THE UNIVERSITY OF ADELAIDE.

A. The geology and petrography of an Archaean inlier, south of Normanville.

B. The origin of the "Houghton" granulite.

by M. B. Davies.

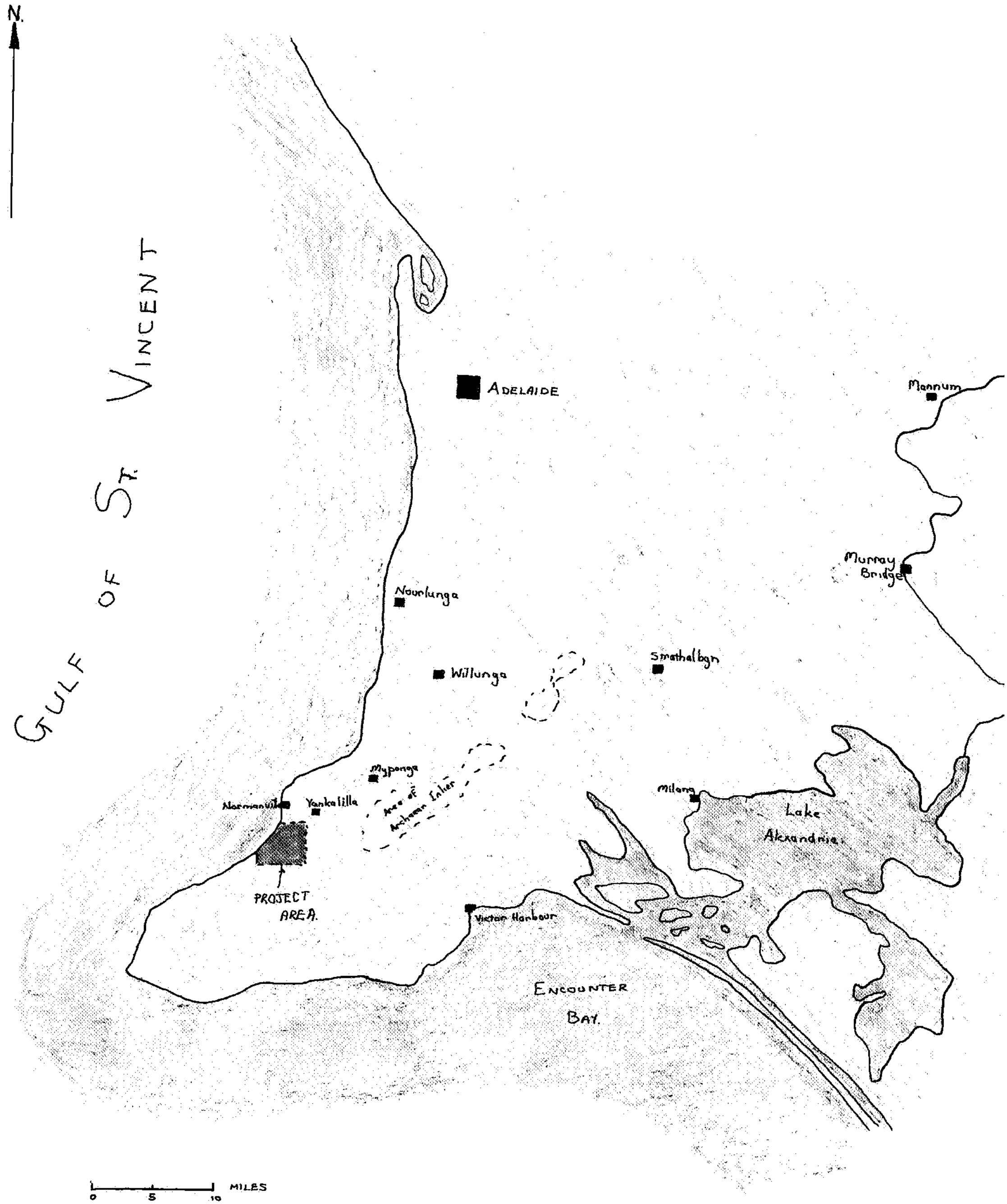
1972.

Submitted as partial requirement for the Honours degree in Geology, University of Adelaide.

Supervisor: R L Oliver

CONTENTS.

LOCATION MAP



ABSTRACT.

Detailed mapping established definite rock units within the Archaean inlier south of Normanville. The distribution of the rock types ~~is suggestive of~~ suggests a major antiformal structure.*2 Only metamorphic layering? is recognised in the area?3 Not true. Unable to determine this fact for sure

The first Archaean orogeny produced this layering and reached upper amphibolite grade of metamorphism, as defined by the minerals, sillimanite, garnet, diopside, and scapolite. The temperature and pressure conditions were ≈750°C and 2-3 Kbars.*4 This was established using mineral assemblages and the presence of ~~much~~ considerable partial melting, pegmatitic masses and migmatites.

This same orogeny was also responsible for the development of a strong schistosity, which was always parallel to the metamorphic layering.(5)

A Proterozoic orogeny produced a strong crenulation of the schists ~~This crinulation is~~ which was parallel to the fold axis of a major antiform, which plunges 35° to 138°.

The deformation reached biotite grade of metamorphism, as shown by the minerals biotite, sericite, and epidote, which, commonly replace the higher grade minerals. An antiform overturned to the west was the major structure. Its underlimb was sheared away, so that the inlier represents the eastern limb only. The western outcrops of the inlier represent the shear zone.6.

Geochemical analyses of the Houghton granulite suggest a sedimentary origin. This, coupled with its conformability with the surrounding rocks, and its association with a zircon rich metaquartzite, support this conclusion. 7

Introduction.

This project was completed under the supervision of Doctor Robin L. Oliver. The object of this thesis was to map, in detail, describe, and interpret the mineralogy, metamorphic grades, and structural elements of the area, and to examine the field relationships, ~~along with the~~ and chemistry of the "Houghton" granulite, to decide if it is of sedimentary or igneous origin.

An area of ~~about~~ approx 6 square miles was geologically mapped in (about) 6 weeks. The remaining laboratory work involved making thin sections of the different lithologies, describing these slides using the petrological microscope, and carrying out a detailed chemical analysis of the chosen specimens. Messers S. Wicks and A. McEwin completed similar projects on Archaean inliers at the Mt. Compass and Yankalilla areas respectively.

My area was some 40miles south of Adelaide ~~and just below~~ near Normanville. The Archaean basement rocks are overlain by Adelaide geosynclinal sediments. Generally the outcrop was poor, but good sections were found along the Yankalilla River gorge, and on a cliff face on the seaward side of the inlier. The cliff face section provided about 300 feet of outcrop, across the strike. Small creeks also provided useful sections.

The climate is temperate, with an annual rainfall of 30". The area is intensely cultivated, with natural scrub remaining on isolated hilltops. The maximum elevation of 600 feet occurs on the cliff face section, ~~and is 600 feet~~. Generally, the area is very hilly, with the prominent feature being the large Yankalilla River gorge, which winds through the inlier.

The Permian sediments ~~present~~ cover much of the inlier, ~~They~~ and are mostly sands, clays, ~~and~~ minor tills and conglomerates. ~~Many~~ A few basement outcrops show glacial pavement features, such as smooth surfaces and striations. Other cover sediments were scree slopes on the cliff face, alluvial sand in the river gorge, and soil cover on most hillsides.

Mapping was done on enlarged aerial photographs, on a scale of I2" represents 600 feet. Smaller scale photos were used for stereos, ~~for~~ in attempted photo interpretation, ~~but were of no use~~.

Geology. Geological mapping of the area was carried out on a large scale (as shown on the outcrop map.),with ~~maticulate~~ care taken in recording the lithologies of the outcrops,~~to~~ noting differences such as,degree of feldspathisation,and sillimanite content.In this way a sequence of units was built up,with approximate lithological boundaries drawn in.These boundaries were parallel to nearby Proterozoic boundaries.New outcrops of the Houghton granulite were discovered,but did not prove to be good marker beds,because of their discontinuous -fault nature.The outcrop patterns of the granulite and sillimanite gneiss could be interpreted as reflecting the major anti-formal structure of the area.The outcrop map is the most important map,as it is an accurate record of the rock type,.Faulting,thrust zones,and migmatisation,have all complicated the geology,such that many interpretations can be made to this map.The interprative map is my contribution.

PETROGRAPHY.

Houghton granulite. This rock type has been known by many names, by past workers,such as Houghton Diorite,and Houghton Syenite, but because these names are biased toward an igneous origin, I will refer to the rock as a granulite throughout the thesis. The granulite is very resistant to weathering,with fresh surfaces showing a pink and pale green colour,Excellent ~~metamorphic~~ layering of these minerals,is observed in most outcrops.This layering is planar,for the most part,but,in places,forms tight overturned folds.No axial plane features are recognized,but the fold axis plunges in a S.E. direction.

The feldspar is mainly microcline,which is pink in hand specimen.In thin section it has a granoblastic texture, with an average grain size of I.Omm.The percentage varies,from trace amounts to 45%,with an average of 30%.The grains are only slightly sericitized and show a very prominent cross-hatched twinning. The amphibole present is thought to be hornblende, but is difficult to distinguish from actinolite. The extinction angles range from low angles to 25°, which suggests it is hornblende. The grains have a very ragged appearance, with epidote replacing the amphibole to a large extent.

Quartz is not present in all slides, but where it does occur it has a very embayed shape, with a strong undulose extinction. Definite bands of quartz rich and microcline rich layers can be seen.

Two minerals which are closely associated in a granoblastic aggregate are diopside and scapolite. The diopside is recognised in hand specimen by its dark green colour. In thin section its pleochroism is distinctive. The scapolite is a tan colour in hand specimen, with many excellent cleavage surfaces present. In thin section its excellent uni-axial(-ve) figure, birefringence, and parallel extinction are most distinctive. The scapolite contains small, xenoblastic inclusions of epidote within the grains. One particular slide shows, in addition to scapolite, diopside and microcline, a tan coloured garnet, which is probably a grossularite-andradite garnet. (see plate I2)

Plagioclase is rare and only a few grains have been found. Epidote is a very prominent mineral. It has a distinctive yellow to green pleochroism, high refractive index, and mottled bi-refringence. It varies from I0 to 50%, with an average of 30%. Instances can be seen where the epidote is replacing the amphibole, but in most instances the epidote has completely replaced the original mineral.

Common accessories are apatite and sphene. The sphene grains are rounded and become very abundant in slides containing the diopside-scapolite assemblage. In one particular slide (H5) Calcite is associated with epidote, both being alteration products of amphiboles. Very minor amounts of opaques occur.

~~Field relationships of the granulite are~~ The Houghton granulite, that it is conformable with the surrounding rocks, in all instances. No obvious igneous or sedimentary features are noticed. ~~I interpret this as~~ which may be, due to complete destruction of such features by the high grade of metamorphism, ~~to~~ producing the granoblastic texture. The granulite is the least altered unit by the proterozoic orogeny.

<u>Quartzite</u>. This unit is closely associated with the granulite, being found on either side of it, in all locations ~~instances~~. In hand specimen, it is a white rock, consisting almost entirely of quartz, with small grains ~~amounts~~ of pink feldspar scattered throughout. In thin section, the quartz exists in two forms. Firstly, there are large embayed grains, showing a strong undulose extinction, which sometimes shows a preferred orientation within the grain. The preferred orientation is parallel to the poor foliation developed.

The other form of quartz is a polygonal recrystallized form. This type occurs between the larger grains, and in pressure shadows around microcline grains. Within the larger grains trails of dusty inclusions occur and in some instances seem to indicate former grain boundaries.

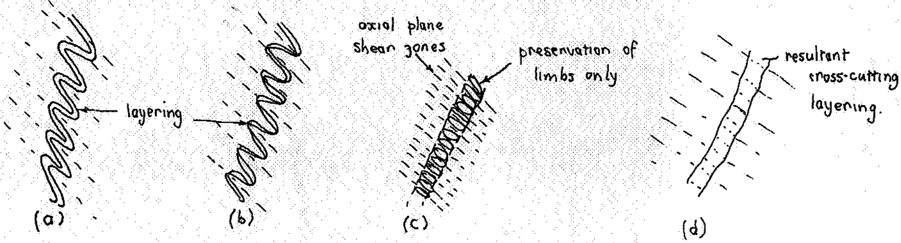
Rounded grains of microcline are prominent, showing the distinctive cross hatched twinning (plate 13). The grains show minor sericitization around the edges.

lo Zircon is a prominent accessory. It is oval shaped, and evenly distributed throughout the slides. No sedimentary layering is seen. I consider the zircon may ~~to~~ be of sedimentary origin, because of its concentration and shape.

The original sediment may have been a slightly arkosic sandstone. Its association with the granulite may represent a sedimentary assemblage of a close to shore sand (marine), with the facies more seaward being a calcareous marl. //

The strain features of the quartz were caused by the Proterozoic orogeny. Other horizons occur, distinct from those associated with the granulite, and they show the same features.

11 One particular horizon is cross-cutting the layering of the surrounding gneisses. It may be intrusive, although there is no concrete evidence to support this, but I favour a tectonic explanation for the relationship. ie.,



The Archaean orogeny may have produced tight isoclinal folding of the original unit. As I suspect, considerable shearing may have occurred in the area, and the noses of these tight folds may have been sheared away (as in diag above), to result in the ~~o~~ observed outcrop pattern.

The majority of the rocks in the area are gneisses, but by ~~close~~ detailed descriptions, using mineralogical and textural differences, I was able to sub-divide these ~~rocks~~ gneisses into smaller units

12 Augen gneisses. These rocks have a strong foliation developed, which, in places, is a schistosity. The rock appears to be mainly sericite, with large augens of quartz strung out along the foliation. The strike of the foliation varies in a gently ~~warped~~ undulating manner, with a strong crinulation developed on the foliation surfaces.

In thin section, considerable sericitization is evident. Layers of quartz alternating with sericite are a common feature. The sericite is replacing plagioclase, so this indicates the original rock had quartzose and feldspathic layers, which I would attribute to the original sediment and not to a migmatization or granitization process.

Mostly the quartz grains are very embayed,with strong undulose extinction,but a few show uniform extinction,and contain very few inclusions.The average percentage is 40%, with a mean grain size of 0.7mm.The amount of recrystallization is widely varying.

Biotite is a common constituent,averaging at 20%.It is always associated with muscovite and opaques,possibly representing a chemical reaction between these three minerals The opaques form exsolution features in the biotite grains.

Sericite forms 40% of the slides.Occasionally plagioclase can be recognised beneath the sericitic mass. In most slides remnant sillimanite is found,which is also sericitized.(plate 5).The distinctive diagnol cleavage, high refractive index and parallel extinction ~~are most obvious.~~ identify the mineral as sillimanite

A pink garnet is found in some slides.The original grains are quite large,up to 3.0mm,but are now shattered, and greatly chloritized.The garnet is probably grossularite.

Other more exotic minerals occur,such as large bladed grains of muscovite,and bladed and fibrous aggregates of pyrophyllite.Both these minerals are pseudomorphing sillimanite.

The foliation and schistosity are Archaean features While the lineations and folding are Proterozoic.

13 Augen schist. These rocks have a strong schistosity developed.As in the augen gneisses,these rocks show an undulation of the schistosity along the strike.Large augens of quartz can be seen,and very tight folding of the micas results in the formation of a pronounced crinulation.(plt.2) The schistosity is of the same generation as the foliation in the gneisses.

Figure I. Mylonitic augen schist, showing larger augens of strained qyartz and microcline. There is considerable recrystallization of quartz. The micas are aligned along the strong foliation developed.

Plate 2. AUGEN SCHIST. Shows the development of a new crinulation. It is a crinulation of micas and recrystallized qyartz.

Features of a thrust zone?

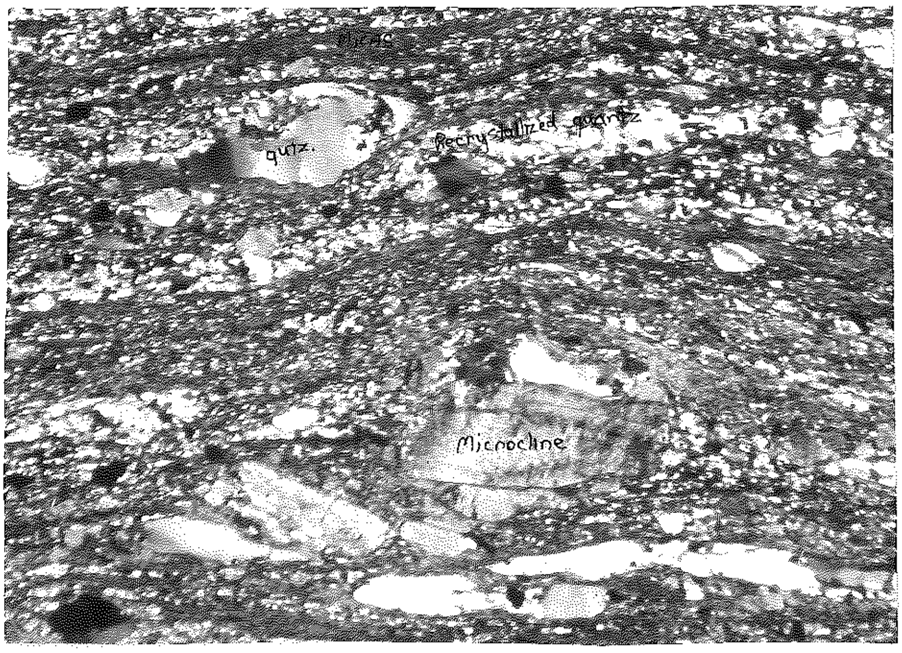


Figure I.

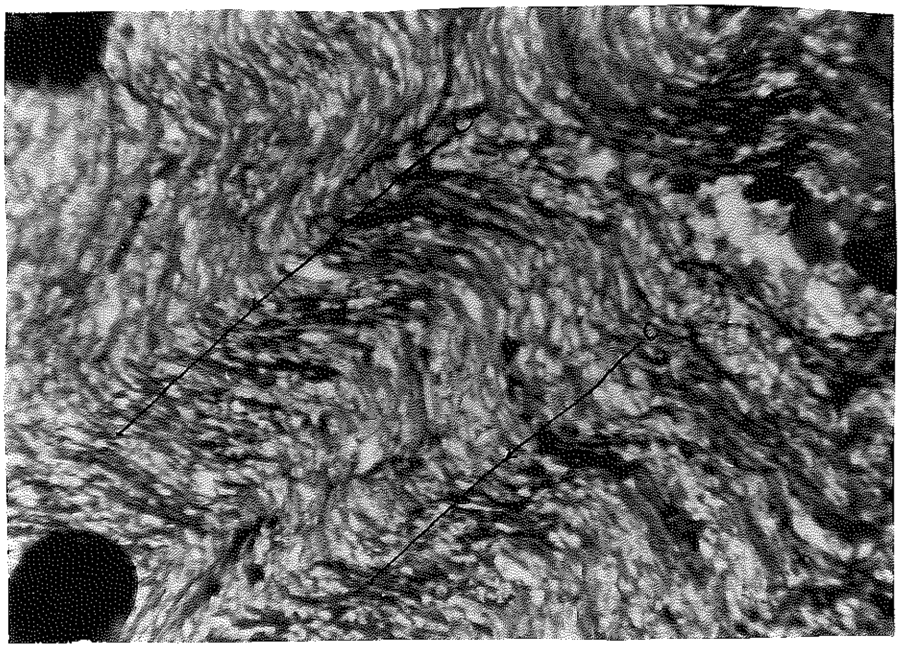


Plate 2.

Plate 3. AUGEN GNEISS. Larger strained quartz and smaller recrystallized quartz, with considerable sericite present. Minor opaques.

Plate 4. HOUGHTON GRANULITE. Granoblastic texture of microcline, showing cross-hatched twinning, and epidote.

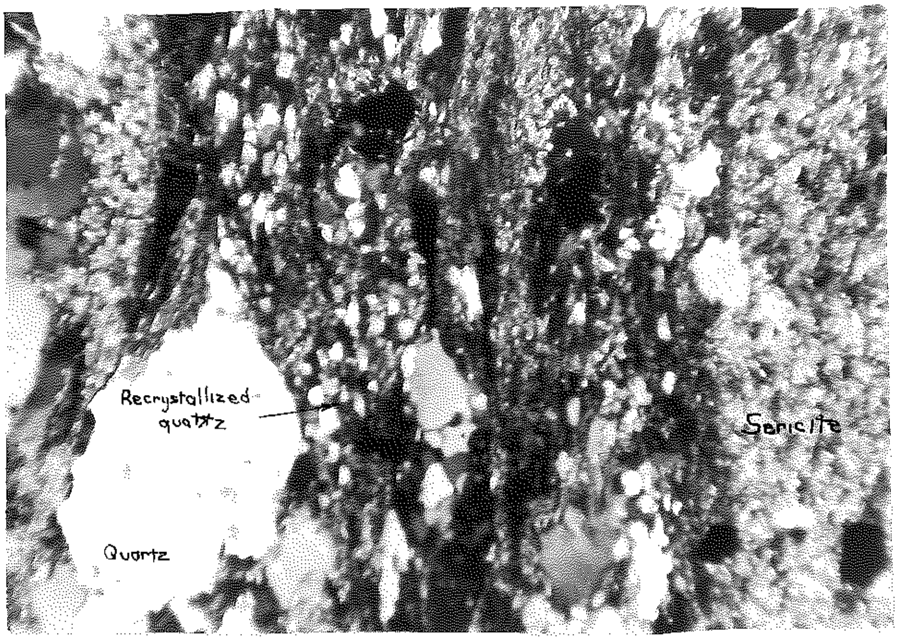


Plate 3.

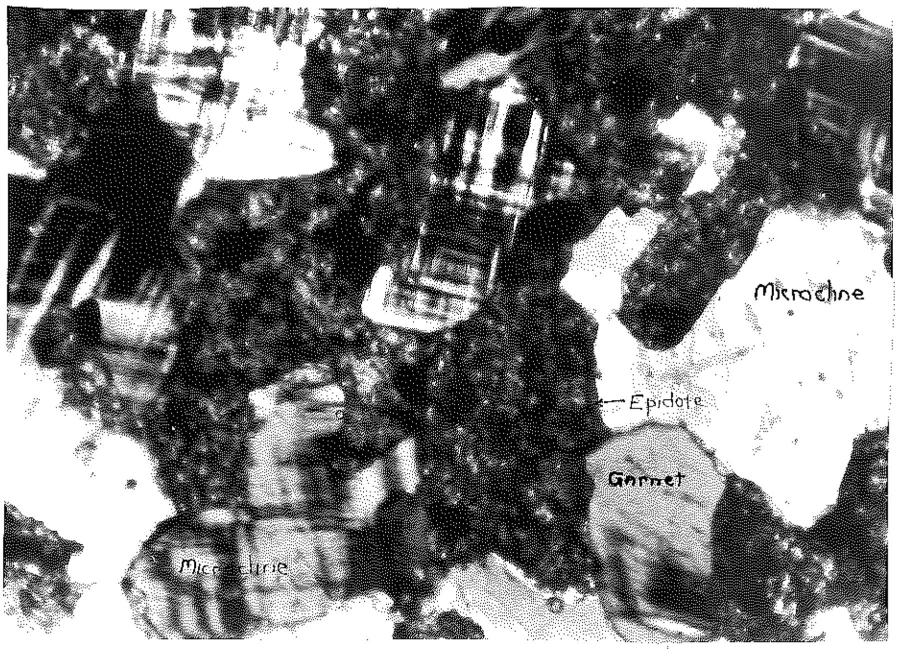


Plate 4.

ate 5. **GRANITE GNEISS.** Shows a large, cross-hatched microcline grain, with blebs of plagioclase. ie. perthitic texture. Also considerable quartz.

Plate 6. **GRANITE GNEISS.** Shows zoning of the central plagioclase grain, with a mermekitic texture developed around this grain. Also plagioclase with albite twinning prominent.

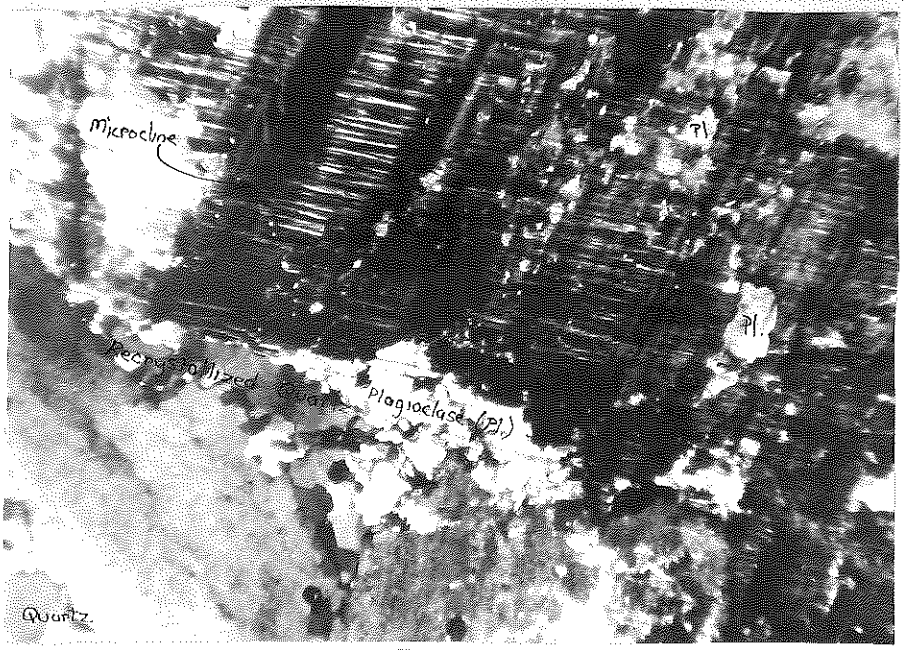


Plate 5

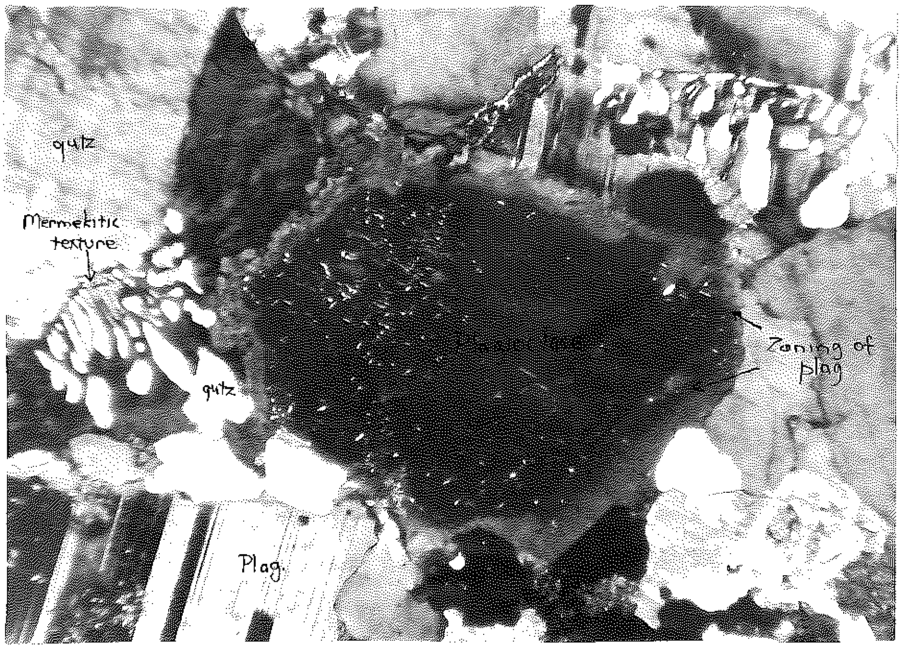


Plate 6.

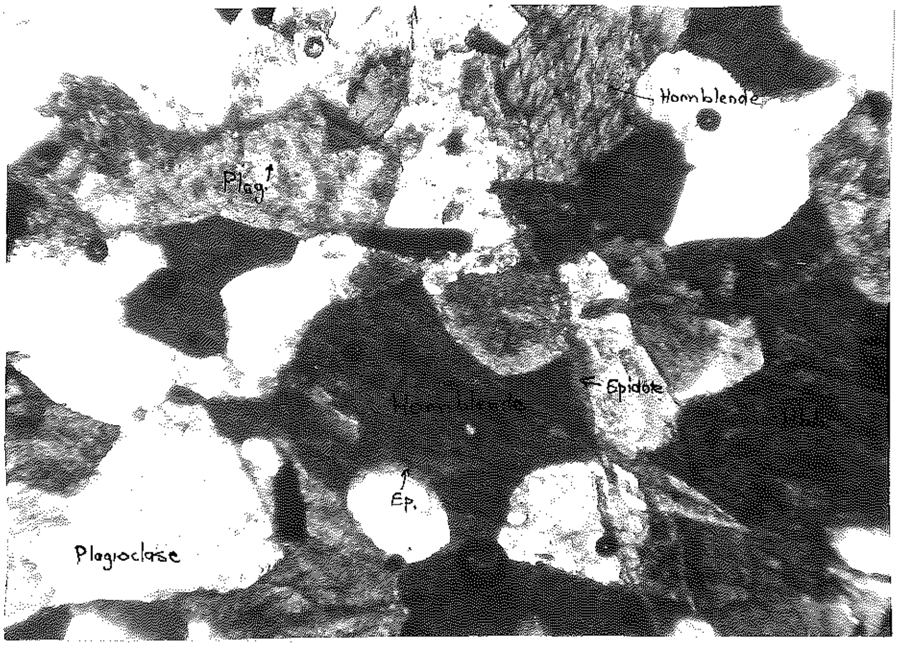


Plate 7.

~~Houghton-granulite.~~
Metasomatized amphibolite.

Granoblastic texture of Hornblende and Plagioclase. Epidote forms coronas around hornblende and an alteration product of plagioclase.

Plate 8. Augen gneiss.

Sill.	-	Sillimanite. - ser. margin, bladed shape-
Ser.	-	Sericite.
qu.	-	Quartz.

shows the sericitization of sillimanite.

Plate 9. Metasomatized Amphibolite.

Am.	-	Amphibole
Pl.	-	Plagioclase
Ep.	-	Epidote
Op.	-	Opaques
Sp.	-	Sphene

shows the alteration of Plagioclase cto Epidote.

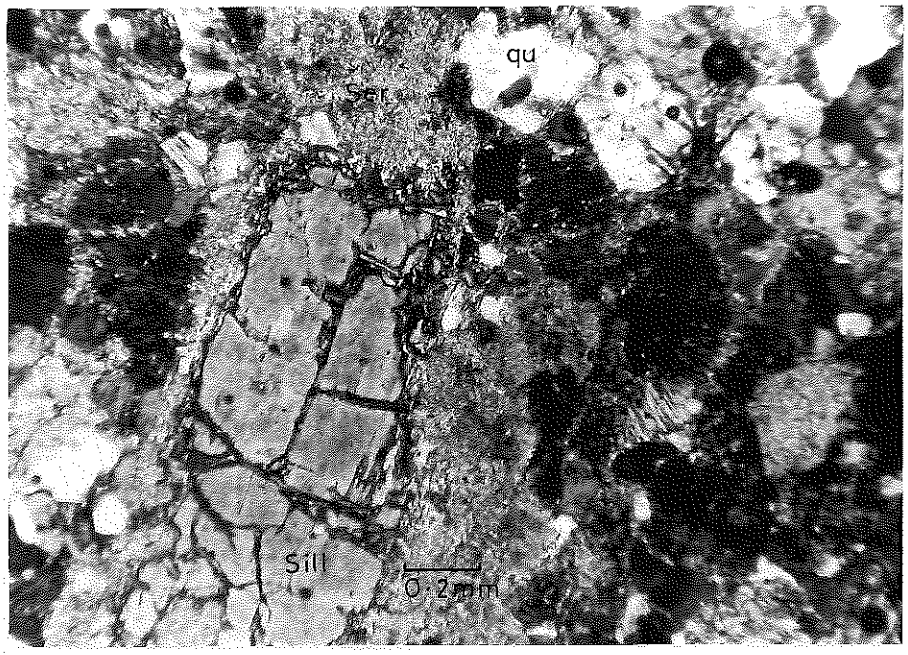


plate 8.

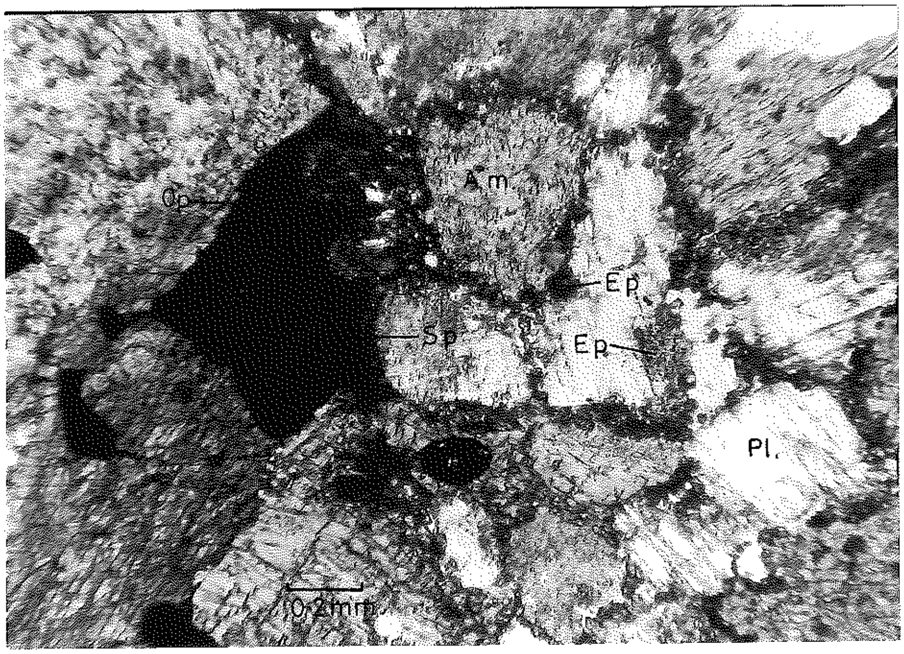


plate 9.

Plate # IO. Augen schist.

shows the development of a new crinulation (S4) on the older schistosity surface (S2).It is a crinulation of micas.

Plate #. II. Augen schist.

Am. - Amphibole. overgrowth of Am.

shows the growth of Amphibole grains across the foliation direction as developed by biotite(bi) and opaques.

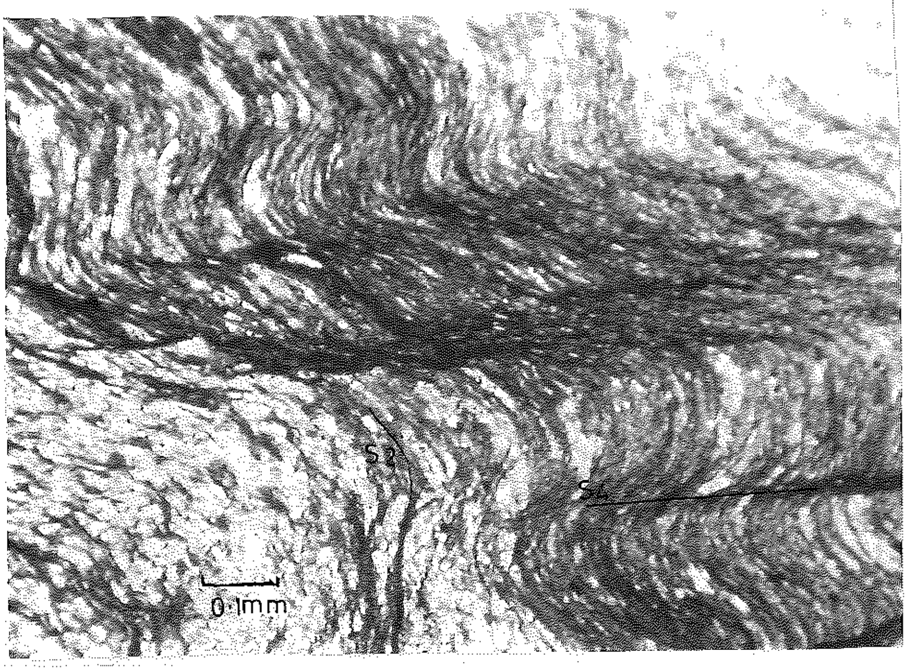


plate 10

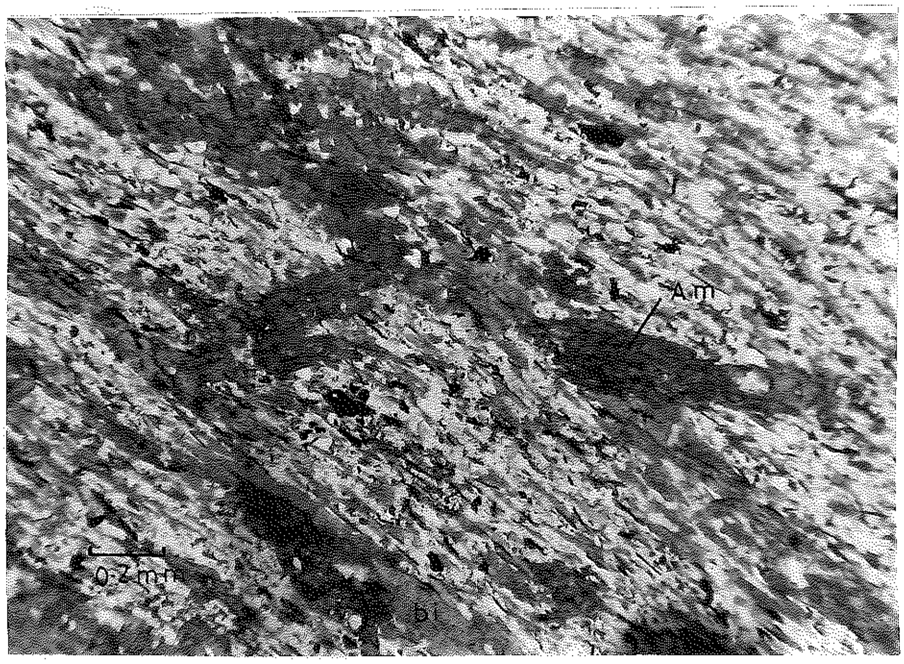


plate 4 11.

Plate 12. **Houghton granulite.**

interlocking mosaic,

Di.	-	Diopside.
Sc.	-	Scapolite.
Mi.	-	Microcline.
Ga.	-	Garnet. — Crystalloblastic growth

Plate ~~2.~~ 13. **Quartzite.**

margin does not appear to be a crush zone i.e. the rounded shape is original i.e. sedimentary.

Mi.	-	Microcline.
qu.	-	Quartz.
ser.	-	Sericite.

The considerable undulose ext + re-X qtz indicating much stress.

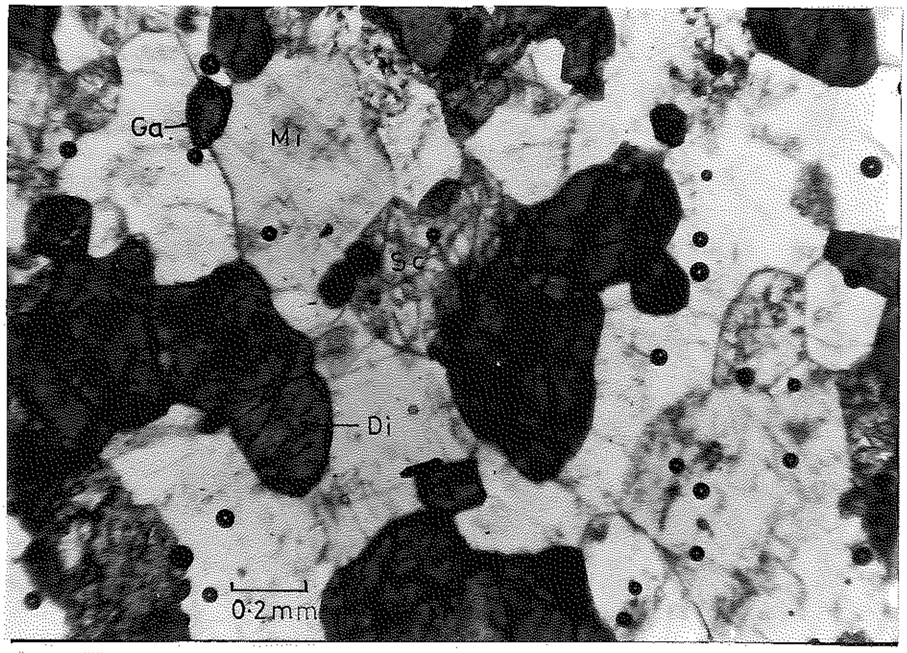


plate 12

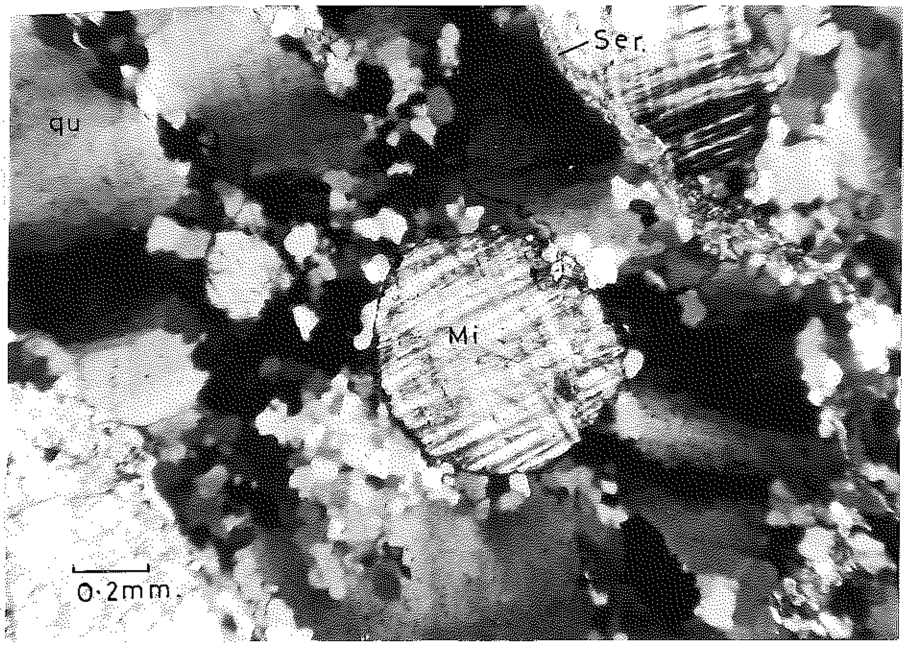


plate 13.

Plate I4.

Augen Gneiss.

Very similar to the augen schist,but more quartz rich.It shows excellent folding of quartz layers. The micas are folded around with the quartz,which is completely recrystallized.

Plate I5.

Sillimanite gneiss.

Shows a central quartz grain,surrounded by a garnet mass,which is extensively chloritized. The garnet is almandine,related to the upper amphibolite facies,whilst the chlorite is a retrograde mineral.

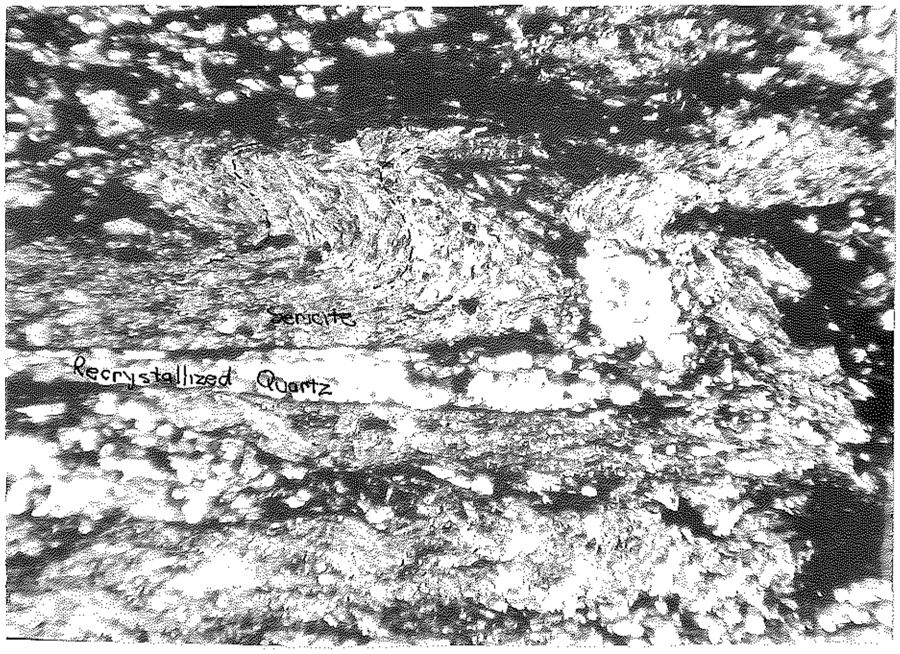


plate 14

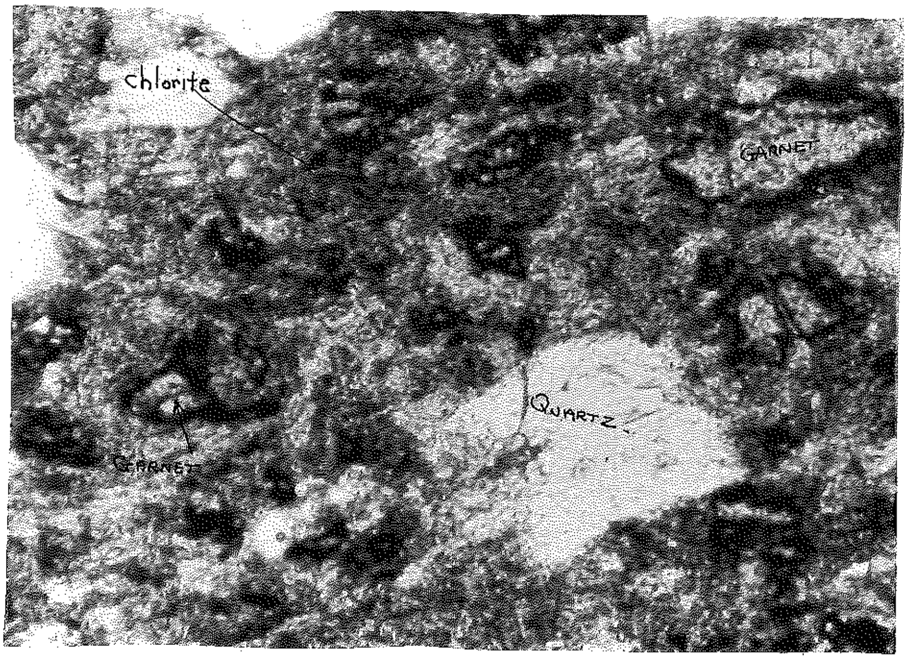


plate 15.

Biotite is very prominent and is parallel to the schistosity surface.From this we deduce the biotite to belong to the Archaean phase.The quartz is completely recrystallized,forming a polygonal matrix,with a mean grain size of 0.Imm.Muscovite is of the same generation as the biotite,but much less concentrated.Other accessories are opaques and tourmaline.

One slide,(376-197) plate II,is markedly different in mineralogy, although it shows the same texture.A strong orientation of almost colourless biotite,and unidentified,tabular opaques occurs,developed in a matrix of recrystallized quartz.The opaque may be graphite.An elongate,mottled,hornblende is developed cross-cutting this orientation direction,and,in some instances,paralleling it.This suggests the hornblende grew at the same time,or just after the development of the foliation.

This unit is easily recognised,and could be used as a marker unit.On the geological map,several long horizons are seen and they are all straight.The interpretation is that the area represents the eastern limb,only,of a major antiform,and so ~~meso~~folding is ~~lacking~~.not evident.

The complete recrystallization of the quartz,resembles that found in thrust zones of similarly aged rocks,.For this reason,I ~~mention~~ suggest that these horizons could represent Archaean thrust zones,which ~~may account for~~ would add to the geological complexity of the area.

Sillimanite gneiss. This is the most widespread gneiss in the area mapped.It is poorly foliated in most instances.On the foliation surface elongate grains of relic sillimanite occur. They show a rather poor mineral lineation.More quartzose varieties can be differentiated,but are not mappable units.

In thin section the minerals are quartz,muscovite, biotite,microcline and opaques.The quartz is mostly recrystallized with some larger elongate grains present.The muscovite and biotite are parallel to the foliation.The same crenulation as was found in the augen schist occurs.

The rock is, mineralogically, very similar to the augen gneiss, but distinguished in the field by its poorer foliation and the ~~most~~ characteristic elongate, relic crystals of sillimanite, which are sericitized in thin section.

This extensive unit shows no recognizable meso-folding, although considerable variations in strike of foliation occurs. Stereo plots of these measurements defined a poor great circle which defined a fold axis, parallel to the known fold axis of the major antiform. This unit is extensively affected by the retrograde metamorphic event.

Migmatite gneiss. As the name implies, this unit has undergone more feldspathization than the other gneisses. It is ~~most~~ similar, mineralogically, to the augen gneiss, except for the higher concentration of ~~f~~ feldspars. The augens are predominantly pink feldspar, strung out along the foliation plane.

Microcline is the dominant feldspar, showing only slight sericitization. The augens vary considerably in size, from 0.5mm.- to 2.0mm. Minor amounts of plagioclase are recognisable, but mostly sericitized beyond recognition. One particular slide contains considerable unaltered plagioclase, and the albite twinning gives a composition of Ab75. In this slide many basal sections of biotite occur. Needle inclusions in these grains suggest this biotite is of the Archaean orogeny. Accessories are opaques and tourmaline.

Migmatitic Sillimanite gneiss. This unit is identical with the sillimanite gneiss, apart from the considerable migmatization which has occurred. Quite good pink feldspar layering occurs, with large augens of feldspar, commonly 5.0mm, found. Sillimanite, biotite and quartz still occur, but microcline is much more prominent. Sericitization is not as severe, and only partly sericitized plagioclase grains are recognised.

Biotite rich gneiss.

It is most distinctive in the field,being a very black rock, with the most obvious minerals being biotite,quartz and plagioclase.

It contains about 30%,biotite.The biotite is most unusual in that,there are many basal sections,showing a uni-axial(-ve) figure,and full of needle like inclusions,in a hexagonal pattern. The quartz is very embayed and the plagioclase shows little sericitization.

This is one of the puzzling units of the area,as the outcrops of it appear to bear no relationship with the other units.It appears "squashed" in between the other rock types. I consider that faulting may have caused this complication of the sequence.

Amphibolites. In hand specimen,they have a granoblastic texture,are a dark green to black colour,and the plagioclase grains show excellent cleavage surfaces.Minor sulphides appear disseminated in some.

In thin section,the granoblastic texture is most prominent,with many triple points evident.The average grain size is 0.8mm.A pale green,mottled mineral,often rounded, inclined extinction,2V-50°-60°,has been identified as augite. A dark green hornblende often rims the clinopyroxene.Other hornblende is a brown variety,and may reach 40%.The remainder of the slide is plagioclase.These grains show slight alteration along the twin planes,which are well developed.The composition of the plagioclase is most consistent,ranging from Ab65-Ab75. Apatite is a very common accessory occurring in large rounded grains.Sphene occurs as a corona around opaques.Quartz is rare. Epidote rims hornblende in one slide,and other accessories are sericite and biotite.

The amphibolites occur as a distinct unit within the granite gneiss terrain.The boundaries between these units are sharp,and not crosscutting.Excellent layerings of some,resembles layering seen in sedimentary calc-silicates.

Chemical analyses were carried out for various trace elements (see appendix V),And using these,plus field evidence,I favour a sedimentary origin of the amphibolites.[16]

<u>Clinopyroxene unit</u>. It is a most distinctive unit,being dark green and very heavy.The rock weathers to give a very red soil, which reflects the high iron content of this rock.There is no layering,nor any igneous features,such as chilled edges or igneous differentiation.It is very coarse grained and the mineralogy suggests it has been highly metamorphosed.

The main mineral is augite,with minor amounts of a retrogressive hornblende,and plagioclase occurring.

Chemical analyses of these rocks was also done,for trace elements only,but these results were inconclusive.

Examination of the outcrop map shows these rocks as occurring in large masses and small blobs,seemingly randomly distributed which would indicate,to me,that they were intrusive.Because they are affected by the Archaean phase,they would be very ancient.

<u>Metasomatized amphibolite</u>. These units are confined to the cliff face section of the area,on the western extent of the inlier.They are often of a very blotchy appearance,~~with huge~~ containing largeish crystals of hornblende,up to 2" across~~,found~~.In other instances good layering is exposed,which is markedly cross-cutting.[17]

Flesh coloured feldspar and pale green epidote are the main minerals.The hornblende often has a corona of epidote.The plagioclase is strongly sericitized along the twin planes,with the composition ranging from Ab67 to Ab73.Epidote forms a corona around these grains as well.Rounded microcline grains appear surrounded by the plagioclase grains.This feature suggests growth of the plagioclase around the microcline.

I think that these rocks have undergone sodium metasomatism,and at the time of mobility,the forces present caused the formation of a layering,parallel to the axial plane present at that time,whhich would be the Archaean axial plane. The measurements of the layering give a reading of Strike I70° Dip, 70°W .Another possible explanation is that the layering represents the nose of a fold,where the cross-cutting relationship is preserved,and the limbs of the fold,where the layering is parallel,have been sheared away.

Granite gneiss. Mostly pink feldspar,with minor biotite.The rock has well developped metamorphic layering.It has a granoblastic texture,with an average grain size of I.5mm.Both microcline and plagioclase occur,each recognisable by its distinctive twinning. There are about equal quantities of each.Minor perthitic microcline occurs,ie. plagioclase exsolution from microcline. The composition of the plagioclase ranges from Ab65 to Ab72. Larger and recrystallized quartz forms about 30% of the slides.

Cleavage traces of biotite,showing a strong pleochroism are prominent.Pale green hornblende forms as much as 30% of one slide.It is altered to epidote at the edges.Accessories are apatite,sphene,rutile,muscovite,sericite and zircon.

Small folds in this unit are tight,showing the same S.E. fold axis.The rocks are very similar,mineralogically,to the granites,.Three distinct types of granite gneiss are recognised. There is the well layered type,another containing mafic minerals, and a third resembling a poorly foliated pegmatite.These rocks are almost free from retrogradation.

Granite. The minerals are coarse grained pink feldspar,white quartz,and black biotite.

The biotite shows a strong pleochroism and slight chloritization.Microcline and plagioclase are present in equal amounts.The plagioclase shows large variation in degree of sericitization,and a composition of Ab77.The microcline is unaltered.Quartz is very strained,with trails of inclusions and needles occurring within the grains.

The plagioclase shows ~~excellent~~ well developed zoning in one slide,an excellent igneous feature.A mermekitic texture is observed in this same slide,showing exsolution blebs of quartz within plagioclase.A prominent accessory is a large zircon grain,I.5mm long.

Pegmatites. In hand specimen they are the same as the granite, but lack biotite.They form large vien-like intrusions,and huge structureless masses.On the beachfront they are crosscutting,but more often,they are conformable with the surrounding rocks.

Basaltic dyke. The most prominent igneous texture is the random orientation of plagioclase laths.Very minor retrogradation has occurred.In hand specimen it is readily identified as a basalt,and its field occurrence as a cross-cutting dyke,about 6 feet wide suggest that this is a recent event,related to the Proterozoic event.[18]

Cambrian. Occurs faulted against the Archaean on the South-east boundary.It is a grey,slightly calcareous siltstone.

~~In hand sp~~ thin section,it shows a matrix of quartz,with a strong preferred orientation of muscovite and biotite evident.

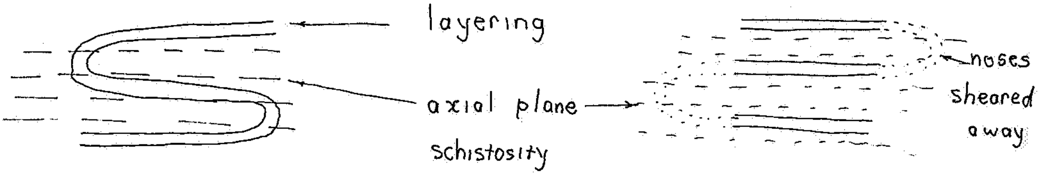
STRUCTURE.

An interpretation was attempted,using field relationships of folding,layering,cleavage-layering intersections,and measurements of schistosity and lineations.From examination of the Proterozoic-Archaean boundary,as established by previous geologists,an overturned anticline to the west was the major structure present, and was related to a Proterozoic orogeny.

The measurements taken were mostly metamorphic layering, Which appears in most units,including the granulite.No evidence is found to suggest the layering mimics sedimentary layering.An Archaean orogeny produced this layering.[19]

In all instances the schistosity surfaces are parallel to

[20] the metamorphic layering.My interpretation of this,is that tight isoclinal folding occured in the Archaean orogeny,as in figure(a)



(a)

The result is shown in figure(b),where the two surfaces are parallel.The noses of the tight folds were destroyed by shearing. From measurements of the schistosity surfaces,the axial plane of the Archaean orogeny would appear to be strike,030°,dip,40° S.E.

On the cliff-face section,one of these nose sections is found.In a more quartzitic section of an augen gneiss,a very tight fold is found.The limbs of the fold are parallel with the surrounding schistosity,with the axial plane also parallel to ~~th~~ this surface.[21]

The next orogeny[22] is proterozoic and produced the major antiform present.This being the case,we should expect to find meso and micro folds mimicing the major structure.No meso-folds are found,but microfolds and folds up to 6 feet across are. All these folds are overturned to the west,although the plunges of the folds are quite variable.The sense of the folds is random,giving no clues to mesofolds.

Intersections of the cleavage and layering can be used to determine,whether the beds are overturned.Two outcrops show this intersection.One occurs on the eastern extent of the inlier,where the cleavage is at a steeper angle than the layering.This is interpreted as,the beds being right way up. The other outcrop occurs in "Little Gorge",on the western side of the inlier,and shows the same relationship.The conclusion reached is,that the inlier represents the eastern limb only of the antiform.[23]

The fold axis of the antiform,as defined by lineations and minor folds was I9° to I37°.

Figure I. Plot of poles to layering, contoured on I%, 3%, 4%, 5%, 8% and I0% intervals, of the eastern section of Yankalilla River gorge. The fold axis thus defined is 35° to I35°.

Figure 2. Represents contour plots (same intervals as fig I) of the lineations of the whole area. The maximum occurs at 40° to I34°. The rounded section in the south-west section represents rodding. Fold axis of this is I0° to 207°.

Figure 3. Plots of poles to layering in sub-area I.(see interpretive map)∘ represent lineations. The fold axis is 35° to I28°.

Figure 4. Poles to schistosity in sub-area I. The fold axis is 35° to I38°.

Figure 5. Poles to schistosity in Yankalilla River gorge, north of sub-area I. The fold axis is 3I° to I35°.

Figure 6. Poles to layering in the same area as figure 5. The fold axis is 32 to I26. The lineations seem to define a small circle, suggesting it is folded by a later event.

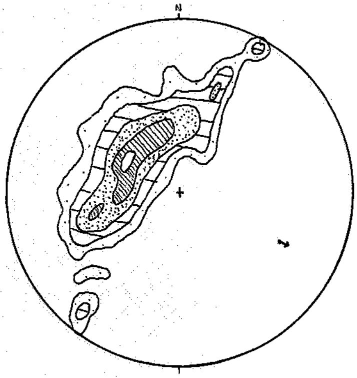


fig.I.

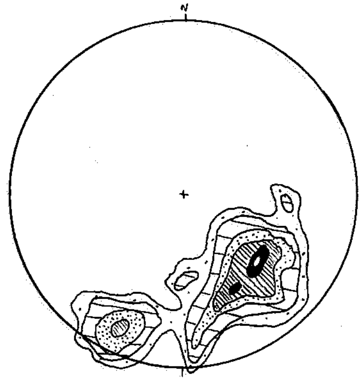


fig.2.

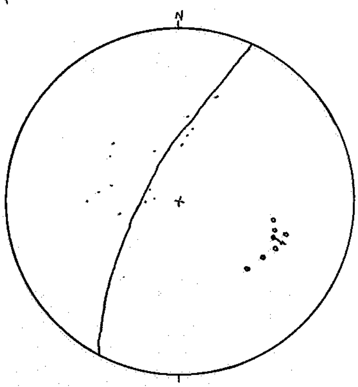


fig.3.

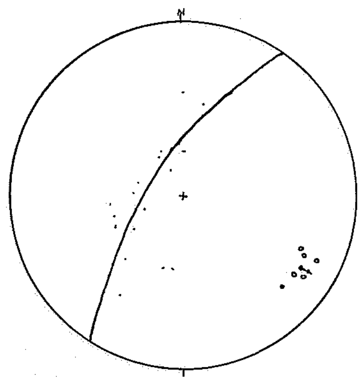


fig.4.

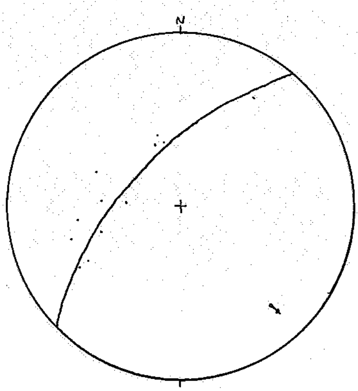


fig.5.

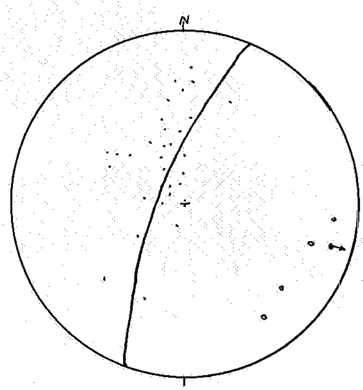


fig.6.

Figure 7.

Poles to layering on northern section of beachfront. Fold axis 23° to I48°.

Figure 8. Poles to ~~layerin~~ schistosity in same area as figure 7.Fold axis 20° to I25°.

Figure 9. Overturned fold in a pegmatitic gneiss from the area of the prior two figures.Poles to layering. Fold axis I9° to I37°.

Figure IO. Poles to layering in sub-area 2.Fold axis 45° to I75°.

Figure II. Poles to layering on southern portion of the beachfront section.Fold axis 27° to I38°. The lineations seem to lie on a small circle.ie. folded by a later event.

Figure I2. Same sub-area as figure II.Poles to schistosity.No great circle defined The lineations are crinulations,and show a large spread of readings,which may be related to later events.

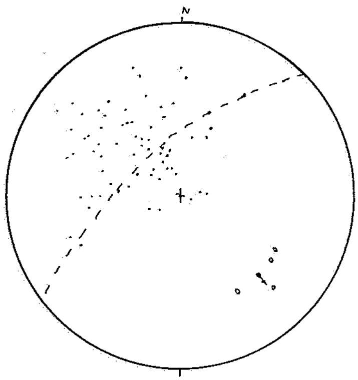


fig.7.

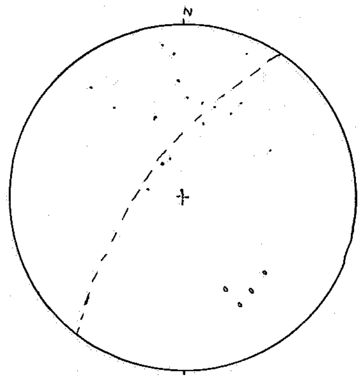


fig.8.

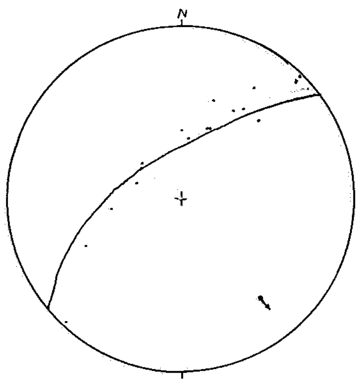


fig.9.

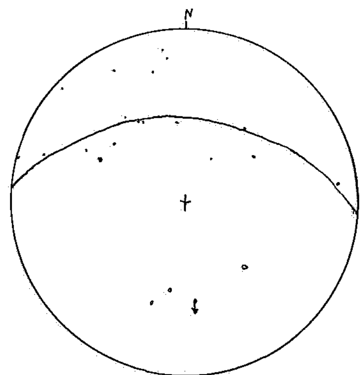


fig.IO.

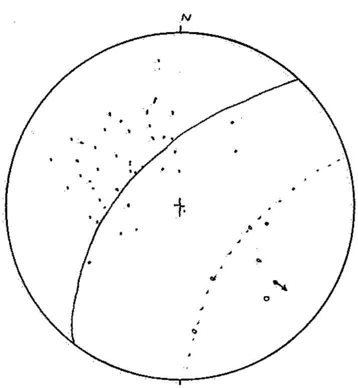


fig.II.

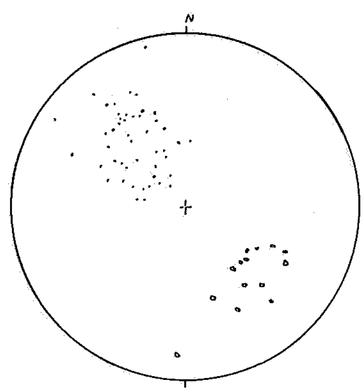


fig.I2.

Mæcrofolds were found in pelitic and granitic lithologies. Only one generation of folds was recognized. A prominent quartz layer occurs within one of the augen schists, which showed excellent folding and, most importantly, the micas were folded around with the quartz. This is ~~final~~ good proof that the schistosity is earlier than the proterozoic folding.

Although no large scale folding was recognised, plots of schistosity and layering were done usigg an equal area net. A change in strike directions was noted in the field, but could not ~~b~~ be related to any folding. These plots of poles to layering defined a great circle, and the pole of this ~~cicle~~ circle defined the fold axis of the plots. This plot always defined a fold axis, the same as the Proterozoic fold axis. We can conclude the ~~shift~~ variation in strike is due to the Proterozoic orogeny.

The area was divided up into sub-areas, which contained different rock units. A sub-area containing schists defined a great circle most clearly, but sub areas of layering were less ~~clear.~~ useful

A weak lineation in the form of a broad warp is found in some outcrops. The dominant crinulation is folded around this lineation, making it later than the proterozoic lineation. Geologists in Nearby Proterozoic terrains have recognised at least 3 periods of deformation. Assuming the lineation is parallel to the fold axis of one of these deformations, its direction is 6° to 78°.

FAULTING.

A thrust zone occurs on the western extent of the inlier, in "Little Gorge",. This zone is recognised by the mylonitic augen schists, considerable feldspathization, and occurence of large cross-cutting pegmatites. This zone may be ~~represented~~ interpreted as thrusting on the underlimb of the antiform.

Other faults are less well defined. It may be that the schists that occur within the granite gneiss terrains, represent old shear zones.[25] These rocks appear very mylonitic.

Small faults[26] are seen in "The Gorge", with only a small displacement noticed. There is intense fracturing, and pegmatization. The granulite between these two small faults dips from gently north to low south-east, but either side of these faults the granulite dips steeply south-east. Tilting of a block of the granulite seems to have occurred. The faults are not folded, and are steep.

The boundary between the Archaean inlier and Cambrian siltstone ~~is extremely shattered~~ shows considerable shattering of the lithologies, suggesting it ~~to be~~ is faulted.[27] In "The Gorge", Feldspathization occurs on the lower boundary between the granulite and gneisses. I ~~think~~ interpret it as representing a thrust fault.

Mr. D. Maughan, using geophysical measurements, has defined anomalies which may represent steep faults. If this is so, it may explain the outcrop pattern of the granulite, which may be an expression of these faults.

In my opinion, there are many unidentified faults in the area, which complicate the geology, making interpretation of the outcrop map most difficult. ? Why even say this. Is it a guess?

METAMORPHISM.

Two metamorphic grades are recognised in the area, one reaching upper amphibolite facies, and the other a retro-grade metamorphism, reaching biotite grade. The higher grade is related to the Archaean orogeny, and the lower grade to the Proterozoic phase. No isograds are recognised.

The Houghton granulite appears the least altered, and shows the best high grade assemblages. When plotted on ACF. and AKF. diagrams, as used by Winkler, the mineralogies indicate an ~~the~~ upper amphibolite facies.The use of these diagrams assumes equilibrium was reached at this high grade,and that no metasomatism occurred.The granoblastic texture rules out the possibility of large scale mobility of elements,required for metasomatism,and also suggests complete reconstitution of the original texture,explaining the lack of igneous or sedimentary features.[23]

Plagioclase composition is most consistent,ranging from Ab63 to Ab75.Turner and Verhoogen suggest this composition is most indicative of a high grade of metamorphism,such as upper amphibolite.

Other units are much more altered,but do show relic minerals,which are not as specific as those of the granulite,. ACF.and AKF. plots of these assemblages also indicate upper amphibolite facies.(see appendix 4).

Assuming water saturation conditions,the reaction of muscovite converted to sillimanite is most indicative of this high grade.[29] If temperature and pressure conditions were such that they delineated a point on the curve of this reaction,(appendix 4 fig.3),then both minerals should occur.But only sillimanite is recognised,the muscovite present belonging to the lower grade,so temperature and pressure conditions must lie above this curve.

To pinpoint these conditions,the considerable granitization is taken into account.The granite melt curve(appendix 4 fig.3) intersects the above mentioned curve,thus defining the conditions reached.These were,temperature 750°C and 2-3 K-bars.

Other high grade features are perthitic textures and needle inclusions in Archaean biotite grains.

The retrograde metamorphism reached biotite grade of the Greenschist facies.Prominent field features of this grade,are a strong lineation,and tight folds.

Considerable recrystallization of quartz occurred, with larger grains showing pronounced strain features.

In the granulite retrograde minerals are epidote,calcite, chlorite and biotite,.In the gneisses sericite is prominent, with other minerals being biotite,opaques,sphene,muscovite and hornblende.These assemblages,when plotted on ACF.and AKF. diagrams support the biotite grade(appendix 4).

METASOMATISM.

An extensive area of a metasomatised amphibolite occurs on the beachfront.The amphibolites show a very blotchy character,with large crystals of hornblende coexisting with good layering of mafic minerals.

The plagioclase content indicates sodium metasomatism. The plagioclase is retrograded by epidote,indicating the metasomatism occurred prior to the Proterozoic metamorphism.I suspect it took place the same time as the granitization event. The metasomatism is related to the amphibolites only,suggesting the Na was mobilised because of its higher concentration in these rocks.Because the surrounding rocks are not affected,it seems the Na had only limited mobility,and was not widespread.

3. IGNEOUS ACTIVITY.

The most obvious igneous activity occurs in the form of two cross-cutting basaltic dykes.They are unaffected by later retrogradation,so must postdate the Proterozoic orogeny.

Some dark green amphibolites,of older appearance,in that they are coarse grained,may represent an earlier basalt.Chemical analyses of a few trace elements were carried out,but were not conclusive.They occur as isolated pods and large masses,which would suggest an igneous origin,and I conclude that they represent an early igneous phase,prior to the Archaean phase.

Extensive outcrops of pegmatite and minor outcrops of granite,occur.The granites are cross-cutting and affected by the retrograde event.Large structureless "blobs" of pegmatite occur along with the granite,so are the same generation as it.

I interpret this granitization as late stage Archaean activity.I think that minor intrusions of granite did occur, but the majority of the pegmatite represents the low melt fraction of the country rocks.This represents considerable ~~m~~ mobility of the potassium content,along with some silica mobility.Where the rock composition has been suitable,Na mobility has occurred.The high K content may support the theory that the gneisses represent sediments.Migmatitic rocks are an intermediate expression of the K mobility.

MINERALISATION.

Slides 376-263 & 264,describe an amphibolite which shows copper mineralisation.Polished sections show the minerals are chalcopyrite mainly,with minor pyrrhotite.The copper content,by chemical analysis(appendix 5 fig.),is I600ppm.Acid digestions by different leaches show the Cu is confined to the sulphides.Minor disseminated sulphides occur in other ~~sulphi~~ amphibolites.

Blue disseminated azurite occurs in augen gneisses,and small adits are found at these outcrops.

In the pegmatitic region of the beachfront,large viens of ilmenite are found.One pegmatite has been worked extensively for monazite and rutile.

GEOPHYSICS.

Mr.D.Maughan carried out an extensive magnetic survey on the Permian sediments surrounding the inlier.He discerned an anomaly which he attributed to the granulite.

Using this information I was able to extend the main horizon of granulite,considerably to the north-east.

GEOCHEMISTRY.

The "Houghton" granulite was chemically analysed to determine whether it was of igneous or sedimentary origin.

Field relationships were inconclusive.[31] The granulite was conformable in all instances. Associated with it was a zircon rich[32] quartzite. The boundary between these units was very sharp, and the strictly conformable nature of all outrops of the granulite, which includes outcrops in other areas, together with the mineralogy, lead me to favour a sedimentary origin.

The major elements, plus certain trace elements, are then used to attempt to solve this question. (appendix 5 fig.).

The major elements were analysed by X-ray Fluorescence spectrometry (XRF.) A search of the literature revealed that the rocks with almost identical major element content as the granulite, were Syenites, Diorites and ferruginous, dolomitic marls. Thus we have possibly reduced our search to two possible igneous parents and one sedimentary parent.[33] The most distinctive major elements were FeO and Fe_2O_3, as well as K:Na ratios.

Having pinpointed likely parents, the trace element contents of these rocks ~~must be~~ were examined. I was able to gather sufficient information for the Diorite model, but was less successful with Syenites and marls, making these comparisons less reliable.

It was argued that the different processes of igneous and sedimentary fractionation would result in different contents of elements, or different ratios of elements. A comparison with literature values would help define these trends.

Niggli numbers were used by Leake and Evans to distinguish between ortho and para amphibolites, so I tried the same, hoping to distinguish between Diorites, greywackes, and the granulite. I was not able to do so for Syenites or marls. Appendix 5 figures 1 to 10, show various plots of results. Figure 1 shows the granulite plotting midway between a pelite and a limestone.This fits very nicely with our concept of a rock of a calcareous marl origin.Diorites and Syenites plot in a slightly different field.

Figure 3. does not distinguish between diorites,syenites and granulites,which all plot in similar positions.

Figure 4. shows the granulite plotting in a sedimentary field in all cases,separate from the igneous fields,but,not at all,conclusive evidence.

Figures 5,6,7,9, and IO; show the same trend as figure 4.Figure 8. shows the granulite plotting in a sedimentary field,quite distinct from any igneous trends,particularly the mg to k plot.

An overall examination of the niggli number method reveals two promising plots which reveal sedimentary origins of the granulite.These plots are figures 2 and 8.The remainder were inconclusive.But,still,the evidence is not conclusive and log-log graphs were used,to further define any sedimentary trends.

Some of these plots show the granulite plotting in a field of its own.These graphs are of no use,as no comparisons can be made.More useful graphs are V-Cu;Cr-Cu;Zn-Cu;La-Ce; Cr-V;Co-Cr; and Ni-Cr;

Examination of these graphs,shows the granulite to plot in the marine sediment field in all cases,and in igneous fields,seldom.Once again there are no conclusive graphs,but a sedimentary field does seem ~~evident.~~ to be more the trend.))

Tables 2 and 3 of appendix 5,contain lists of the various lithologies showing the ranges of major and trace elements present.Examination of these tables supports the conclusions reached from the graphs.

My final conclusion is that the Houghton granulite is of sedimentary origin,probably a dolomitic,ferruginous marl.

My conclusions could be substanciated by analysing for more trace elements,and by analysing more specimens of granulit to establish any trends.

CONCLUSIONS.

There were three periods of deformation recognised. The first was an Archaean orogeny, which produced a strong metamorphic layering. This phase reached upper amphibolite grade of metamorphism. The second phase was recognised by the tight isoclinal folding, with a south-east plunging fold axis.

The third phase was a weak tertiary orogony producing a waek lineation in a north-east plunge, of very low dip.

The second phase produced a major overturned anti-cline and it reached biotite grade of metamorphism. This phase also affected the Adelaidean sediments surrounding the inlier.

A thrust zone was recognised on the underlimb of the anti-cline, by the presence of mylonitic rocks. The main lineation of the area is parallel to the fold axis of the anti-cline, and is plunging 20° to 137°.

Field relationships proved inconclusive as to deciding whether the granulite was igneous or sedimentary. The granulite was conformable with the surrounding rocks in all instances. It was associated with a quartzite in all instances, which itself was interpreted as being sedimentary, due to the ~~high concentration of zircon found in thin section~~. This association suggests a sedimentary origin of the granulite

Chemical results reveal sedimentary trends of the granulite, but there is no conclusive evidence. To reach a positive conclusion I would recommend further work to be carried out on the granulite, such as analysing for Th, U?all the rare earths Sc, and Zr. Iwould also recommend many more analyses of the granulite to be done, to define any trends which may be present.

A more detailed analysis of the quartzite may also be beneficial. Also examination of the zircon grains of the quartzite to see if they define sedimentary layering.

Acknowledgements

I would like to acknowledge the staff of the Geology department,especially Dr. Robin Oliver for his invaluable assistance during the year.Also to my fellow student Mr. S. Wicks with whom I carried out my chemical analyses,and Messers A. McEwin and D. Maughan and Miss J. Heaslip for helpful contributions throughout the year.I would also like to thank the technical staff for their assistance .

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APPENDIX I.

Slide numbers which correspond to the rock units.

Houghton Granulite. 376- H5, H6, H7, H8, H9, HII, HI7, 238, 269,.

Quartzite unit. 376- 5B2, I4B, 69,.

Amphibolite. 376- AI8, 28, 265, 264, 263, 300, 29,

Metasomatised amphibolite. 376- AI7, 83,.

Sillimanite gneiss. 376- 4A, 5A, II6, I73, 223,.

Migmatitic sillimanite gneiss. 376- I68, I7I, 249, 253,.

Augen gneiss. 376- IA, I, 79, 97, I92,. 99,

Calc-silicate. 376- 286,.

Augen schist. 376- I42, I97, 252,.

Granite gneiss. 376- I44, I86, 22I,

Granite. 376- 3A

Pegmatite. 376- 8I, II7, I46,.

Clinopyroxene unit. 376- 90, I2I,.

Basaltic dyke. 376- 26I,

Biotite unit. 376- I30,.

Cambrian. 376- K

APPENDIX II.

Slide Descriptions.

376-H5. "Houghton" granulite.

Macro. Medium grained granoblastic texture, with a weak foliation developed. Main minerals are pink feldspar, dark green amphibole, and pale green epidote.

Micro Granoblastic texture, with a mean grain size of 0.7mm. Quartz. About 35%. Size 0.2mm. Uniform extinction with an embayed shape. Amphibole. About 10½%. Size 0.7mm. Commonly associated with calcite. Pale green, weakly pleochroic. Extinction angles range from 5-23 Probably hornblende. Epidote. About 50%. Size 0.7mm. Commonly associated with calcite. Plagioclase. Trace amounts. Size 0.5mm. Excellent albite twinning giving a composition of Ab.75. Microcline Trace amounts. Size 0.7mm. Cross hatched twinning prominent. Calcite 5%. Size 0.5mm. Distinctive cleavage showing twinkling effect. Accessories. Sphene, apatite, dark green mineral. Uniaxial (-ve), distinctive maximum absorption with the c-axis normal to the polarizer vibration direction. i.e. Tourmaline.

376-H6 "Houghton" granulite.

MACRO. Same as above. A courser layer of pink feldspar and epidote is seen.

MICRO. Same as above. A small section of the slide contains diopside and scapolite, with a sharp boundary existing between this section and the remainder of the slide.

Microcline. About 30%. Size 0.7mm. Quartz. About 30%. Uniform extinction Epidote. About 30%. Diopside. About 5%. Distinctive dark green, with prominent cleavage traces. Scapolite. High birefringence, uni-axial (-ve), parallel extinction. Accessories. Sphene and opaques.

376-H7. "Houghton" granulite.

MICRO. weak foliation developed.

Amphibole. 10%. 1.0mm. Mottled appearance, very pale green, non pleochroic, extinction angles 5°-17° Probably actinolite. Epidote. 60%. Quartz. 30%. Weak undulose extinction. Microcline. Trace amounts. Accessories. Sphene and apatite.

<u>376-H8</u>. "<u>Houghton" granulite</u>.

<u>MACRO.</u>Adarker coloured rock,foliation well developed.

<u>MICRO</u>.Granoblastic texture.<u>Scapolite</u>.5-I0% Size I.0mm.8 sided crystals.<u>Amphibolite</u>.5% very pleochroic,bi-axial (-ve),2V)=70° maximum extinction angles are 24 .Probably hornblende.<u>Microcline</u>. 40%.<u>Epidote</u>.25% alteration product of the amphibole in most instances.<u>Diopside</u>.I0% Confined to small sectionoof the slide.<u>Accessories</u>. Sphene 2%,apatite,opaques and quartz.

<u>376-H9</u>. "<u>Houghton" granulite</u>.

<u>MACRO.</u> Fine to medium grained.

<u>MICRO</u> .Same as above.<u>Microcline.</u> 50% well developed granoblastic aggregates.<u>Amphibolite</u>.I0% Pale green hornblende.<u>Epidote</u>. 25% <u>Sphene.</u> 2% rounded grains of high relief.<u>Opaques.</u> 2% embayed shapes. <u>Accessory</u>. apatite.

<u>376-HII</u>. "<u>Houghton" granulite</u>.

<u>MACRO</u>.Grey coloured rock with lineation of dark green minerals.

<u>MICRO</u>.Same as above.<u>Scapolite</u>. 30% tabular crystals occur within the grains,epidote?<u>Diopside</u>. 30% closely associated with ~~diopside~~. scapolite.<u>Microcline.</u> 40% <u>Accessories</u>. sphene and apatite.

376-269. "<u>Houghton" granulite</u>.

<u>MACRO</u>. Pale green,obviously much more quartz content.

<u>MICRO</u>.Prominent quartz rich layer.<u>Amphibolite</u>. 5% actinolite. <u>Quartz</u>. two distinct layers recognizable.One is quartz rich,the other microcline rich.The quartz layer contains,bboth ,large grains showing strain features,and undulose extinction,and small re-cryss-tallized quattz grains.This layer comprises quartz:epidote I:I. Overall it is 40%.The other layer is quartz,microcline,and epidote. <u>Microcline</u>. 30% <u>Epidote</u>. 30% <u>Accessories</u>.apatite,opaques,sphene, amphibole.

376-AI8. Amphibolite.

MACRO. coarse grained black amphibolite, mainly hornblende.

MICRO. Hornblende.60% dark green,strongly pleochroic,maximum extinction angle 23°.Often found as an alteration product on a paler mottled mineral,probably hornblende.Actinolite.5% albite twinning prominent,surrounded by a corona of epidote.Plagioclase. 30% albite twinning,composition Ab74.Forms a granoblastic aggregate Microcline. IO% The plagioclase forms around the-se grains. Accessories. opaques surrounded by a spene corona.i.e. ilmenite or rutile,quartz,.

376-28. Amphibolite.

MACRO.fine grained granoblastic texture,black a and white speckled appearance.

MICRO. mean grain size 0.4mm. Plagioclase.75% albite twinning gives composition of Ab73.Sericitization along the grain boundaries and along the twin planes.Quartz I5% uniform extinction,very clean grains.Biotite. IO% closely associated with muscovite.Needles of inclusions within the biotite.Accessories. zircon within the quartz grains.An absence of opaques is prominent.

376-5B2. Quartzite.

MACRO.coarse grained gneiss,almost all quartz, a poor foliation is developed.

MICRO.Quartz. 70% large grains with a strong undulose extinction showing a preferred orientation,parallel to the foliation developed.Surrounding these grains is a mass of small re-crystallised quartz.Many inclusions occur.Muscovite. ~~30%~~trace.Microcline. 30% very rounded,recrystallised quartz,sometimes,forms large pressure shadows around these grains.Minor sericitization.Accessories. A single plagioclase grain occurs,sericite masses,iron oxides forming yellow stain-like areas,and prominent zircon.

376-3A. Granite.

MACRO . coarse grained,pink granite.

MICRO.Biotite . 5% Size 2.5mm slight alteration to chlorite,minor muscovite. Quartz. 30% inclusions of needles and trails of bubbles. Plagioclase. 35% almost completely sericitized. Microcline. 30% weak perthitic texture. Accessory. A large zircon grain, I.5mm, corona of opaques, uni-axial (+ve).

376-K. Cambrian siltstone.

MACRO. fine grained grey siltstone, cleavage well developed.

MICRO. well oriented biotite and muscovite, inaa groundmass of quartz. Quartz. 60% size 0.06mm. Muscovite:Biotite. is 60:40 and total %age of micas is 35%. Plagioclase. trace, unaltered. K-feldspar. 5%. Accessories. zircon, opaques.

376-I42. Augen schist.

MACRO. grey schist with a wavy foliation. The gentle undulation along the strike forms small folds, in places whose fold axes are responsible for a strong crinulation developed on the schistosity surface.

MICRO. excellent crinulation of micas seen. Quartz. 30% most is recrystallised, but a few very large grains exist, showing considerable strain features. Biotite. 50% strong preferred orientation. Very elongate grains. Muscovite. 20% same form as biotite. Accessories. ilmenite.

376-99. Feldspar-biotite gneiss.

MACRO. well foliated gneiss, very prominent black biotite content.

MICRO. strong preferred orientation of biotite and sericite. Biotite. 30% pleochroic from grey-green to pale yellow. Uniaxial (-ve) figure obtained. Plagioclase. 40% dusty sericitisation along the twin planes. A few grains completely sericitized. Composition Ab75. Quartz. 20% mostly large, strained grains, surrounded by a mass of polygonal, recrystallised quartz.

376-26I. Basaltic dyke.

MACRO. fine grained basalt, minor sulphides.

MICRO. random laths of elongate plagioclase. Plagioclase. 60% Amphibole. 30% I20° cleavage traces prominent. Pleochroic from olive green to yellow-green, bi-axial (-ve), ragged appearance probably hornblende. Epidote. 5% colourless, high relief, bi-axial (-ve), straight extinction, length slow. Accessories. opaques.

376-81. Pink pegmatite.
MACRO. coarse grained, pink feldspar and white quartz.
MICRO. Microcline. 50% size 0.4mm. Prominent cross-hatched twinning, minor sericitization. Perthitic microcline. Plagioclase within the microcline. Quartz. very strained, minor re-crystallisation.

376-221. Granite gneiss. MACRO. coarse grained granodiorite.
MICRO. Quartz. 30% size 1.0mm. straight trails of inclusions, mainly in two directions, running perpendicular. minor re-xtallised quartz. Plagioclase. 50% both twinned and untwinned grains present. Ab77. prominent zoning of plagioclase. Microcline. 10% a mermekitic texture, of quartz exsolved within microcline, is noticed. Biotite. 10% size 2.0mm. associated with apatite in clusters.

376-186. Granite gneiss. MACRO. coarse grained granoblastic texture of pink feldspar and green amphibole.
MICRO. Plagioclase. 30% granoblastic texture, but grain boundaries very embayed. Perthitic microcline. 5% Amphibole. 10% pale green, non pleochroic, length slow, extinction angles low to 19 . Hornblende Epidote. 10% Opaques. 5% rhombic shapes with sphene coronas. Quartz. 10% minor recrystallization. Accessories. sphene and zircon.

376-121. Clino-pyroxene unit. MACRO. coarse grained, green mafics in a granoblastic texture.
MICRO. mean grain size 1.3mm. Plagioclase. 60% Ab73. Clinopyroxene. 30% bi-axial (+ve), weak pleochroism, $2V= 60^{\circ}$, length fast, extinction angles 33° to 52°. Augite. Quartz. 5%. Accessories. sphene, opaques.

376-286. Calc-silicate unit. MACRO. amphibolite, consisting of medium-grained granoblastic aggregate of hornblende and plagioclas

MICRO.Plagioclase.50% size I.Omm.albite twinning prominent,Ab75. Hornblende.30% brown to green pleochroism.Amphibole.I5% rounded grains,surrounded by hornblende.Opaques.5% sphene corona.Accessories.apatite.

376-5A. Sillimanite gneiss. MACRO. Quartz,sericite gneiss,well foliated.

MICRO. Garnet. I% size 0.3mm.colourless to pale pink.Thin anisotropic needles within the grain.Extensively chloritized.Grossularite Biotite.Associated with chlorite,IO%.Chlorite. 50% low birefringence.,bi-axial,length slow,pleochroic.Quartz 20% mostly recrystallized,some larger grains.Plagioclase trace,almost completely sericitized.Sericite.Prominent alteration product. 30%.Accessories.Fe staining,opaques,.

376-249. Migmatitic sillimanite gneiss, MACRO.well layered

MICRO.Alternating bands of sericite and quartz.Sericite.50% alteration product.Plagioglase. IO% large variations in degree of sericitization.Quartz.40% mixture of recrystallized and larger unaltered grains.Sillimanite. 5% forms relic cores in the sericite layers.Accessories.zircon in the quartz grains

376-265. Amphibolite. MACRO. very granoblastic texture,grey colour.

MICRO.mean size 0.5mm.Hornblende.25% form between the granoblastic aggregate of plagioclase,dark green,pleochroic.Plagioclase. 65% grain boundaries somewhat lobate,Ab68.Clinopyroxene.5% bi-axialϕ+VE, 2V=50°-60°,colourless,extinction angles low to 68°.ie.Augite.Apatite. 5% rounded and hexagonal grains,high relief,low birefringence. Opaques.5% sphene forms a corona around the opaques.ie.Rutile.

376-HI7. "Houghton" granulite. MACRO.Grey coloured,dark green diopside and tan scapolite recognised..

MICRO.mean size 0.7mm.Microcline.30% Diopside.20% very pleochroic, minor alteration to epidote.Scapolite.I5% small inclusions can be traced from a few crystals,to a more concentrated mass,identifiable as epidote.Garnet.IO% tan colour,grossularite-andracite.

Epidote.20% alteration product of plagioclase.Plagioclase.5% accessories.apatite,sphene,opaques.

376-I30. Biotite rich unit. MACRO. Dark grey gneiss with poor schistosity developed.

MICRO.mean grain size 0.7mm.Groundmass of recrystallized quartz, with a few larger quartz grains scattered about.Biotite. 30% brown variety,many basal sections showing a uni-axial(-ve) figure. Long needles with a hexagonal configuration within the grains. Plagioclase.15% I.2mm.Considerable dusty sericitization.Quartz. 30% larger grains show sutured boundaries,uniform extinction,about 20% is recrystallized.Tourmaline 2% charicteristic pleochroism. Opaques. 3%.

376-83. Metasomatised amphibolite. MACRO.coarse grained,granoblasti

MICRO.Plagioclase. 60% I.2mm.Considerable dusty sericitization, Ab7I,contains rounded microcline grains.Epidote.5% forms a corona between amphiboles and plagioclase.Amphibole.30% extinction angles range from 7°-I7°.Probably hornblende.Accessories.sphene and apatite 5%.No opaques.

376-AI7. Metasomatised amphibolite. MACRO.Well layered gneiss.

MICRO.Plagioclase.60% dusty sericitization,especially around the e edges of the grains,Often an epidote corona.Amphibole.20% pale green,mottled,surrounded by a greener,more pleochroic hornblende, Epidote. 30% alteration product of plagioclase.Accessories.sphene and biotite.

376-II6. Sillimanite gneiss. MACRO. well layered gneiss,with schistosity developed along more micaceous layers.

MICRO.Distinctive quartzose and sericitic layers,much fractured and recrystallized.Quartz.30% strong undulose extinction, preferentially oriented parallel to the layering.Sericite.50% alteration product of feldspars.Sillimanite.I% Prominent diagnol cleavage,and higher refractive index,also strongly sericitized Biotite.5% Occurs inbetween the quartz grains,in a more quartzose layer.Opaques.5% occur in layers.

376-223. Sillimanite gneiss. MACRO. dark,fine grained,well layered gneiss,mostly sericite.

MICRO.Can see 3 layers ,consisting of sericite and quartz,microcline quartz and sericite,with a mean grainsize of I.5mm.,and a layer of quartz,sericite,and plagioclase with a mean grain size of 0.7mm.
Garnet.2% Actually is one large grain,broken up and chloritized.
Quartz.40% strong undulose extinction,considerable recrystallization Needle-like inclusions seen.Plagioclase. I0% Ab72. All have undergone various degrees of sericitization.Microcline.I0% I.5mm..

376-4A. Sillimanite gneiss. MACRO. well foliated gneiss,prominent augens of quartz.

MICRO.Quartz. 30% 0.7mm.Mostly uniform extinction,few inclusions.
Biotite.30% many basal sections,intimately related with muscovite and opaques.Sillimanite.2% almost completely sericitized.Plagioclase 5% very much altered.Pyrophyllite. Long tabular grains pseudomorphing sillimanite.Form fibrous bundles.

376-252. Augen schist. MACRO.extremely schistose,mostly micas.

MICRO.Minor crinulation of micas seen.Muscovite.30% bi-axial(-ve), associated with biotite.Quartz.Granoblastic aggregates,some larger grains show a preferred orientation.45% .Opaques I0% .evenly scattered throughout the slide.Chlorite. 5% Accessories.apatite, sphene,and considerable Fe staining.

376-90. Clinopyroxene unit. MACRO.dark green rock,allmafics

MICRO. coarse grained.Plagioclase. Ab67. 5% Hornblende. 90% green mineral,bi-axial(-ve).,faintly pleochroic,length slow.Epidote.5%

376-263. Ore containing amphibolite. MACRO.Prominent chalcopyrite and pyrrhotite,and opaline quartz.

MICRO.Apatite. 20% high refractive index,low birefringence.Quartz. strong linear features,slight undulose extinction.Pyroxene. 30% bi-axial(+ve).$2V=30^\circ-35^\circ$,weak pleochroism,ie.Augite.Hornblende.Forms a corona around the pyroxene.Plagioclase. Prominent albite twinning minor sericitization.

<u>376-IA</u>. <u>Augen gneiss</u>. <u>MACRO.</u> very schistose gneiss,with many augens of quartz.

<u>MICRO</u>.<u>Biotite</u>.Needle-like inclusions,20%,pleochroic from dark brown to straw yellow,preferred orientation parallel to the layering.<u>Quartz</u>.40%,slight undulose extinction,clean grains,a few xenoblastic opaques,poor layers of quartz seen,larger grains are ve very embayed,with recrystallization around the edges.<u>Feldspar</u>. 30% same habitat as quartz,but grains more embayed,mostly microcline, minor plagioclase is extremely altered.<u>Muscovite</u>.IO%,high birefingence,elongate,encased in sericite,opaque rods with sub parallel distribution within grains,length slow,parallel extinction,mostly associated with biotite,and quartz.It seems to be pseudomorphing an elongate,bladed mineral,ie. Sillimanite.<u>Accessories</u>. opaques.

<u>376-264</u>. <u>Amphibolite</u>. <u>MACRO</u>. Granoblastic texture,grey.

<u>MICRO</u>.Granoblastic texture of plagioclase,mean grain size of 0.5mm. Grain boundaries somewhat lobate.<u>Clinopyroxene</u>.bi-axial(+ve), 2V=50°-60°,colourless,non pleochroic,extinction angles low to 68°. Augite.<u>Plagioclase</u>.65% composition Ab68,form a prominent granoblastic aggregate,grains only slightly sericitized along twin planes <u>Hornblende</u>. form anhedral shapes between the granoblastic plagioclase grains,very pleochroic,dark green to pale green,bi-axial(-ve) 2V-40°-45°,alteration product of the rounded clinopyroxene grains. <u>Opaques</u>.5% sphene coronas,some show a rhombic shape.<u>Apatite</u>.5% rounded,high refractive index.

<u>376-I68</u>. <u>Migmatitic sillimanite gneiss</u>. <u>MACRO</u>.fine grained,well foliated.

<u>MICRO</u>.<u>Quartz</u>.45% very embayed shapes,slight undulose extinction, clean grains,little recrystallization.<u>Sericite.</u>45% some,slightly larger muscovite grains,associated with opaques,<u>Biotite</u>.5½%. <u>Garnet</u>.one large,broken grain,surrounded by red Fe staining,and a corona of chlorite.

<u>376-I46</u>. <u>White pegmatite</u>. <u>MACRO</u>.coarse grained,rounded quartz.

MICRO Quartz.35%,very strained,prominent recrystallization,in and around plagioclase grains,strong undulose extinction.Plagioclase. 60%,grains rounded,with sutured edges,multiple twinning prominent, size 0.7mm,composition Ab67.,very little alteration.Opaques.5% rhombic shapes,Accessories.biotite.

376-I92. Augen gneiss. MACRO.mylonitic rock,minor folding seen MICRO.Quartz completely recrystallized.,complete preferred orientation of micas,strong crinulation developed,in one instance the micas are folded around a small quartz fold.Quartz.completely recrystallized,50%?Muscovite-biotite. 50:50,overall is 50%. Accessories.opaques scattered randomly,chlorite,apatite,.

376-I44. Granite gneiss. MACRO. medium grained,granoblastic rock MICRO.Quartz. large grains with an undulose extinction,much recrystallization,40%,size 2.0mm.Plagioclase. 20% Ab70,dusty alteration,and some multiple twinning.Microcline. cross-hatched twinning prominent,unaltered.Biotite. closely associated with muscovite and opaques,,.

376-79. Augen gneiss. MACRO.excellent folding of quartz augens and crinulation of micas.
MICRO.same as 376-I92.In this slide the folding of quartz and micas is even more spectacular.It has the same mineralogy.

376-300. Amphibolite. MACRO. black,medium grained,granoblastic, minor sulphides disseminated throughout.
MICRO.Hornblende.60% bi-axial(-ve).,2V moderate,cleavage sets at I20°.,extinction angles 0-24°,strong pleochroism.Plagioclase.30% Considerable dusty sericitization,with minor,coarser sericitization around the edges of the grains.Albite twinning not prominent. Biotite. associated with hornblende in some instances.Accessories. opaques(sulphides).

376-I97. Augen schist. MACRO.Fine grained,black,schist.
MICRO.extremely well developed orientation of micas and opaques.

Hornblende. 15½%,green pleochroic,mottled grains,whose outstanding feature was their cross cutting relationship with the micas. Tendency of micas to be displaced around the hornblende.The grains are random in their orientation,with a significant proportion parallel to the micas.Quartz. forms a large portion of the groundmass,and is recrystallized.Biotite.30%?pleochroic from colourless to brown.very elongate shape.Opaques .tabular shapes, most strongly oriented,10%.Accessory.apatite.

376-29. Amphibolite. MACRO. coarse grained,poor foliation. MICRO.Granoblastic texture.Actinolite.15%,bi-axial(-ve),pale green,non pleochroic.Sphene. 5% large grains,often broken,and rounded.Plagioclase.Ab66,75%,minor sericitization along the grain boundaries.Shows a very weak perthitic texture.Accessories. opaques and epidote,an alteration product of actinolite.

376-14B. Quartzite unit. MACRO.Poor foliation,specks of opaques. MICRO.About 60% of the quartz present is recrystallized.Quartz. 80%,larger grains are very embayed,and strained.Microcline.more fractured,slightly recrystallized.Accessories.biotite,tourmaline, sericite,opaques,muscovite,.Prominently scattered through the slide is a hexagonal grain,uni-axial(+ve),elongate,length fast, parallel extinction,= zircon.

376-171. Migmatitic sillimanite gneiss. MACRO.well foliated, pink feldspar layered,Fe stained gneiss.
MICRO.Biotite. 10%,strong pleochroism,associated with opaques. Quartz.No preferred orientation,in definite layers,clean grains, uniform extinction,remnant granoblastic texture,associated with muscovite containing needles of opaques.Sillimanite.minor unweathered cores in a sericite mass.Sericite.50%

376-238. "Houghton" granulite. MACRO.Poor foliation developed. MICROEpidote. 60%,high birefingence,very mottled,pleochroic, parallel extinction.Biotite.Pale green,uni-axial(-ve),Quartz. A few larger grains,but most recrystallized.Accessories. calcite sphene,and apatite,rare,rounded opaques.

376-69. Quartzite unit. MACRO.Granoblastic texture,black-grey rock,poor feldspar foliation,minor lineation on layered surface.
MICRO.Quartz.70%,size 0.5mm.strong undulose extinction,a trail of bubbles meeting in a triple point,suggest recementation.Plagioclase.20%,completely sericitized,Microcline.5% less altered.
Biotite. 5% preferred orientation.Accessories.scattered opaques, muscovite,zircon.

376-173. Sillimanite gneiss. MACRO.Grey,fine grained,well foliated
MICRO.Opaques.5% larger,embayed grains and small disseminated specks.Quartz.60%,forms definite layers,usual mixture of larger and recrystallized grains.Sillimanite.trace,very sericitized.
Sericite.36%,alteration of feldspars.Accessories.Chlorite,biotite, muscovite,Fe staining.

376-253. Migmatitic gneiss. MACRO.black,poor foliation .
MICRO.Quartz.Masses of fractured grains,considerably recrystallized,uniform extinction,40%,size 0.7mm.Plagioclase.40%,uniform extinction,forms very large grains,Biotite.15%,within the matrix of recrystallized quartz,very mottled,broken grains.Opaques.2% scattered about the slide.Accessories.muscovite.

376-I. Augen gneiss. MACRO.well foliated,many quartz augens,blue azurite disseminated throughout.
MICRO.Quartz.40%,larger grains show slight undulose extinction onl; trails of bubbles,most is recrystallized,forming a polygonal matrix,Microcline. 10% very large grains,weak sericitization, serrated edgesbroken and fractured.Plagioclase.5% smaller size, sericitized Biotite.closely associated with the polygonal quartz.
Red staining. looks like Fe staining,but the azurite in hand hand speciman is a more likely answer.Accessories.epidote,muscovit

376-117. White pegmatite. MACRO. very coarse grained,prominent multiple twinning in hand specimen.
MICRO.Plagioclase. 95% most grains show dusty sericitization,

and some coarser sericitization.Good albite twinning,Ab67.
Quartz.5%,occurs as a small vienlet,crosscutting plagioclase g grains.

371197. Epidosed augen gneiss,. MACRO.Prominent pale green, epidote,well layered,slightly migmatitic.
MICRO.Biotite.forming foliation between the granoblastic texture present,I5%,very pleochroic,uni-axial(-ve),Quartz.30%,trails within the grains suggest former grain boundaries.Recrystallization has occured between the larger grains,Plagioclase.45% Ab76, all grains sericitized,some extensively.Microcline. trace. Epidote I5%, alteration product of plagioclase.Accessories. muscovite,opaques,apatite,green biotite.

APPENDIX III.

Analytical techniques.

Sampling. Large unweathered blocks of granulite were gathered and 5 samples chosen,of the most widely varying texture and mineralogy.i.e.376-H6,H7,H8,H9,HII.Also two amphibolites were chosen to act as controls for the element ranges expected in the area.i.e.AI7 and AI8.These rocks were crushed and then ground to a very fine powder ,in an agate mill,to avoid possible contamination from Ni or Cr.

X-ray Fluorescence.(X.R.F.)

The fine powder was pressed into briquettes for each sample,using boracic acid as the binding agent.Trace elements were analysed using these briquettes.Fused buttons were prepared for the major element analyses,using the method of Norrish and Hutton.

Rb and Sr. U.S.G.S. standards were run with our samples.Our results were calculated using values of these standards obtained from the literature.This proved to be a most satisfactory method as I was able to check my precision,by running through the X.R.F. 2 or more standards,to compare the values obtained,with those values listed in the literature.The confidence limit of the X.R.F. was found using the formula $\frac{6}{m}\sqrt{\frac{Cb}{T}}$.

where m = number of counts/sec/ppm.

T = total analytical count time.

Cb = c.p.s. on background position.

The mass absorption of the samples was calculated using Compton's scattering.Background counts were obtained using ultra-sil. A combitron programme was used to calculate the final ppm.

La,Ce and Ba. These elements were analysed in the same manner as Rb and Sr,but a computer programme was used to calculate the mass absorption,instead of Compton's scattering.This programme

was devised by A.W.Kleeman and K.Collerson in I97I.Once again the U.S.G.S. standards were used,with success.
Various books of tables were used to determine correct angles, crystals,e.t.c. for the X.R.F.

<u>Atomic absorption spectroscopy</u>. (a.a.s.) The fine powder was digested in acids.To I gm. of rock powder was added 30mls of HF, and the mixture let stand for I2 hours in a plastic beaker.It was then evaporated to a sludge,over a hot water bath,when 8 mls of $HClO_4$ was added.This mixture was evaporated to dryness and the residue dissolved in a small volume of distilled water.This was then,made up to a final volume of 50 mls,using a volumetric flask. For Na and K determinations,by flame photometry,the final volume was I000 mls.The calculation was,

$$\text{ppm.(rock)}, = \frac{\text{ppm.(soln)} \times \text{vol.(cc)}}{\text{wt. of sample.(gms)}}$$

$$50 = \frac{I \times 50}{\text{wt.}}$$

$$\text{wt.} = \text{I gram.}$$

A techron,number 3 was the spectrophotometer used,and the elements analysed were Ni,Cr,Co,V,Pb,Zn,and Cu.

<u>FeO determination.</u> An accurately known weight of rock powder, about 0.5 to 0.7 grams,was digested in HF and H_2SO_4,.This was done in a reducing environment,to prevent oxidation of the FeO present,by using a platinum crucible with a lid.After complete digestion,usually 5 minutes,the solution was rapidly plunged into a beaker,containing 300 mls of a solution of H_2O,I0cc I;I Sulphuric acid,I0cc saturated boric acid solution.,and titrated immediately,to prevent oxidation by the air.The end point was a faint pink.Calculation,

$$\%\ FeO = \frac{\text{titration(mls)} \times .07I84 \times I00 \times \text{Normality } KMnO_4}{\text{Weight of sample.}}$$

B.C.R.I. and B.H.N. were used as standards.The results were,

B.C.R.I.	8.98%	(This thesis)
B.H.N.	6.37%	" "
B.C.R.I.	8.91%	(Standard from literature)
B.H.N.	7.55%	" " "

APPENDIX IV.

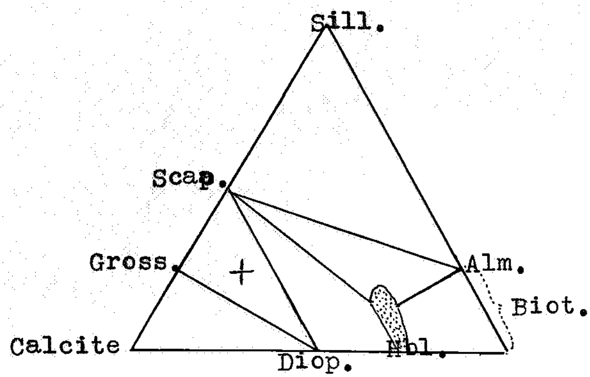


Figure I.

Almandine-amphibolite facies.

+ = assemblage in "Houghton".

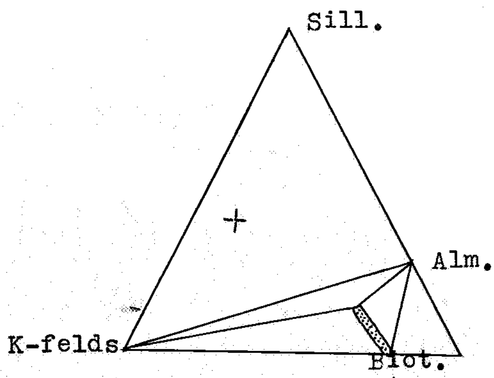
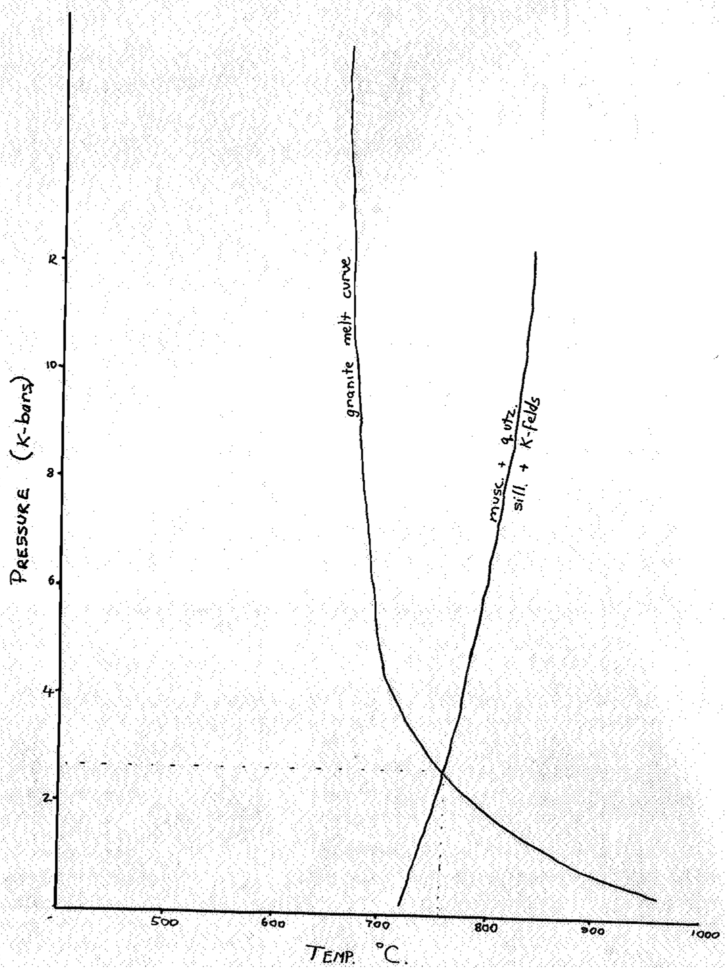


Figure 2.

Appendix 4 Figure 3.



Almandine-amphibolite facies.

APPENDIX 4.

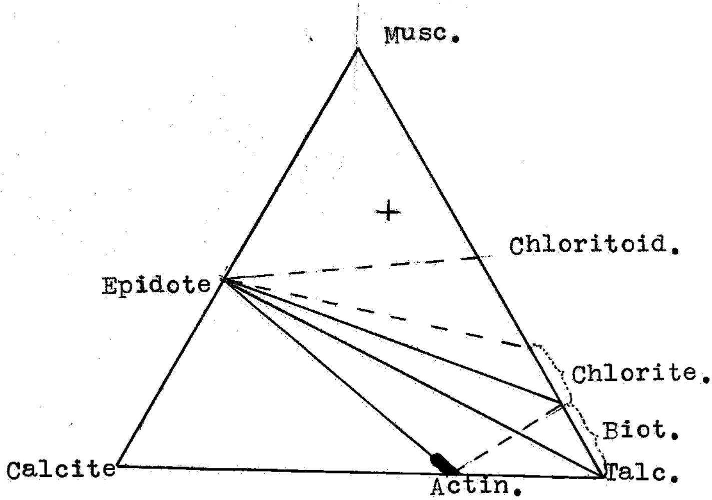


Figure 4.

Greenschist facies.

Quartz-albite-epidote-biotite-.subfacies.

+ = "Houghton" assemblage is

Musc-Epidote-Biot.

APPENDIX V.

Results of chemical analyses.

	Houghton granulite.					Amphibolites.	
376-	H6.	H7.	H8.	H9.	HII.	A-I7.	A-I8.
SiO_2,	54.I5	54.97	55.22	53.79	54.II	58.67	52.96
Fe_2O_3,	3.83	4.4	4.3	5.25	3.02	3.88	5.00
FeO,	2.24	I.66	I.7I	I.82	2.IO	I.I6	7.77
MnO,	.34	.29	.32	.3I	.28	.I2	.I2
* TiO_2,	.65	.63	.65	.63	.63	.66	2.52
CaO,	9.7I	IO.98	II.56	II.64	II.36	7.54	7.3I
K_2O,	7.22	4.9	4.56	6.I2	6.3I	I.52	2.2I
Al_2O_3,	I5.94	I5.78	I6.46	I5.52	I7.06	I6.OI	I2.90
P_2O_5,	.22	.I7	.3I	.20	.26	.29	.45
MgO,	2.55	2.23	2.93	2.I9	2.I5	4.08	4.45
Na_2O,	.99	.83	I.24	.77	I.74	2.22	4.06
H_2O^-	I.73	I.3I	2.I2	2.I8	I.05	I.47	-I.00
total.	99.58	97.77	IOI.77	IOO.4I	IOO.08	97.6I	98.64
			Trace elements. (ppm.)				
La.	60	25	78	70	66	44	I4I
Ce.	79	I25	IO6	83	54	76	I4I
Rb.	369	283	342	3I4	375	43	38
Sr.	263	63	233	I83	86	279	95
Ba.	IO86	864	I47I	906	I574	-	I66
Ni,	57	55	60	57	60	67	3I
Cr.	85	9I	9I	IOO	9I	76	I2
Co.	37	29	37	37	37	37	60
V.	69	69	80	92	46	I38	552
Pb.	28	32	4I	30	39	30	39
Zn.	90	69	8I	52	73	57	90
Cu.	20	32	I2	I4	24	I5	IOO

ANALYSES OF AMPHIBOLITES.

(in ppm.)

	Ni.	Cu.	Cr.	Zn.	Co.	Mn.	Fe.
376-II9.	60.	49.	30.	79.	59.	-	-
376-I23.	50..	34.	6I.	87.	50.	-	-
376-248.	98.	78.	350.	87.	59.	-	-
376-255.	90.	II2.	250.	9I.	70.	-	-
376-263. (Silicate leach.)	575.	I600.	225.	82.	400.	-	-
376-263. (Sulphide leach.)	500.	I625.	250.	27.	480.	IIO.	7.5%.
376-265.	I35.	I07.	200.	75.	95.	-	-
376-300A.	250.	I27.	380.	89.	I08.	-	-
376-300B.	233.	I22.	850.	89.	I08.	-	-

TABLE 2.

Whole rock analyses of rocks similar to the Houghton granulite (%ages)

	I.	2.	3.	4.	5.	6.
SiO_2.	59.93	53.3I	54.95	50.87.	5I.50	55.40.
Al_2O_3.	I4.07	I5.79	I5.88	I8.I3	I6.30	I7.20.
Fe_2O_3.	.75	3.69	.68	5.5	2.8	9.4
FeO.	2.87	I.37	5.84	I.86	7.9	
MnO.	.06	.45	.04	.08	.I7	I.3
CaO.	II.77	I3.8I	I0.09	I2.48	9.8	8.I
MgO.	5.02	I.73	5.06	4.03	5.9	3.I
Na_2O.	3.72	I.04	3.76	2.I5	2.50	I.8
K_2O.	.36	4.I5	.76	4.I5	.86	2.8
TiO_2.	.79	.70	I.80	.75	I.20	.9
P_2O_5.	.76	I.2	.24		.2I	.30
Others.	.2I	.2I	.22		.2I	
Total.	I00.3I	97.90	99.33	I00.00	99.94	I00.30

TABLE 2. (continued.)

	7.	8.	9.	IO.	II.	I2.
SiO2.	55.50.	58.90.	52.32	60.76.	56.06	58.70
Al2O3.	I5.IO.	I6.70	I7.00.	I4.23	I7.6I	I7.05
Fe2O3.	5.8.	2.8.	4.09.	5.4.	I.65	3.I7
FeO.		3.7	7.44	.99	7.59	2.29
MnO.	.7	.09		.I8	.I6	
CaO.	9.7	2.2	9.79	4.36	7.26	4.7I
MgO.	2.3	2.6	4.75	.8	3.38	2.4I
Na2O.	I.0	I.6	I.5	5.3	3.47	4.38
K2O.	2.2	3.6	I.84	3.67	I.67	4.44
TiO2.	.5	.78	.48	.9	.6	.95
P2O5.	.3	.I6		.26		.23
Others.	6.9	6.3	.65	3.42	.95	.89
Total.	IOO.00	99.70	99.9I	IOO.27	IOO.40	99.5

INDEX OF WHOLE ROCK ANALYSES(%).

I. "HOUGHTON" GRANULITE. Alderman.(I938).Transactions of the Royal Society of South Australia.(TRSSA) Vol.62,pt. I.

2. & 3. "HOUGHTON" GRANULITE. England H.N. Ibid. Vol. 58-60. I938-45.

4. Dolomitic marl. Sidorenko et al. Doklady Acad. NAUK. SSSR. Vol.I82. page 84.

5. Average continental basalt. Hallberg J. Journal of Petrology. Vol.I3. pp. 45. I972.

6. Red clay. Crust of the Earth. Special papers 62. Geol. Soc. America.

7. Siliceous ooze. Ibid.

8. Near shore shale.Physics and Chemistry of the Earth, Vol. 8. pp. 578.

9. Diorite. Joplin. B.M.R. Bull. 65. Analyses of Australian rocks I.

IO. Syenite. Ibid.

II. & I2. Diorite and Syenite respectively. Wedepohl,K.H. Executive director,Handbook of Geochemistry.

TABLE 3.

TRACE ELEMENT VALUES FOR DIFFERENT LITHOLOGIES.

(in ppm.)

	I.	2.	3.	4.	5.	6.	7.	8.
Ba.			580.	230.	620.	60.	200.	630.
Rb.	36.		I25.		550.	I8.	39I.	300.
Sr.	428.	465.	440.	260.	600.	I40.	60.	I70.
La.				26.	52.			I8.
Ce.					49.			46.
Ni.	I2.	I50.	I5.	40.	8.	65.	253.	
Cr.		200.	76.	68.	200.	300.		
Co.		48.	8.	32.	8.	56.		
V.		250.	85.		34.	320.	I20.	I20.
Cu.		I00.	I6.	38.	38.	I49.	I60.	I28.
Pb.								
Zn.		I00.		I20.	200.		I60.	

TABLE 3 (cont.)

	9.	I0.	II.	I2.	I3.	I4.	I5.	I6.
Ba.			65I.	I50.	60.	700.		
Rb.			90.	69.	77.	I40.	I40.	
Sr.			I60.	330.	I30.	300.	300.	600.
La.						40.	I0.	I3.
Ce.						95.	22.	27.
Ni.	40.	42.	I5.	I5.	32.	68.		
Cr.	86.	92.	6I.	98.	96.	90.		
Co.	II.	20.	3.	9.	I0.	I9.		
V.	2I.	II8.	I25.	73,	63.	I30.		
Cu.	37.	28.	II.	I9.	27.	45.		
Zn.						95		
Pb.	2.	I3.						

INDEX OF TRACE ELEMENT ANALYSES.

I. Average continental basalt. Geochimica et Cosmochemica Acta.Vol.33,pp 8I.

2. Average Canadian shield basalt. Ibid.

3. Cretaceous calcareous marl.Maurel P.Bull.Soc.Franc. Min.Crist. 92 368-375,1969.

4. Diorite. Rankama and Sahama."Geochemistry."

5. Syenite. " " " "

6. Basalts. " " " "

7. Red clay. " " " "

8. Shales. " " " "

9. Modern marine sediments.Geochimica et cosmochemica acta.I970. pp. 852.

IO. Ancient marine sediments. Ibid.

II. Calcareous clays.Maurel P.Bull.Soc.Franc.Min.Crist. 92. I969.

I2 & I3. Calcareous clays. Ibid.

I4. Near shore shales.Physics and Chemistry of the Earth. Vol.8. pp. 578.

I5. Clays and shales. Geochemistry of the rare earths. Vol.I. I966.

I6. Syenites. Ibid.

NIGGLI NUMBERS OF VARIOUS LITHOLOGIES.

Sh. = Marine shale.

Dio. = Diorite.

Sy. = Syenite.

376-	H6.	H7.	H8.	H9.	HII.	AI7.	AI8.	Sy.	Sy. Dio.	Sh.
si.	I58.	I68.	I56.	I53.	I53.	2I3.	I42.	2I7.	I97.	234.
al.	27.	28.	27.	26.	28.	34.	20.	3I.	33.	39.
fm.	26.	25.	26.	26.	2I.	36.	44.	23.	27.	36.
c.	30.	35.	35.	35.	34.	29.	2I.	I7.	I7.	9.
alk.	I6.	I2.	II.	I3.	I6.	II.	I4.	28.	24.	I5.
ti.	I.4	I.5	I.4	I.4	I.4	I.7	5.I	2.5	2.4.	2.4
p.	.35	.2	.3	.34	.34	.43	.64	.45	.40	.3I
k.	.83	.80	.7I	.84	.70	.3I	.27	.3I	.40.	.59
mg.	.43	.4I	.47	.37	.43	.6I	.38	.I9	.45	.43

$$k. = \frac{K}{Na + K}$$

$$mg. = \frac{Mg}{Fe + Mn + Mg}.$$

List of symbols of lithologies.

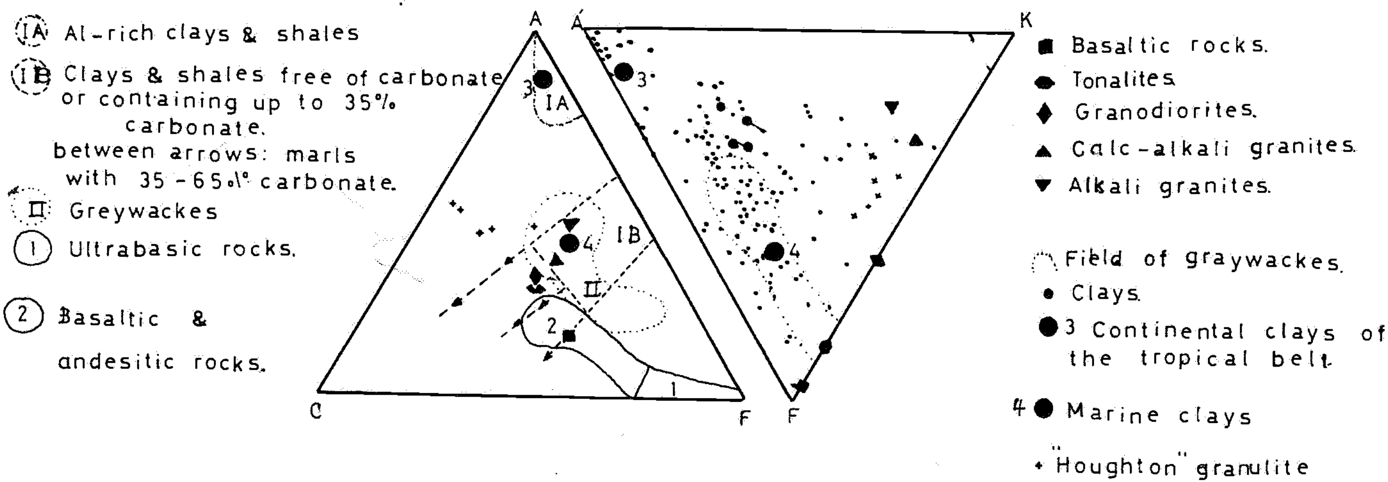
Houghton Granulite,	=	●
Diorite,	=	◉
Marine sediments,	=	▲
Syenite,	=	■
Ortho-amphibolites,	=	⊙
Para-amphibolites,	=	⊗
Greywackes,	=	□
Basalts,	=	△

For appendix 5, figures I to IO, the symbols are the same as those for figure 2, which is the plot of IOOmg + (al+alk) + c = IOO.

Field of Ortho-amphibolites is,

Field of Pelites and semi-pelites is,

Appendix 5 Fig. 1.



Appendix 5. Fig. 2.

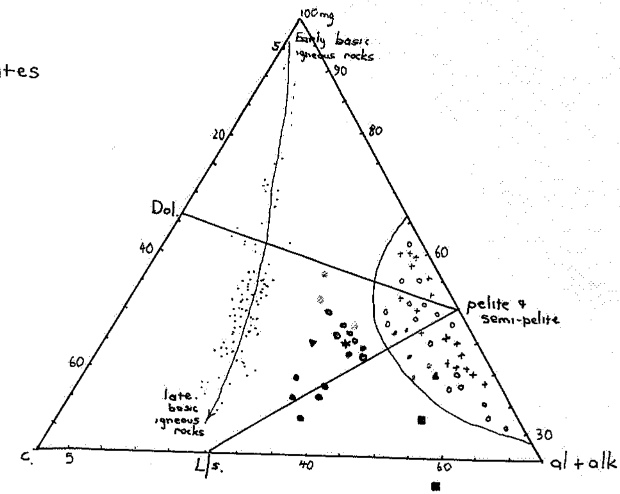
● = Houghton granulite

· = Karroo dolerites & Ortho-amphibolites of the Adirondacks. N.Y.

+, o = Littleton & Connemara pelites

▼ = 376-A17.

✱ = 376-A18.



Plot of 100 mg + (al + alk) + c = 100.

APPENDIX 5.

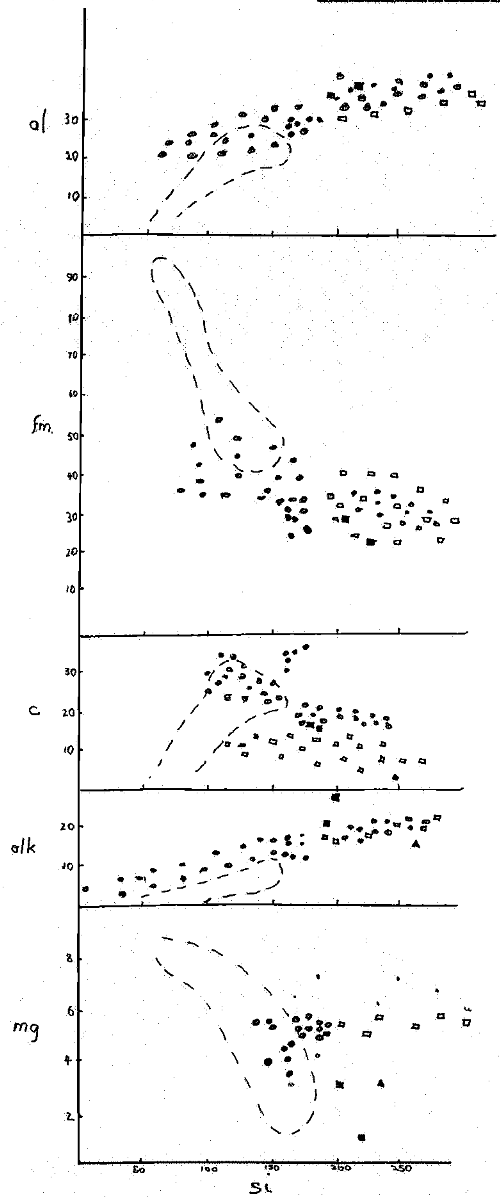


Fig. 3.

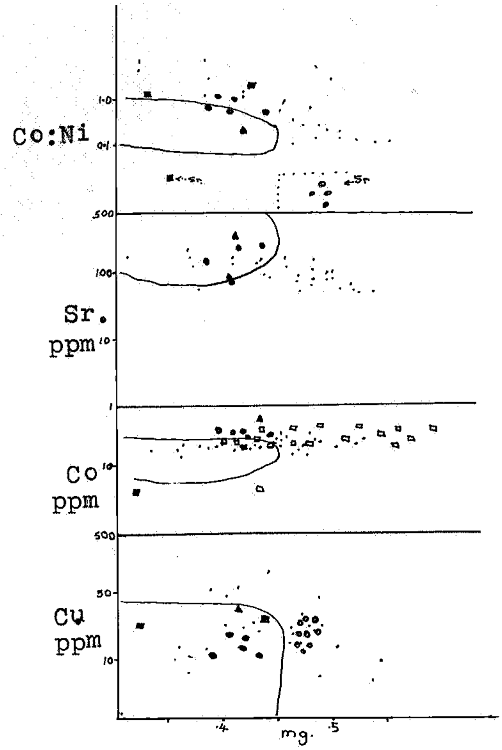


Fig. 4.

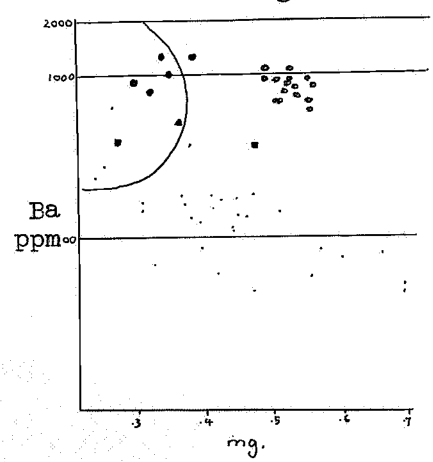


Fig. 5.

APPENDIX 5.

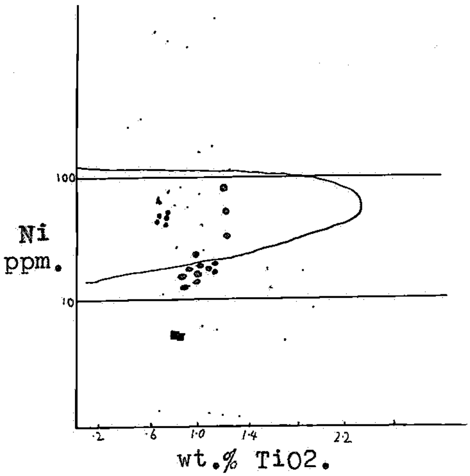


Fig. 6

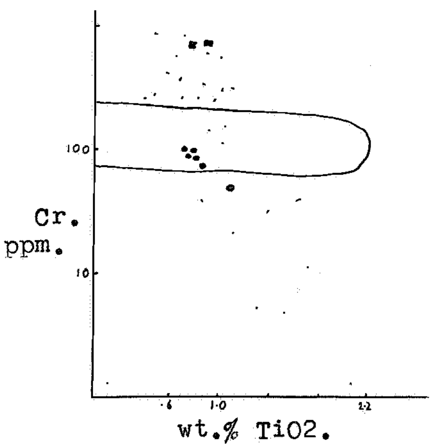


Fig. 7.

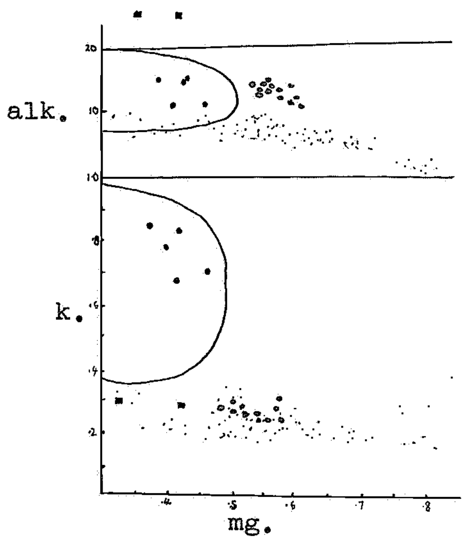


Fig. 8.

APPENDIX 5.

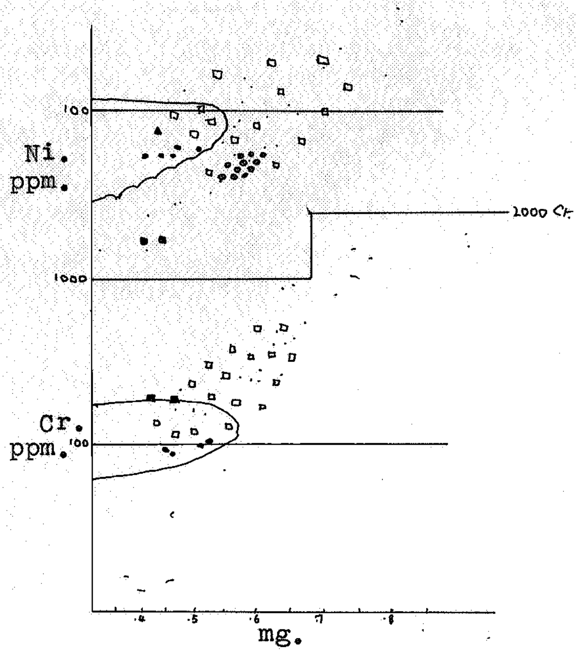


Fig. 9.

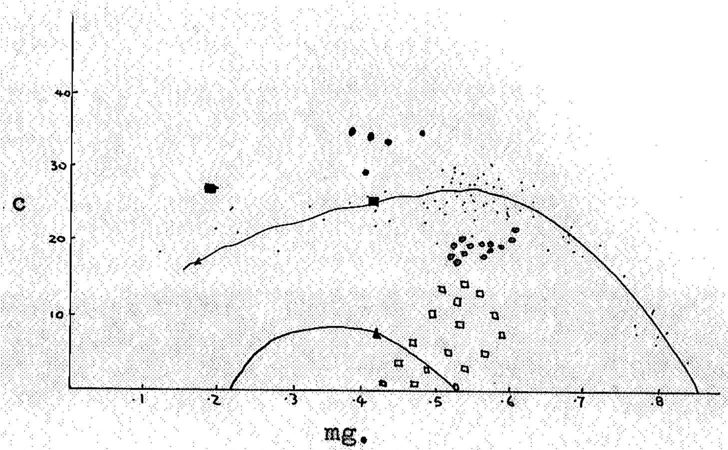
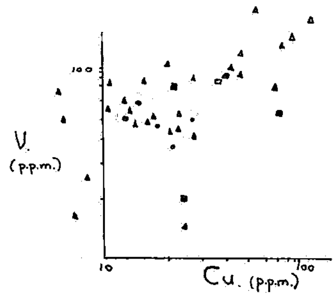


Fig. IO.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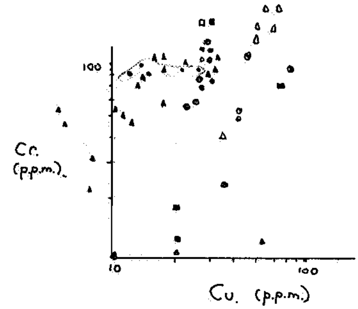
V.
(p.p.m.)
10
Cu. (p.p.m.)
100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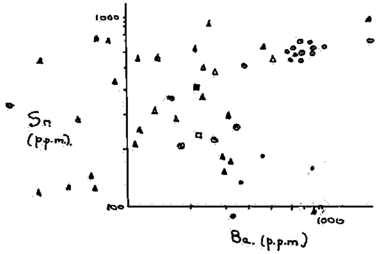
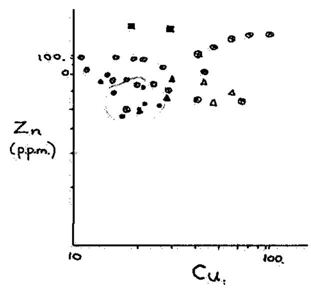
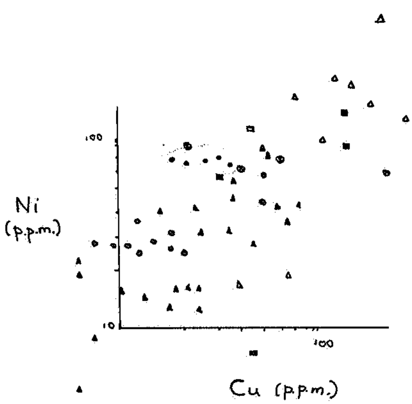
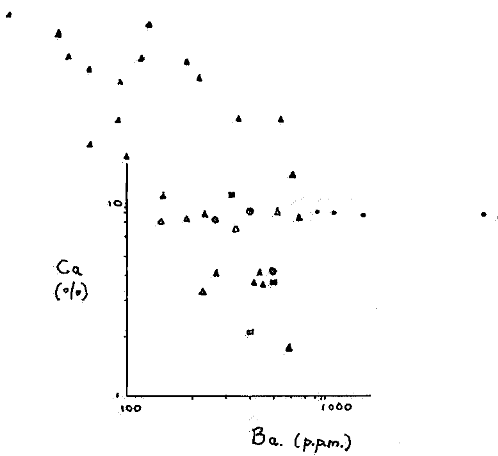
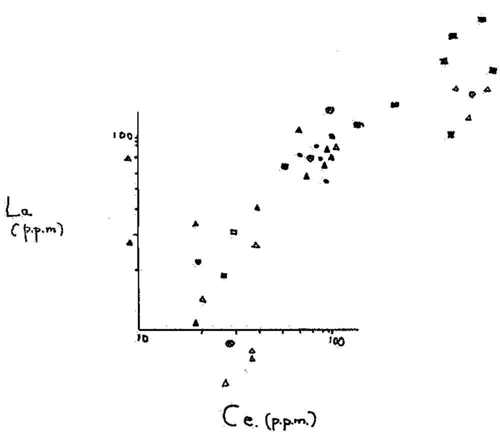
Cr.
(p.p.m.)
10
100
Cu. (p.p.m.)


1000
Sn
(p.p.m.)
100
1000
Ba. (p.p.m.)

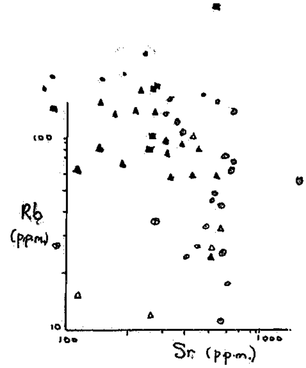

100.
Zn
(p.p.m.)
10
100.
Cu.


100
Ni
(p.p.m.)
10
100
Cu (p.p.m.)

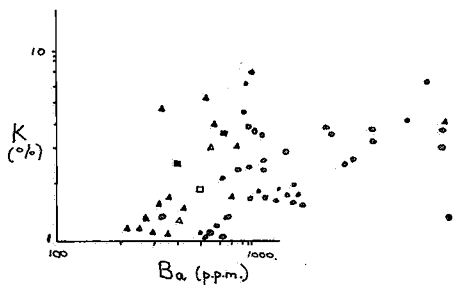

10
Ca
(%)
100
1000
Ba. (p.p.m.)



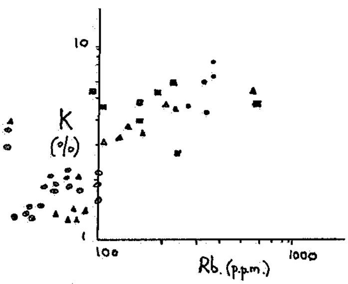
La
(p.p.m)
100
10
100
Ce. (p.p.m.)



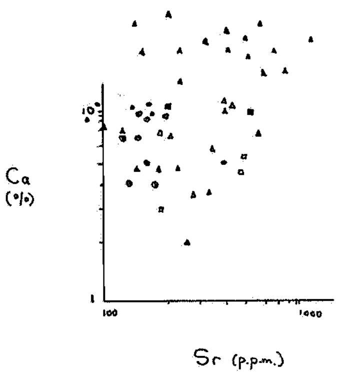
Rb
(p.p.m)
100
10
100
1000
Sr (p.p.m.)



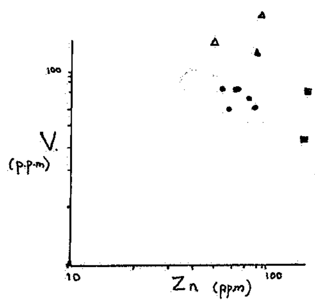
K
(%)
10
1
100
1000
Ba (p.p.m.)



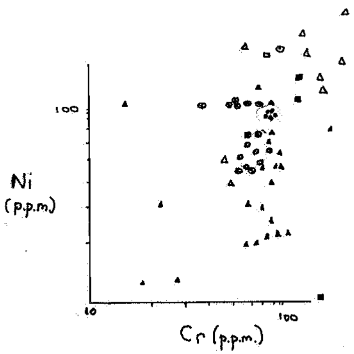
K
(%)
10
1
100
1000
Rb. (p.p.m.)



Ca
(%)
10
1
100
1000
Sr (p.p.m.)



V.
(p.p.m)
100
10
100
Zn (ppm)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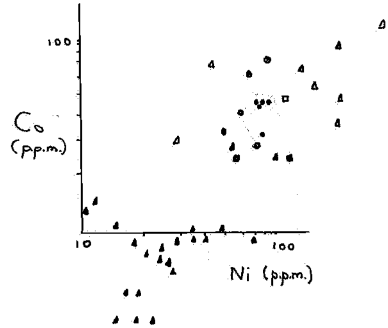
Ni
(p.p.m.)
10
100
Cr (p.p.m.)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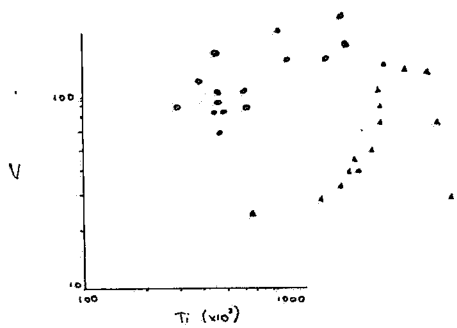
Co
(p.p.m.)
10
100
Ni (p.p.m.)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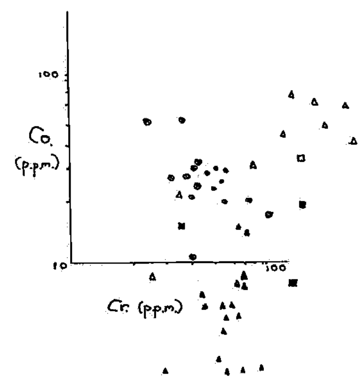
V
10
100
1000
Ti (x10²)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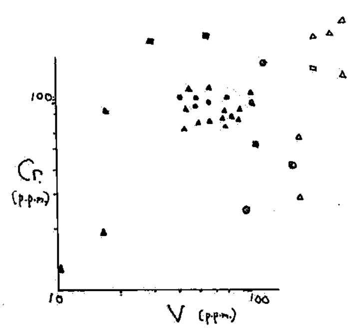
Co
(p.p.m.)
10
100
Cr (p.p.m.)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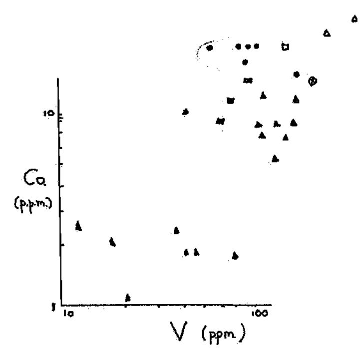
Cr
(p.p.m.)
10
100
V (p.p.m.)

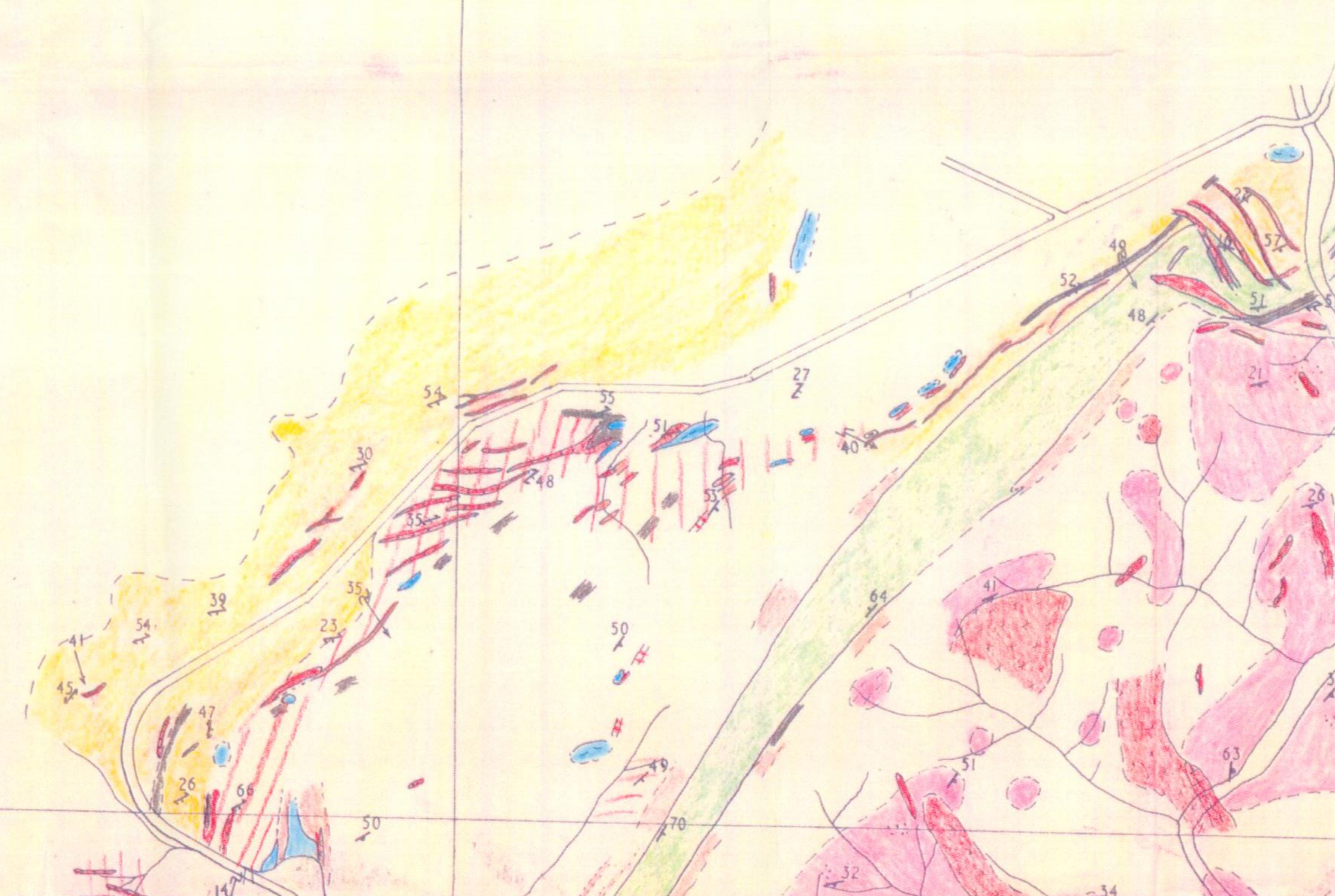

10
Ca
(p.p.m.)
1
10
100
V (ppm)


Outcrop map of Archaean basement rocks
south of Normanville.
Rock Type.
"Houghton" granulite.
Quartzite.
Augen gneiss.
Migmatitic gneiss.
Augen schist.
(schistose)
Sillimanite gneiss.
(quartose)
Granite gneiss.
Foliated pegmatite.
Amphibolite.
Clinopyroxene unit.
Metasomatized amphibolite
Migmatitic sillimanite gneiss
"Layered" gneiss.
Biotite rich gneiss.
Cambrian.
Pegmatite.
Granite.
Basaltic dyke.
Permian.
Alluvium.
KEY.
Layering
Foliation
schistosity
Plunge of lineation
Fold axes
Lithological boundaries
Extent of outcrop
Main roads
Dams
Streams
Rivers
TN
MN
Scale : 1" Rep. 300 Yds.
35° 29'
35° 30'
138° 17
138° 19

Outcrop map of Archaean basement rocks south of Normanville.

Rock Type.

- "Houghton" granulite.
- Quartzite.
- Augen gneiss.
- Migmatitic gneiss.
- Augen schist.
- (schistose) Sillimanite gneiss. (quartose)
- Granite gneiss.
- Foliated pegmatite.
- Amphibolite.
- Clinopyroxene unit.
- Metasomatized amphibolite
- Migmatitic sillimanite gneiss
- "Layered" gneiss
- Biotite rich gneiss.
- Cambrian.
- Pegmatite.
- Granite.
- Basaltic dyke.
- Permian.
- Alluvium.




Outcrop map of Archaean basement rocks south of Normanville.
Rock Type.
"Houghton" granulite.
Quartzite.
Augen gneiss.
Migmatitic gneiss.
Augen schist.
(schistose) Sillimanite gneiss. (quartose)
Granite gneiss.
Foliated pegmatite.
Amphibolite.
Clinopyroxene unit.
Metasomatized amphibolite
Migmatitic sillimanite gneiss
"Layered" gneiss.
Biotite rich gneiss.
Cambrian.
Pegmatite.
Granite.
Basaltic dyke.
Permian.
Alluvium.
KEY.
Layering
Foliation
schistosity
Plunge of lineation
Fold axes
Lithological boundaries
Extent of outcrop
Main roads
Dams
Streams
Rivers
PERMIAN? SANDS
PERMIAN?
TN
MN
Scale: 1" Rep. 300 Yds.
138° 17'
138° 19'
35° 29'
35° 30'

Interpretative map of the geology of the Archaean inlier south of Normanville.