |
| Graphite | Sillimanite |            |

#### SCALE

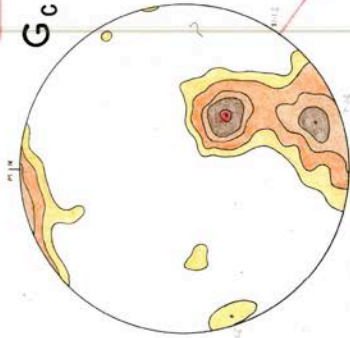




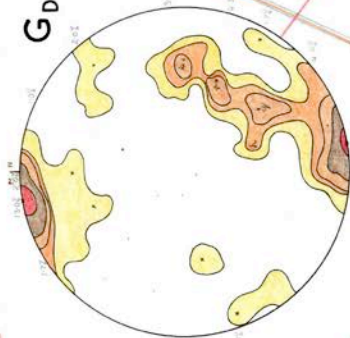
# GEOLOGY OF PORTION OF THE MOUNT CRAWFORD DISTRICT



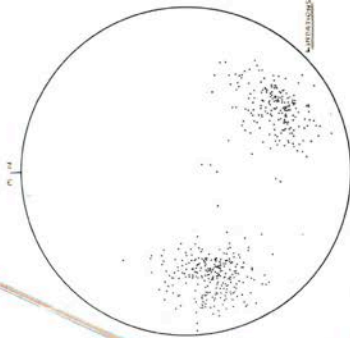
# JOINTS



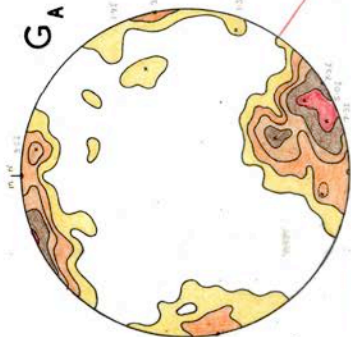
**DIAGRAM 1** Equal Area Projection of poles of 494 joints measured between two gullies and the gully. Contours at 1.0, 2.0, 4.0, 10.0.



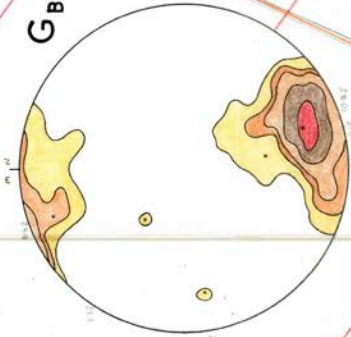
**DIAGRAM 2** Equal Area Projection of poles of 100 joints measured at the north end of the gully. Contours at 1.0, 2.0, 5.0, 10.0.



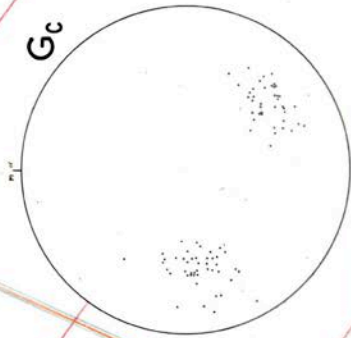
**DIAGRAM 3** Equal Area Projection of poles of 301 foliations and 108 fractures in the granite.



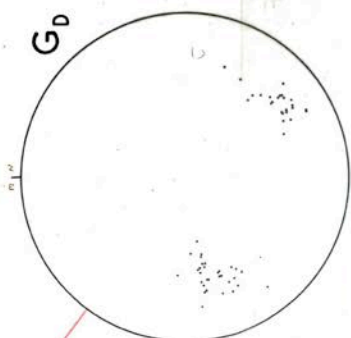
**DIAGRAM 4** Equal Area Projection of poles of 244 joints measured at the north end of the gully. Contours at 1.0, 2.0, 4.0, 10.0.



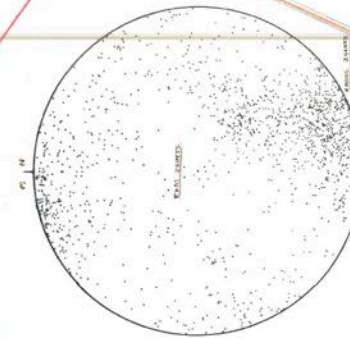
**DIAGRAM 5** Equal Area Projection of poles of 100 joints measured at the north end of the gully. Contours at 1.0, 2.0, 5.0, 10.0.



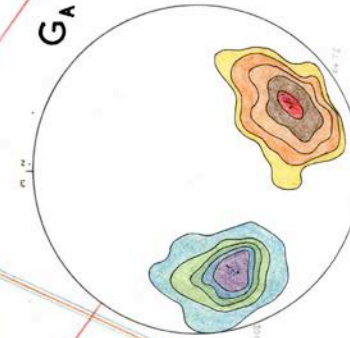
**DIAGRAM 6** Equal Area Projection of poles of 182 foliations and 41 fractures measured between two gullies and the gully.



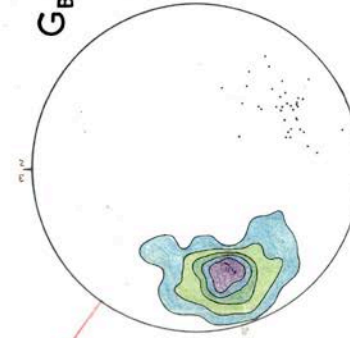
**DIAGRAM 7** Equal Area Projection of poles of 311 foliations and 22 fractures measured at the north end of the gully.



**DIAGRAM 8** Equal Area Projection of poles of 1030 joints measured in the granite.



**DIAGRAM 9** Equal Area Projection of poles of 1030 joints and 15 fractures measured between two gullies and the gully. Contours at 1.0, 2.0, 5.0, 10.0.



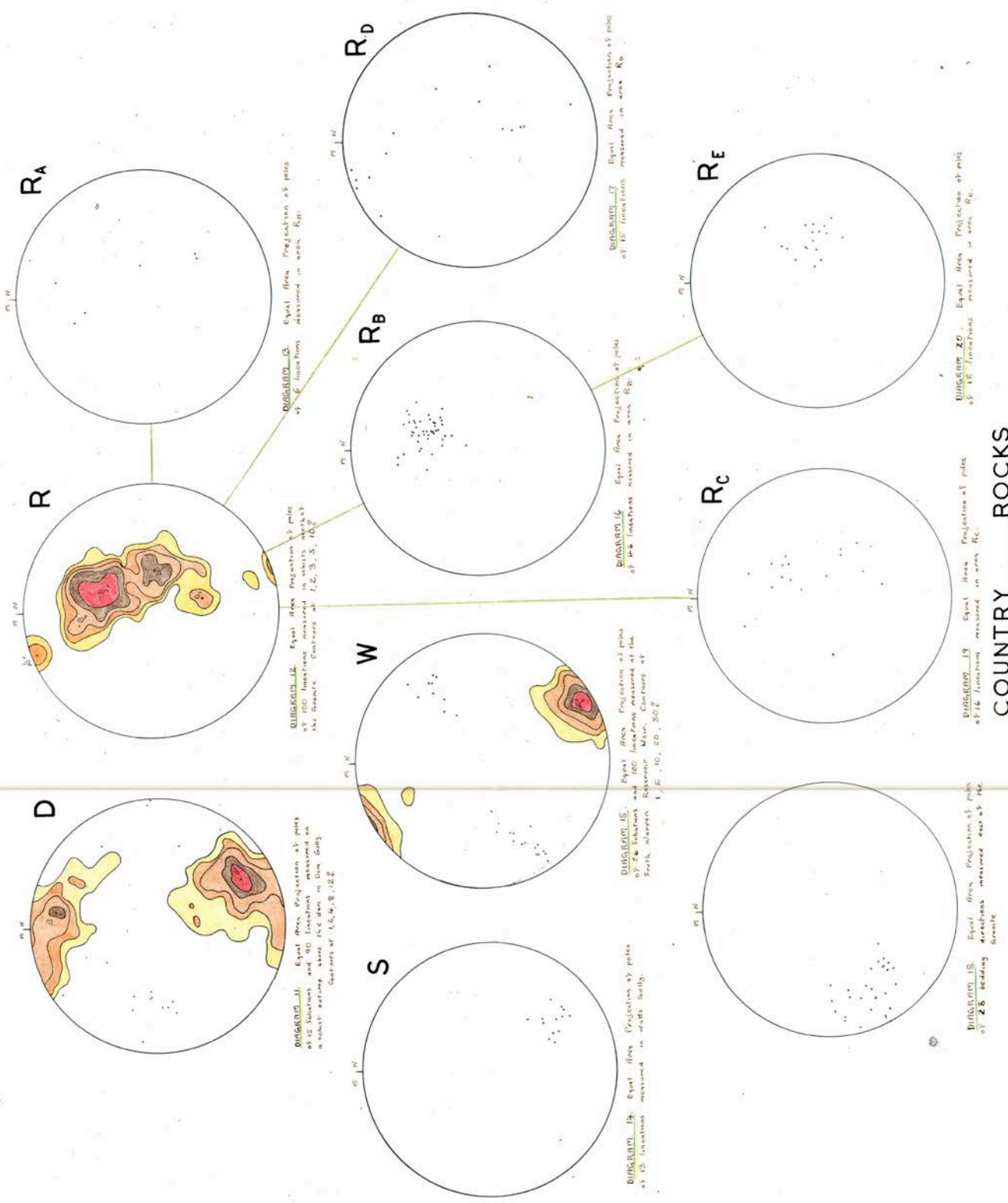
**DIAGRAM 10** Equal Area Projection of poles of 1030 joints and 15 fractures measured between two gullies and the gully. Contours at 1.0, 2.0, 5.0, 10.0.

# FOLIATION - LINEATION

## THE GRANITE

4.7. PHASE  
3.3a. MEMBERS TRAVIS TEST





**COUNTRY ROCKS**