THE UNIVERSITY OF ADELAIDE

GEOLOGY OF PART OF BASEMENT INLIER NORTH-EAST OF MT. COMPASS.

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1972.

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GEOLOGY OF PART OF BASEMENT INLIER N.E. OF MT. COMPASS

by

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ERRATA

The Sub section 'Metamorphism' has been erroneously placed in the section 'Geochemistry'. It should have been included in the section 'Petrology'.

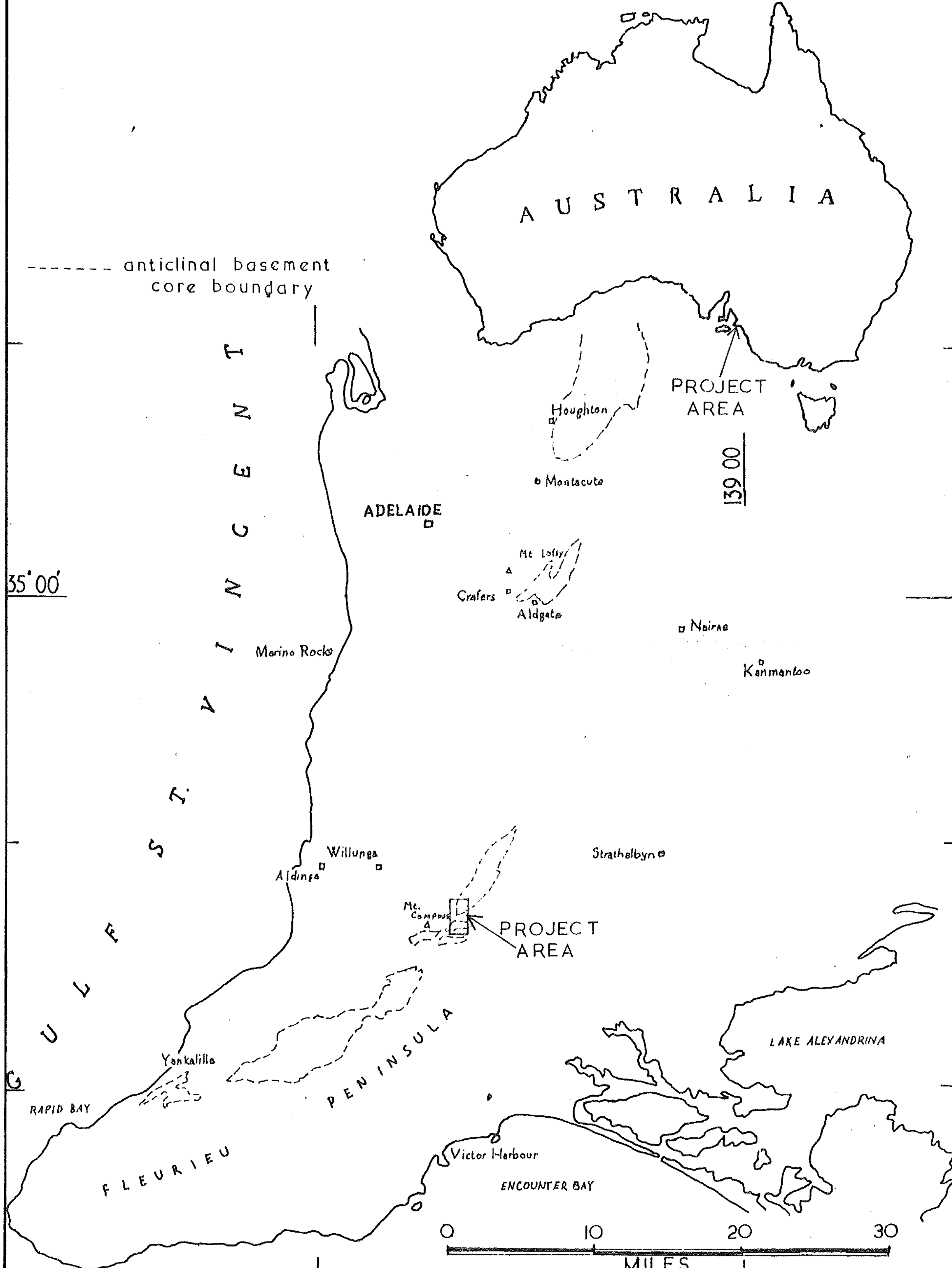
The following reference has been omitted from the bibliography.

ALDERMAN, 1938: Augen-gneisses in the Humbug Scrub Area, South Australia. Trans. Roy. Soc. S. Aust., 62 (1).

CONTENTS.

FIG. 1

LOCATION MAP



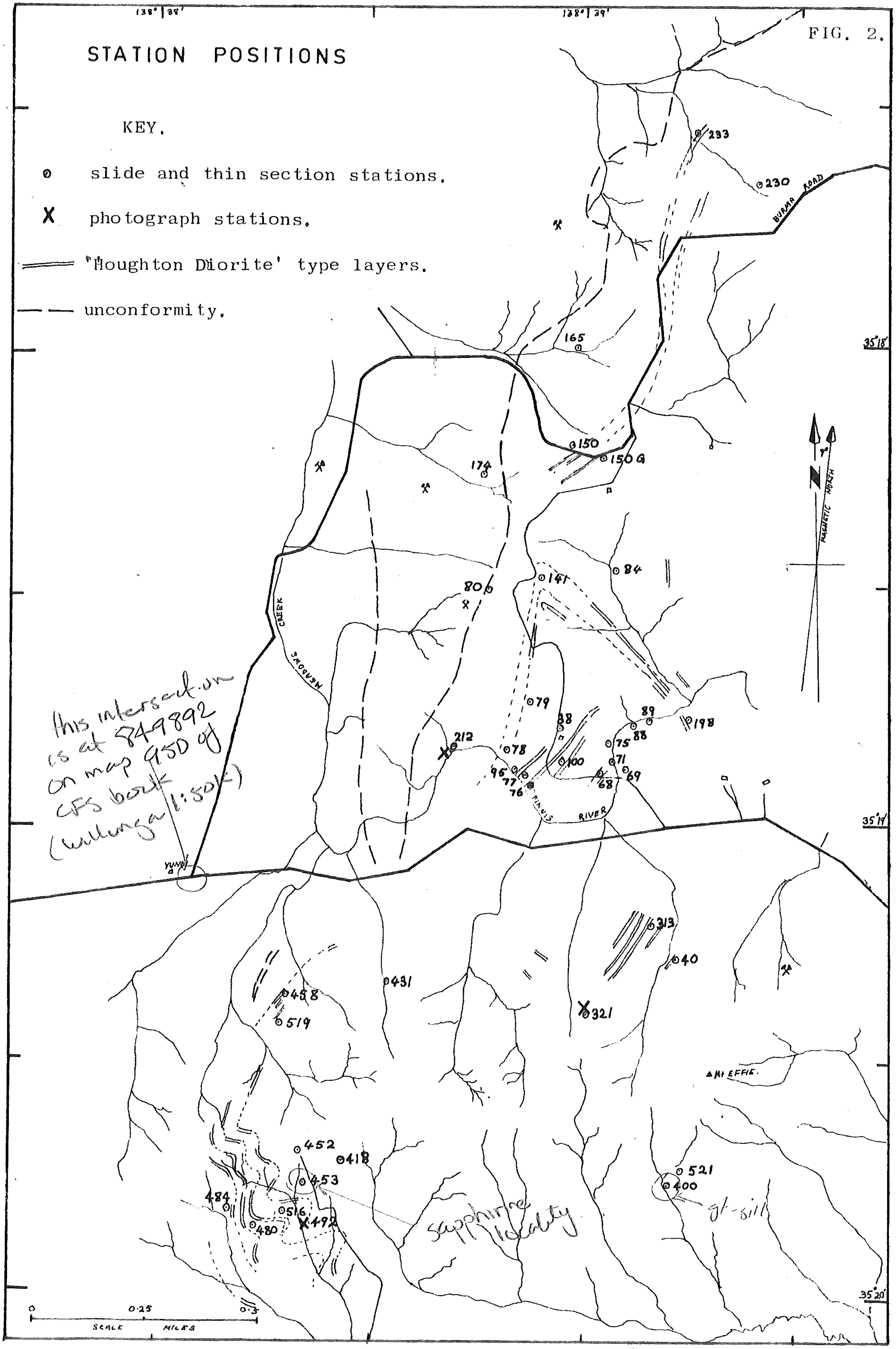

STATION POSITIONS
KEY.
slide and thin section stations.
photograph stations.
'Houghton Diorite' type layers.
unconformity.
138° 38'
138° 39'
35° 18'
35° 19'
35° 20'
BURMA ROAD
CREEK
FINNIS RIVER
MAGNETIC NORTH
Mt EFFIE.
SCALE MILES
0
0.25
233
230
165
150
150 G
174
141
84
80
79
212
78
100
75
71
69
68
198
313
40
431
458
519
321
452
418
453
484
516
480
492
521
400
this intersection is at 849892 on map 950 of CFS book (Willunga 1:50K)
sapphirine locality
gt-sill

FIG. 2.

ABSTRACT:

Basement gneisses, including 'Houghton Diorite' type rocks, show evidence of having been subjected to three deformations the last of which effects the Adelaide Supergroup rocks. Relict sillimanite and sapphirine indicate initial metamorphism to upper amphibolite - granulite facies grade. In an attempt, to ascertain the original nature of the 'Houghton Diorite' type rocks 12 samples were analysed for major oxides and also V, Cr, Co, Ni, Cu, Rb, Sr, La, Ce, and Ba. Comparison of these with those of pertinent known igneous and sedimentary rocks, utilizing multi variant discriminant function analyses, point to a sedimentary origin with a dolomitic shale as parent. Two samples, having both igneous and sedimentary characteristics, are probably the result of local mobilization of 'Houghton Diorite' type rocks.

INTRODUCTION:

The Mt. Compass inlier is one of about six exposed basement anticlinal cores, known as the Barossa Complex in the Mt. Lofty Ranges. 'Houghton Diorite' type rocks consist of a suite of epidote gneiss and albite, pyroxene, amphibole rocks which can be found in almost all the basement inliers. England (1935) has found close chemical similarity between rocks of dioritic and syenitic composition in the different inliers, thus linking them together.

At least two phases of metamorphism are recognised, the former being upper amphibolite to granulite facies and the latter being greenschist facies. These have resulted in the removal of pre-existing sedimentary features so that much controvesy has arisen over the genesis of the rock.

In association with this controversy there has been confusion over what to call the rock since names with genetic connotations have generally been avoided by later workers. The following names have been used by past workers:-

Houghton Diorite	Benson (1909)
Houghton Diorite types	Whittle and Webb (1954)
Epidote Syenite	Glaessner and Parkin (1958)
Epidote Quartzite	Thomson and Horwitz (1960)

Actinolite Gneiss	Chappel (1964)
Epidiorite	Thomson (1964)
Actinolite Epidote Gneiss	Callen (1966)

In order to avoid confusion the rock is here called 'Houghton Diorite' type.

The aim of this project is to study the geology and geochemistry of the 'Houghton Diorite' type rocks in order to gain a clearer understanding of rock genesis. This has become necessary since Cooper and Compston (1971) used the Rb-Sr method on the 'Houghton Diorite' type rocks to obtain an anomalously low age of 867 m.y. This date could represent several possibilities.

Firstly, it is possible that Cooper and Compston (1971) dated the original formation of a sediment so that a need would arise for the redating of Adelaide Geosynclinal events. Secondly, it is possible that the event dated was the first or second phase of high grade metamorphism, although this allows only a short time in which to effect the first retrograde metamorphic event. (Talbot 1972). Thirdly there is a possibility that they dated the intrusion of 'Houghton Diorite' type magma. The following structural, petrological and chemical work is presented in an attempt to solve this problem.

PHYSIOGRAPHY AND VEGETATION:

The area, of 4½ square miles, is situated 2½ miles from Mt. Compass in a Fleurieu Peninsula basement anticlinal core at an average height of 850 feet above sea level. Although the area shows rugged relief with steep ridges and broad glacial valleys, outcrop is poor. The Basement-Proterozoic sheared unconformity is manifested by a long steep ridge in places 1200 feet high. Other areas of high relief, eg. Mt. Effie 1,191 feet are commonly capped with the remnants of the Tertiary laterite surface. Permian glacial debris although present on some hill tops is chiefly present in valleys as boulders and quartz sand.

The drainage system, which comprises Meadow's Creek and Finnis River drains east into Lake Alexandrina.

Soil derived from the dominant rock type "Biotite Feldspar Gneiss" is poor and grey in colour, supporting hakea (Chiefly Mt. Effie Block), mallee, stringy bark and yacka. Sandy soils of Permian origin support only banksia and bracken and are confined to valley bottoms. Igneous amphibolites tend to weather away easily leaving a flattened path, at times resembling a road, over hilly country. Soil derived from these and from 'Houghton Diorite' type rocks is yellow brown, calcium rich and supports luxuriant native grasses and very large Pink and Blue Gums. The transition Zone between the two soil types commonly supports Cup Gum. Manna Gum, Red Gum, and dense blackberry thickets are confined to the creeks and river.

GEOLOGY:

THE POSITION OF THE BASEMENT PROTEROZOIC UNCONFORMITY.

The interesting unconformity strikes about 025°T and lies on the east side of Meadow's Creek. Intensive shearing has retrograded Basement gneisses to produce quartz muscovite sericite gneisses. At the same time bedding in the proterozoic cover rocks has been erased. It is of interest that Spry (1951), in the Houghton area, also had trouble distinguishing Basement and Proterozoic rocks.

After a close study of the unconformity on the Hope Forest anticline to the west, it became apparent that the unconformity could be traced on the basis of:

(a) Lithological change from biotite and feldspar in the Basement to quartz mica schists in the cover.

(b) Very quartz rich gneisses which stand out in relief producing Billygoat Ridge.

(c) Occasional large outcrops of porous sandstone and arkose. The porous sandstone is probably the result of weathering out of feldspar grains from an original arkose. These outcrops, which are especially good in the Finnis River, have previously been mistaken for Basement rock. They probably occur just above the basal ilmenitic sandstone of which only a small amount remains.

(d) Weathered rocks of Proterozoic origin have a distinctive pale brown colour while weathered Basement rocks are generally light grey.

The position of the unconformity as shown on the Mines Department map is now moved some 400 metres to the east so that many of the Gold mines along this unconformity would now be placed in Proterozoic Cover rock.

The unconformity also continues south of the Finnis River but here it is possible that the thrust fault and the basal sandstone are not strictly coincident. The syncline has narrowed to such an extent that only occasional outcrops of basal sandstone are present, surrounded by Basement.

South of the Burma Road the unconformity dips steeply to the east at about 75°. North of the Burma Road the surface trace of the contact becomes more sinuous as a result of hilly topography and a shallow dip of 30° to the east.

STRUCTURE.

Introduction:

The area is dominated structurally by the major overturned Proterozoic anticline (with its basement core), by the tight sheared syncline (through which Meadow's Creek runs), and by the smaller western drag anticline (Hope Forest area).

Basement structure was studied by dividing it into three sub areas on the basis of major faults. (All faults are designated by a number on the tectonic map).

Sub Area I: The Mt. Effie Block lying south of fault 2. Best plots are produced in this area because it is possible to measure all positions around folds.

Sub Area II: The area comprising Government Farm between faults 1 and 2 The outcrop pattern of two fold limbs is indicated on the plot but, as is often the case, the fold nose is dissected by a steep gully and no measurements are possible.

Sub Area III: The area between faults 1 and 4 where outcrop is especially poor and because only one fold limb is present, great circle plots of poles to layering are not present (Fig. 3).

Sequence of Events With Particular Reference to Folding Phases:

1) The first folding phase is characterised by "Biotite Feldspar Gneisses" which have schistosity parallel to the feldspar layering. This situation could have arisen in two ways.

(1) Isoclinal folding could develop initially so that the axial plane schistosity was parallel to the layering for the most part. No fold noses were found which featured the early schistosity at an angle to the layering and for this reason the second solution is preferred.

(2) Folding in the F_1 folding phase may have been more open so that S_1 layering formed as a result of segregation of feldspathic minerals along the axial plane schistosity. 'Houghton Diorite' type rocks are conformable with this layering and so must have formed before, or as a result, the F_1 fold episode. No field evidence is present in this area to suggest that this layering is bedding although this may well be the case. (Thomson and Horwitz 1960 report on relict cross bedding in 'Houghton Diorite' type rocks in an area two miles west of Spring Mount , which is itself ten miles south-west of Mt. Effie.)

2) A suite of amphibolite dykes were then intruded with a strike of approximately 015°. They mostly have a cross cutting relationship with basement layering and are not found in Proterozoic units.

3) The basement was then eroded and Proterozoic sediments, beginning with basal conglomerate, were deposited, resulting in an angular unconformity.

4) The first phase of Proterozoic folding (called F_2) occured producing tight synclines and broader anticlines with steep, parallel and overturned sides. Proterozoic bedding is rarely found in the Meadow'S Creek area due to intensive shearing.

F_2 produced an axial plane schistosity, S_2, which was strongly imprinted on Basement and Proterozoic rocks, especially in the viscinity of the sheared unconformity. Schistosity measurements are essentially the same in Basement and cover (see Fig. 4) and give an axial plane striking 020°T and dipping 78°E.

Because the Basement layering bears an angular relationship to Proterozoic cover rocks, the schistosity, S_2, which is axial plane to Proterozoic folding, is not axial plane to Basement folding although they were formed at the same time.

This also explains why Basement folding tends to mimic, but not copy exactly, F_2 folding. S_2 schistosity can only be measured with certainty in the Basement when it is at an angle to S_1 layering in the more competent rocks. Less competent basement schists show S_2 schistosity.

Fig. 3 shows plots of poles to feldspar layering which indicates folds plunging 58° -> 130°T for the Mt. Effie Block and 50° -> 152°T for the Basement north of this. Fig. 5 supports this with rodding, crenulations and folding being essentially parallel and plunging 50° -> 131°T. The slight spread shown on the contoured plot is probably due to rotation between the two blocks on fault 2.

Amphibolite dykes are only effected slightly by this folding phase because their orientation trace is approximately parallel to the F_2 fold axis.

5) A second, weaker phase of Proterozoic folding (called F_3) is indicated by folding of thin schist layers in the south-west map corner. (Plate 2A). Complex folding of quartzo feldspathic gneiss at station 40 (Plate 2B) may also be a reflection of this folding phase, but it may also be a result of an earlier fold phase between F_1 and F_2.

Offler and Flemming (1968) claim to have recognised two final, weaker phases but due to lack of suitable outcrop I was unable to substantiate this.

<u>Sequence of Faulting Events</u>:

1) Fault 1, is proposed to explain the apparent dislocation of 'Houghton Diorite' type layering. Photographic evidence indicates that this fault does not effect the Basement-Proterozoic unconformity and so must have occured immediately after F_1. That being the case, the

POLES TO MINERAL LAYERING S1 IN BASEMENT

FIG. 3

SUB AREA I

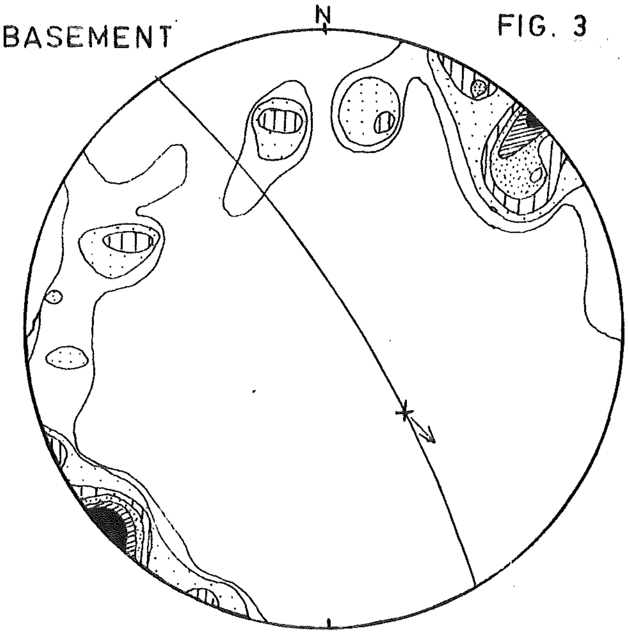
80 measurements.

contours at 1,2,3,4,5,10 % intervals.

FOLD AXIS: plunges 58° -> 130°T.

AXIAL PLANE: strike = 141°T.

dip = 82°E.



SUB AREA II

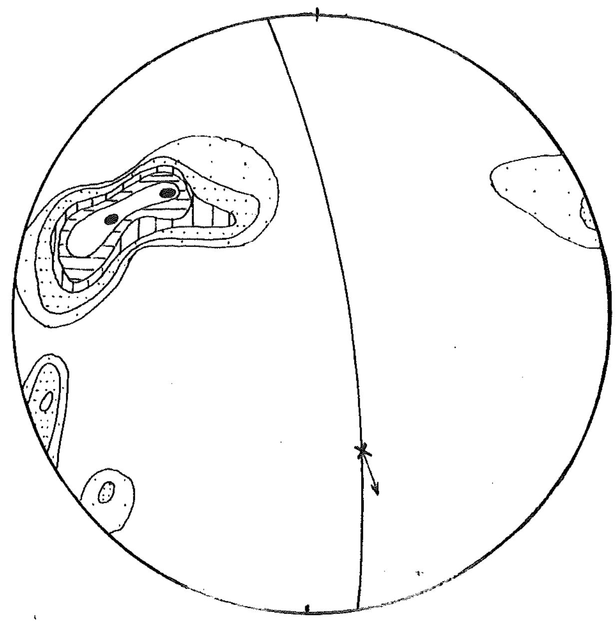
50 measurements.

contours at 2,4,6,8,10,&12% intervals.

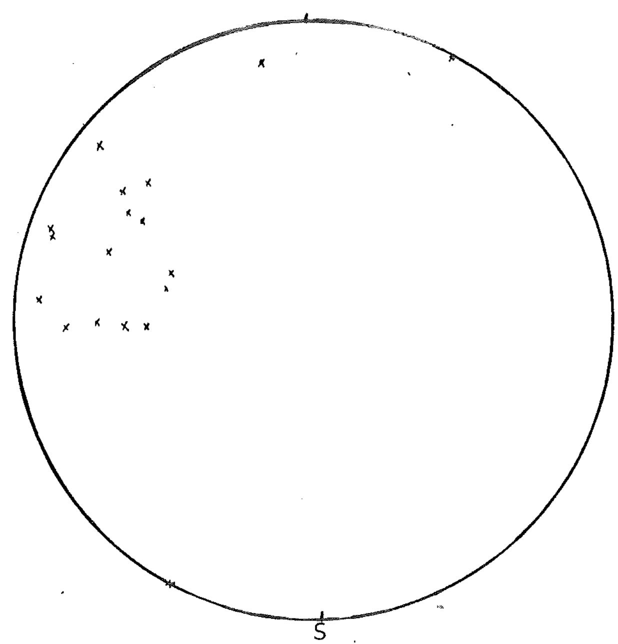
FOLD AXIS: plunges 50° -> 152°T

AXIAL PLANE: strike = 152°T.

dip = 82°E.



SUB AREA III



POLES TO SCHISTOSITY, S2. FIG. 4

<u>BASEMENT</u>

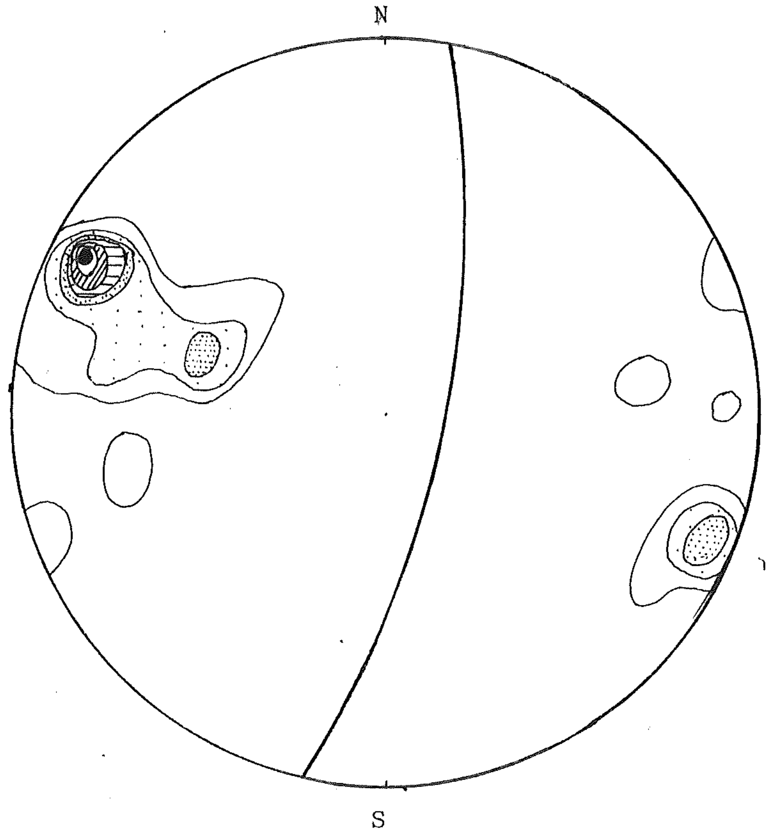
50 measurements

contours at 2,4,6,8,10,
12 & 16 % intervals.

AXIAL PLANE SCHISTOSITY.

strike = 020°T.

dip = 78°E.



<u>PROTEROZOIC COVER</u>

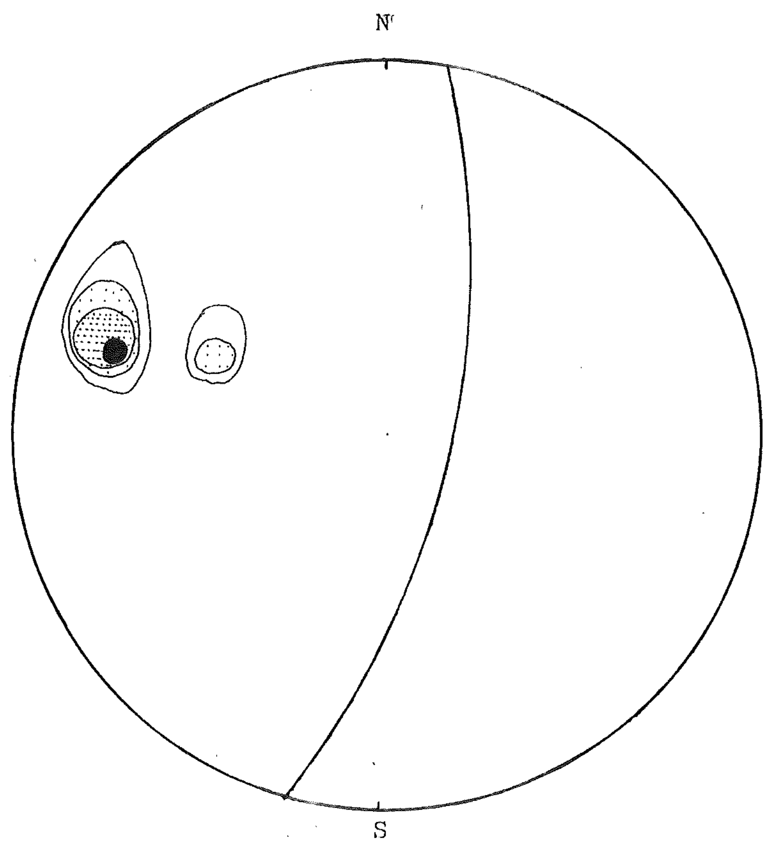
20 measurements

contours at 2,4,6, & 10 %
intervals.

AXIAL PLANE SCHISTOSITY:

strike = 013°T

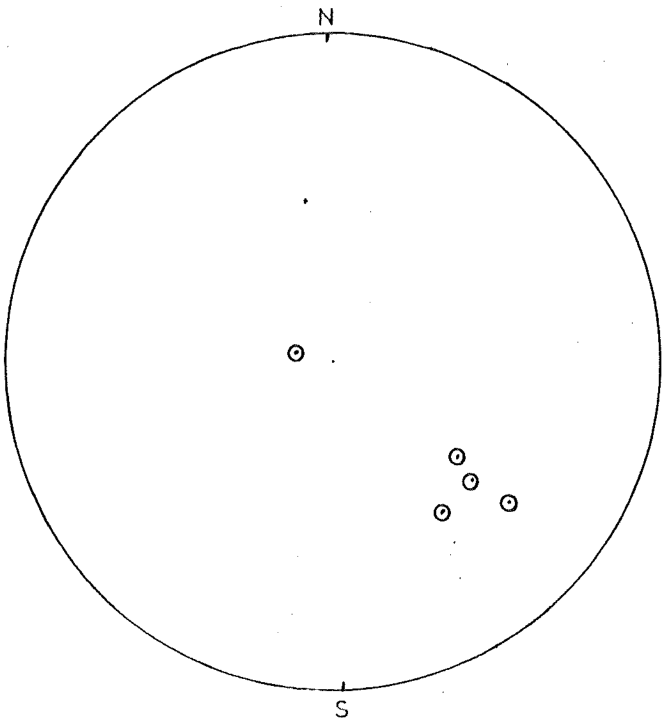
dip = 70°E.



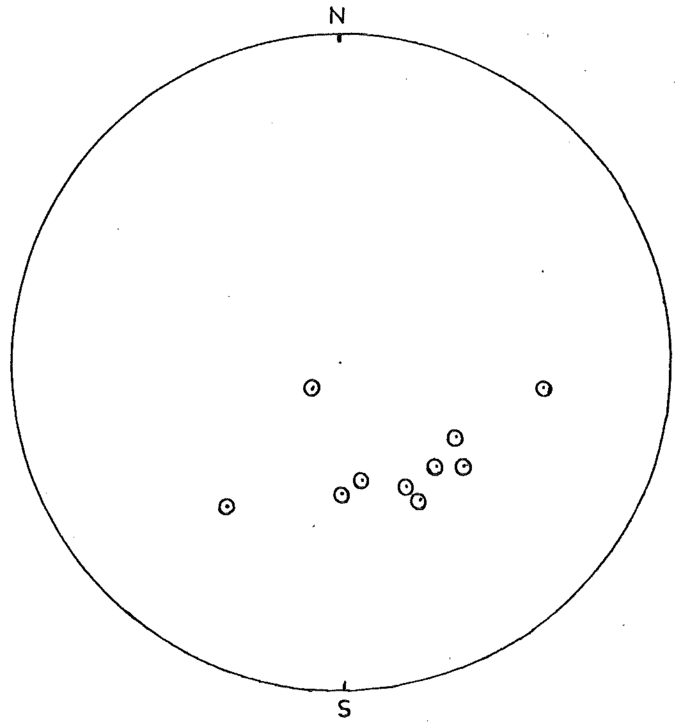
BASEMENT : FOLDS, CRENULATIONS, LINEATIONS

FIG. 5

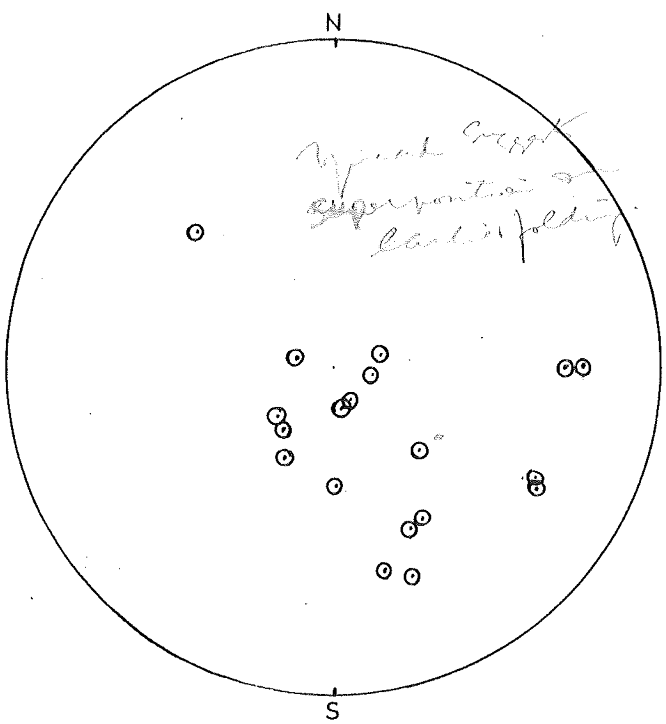
MESOSCOPIC FOLDS



CRENULATIONS

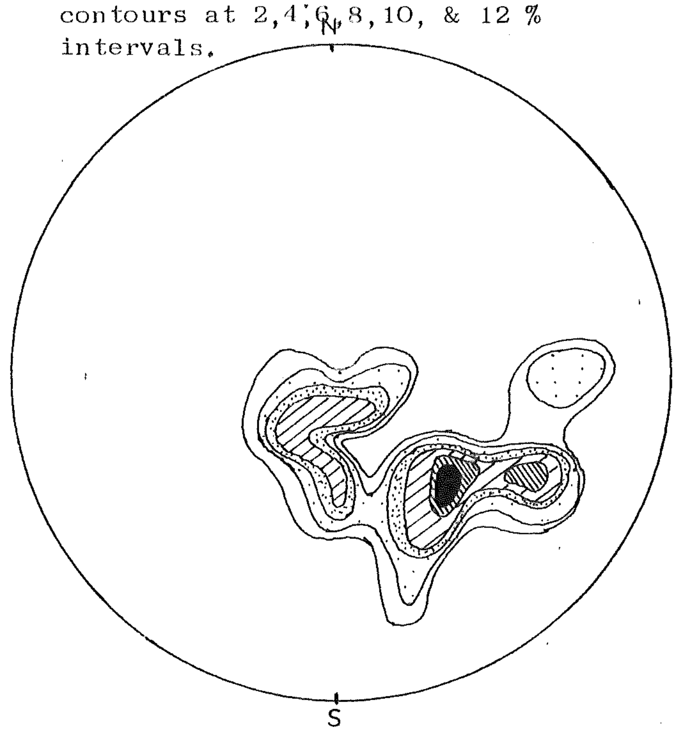


LINEATIONS & RODDING



CONTOURED: FOLDS, CRENULATIONS & OTHER LINEATIONS.

34 measurements.
contours at 2,4,6,8,10, & 12 % intervals.



fault should have been folded by F_2, although there is insufficient topographic detail to show this. Fault 1 is a strike slip fault.

2) Faults 3,4,5,6, and the thrust fault were probably a result of a strong shear movement during the first Proterozoic folding phase, F_2. Evidence for them is based on quartz outcrops, micaceous shear zones, and air photography. In addition fault 6 is clearly depicted by ruptured outcrop in the bed of the Finnis River. Movement on all these faults is predominantly strike slip.

3) Fault 2 is post F_2 folding since it dislocates both basement folding and the Basement- Proterozoic unconformity. The present positions of these two dislocations suggests that the fault had a large dip slip component with the Mt. Effie Block being raised relative to the more northern block. The Finnis River flows through the old glacial valley which probably resulted from this fault.

4) Faults 7 and 8 are probably Cainozoic in age. Fault 7 is clearly depicted by air photographic evidence and has resulted in the preservation of a Tertiary land surface to the south. Fault 8 occurs in the Meadow's Creek valley and is marked by a series of springs with associated water reeds. In addition the block to the east shows a drop of several feet. The Milang 1 mile map designates this fault as monoclinal and Cainozoic in age.

PETROLOGY:

GENERAL:

The Basement and Proterozoic rocks consist chiefly of schists and gneisses. These have been subdivided for the most part according to change in the proportion or type of mineral, however, due to the strong effect of S_2 shearing on some rock types it has been necessary to introduce further subdivisions. For example "Biotite Feldspar Gneiss" is probably just a layered equivalent of "Biotite Feldspar Granite Gneiss". Boundaries between many of these rock types are transitionary and are indicated as such on the geological map.

'Houghton Diorite' type rocks and related quartzo feldspathic rocks have sharp lithological boundaries and form excellent marker beds.

Descriptions of thin and polished sections are described in detail in Appendix I.

BASEMENT:

Biotite Feldspar Gneisses:

These, with their related rock types, form some 95 % of exposed Basement rocks. The Mt. Effie Block is the source of best outcrop with some more strongly layered varieties providing outcrop in creeks west of the Burma Road and in the Finnis River (Plate 1C).

Fresh rock is light grey with white feldspar and muscovite biotite giving the rock a poor gneissisity. The strong Proterozoic schistosity and associated metamorphic phase has greatly affected the rock appearance in some areas, however, it is generally possible to recognise the rock type as 'Biotite Feldspar Gneiss'.

On the western side of the Mt. Effie Block in the thrust fault region, the gneisses become more quartz rich with quartz augen parallel to the strong foliation. West of the Burma Road the gneisses exhibit strong thin layering of feldspar with micaceous minerals. The Proterozoic contact parallels this schistosity. In much of the central Mt. Effie Block the Proterozoic schistosity is at an angle to the feldsparlayering resulting in a more blocky outcrop. In a large area around Mt. Effie the effect of the strong Proterozoic Schistosity is even more strongly imprinted on the gneisses. This rock is referred to as 'Heavily Sheared Biotite Feldspar Gneiss' on the Geological map and may resemble a mylonite. It is more usual to observe weathered specimens which arewhite and porous or crumbly in nature, or laterised rocks, but in each case the feldspar layering can often be found on close examination.

Microscopic examination reveals a feldspar, quartz, muscovite, biotite rock which commonly had less biotite than is evident in the hand specimen. Opaque, apatite and zircon are usually present in small amount.

EXPLANATION OF PLATES:

1A. Amphibole rich rock with xenoliths (a)
LOCATION: Station 321.

1B. Coarse grained pyroxene amphibole pegmatite.
LOCATION: Station 100G.
(a) Clinopyroxene. (b) Amphibole secondary after pyroxene.
(c) Feldspar and quartz. (d) Iron Oxide.

1C. Very strongly layered 'Feldspar Biotite Gneiss'.
LOCATION: Station 212 in bed of Finnis River.

2A. F_3 folds in biotite schists and gneisses.
LOCATION: Station 492 (dam site).

2B. Complex F_3 folding of quartz and feldspar layers.
LOCATION: Station 40 (quarry).

2C. Contacts between 'Houghton Diorite' type and 'Feldspar Quartz Granitic Rock'. (Direction indicated by arrows).
LOCATION: Station 480.

3A. Intersertial quartz (a) with sub euhedral plagioclase grains(b) and fibrous actinolite (c).
LOCATION: Station 38B. MAGNIFICATION: 250 X (crossed nichols).

3B. Sericite nodule from a quartz feldspar pegmatite layer.
LOCATION: Station 431. MAGNIFICATION: 450 X
(a) Rutile. (b) Rounded zircon grains. (c) Biotite. (d) Chlorite.

3C. Phlogopite (c) Schist with Chlorite (b), Sapphirine(A) porphyroblasts
LOCATION: Station 454. MAGNIFICATION: 380 X.

4A. Red brown hexagonal biotite or hematite in K feldspar.
LOCATION: Station 48. MAGNIFICATION: 250 X.

4B. Garnet (a) Sillimenite (b) and Quartz (c) is surrounded by sheaves of Sericite (d).
LOCATION: Station 400. MAGNIFICATION: 450 X (crossed nichols)

4C. Granulated quartz with embayed edges in a sericite groundmass.
LOCATION: Station 282. MAGNIFICATION: 250 X (crossed nichols).

%	'HOUGHTON DIORITE' TYPES.								SPECKLED AMPHIBS. PROBABLY IGNEOUS.			AMPHIB. IGNEOUS.
	68	457	484	453	475	516	313A	100G	321	150	38B	212
SiO_2	64.66	68.27	64.08	54.41	66.68	57.53	60.75	59.89	65.54	50.42	48.77	47.98
TiO_2	1.49	1.08	1.86	.74	.83	.65	.51	.23	.23	1.40	1.23	2.51
Al_2O_3	12.94	14.70	15.14	15.47	13.97	15.11	12.47	12.74	2.58	12.76	14.08	12.67
Fe_2O_3	2.83	1.21	1.05	11.65	1.59	9.96	6.30	3.18	3.25	4.24	4.75	5.13
FeO	1.06	.66	.69	.80	.66	.67	1.86	1.82	2.27	7.15	5.89	10.08
MnO	.11	.06	.10	.06	.08	.07	.06	.18	.09	.23	.19	.27
MgO	2.65	1.18	2.17	1.92	2.27	2.18	6.37	5.15	14.29	6.50	8.85	5.77
CaO	5.15	1.61	3.15	3.29	2.28	1.74	6.71	8.09	8.36	9.87	10.93	9.62
Na_2O	3.69	5.90	6.05	5.64	5.50	6.00	5.40	5.42	.70	3.06	2.23	2.21
K_2O	3.69	3.14	3.11	2.70	3.65	4.31	.87	1.26	.61	1.49	1.00	.94
P_2O_5	.17	.03	.01	.01	.00	.01	.57	.00	.19	.16	.10	.30
WT CHNGE.	.66	.86	.54	.80	.71	.54	.73	.63	.55	.53	.66	.66
TOTAL	99.12	98.70	97.94	97.77	98.21	98.78	101.60	98.55	98.67	97.86	98.67	98.15
p.p.m.												
V	161	92	138	115	138	161	184	161	115	299	322	505
Cr	50	18	20	100	18	88	88	100	34	110	700	144
Co	38	26	40	45	29	26	29	29	47	64	69	69
Ni	50	66	40	53	39	66	76	66	133	93	145	91
Cu	19	42	11	19	25	31	25	19	25	108	299	241
Rb	84	37	63	48	75	75	12	32	5	30	36	43
Sr	176	106	111	86	21	20	130	203	8	218	198	202
La	45	44	89	40	11	21	19	16	13	36	14	26
Ce	182	153	531	72	19	24	51	52	32	69	117	72
Ba	350	194	77	trace	trace	trace	trace	trace	trace	302	trace	trace
Rb/Sr	.48	.35	.57	.55	3.51	3.63	.09	.16	1.86	.14	.18	.21
La/Ce	.25	.29	.17	.55	.65	.87	.37	.31	.41	.52	.12	.36
Ni/Co	1.31	1.57	3.63	2.78	1.56	2.12	3.04	3.47	5.32	.86	.48	.37
K/Rb	439	848	494	563	487	575	725	394	1220	496	278	218
c*	21	8.3	13.9	12.8	10.7	6.9	21.3	26.7	24.8	26.8	27.0	26.02
mg*	.66	.63	.77	.36	.74	.42	.70	.73	.87	.55	.65	.45
F[γ]	9.19	4.89	5.42	28.93	6.93	27.68	17.91	11.91	21.02	17.98	20.30	21.49

%	ORTHO AMPHIB. ave 36 (1)	PARA AMPHIB. ave51 (2)	ANDESITE ave13 (3)	GRANO DIORITE (4)	MARL ave3 (5)	DOLO. SEDS. ave3 (6)	GREY WACKE ave17 (7)	QUARTZ DIORITE ave 7 (8)	SHALE (9)
SiO_2	47.91	51.03	59.50	66.90	56.40	63.50	61.37	58.12	58.00
TiO_2	2.30	1.40	.70	.6	.28	.55	1.00	1.01	.40
Al_2O_3	9.54	13.88	17.2	15.7	8.45	13.13	14.30	17.08	16.0
Fe_2O_3	3.36	1.85	6.10	3.8	3.42	4.00	1.28	1.45	9.44
FeO	10.41	6.23					4.85	4.53	
MnO	.22	.11	.12	.10	.02	.06	.09	.07	.08
MgO	5.75	5.33	3.42	1.6	.75	1.90	3.44	4.00	3.00
CaO	9.02	10.44	7.03	3.6	13.16	4.53	2.68	5.54	4.42
Na_2O	3.43	3.33	3.68	3.8	.23	.36	2.61	4.49	1.92
K_2O	.40	1.42	1.60	3.1	1.32	3.56	2.19	2.62	5.32
P_2O_5	.57	.20	-	-	-	-	.06	.31	.07
WT CHNGE.									
TOTAL									
p.p.m.									
V	315	226	175	75	77	69	138	142	130
Cr	126	69	56	30	88	81	196	140	90
Co	37	25	24	10	9	3	38	20	19
Ni	142	35	18	15	26	14	81	54	68
Cu	60	87	54	25	20	16	37	42	45
Rb	7	38	31	110	80	171	-	-	140
Sr	395	402	385	440	340	186	230	451	300
La	5	8	12	40	-	-	-	-	92
Ce	43	45	24	80	-	-	-	-	59
Ba	479	339	270	500	100	493	408	614	580
Rb/Sr	.02	.09	.08	.25	.24	.92	-	-	.47
La/Ce	.11	.17	.50	.50	-	-	-	-	1.56
Ni/Co	3.84	1.40	.75	1.5	2.89	4.67	2.13	2.70	3.58
K/Rb	571	371	516	282	164	208	-	-	380
c*	26.04	29.90	24.90	16.97	62.66	24.77	11.56	18.53	17.24
mg*	.45	.57	.68	.61	.47	.64	.53	.57	.55
F[γ]	19.72	13.77	-	-	-	-	9.83	10.30	-

* c and mg are Niggli numbers (Niggli 1954 p 13.)

γ F is the iron enrichment ratio of Osborn (1959) and = $FeO + Fe_2O_3 + Fe_2O_3/FeO + MgO$.

(1) & (2) Average of Shaw and Kudo (1965) and Van de Kamp (1968)

(3) Taylor, Capp and Graham (1969).

(4) Average of Turekian and Wedepohl (1961), Kolbe and Taylor (1966) and Nockolds (1954).

(5) & (6) Maurel (1969).

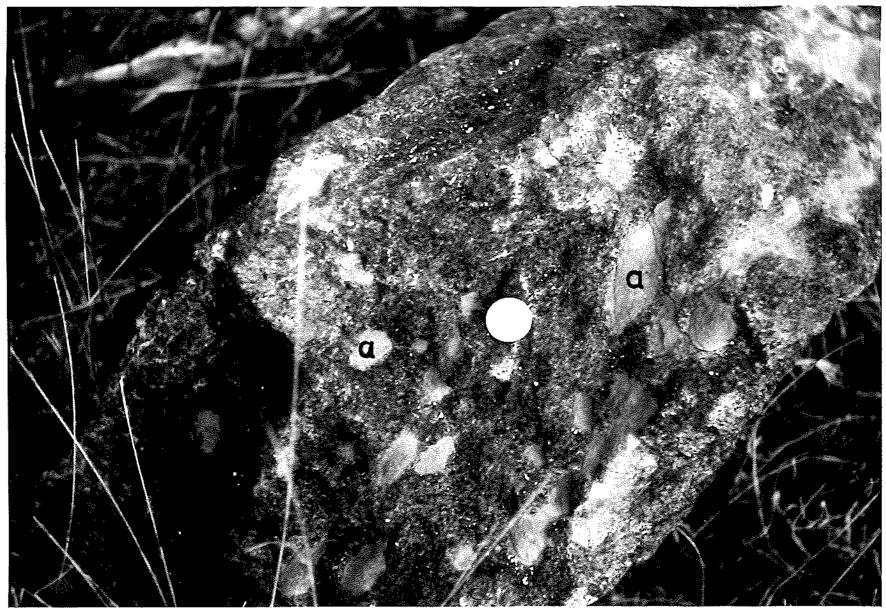
(7) Rivalenti and Sighinalfi (1969).

(8) Average of Haslam (1968) and Byers (1972).

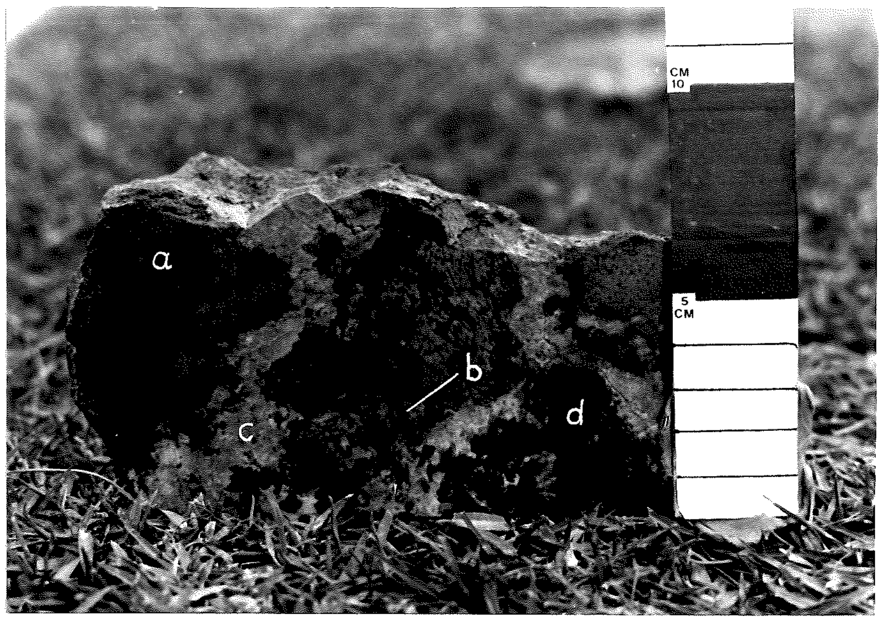
(9) Turekian and Wedepohl (1961).

TABLE I

PLATE 1.



A.



B.

C.

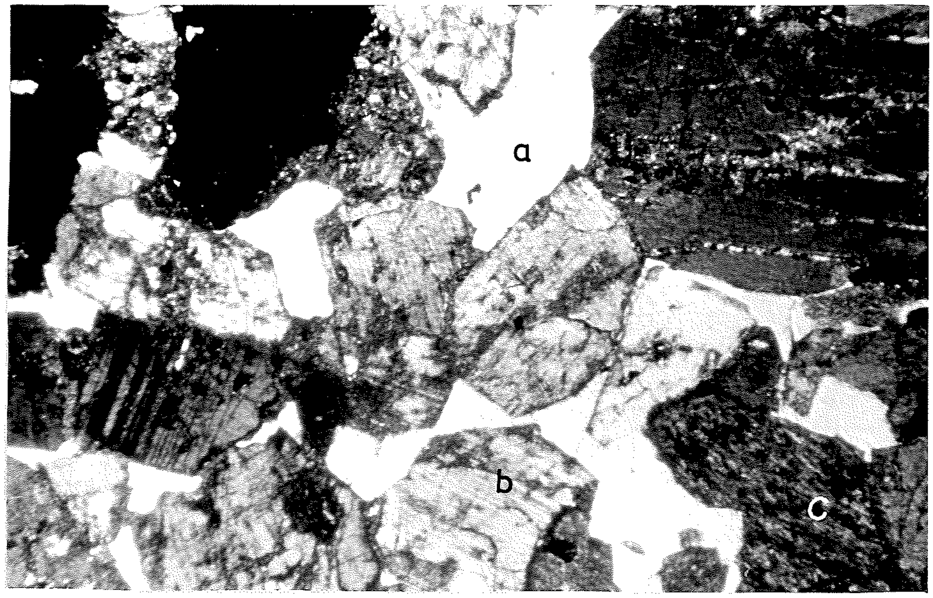
PLATE 2.

A.

B.

C.

PLATE 3.



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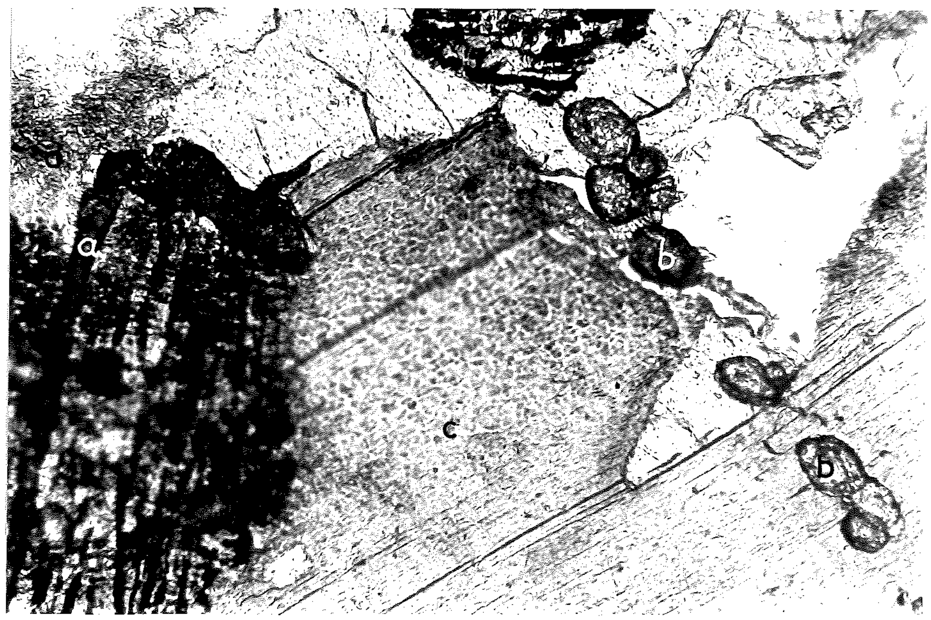

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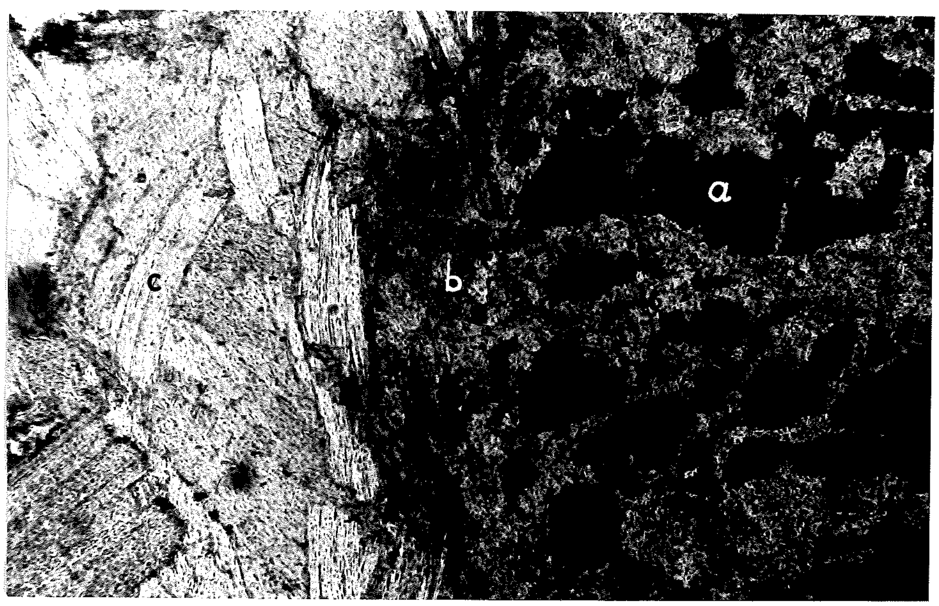
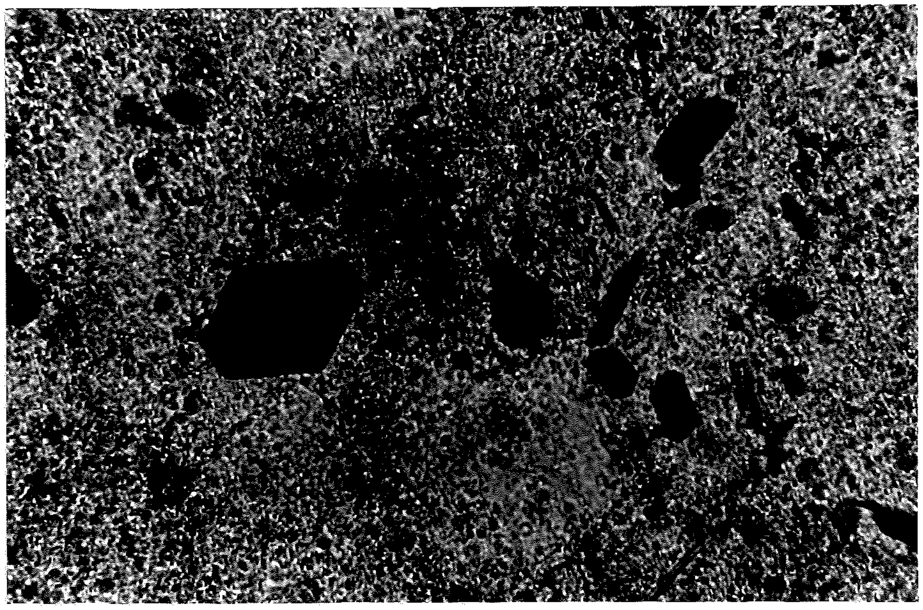
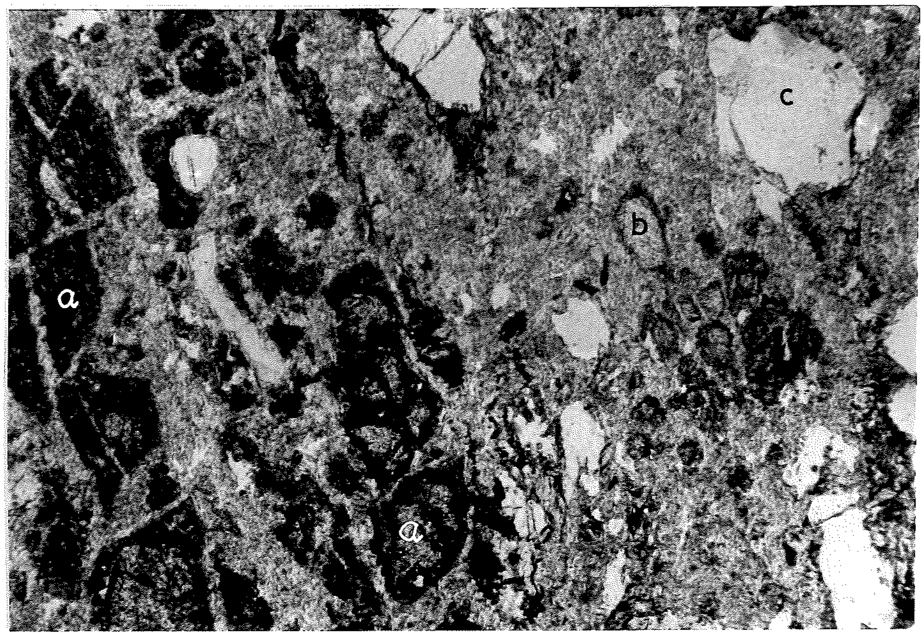


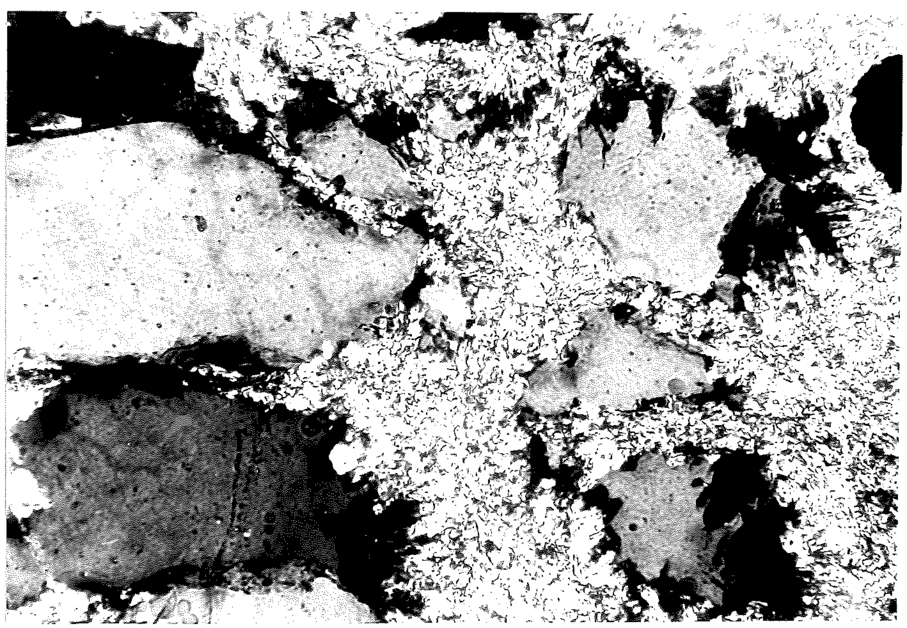
C



A.



B.



C.

In rare cases (sample 400), minor garnet and sillimanite are present surrounded by thick sheaves of sericite (Plate 4B). This is further discussed in the section headed 'Metamorphism'.

The feldspar is plagioclase, Ab_{90}, and commonly has abundant sericite inclusions. The quartz has strong undulose extinction and recrystallized aggregates of quartz are evidence of strain.

<u>Muscovite Sericite Schists</u>: (Phyllonites).

These schists outcrop in lens-shaped bodies which are parallel to the dominant Proterozoic schistosity, S_3, and commonly outcrop close to the Basement-Proterozoic unconformity and thrust fault.

It appears as a muscovite schist usually, but north of the Burma Rd. chlorite and quartz are also present. Where quartz is present, it shows evidence of strong shearing: viz. strong undulose extinction and recrystalization (sample 80).

The schistosity is probably the result of intensive shearing and retrogradation of 'Biotite Feldspar Gneiss' since these bodies are lenses superimposed on, and therefore not conformable with, basement layering.

<u>Biotite Feldspar Granite Gneiss</u>:

Fresh rocks may have the appearence of a granite with large pink feldspar grains and books or layers of Biotite and muscovite. Iron oxide and quartz are commonly present. These rocks are transitionary to 'Biotite Feldspar Gneiss' which is more strongly layered, and to 'Feldspar Iron Oxide Granitic Rock' which has no micaceous minerals.

Microscopic examination reveals variations in mineral type and percentage. Although all samples have a high feldspar content the feldspar type varies. Plagioclase, Ab_{90}, is most common (samples 76 &78), however, samples 77 and 79 have microcline and sample 150G has perthite. More minor mineral constituents include muscovite, chlorite, epidote, apatite, sphene, tourmaline, rutile and zircon (rounded or sub angular grains).

Phlogopite Schist with Chlorite Sapphirine Porphyroblasts:

This unusual rock type has only one locality in the Mt. Effie Block (location 453). The outcrop is surrounded by 'Biotite Feldspar Gneiss' and inferred folding of 'Houghton Diorite' type rocks suggest it may occupy a small fold core.

The outcrop consists of massive boulders of grey green phlogopite schist which have green blue porphyroblasts about 10mm. in size. The petrography is described in sample 453. The significance of the high grade mineral, sapphirine, in regard to metamorphic grade is discussed in the section headed 'Metamorphism'.

Feldspar Gneiss with Quartz Layers:

Outcrops of this type are found, always closely associated with 'Houghton Diorite' type rocks, both immediately north and south of the Finnis River. Excellent exposures can be seen in the southern outcrop which forms the site of a quarry.

The rock is predominantly light pink plagioclase, Ab_{84}, through which thin layers (1mm) of quartz may extend several cms. before leasing out. Rutile occurs in small highly elongated grains (sample 40A) which are 1 layered. Opaques are present, parallel to the layering in some specimens. The effects of considerable shear stress can be seen by

(a) The elongated or stretched rutile grains.

(b) The fracturing of some plagioclase multiple twinning which was at an angle to the layering.

(c) The formation of continuous thin quartz layers which show strong undulose extinction and recrystallization.

It seems likely that the quartz layering was formed in response to the major Proterozoic shearing since it only occurs on the fold limb which is parallel to the Proterozoic axial schistosity. This is supported by the apparent transition to 'Feldspar Iron Oxide Granitic Rock' which is its unlayered equivalent. Some layering in the quarry at location 40 has been complexly folded (Plate 2B).

In fresh rock the quartz layers are often difficult to recognise but with weathering the feldspar is bleached revealing the quartz.

Feldspar Iron Oxide Granitic Rock:

This rock type outcrops north and south of the Finnis River and seems to be chiefly confined to the core of folded 'Houghton Diorite' type rocks. These feldspar rich rocks are transitional into biotite containing 'Granite' gneiss.

The dominant mineral is plagioclase, $Ab_{(83-87)}$, although most specimens usually have microcline as well. ALthough quartz forms about 10 % of the rock, it is not readily evident in the hand specimen. The other major constituent is opaque having no regular shape or size and occuring as blebs or veins and sometimes giving the rock a rough layering.

Feldspar and Quartz Feldspar Pegmatite:

Such rocks outcrop predominantly in the Mt. Effie Block where they form continuous layers (several metres wide) which are parallel to small scale feldspar layering in the 'Biotite Feldspar Gneisses'.

Mineralogy consists almost entirely of albitic plagioclase with some microcline and quartz. Sericite 'pebbles' (up to several cms.) were found in one outcrop (Plate 3B).

They are probably related to other quartz, feldspar and to quartz, feldspar, opaque rocks. The use of the word 'pegmatite' is only intended to emphasize the coarse crystalline nature of the rocks. It is possible that the feldspar layers are the result of segregation of feldspar, perhaps into original feldspar rich layers and they could thus be envisaged as a large equivalent of the 'Biotite Feldspar Gneiss' layers.

The sericite 'pebbles' referred to in sample 431 are given a metasomatic origin by Chappel (1964, p.8) but could easily be remnants of country rock which were trapped by feldspar as it 'sweated' from the basement.

Fine Grained Quartz Feldspar Iron Oxide Rock:

This rock type occurs as a belt or irregular layer some 2Km. long which is approximately parallel to the Basement-Proterozoic unconformity. Although it is not obviously cross cutting neither is it strictly conformable with layering in the basement. All outcrop is north of the Finnis River.

At first glance the rock resembles a fine to medium grained arkose with heavy minerals, however, it is realized that the granular appearance could be the result of weathering. Microscopic examination reveals that the dominant minerals are microcline, microcline perthite, quartz and opaque. The quartz grains are rounded while the opaque is usually uniform in size and sometimes has a square outline. Zircon grains are relatively large and angular in outline (sample 230).

Fine Grained Massive Grey 'Houghton Diorite' Type:

Referred to as 'Epidote Quartzite' by Chappel (1964).

Outcrop occurs in two localities immediately north and south of the Finnis River (stations 68 & 313). Although outcrops are large their linear extent is small and it is probable that they are transitionary with 'Streaky Houghton Diorite' type. The presence of this rock type at the above two stations makes possible a correlation across the Finnis River valley, so that a fault (no 2) is proposed to explain the movement.

The rock is fine grained, hard and grey with a faint streaking of epidote and amphibole. Superficially it resembles a fine grained quartzite. Microscopic examination reveals microcline, microcline perthite and quartz (some specimens have plagioclase Ab_{84} as a major constituent) as the dominant minerals with epidote, amphibole and opaque in significant quantities. Accessories include sphene, apatite and sub angular zircons.

Layered 'Houghton Diorite' Type:

The blocky nature of these and other Houghton Diorite rocks results in outcrops being scarce or non existent. Local farmers have also tended to break up outcrops with the result that although they are not strictly in place large amounts of float are present. There are two localities immediately north and south of the Finnis River at stations 100 and 313B.

Macroscopically the rock has dark green amphibole layers 2mm wide in buff coloured feldspar. Microscopic examination reveals plagioclase, amphibole, epidote and opaque as major minerals with apatite, sphene and zircon as minor constituents. In both cases the plagioclase is Ab_{60}. The amphibole is probably uralite indicating change from original pyroxene. Zircon grains may be either angular or rounded.

Pink Feldspar 'Granite':

This is an unusual rock type found at only one locality (480) in the Mt. Effie Block. The outcrop measures about 10 yards across and occurs approximately at the intersection of a very large amphibolite dyke and the 'Houghton Diorite' type rock. The actual contact between the Pink Feldspar 'Granite' and the 'Houghton Diorite' type was visible in the outcrop (Plate 2C).

The rock consists of coarse grained pink orthoclase, blebs and veinlets of iron oxide and quartz, and amphibole in some areas. Graphic intergrowth of quartz in feldspar are common.

Coarse Grained Feldspar Pyroxene Pegmatite:

This unusual rock type has only one location, approximately 200 metres south of 'Government Farm' farm house, at station 100. The outcrop has been bulldozed and so very little is in place.

Pyroxene tends to weather easily leaving a quartz feldspar rock with large rectangular voids. Fresh rock (sample 100A) shows an igneous texture with large euhedral or sub euhedral grains of green grey clinopyroxene, and pink or white feldspar. Hornblende is dark green and obviously secondary to pyroxene. It forms blebs and stringers throughout the larger pyroxene grains. (Plate 1B). Iron oxide and quartz are both plentiful and form veins and blebs throughout the rock. Microscopic examination reveals saussuritised plagioclase, Ab_{92}.

It is interesting to note that Benson (1909) and Thomas (1924) both note the presence of a coarse grained pegmatite which is related to the Houghton Diorite, at Houghton and Normanville respectively.

Streaky Amphibole in 'Houghton Diorite' Type:

This is the most common of the 'Houghton Diorite' type rocks and has a wide distribution over the mapped area, however, bulldozing activities make it rare to find the rock in place.

The rock is usually medium grained with elongate amphibole grains in cream or pink feldspar. Quartz and epidote are common. Microscopic examination shows variation in Ab content which is usually Ab_{87} but is Ab_{48} in sample 484. Sample 1500 has 10 % microcline. In addition zircon grains were generally well rounded but in sample 1008 had a definite square outline.

The presence of elongated grains is probably due to tectonic stretching since the thinnest layers have the most mineral elongation. Undulose extinction and recrystallization of quartz also indicate that strain is present.

Speckled Amphibolite:

Outcrops in scattered occurrences throughout the area, but covers large areas around 'Government Farm' farm house and 800 metres north around the Burma Road.

There seems to be a close association, between 'Speckled Amphibolite' and 'Houghton Diorite' rock types although it does not form conformable layers.

'Speckled Amphibolite' is predominantly a fine to medium grained massive rock with green amphibole and cream plagioclase. The amphibole consists of black hornblende and green fibrous actinolite (uralite ?) so that some rock types are black due to a predominance of hornblende. It is significant that samples which possess clino-pyroxene do not possess fibrous actinolite and vice versa. This suggests that fibrous actinolite is uralite derived as a secondary product of clinopyroxene. The plagioclase is nearly always Ab_{60} but some specimens have transparent plagioclase grains making Ab determinations impossible. Chief accessories are rutile, apatite, sphene and zircon.

Green Black Igneous Amphibolite Dykes:

These dykes can be traced for many hundreds of metres although outcrop is scarce. An excellent outcrop is found at station 212 in the bed of the Finnis River. The rock has a Blocky nature and there is a distinct decrease in grainsize towards the edges of the dyke. Onion shell weathering is usual.

Commonly dark amphibole is the dominant mineral resulting in a black coloured rock. At station 418 the amphibolite has 50 % iron oxide. Microscopic examination shows an igneous texture with pink plagioclase laths, Ab_{37}.

Amphibolite Body:

This unusual rock type occurs in only one outcrop, 30 metres across, at station 321. Large boulders of rock remain because the rock is very resistant to weathering. It consists almost entirely of green amphibole with variable grainsize up to 3.5mm. Occasional blebs of iron oxide (polished section 321; appendix I) are present. Several excellent examples of xenoliths (several cms. across) can be seen which have been partly converted to amphibole. (Plate 1A).

PROTEROZOIC:

Basal Coarse Sandstone Arkose and Quartzite:

The basal conglomerate and overlying ilmenitic sub arkose are present as outcrop around the Hope Forest anticline but due to extensive shearing are not found on the east side of the Meadow's Creek syncline. Here the basal unit is represented by porous sandstone, arkose and quartzite. Large outcrops of porous sandstone are present on Billygoat Ridge in the viscinity of the Finnis River and in the extreme north of the area mapped. These are probably the result of weathering of feldspar from arkose. Where the unconformity crosses the Finnis River very large outcrops of massive pink quartzite and arkose are present.

Quartz Muscovite Gneiss and Schists:

They occur along the sheared Basement-Proterozoic unconformity and consist of grey, quartz-muscovite-sericite gneiss with minor biotite, zircon and tourmaline. The quartz is variable both in amount and grainsize. Grainsize and quartz percentage are greatest along Billygoat Ridge but decrease towards the north. Samples show evidence of strong shearing, especially towards the north, with strong undulose extinction and recrystallized quartz. These rocks weather a characteristic pale brown colour.

PERMIAN:

The Permian rocks consist of fluvioglacial sands, gravels and grits. Although pebbles are found on hilltops and ridges most sediments are present in the east-west U-shaped valleys between the Mt. Effie Block and Government Farm Block and between Mt. Effie Block and Mt. Moon Block.

TERTIARY:

Present as remnants of an old laterized land surface. Basically it consists of ferrugenized sandstone, conglomerate, or 'Biotite Feldspar Gneiss'. While it is usually present as a capping on hills, it sometimes covers hillsides in the south Mt. Effie Block, where drainage has been fault controlled and does not interfere with the laterite.

ORIGIN OF BASEMENT ROCKS:

Field relationships, rock texture, and shapes of zircon grains are probably the best indicators of rock origin. Eckelmann and Kulp (1956) use zircons to help with rock genesis, however, Poldervaart (1955, 56) points out that zircons which look rounded in thin section may turn out to be more angular when viewed in three dimensions. Thus, grains such as those in sample 100G which are sub angular in thin section would indicate an igneous origin.

Biotite Feldspar Gneisses invariably have well rounded zircon grains (Plate 3B) which probably indicates a sedimentary origin. Streaky 'Houghton Diorite' type probably has the same origin for the same reason. The Feldspar Quartz Gneiss which is associated with the 'Houghton Diorite' type rocks shows elongated rutile grains in parallel layers. While this may represent original bedding, it is also possible that the rutile grains formed in response to shear stress, so that no definite conclusion concerning rock origin can be reached.

An igneous origin is suggested for 'Speckled Amphibolite' on the basis of field relationships and the presence of black hornblende, and for 'Fine Grained Quartz Feldspar Iron Oxide Rock' on the basis of field relationship, and the idioblastic nature of iron oxide and zircon grains.

The coarse grained pyroxene pegmatite (sample 1000) has an obvious igneous texture with large euhedral pyroxenes, poorly rounded zircons, and remobilized quartz and iron oxide.

'Pink Feldspar Granite' from station 480 may be a small, igneous intrusion or more probably resulted from interaction between amphibolite and 'Houghton Diorite' type rocks.

GEOCHEMISTRY:

INTRODUCTION:

Using minor elements and to some extent major elements it is hoped to distinguish between rocks of igneous (ortho) and rocks of sedimentary (para) origin.

Major elements by themselves have been used by many early workers in the field, but it can be shown that major elements are undiagnostic. The arguement is summed up by Heier (1960):-

"The fact that the major elements of the diverse rocks all plot on relatively smooth curves on the variation curves of the Larson type, shows especially well, the futility of using them as indicators of these highly metamorphosed rocks".

It is evident then, that trace elements must be relied upon as indicators, although they may be used in conjunction with geochemically related major elements. During weathering processes, and during deposition of sediments, fractionation of trace elements occurs, especially where chemical precipitation from solution is present. Some understanding of the effects of physical processes, such as pH, Eh, Temperature and salinity, would be desirable for an understanding of the best elements to use. In addition fractionation also occurs in igneous rocks in response to crystallization of different phases.

Where fractionation occurs it is often the elements with similar chemical and physical properties which make the best indicators. This is because such elements always have slight differences so that a small change in conditions of sedimentation or weathering may cause one element to substitute for another.

Major elements are used to compare igneous and sedimentary rocks of similar composition. Nockolds (1954) supplies numerous average bulk analyses of igneous rocks and from these, the following had a bulk composition similar to 'Houghton Diorite' type rocks: The plutonic rocks; diorites, quartz diorites, granodiorites, quartz monzonites and the volcanic rocks; andesites, quartz andesites (tonalite) and quartz latite could be possible parents. Similarly, sedimentary arenaceous rocks having a small amount of calcareous or dolomitic material could be a parent. Such rocks include marls, greywackes, and shales.

I have endeavoured to compare 'Houghton Diorite' type rocks from the Mt. Compass area directly with obvious igneous amphibolitic rocks in the same area and also with average rock compositions from elsewhere. Ideally rocks of similar bulk chemistry, with known sedimentary and igneous origins, and from the immediate area should be used as 'controls', since they have suffered the same metasomatic and metamorphic history as the unknown rock.

The trace element compositions of those rocks with similar bulk chemistry can then be compared in a variety of ways in an effort to indicate rock origin. Compositions approaching average crystal rocks may occur via igneous or sedimentary processes so that it is the extremes in trace element concentration and the unusual combinations which are most highly diagnostic.

Numerous complications and difficulties arise with the following being the most prominent.

(a) Trace element analyses from the literature commonly are incomplete, have low absolute accuracy, or have done rocks of dubious origin.

(b) Where a sediment has been locally mobilised, it will assume an igneous texture but will have the same chemistry as the sediment.

(c) The degree of country rock assimilation by igneous rocks is commonly unknown and can cause obvious complications.

(d) Little is known about possible metasomatism of these rocks, and since comparisons of rock chemistry are involved it is necessary to assume that the 'Houghton Diorite' type rocks are isochemical. Where layers are very thin it is possible for elements to be transported a small (inches or less) so that the bulk chemistry is altered (Orville 1969). However, in the Mt. Compass area, the 'Houghton Diorite' type layers are usually upwards of three feet in thickness so that a metasomatic change in bulk chemistry is less likely.

COLLECTION AND ANALYSIS OF SAMPLES:

Eight 'Houghton Diorite' type samples were chosen so as to represent both the widest range of modal variation possible, and also a wide areal extent. Three amphibolites (numbers 321, 150, 38B) were chosen because they are closely associated with the 'Houghton Diorite' type rocks and have an unknown origin. Lastly, one amphibolite (number 212) which was definitely igneous on field evidence, was chosen as a 'control' for igneous rocks.

The samples were analysed for the following trace elements - V, Cr, Co, Cu, Rb, Sr, La, Ce, Ba. They were chosen on the basis of their use for this problem in the literature and also on their physical properties and associations with other elements. A summary of their physical properties and associations, together with methods of analysis, are present in Appendix III.

METAMORPHISM:

The degree and date of metamorphic phases effecting rocks in the Adelaide Geosyncline are of critical importance because
(a) Should a sufficiently high grade of metamorphism have been reached, then certain igneous textured rocks with sedimentary trace element ranges, could be the result of local granitization.
(b) Cooper and Compston's (1971) date for the 'Houghton Diorite' has been suggested as being due to the last major prograde metamorphic event and for this to be so, the dates should coinside.

Talbot (1963) has recognised 3 metamorphic phases, the first being of upper amphibolite facies while the second and third are lower greenschist retrograde events. Furthermore he has concluded that the retrograde events occurred in response to deformation before and after deposition of the Torrens Group. Metamorphic features from the Mt. Compass area support Talbot's conclusions although it is not possible to recognise the two regrograde events.

The initial prograde metamorphic phase (or phases) is recognised by relict textures and minerals in the more competant basement layers. Since these features are not found in Proterozoic rocks the event must have occurred before the F_3 folding phase perhaps in response to the F_2 isoclinal folding.

Evidence concerning the degree of metamorphism comes from several sources.

Firstly the Ab composition of Plagioclase is recognised as being a sensitive indicator of metamorphic grade if the rock has sufficient calcium to produce a change to more An rich compositions. Microscopic examination of thin sections shows two distinct Ab compositions. Ab_{90} (range 85 - 92) indicates retrograded Greenschist facies rocks (Turner and Verhoogen 1960 p 533). Ab_{57} range 55 - 64) was common in a amphibole bearing rocks. Turner and Verhoogen (1960 p 549) suggest Ab_{50} as a suitable composition for Upper Amphibolite facies so that Ab_{57} indicates at least Upper Amphibolite facies.

Secondly, the micro texture of many leucocratic rocks often shows a granulite texture with feldspar grains commonly meeting in triple points. Spry (1951) uses this as evidence that Houghton Diorite were granulites.

Thirdly, microscopic examination of thin sections shows relict high grade minerals such as sillimanite and garnet. (Plate 4B). The high grade mineral Sapphirine, with its associated minerals chlorite spinel? and phlogopite, deserves special attention because not only is it rarely found (3 Australian occurences in the literature), but it may be a sensitive indicator of metamorphic grade. Experimental work, carried out by Schreyer and Seifert (1969), show that the sapphirine most often found in nature ($Mg_2Al_4SiO_{10}$) could be synthesised at 13Kb and 900°C (granulite facies conditions) while at 24Kb and 950°C it became unstable. However, a more aluminous sapphirine (which is sometimes found in nature; Vogt 1947) can be synthesised at high temperatures and atmospheric pressures. It is important to note, however, that nearly all occurrences of sapphirine described in the literature are found in granulite facies rocks (Hudson and Wilson 1966, Katz 1972, Morse and Talley 1971, Forrestier et al 1969). Morse and Talley (1971) quote strong experimental evidence for recrystallization at the base of the crust (11-13Kb and 1100 -1150°C). The association of sapphirine with phlogopite mica and with spinel (from which it may form) is also a common one (Hudson and Wilson 1966, Lensch 1971, Morse and Talley 1971, Touret et al 1971, Segnit 1957). It is interesting to note that chlorite was also found with sapphirine in a specimen from the Basement at Mt. Painter (South Australia) by Oliver and Jones (1965).

Summing up, I think the weight of evidence suggests a metamorphic grade at about the upper amphibolite-granulite facies boundary and perhaps even higher into the granulite facies.

Greenschist facies retrogressive events (or event) can be seen in both Basement and Proterozoic rocks suggesting that the major metamorphic phase occurred after deposition of the Torrens Group. It is distinguished by the presence of muscovite and sericite with a small amount of chlorite.

Where such retrograded zones are present in the Basement evidence of strong shearing forces are present on both a macro and micro scale. Quartz grains are heavily strained or recrystallized, broken, and have edges which are granulated with sericitization (Plate 4C). Alderman(1938) quotes this as evidence of dynamic metamorphism. In addition retrogradatic can be seen in 'Houghton Diorite' type rocks where actinolite has formed from hornblende (Uralitization), hornblende from pyroxene (Plate 1B) and epidote and sericite from feldspar (saussuritization). Thick sheaves of sericite surround relict sillimanite (Plate 4B) which is used as retrograde criteria by Kleeman and White.

MULTIVARIATE DISCRIMINANT FUNCTION (D.F.): (Davis and Sampson 1966).

D.F. analysis is a statistical method of assigning samples to previously defined populations (in this case ortho and para), on the basis of a number of variables considered simultaneously. A population defined by K variables (trace elements) may be pictured as a cluster of sample points in K dimensional space. D.F. analyses separates 2 populations by a K dimensional plane. The means of each population, $\bar{x}_1$

and R_2, are calculated and the degree of distinctiveness is a measure of the distance between the two points (called MAHALANOBIS D^2 in the computor program). Probabilities of misclassification to either population are equal.

The percentage contributed (PRCT. ADDED in the computor) by the different varibles is computed so that the relative importance of each may be ~~dropped from~~ ascertained. Those with negative or slightly positive values may be dropped from the equation since they only have slight or zero effect. Before delesting these values their actual overall effect may be tested using the F (Fisher) test. An equation for this is present in Rao (1965) and an example is presented in Appendix V.

A similar D.F. was used by Shaw and Kudo (1965) on 20 ortho and 20 para amphibolites. This resulted in Co, Sc, and Cr being important discriminators. Although I obtained a different D.F. equation on the same data the same elements were important. V, Ni, Sr were shown to have little contribution and so were delested.

From Shaw and Kudo's data the following D.F. emerged: -0.55 log Cr + 4.52 log Co with an R zero of 5.30 midway between the two populations. Van de Kamp's (1968) data, which had a slightly different range of trace elements produced the D.F. 6.14 log Cr + 1.98 log Ni - 3.12 log Rb with an R zero of 12.13 In addition it was decided to try some new element ratios based on close element associations. Van de Kamp's (1968) data was used as a basis and the resultant D.F. -2.7 log Rb/Sr -0.2 log La/Ce - 4.5 log Sr/CaO + 5.6 log Cr/MgO + 3.7 log Ni/MgO, with an R zero of 12.63, was a successful discriminator.

The following elements and ratios were tested. TiO_2, Al_2O_3, Fe_2O_3, FeO, Cr, V, Ni, Co, Sr, Rb, Ce, La, Cu, Zn, Ba, Rb/Sr, La/Ce, Rb/K_2O, Sr/CaO, Cr/MgO, Ni/MgO. Of these the following (In approximate order) were most discriminatory Cr, Rb, Ni, Cr/MgO, Sr/CaO, Rb/Sr, Co, and La/Ce. It should perhaps be mentioned that although Shaw and Kudo's (1965) data indicated that Sc was an excellent discriminator it was not possible to analyse for it due to technical difficulties.

The above D.F. equations were then applied to the 'Houghton Diorite' type rocks and to the rock averages from the literature (Table 2). It should be borne in mind that due to the difficulty of finding trace element analyses in the literature, the control data is from rocks of

TABLE 2

MULTIVARIATE DISCRIMINANT FUNCTION CLASSIFICATION.

D.F.	− 0.55 log Cr + 4.52 log Co.		6.14 log Cr + 1.98 log Ni −3.12 log Rb.		− 2.7 log Rb/Sr −4.8 log Sr/CaO + 5.6 log Cr/MgO + 3.7 lg Ni/MgO − 0.2 log La/Ce.	
POPULATION	> R zero = ORTHO* R zero = 5.30 < R zero = PARA*		> R zero = ORTHO R zero = 12.13 < R zero = PARA		> R zero = ORTHO R zero = 12.63 < R zero = PARA	
'HD' TYPES.	VALUE	CLASSIFICATION	VALUE	CLASSIFICATION	VALUE	CLASSIFICATION
68	6.2	ortho	7.8	para	11.4	para
457	5.7	either	6.4	para	11.6	para
484	6.5	either	5.5	para	9.3	para
453	6.4	either	10.4	para	14.7	ortho
475	5.9	either	6.0	para	9.2	para
516	5.3	either	9.6	para	13.6	ortho
313A	5.5	ortho	12.3	either	14.9	ortho
100G	5.5	either	11.2	either	12.8	either
MT. COMPASS AMPHIBOLITE						
321	6.7	ortho	9.9	para	10.4	para
150	7.1	ortho	11.6	either	22.1	ortho
38B	6.7	ortho	16.9	ortho	17.0	ortho
212	7.1	ortho	12.1	either	13.9	ortho
AVE. ROCKS						
ortho amphib.	5.9	ortho	14.5	ortho	15.5	ortho
para amphib.	5.3	either	9.4	para	10.6	para
andesite	5.3	either	8.6	para	10.0	para
granodiorite	3.7	para	5.1	para	8.4	para
marl	3.2	para	8.8	para		
dolomitic sediment	1.1	para	7.0	para		
shale	4.7	para	8.9	para		

* ORTHO represents rocks of igneous origin.

PARA represents rocks of sedimentary origin.

amphibolitic composition, and thus the major element composition is slightly different to the 'Houghton Diorite' type rocks which are more siliceous.

The following are the overall results of the 3 D.F.'s, most weight goingto those functions with the most variables.

The 'Houghton Diorite' type rocks are usually discriminated as Para with samples 313A and 100G having a possible ortho classification. Of the four amphibolites, 150, 38B, and 212, are of obvious igneous origin, (para), while 321 could be either igneous or sedimentary. From the average rock compositions in the literature the average ortho and average para amphibolites are assigned to their correct categories. The sedimentary rocks, marl, dolomitic sediment, and shale are correctly assigned to the para category, along with andesite and granodiorite. Andesite and granodiorite may have been assigned in this way because they were metamorphosed sediments which were mistaken for igneous rocks.

In theory, the method provides an excellent way of distinguishing the two populations ortho and para, but in practice, due to the lack of good local control analyses of similar major element composition, results can only be used as a guide. It does, however, indicate the most discriminating elements for use in the next section.

TWO DIMENSION AL REPRESENTATIONS:

Graphs of this type have been extensively used in the past, and while they provide 'an easy to understand' picture, they can use, at the most three variables. It is not intended to discuss each graph separately because most are self explanatory and the majority reach the same conclusion.

As predicted earlier, plots of major elements vs. major elements are unsuccessful (Fig 6D). Plots of trace elements vs. major elements (or niggli ratios) are rather more successful. (Figs. 7A,C). By far the most successful are plots of trace elements vs. trace elements (Trace elements are log distributed and so log-log graph paper is used). Cr vs. Ni, Co vs. Ni, Ni vs. Cu and Cr vs. V produce the best groupings.

Those trace elements producing the most significant groupings are

EXPLANATION OF FIGS. 6, 7, and 8.

⊙ Houghton Diorite Types (numbers 68, 457, 484, 453, 487, and 516.) These plot similarly and so are un-numbered.

⊙ 100G Houghton Diorite Types (numbers 100G and 313A which are numbered on most diagrams because of the chemical differences they show.

● Amphibolites from the Mt. Compass area which are numbered to indicate which samples are variant.

Average Ortho Amphibolite (Authors as in Table 1)

Average Para Amphibolite.

Average Andesite.

Average Granodiorite.

Average Marl.

Average Dolomitic Sediment.

Average Greywacke.

Average Quartz Diorite.

Average Shale.

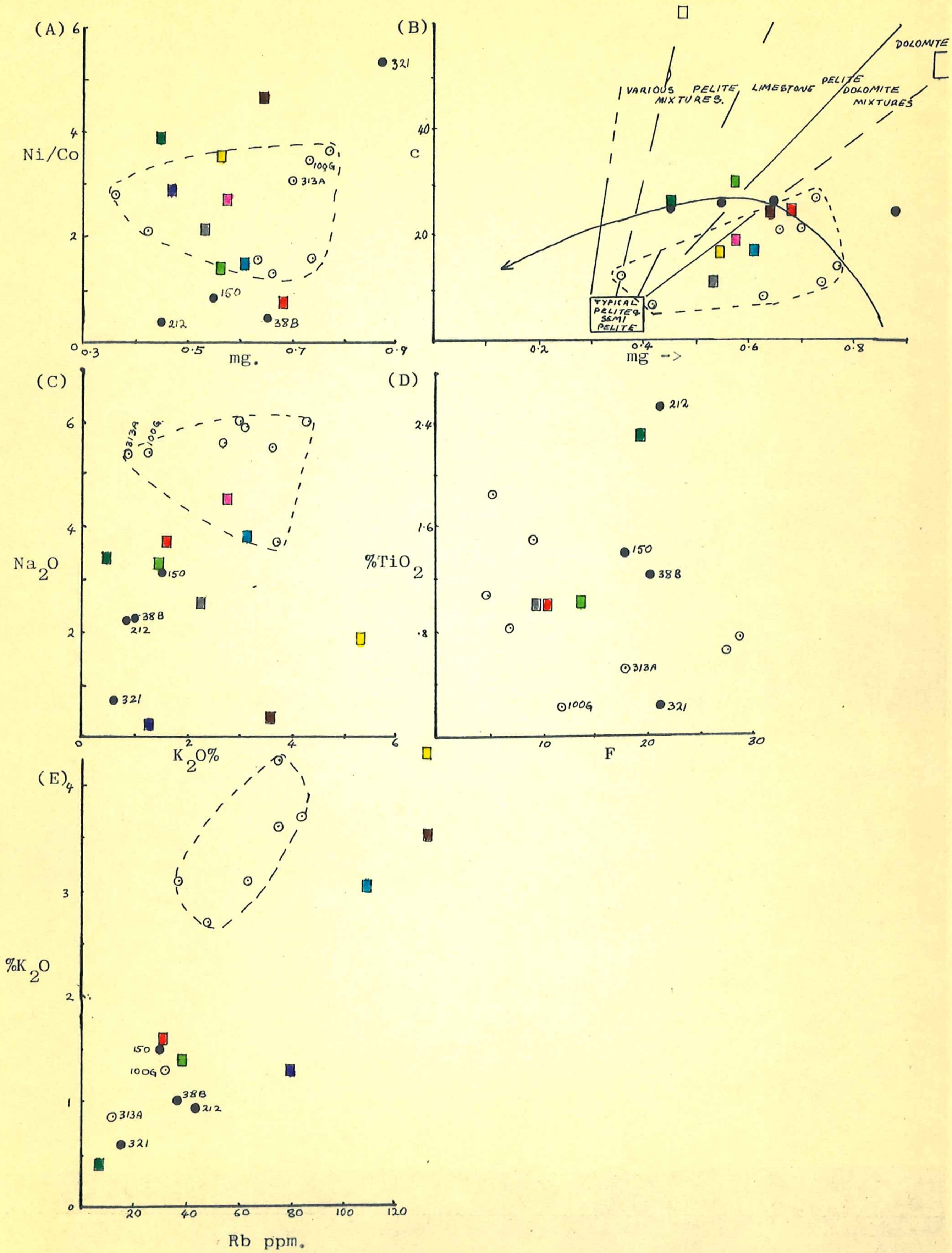
The broken line delineates the field covered by 'Houghton Diorite' type rocks.

The unbroken line is sometimes used to indicate the effect of separating the samples 100G and 313A.

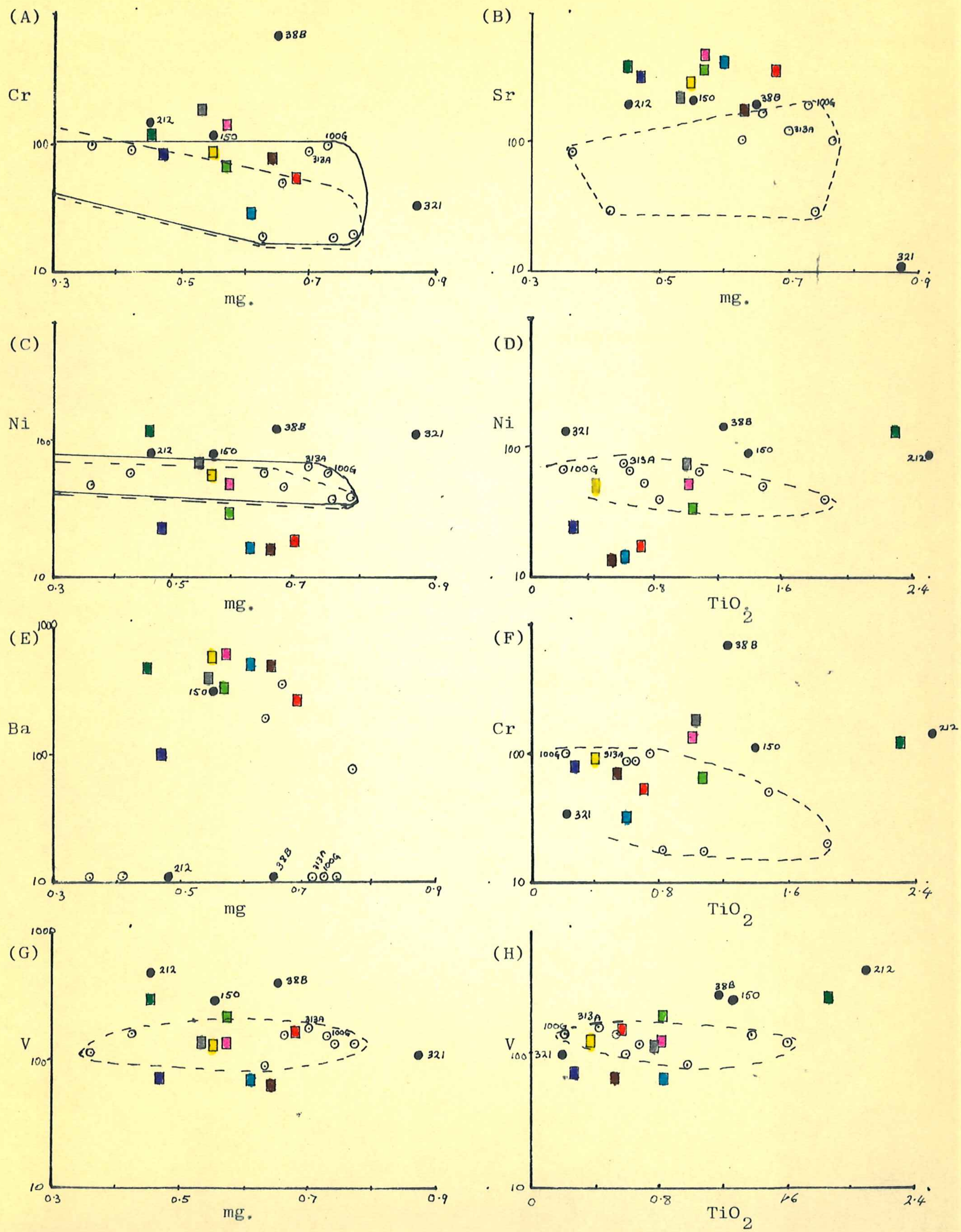
Derivation of diagrams is summarised in Appendix V.

NORMAL - NORMAL GRAPHS.

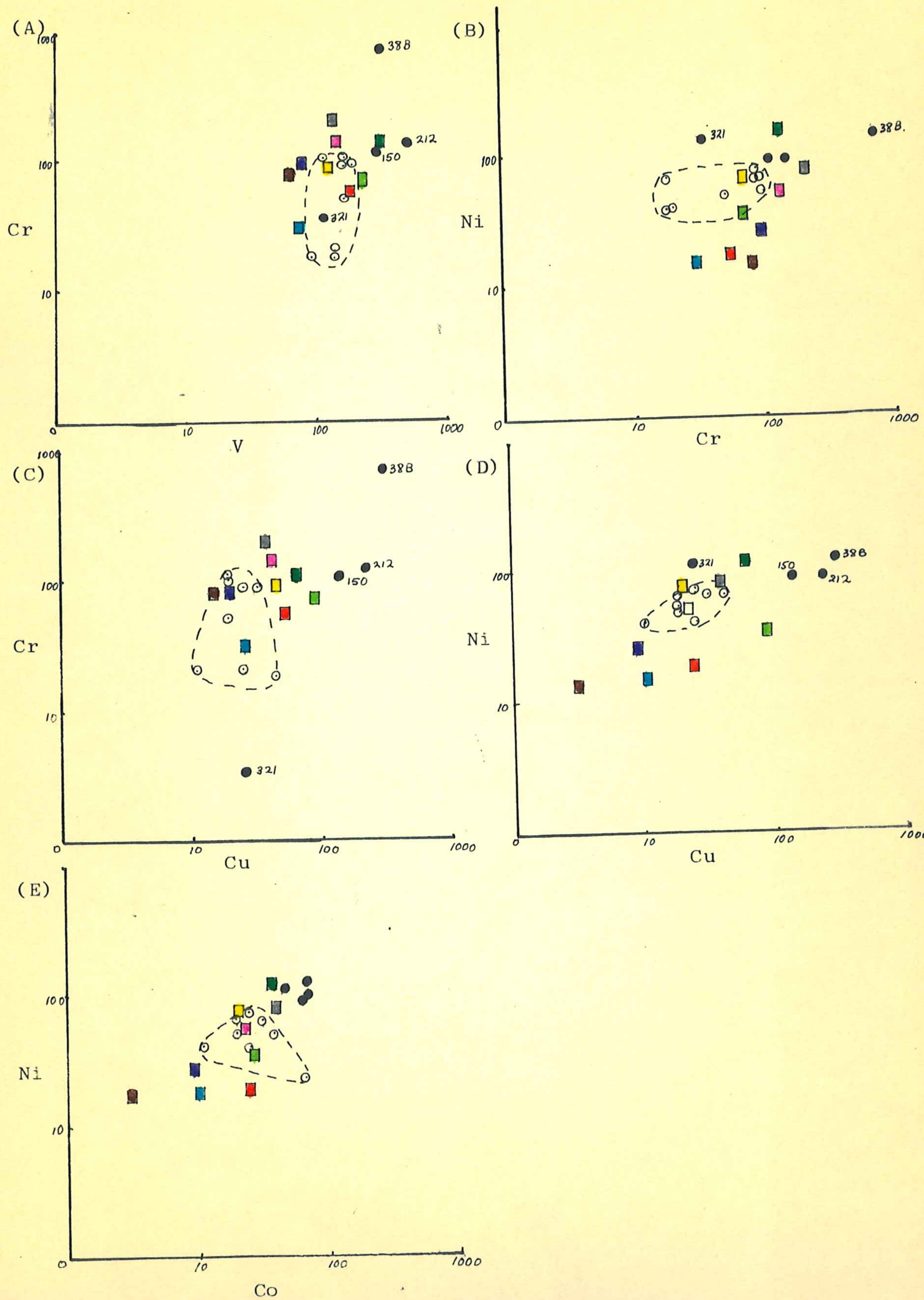
FIG. 6.



LOG - NORMAL PLOTS.



LOG - LOG GRAPHS. FIG. 8.



invariably those classed as most discriminating by the Discriminant Function Analysis.

Where the 'Houghton Diorite' type rocks form a regular grouping they have been enclosed by a broken line. This makes it possible to see, at a glance, which average element compositions plot within or close to this boundary. It is notable that the average shale invariably plotted within this boundary (12 times) while the quartz diorite and para amphibolite each had a significant score (7 times). This would suggest quite strongly that the 'Houghton Diorite' type rocks had a sedimentary origin. It would also throw some doubt on the origin of the seven quartz diorites used in the average.

It is significant that the average ortho amphibolite which can be easily proved igneous in origin, and also the igneous rock 212, never plot within the 'Houghton Diorite' type boundary. Amphibolites 38B and 150, which have an uncertain origin on the basis of field work, always plot with the igneous amphibolites and so are almost certain to be of igneous origin.

Sample 321, while showing both igneous (Fig 8E) and sedimentary (Fig 7F) features, usually plots in a field of its own. (eg Figs. 8A, 7G, 8C). In view of this unusual behaviour and in view of the obvious igneous field characteristics (Plate 1A) it seems probable that it represents a locally remobilized sedimentary rock. In addition the K/Rb ratio is extremely high (1220 ; Table 1) so that the average value of 240 is far exceeded. (Taubeneck 1965). This, together with the evidence from Leake's (1963) diagram (Fig. 6B), indicates very low fractionation, thus supporting the above origin.

Samples 100G and 313 deserve special mention because, while they usually plot in the sedimentary field, they not uncommonly plot in igneous fields (especially Fig 6E). Since they both have obvious igneous petrological features (sample 100G is a coarse grained pegmatite) it is possible they represent locally remobilized 'Houghton Diorite' type rock.

Fig 6B is Leake's (1963) fractionation diagram which has been extensively used with success by later workers. (Moldhus 1971, Sillings, Ragland and Harris 1966). The arrow represents the fractionation path of the Karroo dolerites and should be approximately followed by any suite of basic or semibasic igneous rocks from the same area. Rocks of sedimentary origin should plot between pelite and dolomite-limestone compositions. 'Houghton Diorite' type rocks show themselves to be of sedimentary origin while samples 212, 150 and 38B lie exactly along the igneous fractionation trend as expected. Sample 321 is again enigmatic. Furthermore, the original sedimentary rocks appear to have been dolomitic shales.

DISCUSSION:

Evidence for the origin of the different rock types in the area is presented in the sections Geology, Petrology and Geochemistry. Further discussion is warranted on 'Houghton Diorite' type and associated rocks.

On the basis of field relations and geochemistry the 'Speckled Amphibolites' are obviously of igneous origin, however, although they seem to be related to the 'Houghton Diorite' type rocks on field evidence, the exact mature of this relationship is unknown.

Data has been presented which shows that the 'Houghton Diorite' type rocks have a sedimentary origin, while the pegmatitic variety has a remobilized sedimentary origin. Evidence for a sedimentary origin is summarised as follows:

(a) The wide chemical and mineral variation between samples is unlike an igneous rock.
(b) A predominance of well rounded zircon grains suggests a detrital origin.
(c) The close conformity with the basement layering, and lack of discordant contacts, does not support an igneous origin.
(d) Multivariate Discriminant Function based mainly on Cr, Ni, and Rb, supports a sedimentary genesis.
(e) Two dimensional diagrams tend to separate igneous and sedimentary (including 'Houghton Diorite' type) rocks, into separate fields.

Pegmatite, 100G, which geochemical evidence suggests was formed as a result of local mobilization of 'Houghton Diorite' type rock, has an equivalent near the Normanville 'Houghton Diorite' type rocks (Thomas 1924). This pegmatite was dated on the basis of the Pb:Th ratio in monazite and found to be 1,073 m.y. old.

CONCLUSION:

Due to the number of unknown variables, such as dates of metamorphic events, it is not possible to make a definite statement concerning Cooper and Compston's (1971) age of 870 m.y., for the Basement. It is, however, unlikely to represent intrusion of a dioritic magma since trace element data suggests a dolomitic shale as parent to 'Houghton Diorite' type rocks.

A discrepancy is caused by Thomas's (1924) age of 1,073 m.y. for a pegmatite which is related to, and probably remobilized from, 'Houghton Diorite' type rocks. Relict minerals suggest a sufficiently high grade of metamorphism, possibly into the granulite facies, has been attained.

The problem could be best tackled in the future, by isotopic dating of 'Houghton Diorite' type and related pegmatitic rocks in different inliers of the Adelaide Geosyncline.

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APPENDIX I

SELECTED THIN AND POLISHED SECTION DESCRIPTIONS:

The following selected rock specimens along with others, are lodged in the Department of Geology under the prefix 375.

Thin Sections:

38A	Speckled Amphibolite.
38B	Layered Amphibolite.
40A	Feldspar Quartz Layered Gneiss.
40B	Speckled Amphibolite.
40C	Layered Fine Grained 'Houghton Diorite' Type.
67	Fine Grained Igneous Amphibolite.
68B	Fine Grey 'Houghton Diorite' Type.
69	Feldspar Iron Oxide Granitic Rock.
71	Feldspar Iron Oxide Granitic Rock.
75	Quartz Feldspar Iron Oxide Biotite Gneiss.
76	Quartz Feldspar Iron Oxide Granite Gneiss.
77	Feldspar Iron Oxide Granite Gneiss.
78	Biotite Feldspar Granite Gneiss.
79	Biotite Feldspar Granite Gneiss.
80	Muscovite Quartz Gneiss.
84	Igneous Amphibolite.
88	Feldspar Quartz Iron Oxide Gneiss.
89A	Feldspar Quartz Iron Oxide Granitic Rock.
95	Fine Grained Grey 'Houghton Diorite' Type.
100B	Streaky 'Houghton Diorite' Type.
100C	Layered 'Houghton Diorite' Type.
100G	Coarse Grained Feldspar Pyroxene Pegmatite.
118	Speckled Amphibolite.
141	Speckled Amphibolite.
150	Black Speckled Amphibolite.
150D	Streaky 'Houghton Diorite' Type.
150F	Streaky 'Houghton Diorite' Type.
150G	Granitic Biotite Feldspar Gneiss.
165	Biotite Feldspar Gneiss.
174	Quartz Rich Muscovite Biotite Gneiss.

198 Speckled Amphibolite.

212F Igneous Amphibolite.

230 Fine Grained Feldspar Quartz Iron Oxide Rock.

233 Black Speckled Amphibolite with unusual White 'Pebbles'.

313B Layered 'Houghton Diorite' Type.

313D Fine Massive Grey 'Houghton Diorite' Type.

321 Massive Amphibole.

400 Biotite Feldspar Gneiss.

431 Sericite Nodule From Pegmatite Layer.

453 Phlogopite Schist with Chlorite Sapphirine Porphyroblasts.

480 Pink Feldspar 'Granite'.

484 Streaky 'Houghton Diorite' Type.

516 Fine Grained Grey 'Houghton Diorite' Type.

521 Sillimanite Gneiss.

532 Feldspar Iron Oxide Gneiss.

Polished Sections:

321 Hematite.

100 Magnetite and Hematite.

519 Hematite.

452 Maghemite and Ilmenite.

375/38A **SPECKLED AMPHIBOLITE.**

MACRO: A fine to medium grained amphibolite with a faint amphibole layering. Green and black amphiboles are present in a cream coloured feldspar matrix. The weathering product is yellow brown.

MICRO: Granoblastic texture with hornblende partly retrograded to actinolite. Sericite occurs as a fine haze through plagioclase while epidote occurs in thin veins and on plagioclase amphibole boundaries.

HORNBLENDE: About 35%. Size average 0.5mm. Sub idioblastic grains. Strongly pleochroic, α = light straw yellow, β = dark khaki green, γ = olive green. Biaxial (-), $2V = 85^\circ$, $z \wedge c = 24^\circ$.

ACTINOLITE: About 40%. Size average 0.6mm. Xenoblastic grains. Moderately pleochroic, α = very pale cream, β = pale yellow green γ = pale green or deep green. Colour patching is common and particularly concentrates around edges and inclusions. Commonly has a fibrous nature. Biaxial (-), $2V = 70 - 85^\circ$, $z \wedge c = 20^\circ$.

PLAGIOCLASE: About 20%. Size average < 1mm. Multiple twinning is uncommon. Grains are equidimensional. Biaxial (-), $2V = 80^\circ$, Ab_{57} (Michel Levy).

OPAQUES: About 3%. Size average 0.1mm and constant. Generally altered to sphene on the margins. Some are octahedral in shape.

EPIDOTE: About 2%. Size average <0.1mm. Weakly pleochroic.

ACCESSORIES: Apatite, Sphene, Limonite (associated with actinolite.)

375/38B LAYERED AMPHIBOLITE.

MACRO: Amphibole grains are variably in size and distribution and form a rough layering in pinkish feldspar. Opaques are also present with the medium green and dark green amphiboles. Average grainsize 1.5mm up to 3mm.

MICRO: Nematoblastic to granoblastic texture which has igneous affinities. Large plagioclase, hornblende and actinolite crystals have a groundmass of quartz. Boundaries between the two amphiboles are transitionary. Some microperthite is present.

HORNBLENDE: About 20%. Size average - large and variable. Sub idioblastic grains. Strongly pleochroic, α = straw yellow, β = yellow brown, γ = dark green. Occasional plagioclase inclusions may be present. Biaxial (-), 2V = 80^{o}, $z^{\wedge}c = 26^{o}$.

ACTINOLITE: About 30%. Size average 3mm. anhedral. Obviously sedondary to hornblende. Some fibrous grains make optical measurement difficult. Dull brownish green colour, weak pleochroism. There are many small quartz and opaque inclusions. Biaxial (-), High 2V, $z^{\wedge}c = 20^{o}$.

PLAGIOCLASE: About 44%. Size up to 5mm. Euhedral shape. Fine sericite is common especially along twin boundaries. Multiple twinned, plagioclase occurs in patches in non twinned plagioclase and amphibole grains. (Plate 3A). Usaully has slight undulose extinction. Uniaxial (+).

OPAQUE: About 1%. Grainsize <0.5mm but may be 1mm. Rimmed with sphene.

ACCESSORIES: Sphene, Apatite.

375/40A (2 slides made) FELDSPAR QUARTZ LAYERED GNEISS.

MACRO: A quartzo feldspathic gneiss with light pink feldspar. Feldspar is coarse grained while the quartz forms stringers or veins (up to 7mm) about 1mm apart. Also parallel to this layering is a small grained strongly elongated dark brown mineral which is also in layers. Does this represent rutile or monozite from past sedimentary bedding? The quartz stringers are complexly folded in some specimens. (Plate 2B)

MICRO: Plagioclase forms a granoblastic texture but through this in layers or zones are elongate feldspar, rutile (?), and quartz indicating micro shear zones. Minor quartz filled cracks also occur at 90° to the main layering.

PLAGIOCLASE: About 60%, grains commonly up to 3mm. Multiple twinning is common. These may be fractured parallel to the overall layering. Hazy sericite is especially present along cleavage and twin planes. R.I. plagioclase < R.I. quartz. Ab_{84} (Michel Levy).

QUARTZ: About 38%. Size average 0.5mm. Most grains occur in veins and show strong undulose extinction.

RUTILE: About 2%. Size average 0.4mm. Usually in cigar shaped bodies (3mm X 0.2mm). Deep yellowish brown colour, pleochroic. Small size prevented determination of optical measurement.

375/402 **SPECKLED AMPHIBOLITE.**

MACRO: Very fine grained amphibolite with equigranular green and white minerals. Moderately weathered.

MICRO: Granoblastic texture. Epidote commonly forms stringers between actinolite and plagioclase or hornblende and plagioclase.

HORNBLENDE: About 30%. Size average 0.4mm. Two good cleavages at 120°. Strongly pleochroic, α = cream to white, β = olive green, γ = pale green. Biaxial (-), 2V = 90°, $z \wedge c = 30^{\circ}$.

ACTINOLITE: About 20%. Size average 0.5mm. Weakly pleochroic, α = pale cream, β = pale greenish yellow, γ = deep green. Biaxial (-).

PLAGIOCLASE: About 36 %. Size average 0.3mm. Plagioclase twinning is uncommon. Ab_{60} (Michel Levy). Biaxial (-). High 2V.

MICA (Biotite?) : About 5 %. Mainly associated with hornblende. Biaxial (-). Parallel extinction, 2V = 15°. Strongly pleochroic, α = cream, $\beta = \gamma$ = bright yellow.

OPAQUES: About 1 %. Some have octahedral outline.

SPHENE: About 2 - 3 %. Size average 0.2mm. As coronas around opaques and as individual grains.

EPIDOTE: About 5 %. Size average 0.1mm. Weakly pleochroic.

ACCESSORIES: Rutile, Apatite.

375/40C LAYERED FINE GRAINED 'HOUGHTON DIORITE' TYPE.

MACRO: Fine grained layered amphibole gneiss (heavily weathered). Amphibole : Plagioclase is 1 : ½. Amphibole grainsize average is 0.5mm. but may be up to 4mm.

MICRO: Nematoblastic to granoblastic texture. A slight grain orientation is present giving indistinct layering, but grainsize is mostly even

EPIDOTE: About 20 %. Size average 0.1mm. Slightly pleochroic. Biaxial (-), 2V = 90°.

PLAGIOCLASE: About 50 %. Size average 0.5mm. Cloudy with sericite inclusions. Multiple twinning is uncommon.

ACTINOLITE: About 10 %. Size average 0.4mm. /Fibrous appearence. Slightly pleochroic. Biaxial (-), High 2V, z^c = 18°.

OPAQUE: About 5 %. Often has a sub idioblastic outline. (octahedral).

ACCESSORIES: Sphene, Apatite, Rutile.

QUARTZ: About 15 %. Size average 0.3mm. Boundaries are irregular clear grains show strong undulose extinction. Grains are slightly elongate and oriented.

375/67 FINE GRAINED IGNEOUS AMPHIBOLITE.

MACRO: A dark green-black fine grained amphibolite with more amphibole than plagioclase.

MICRO: Strongly interlocking euhedral actinolite crystals in a plagioclase groundmass. Texture looks igneous.

ACTINOLITE: About 60 %. Size is variable, <0.6mm. Pleochroic, α = light greenish yellow, β = green, γ = bright green blue. Some grins are twinned. Biaxial (-), High 2V, $z\wedge c = 20^{o}$.

PLAGIOCLASE: About 35 %. Size average 0.4mm. Grains are elongated and pinkish in colour. Multiple twinning is uncommon. Ab_{37} (Michel Levy).

EPIDOTE: About 3 %. Size average 0.imm.

OPAQUE: About 2 %. Irregular size and shape.

ACCESSORIES: Sphene.

375/68B **FINE GREY 'HOUGHTON DIORITE' TYPE.**

MACRO: A fine grained saccaroidal, hard, grey felsic fock with faint short streaks of green brown and black mineral. It resembles a quartzite at first glance.

MICRO: Granoblastic, fine grained, with perhaps a slight orientation of actinolite and epidote.

MICROCLINE: About 45 %. Size average 0.3mm. Cross hatching and perthite are fairly common.

QUARTZ: About 40 %. Uniform grainsize (average o.25mm). Outlines are generally rounded.

EPIDOTE: About 8 %. Grainsize <0.2mm. Often forms in association with amphibole grains.

AMPHIBOLE: About 5 %. Size average 0.2mm. Pleochroic, α = straw yellow or clear, β = green, γ = blue green. Biaxial (-), Large 2V, $z \wedge c = 20^{o}$.

OPAQUE: About 2 %. Grainsize and shape variable.

ACCESSORIES: Sphene (associated with opaques), Apatite, Zircon (up to 0.2mm with square, rectangular, or sub rounded outlines), Plagioclase (with a brown haze of fine inclusions).

375/69 FELDSPAR IRON OXIDE GRANITIC ROCK.

MACRO: Massive pink feldspar with iron oxide in veinlets and blebs. Minor quartz is also present.

MICRO: Grains are mainly equidimensional but variable in size. Boundaries are irregular. Evidence of shear stress is present in frequent infilled fractures, broken plagioclase grains and recrystallized grain aggregates.

PLAGIOCLASE: About 78 %. Grainsize <1.5mm. Multiple twinning common. Ab_{87} (Michel Levy). Sericite haze is common.

QUARTZ: About 10 %. Grainsize <3mm. Grains aggregates of small grains (0.2mm) are common. Quartz filled veins are common. Grains show strong undulose extinction.

OPAQUE: About 10 %. Boundaries are very irregular suggesting mobilization.

MICROCLINE: About 1 %. Size average 0.5mm. Cross hatching is present.

MUSCOVITE: About 1 %. Size average 0.1mm. Its uneven distribution may suggest it is secondary.

ACCESSORIES: Tourmaline, Rutile, Apatite, Zircon (occasional well rounded grains <0.1mm).

375/71 <u>FELDSPAR IRON OXIDE GRANITIC ROCK</u>.

MACRO: A massive feldspar quartz gneiss with minor opaque giving a rough layering.

MICRO: Equidimensional grains with irregular size. Grain boundaries are highly irregular and texture could be called sub mylonitic.

PLAGIOCLASE: About 80 %. Size average 2mm. Multiple twinning is common. Ab_{83} (Michel Levy).

QUARTZ: About 10 %. Size average of large grains = 2mm. Recrystalized aggregates are common with polygonal grains 0.1mm.

OPAQUES: About 5 %. Size and shape variable.

ACCESSORIES: Tourmaline (Green, slightly pleochroic), Zircon (small grains <0.1mm, sub rounded).

375/75 **QUARTZ FELDSPAR IRON OXIDE BIOTITE GNEISS.**

MACRO: A strongly layered quartz feldspar opaque biotite gneiss. Pink feldspar layers (5mm thick) are interbanded with muscovite, quartz and opaque. Feldspar augen (30mm X 6mm) are present.

MICRO: Granoblastic to nematoblastic texture. Most feldspar grains are equidimensional but those that are elongated are orientated parallel to the quartz and opaque layering. Grainsize and boundaries are irregular and there is evidence of considerable deformation.

PLAGIOCLASE: About 75 %. Size average 1.5mm. Most grains show multiple twinning. Ab_{88} (Michel Levy). Some grains are fractured and infilled with quartz.

QUARTZ: About 20 %. Usually in vein form ($\sim$1mm wide) and consists of recrystalization aggregates with individual grains (0.2mm). Other areas of quartz show strong undulose extinction.

OPAQUE: About 4 %. Grains are irregular in shape and size but are orientated parallel to layering.

BIOTITE: About 1 %. Grains <0.5mm.

ACCESSORIES: Tourmaline (green), Zircon (rounded, oval shape grains <0.1mm).

375/76 <u>QUARTZ FELDSPAR IRON OXIDE GRANITE GNEISS</u>.

MACRO: Quartz feldspar opaque granite gneiss with a faint layering of opaque and buff coloured feldspar.

MICRO: Coarse grained sub-granoblastic rock.

PLAGIOCLASE: About 60 %. Size average 1.5mm. Grains are equidimensional. Multiple twinning is common. Ab_{87} (Michel Levy).

QUARTZ: About 30 %. Variable grainsize 0.5 - 1mm. Strong undulose extinction.

OPAQUES: About 5 %. Size average 0.2mm in clusters. Strongly pleochroic, α = dark green brown, $\beta = \gamma$ = light khaki green.

ACCESSORIES: Muscovite, Apatite, Zircon (Sub rounded).

375/77 **FELDSPAR IRON OXIDE GRANITE GNEISS.**

MACRO: Granitic rock with large (1-6mm), pink, equidimensional feldspar grains, biotite and opaque. Biotite : feldspar ratio is 1 : 5. A very faint gneissic layering is present.

MICRO: No layering is evident on micro scale. Grainsize is extremely variable but shape is equidimensional.

MICROCLINE: About 70 %. Grainsize <5mm. Perthite is common. Undulose extinction is common. Biaxial (-). $2V = 75^{o}$.

QUARTZ: About 18 %. Size average 1mm with polygonal grain aggregates. Larger grains show strong unduloso extinction.

BIOTITE: About 7 %. Grainsize <0.5mm. Strongly pleochroic, α = dark brown black, $\beta = \gamma$ = straw yellow.

MUSCOVITE: About 3 %. Broken and scattered aggregates closely associated with biotite.

CHLORITE: 1 %.

EPIDOTE: 1 %.

ACCESSORIES: Opaque, Apatite, Plagioclase.

375/78 **BIOTITE FELDSPAR GRANITE GNEISS.**

MACRO: Fine even grained feldspar opaque rock. A weak layering is apparent.

MICRO: Granoblastic, medium, even grained rock with no preferred mineral orientation. Quartz and biotite grains are evenly distributed.

PLAGIOCLASE: About 40 %. Size average 0.5mm. Multiple twinning rare. Grains are strongly serisitized. Ab_{90}(Michel Levy).

QUARTZ: About 5 %. Grainsize <0.5mm. Strong undulose extinction.

OPAQUE: About 5 %. Highly variable shape and size.

BIOTITE: About 5 %. Strongly pleochroic, α = dark green, $\beta = \gamma$ = light yellow.

ACCESSORIES: Sphene (associated with opaques), Apatite, Muscovite, Zircon (<0.1mm, usually well rounded but some look 'broken').

375/79 **BIOTITE FELDSPAR GRANITE GNEISS.**

MACRO: Granite gneiss with large (4mm) pink feldspar, biotite and opaque. Augen of feldspar are present.

MICRO: Lepidoblastic gneissic texture with muscovite and biotite forming layers and lenses between large quartz and microcline grains.

MICROCLINE: About 45 %. Grainsize 1-4mm. Cross hatching is common. Some grains are perthitic.

QUARTZ: About 25 %. Size average 1mm. Strong undulose extinction. Recrystalized aggregates (individual grains 0.1mm) are common.

MUSCOVITE: About 20 %. Irregular layers (0.7mm wide) consist of fine grains (<0.1mm).

BIOTITE: About 5 %. Usually associated with the muscovite. Strongly pleochroic, α = dark green, $\beta = \gamma$ = straw yellow.

OPAQUES: About 5 %. Irregular in shape and size and associated with the micas.

ACCESSORIES: Tourmaline, Limonite, Rutile.

375/80 <u>MUSCOVITE QUARTZ GNEISS</u>.

MACRO: Fine grained muscovite schist with occasional clear quartz grains (~1mm).

MICRO: Fine grained lepidoblastic rock with quartz in grains and veins. Porphyroblasts (1mm) of a high relief yellow brown material are present.

MUSCOVITE: About 80 %. Size average 0.2mm. Biaxial (-). $2V = 10^{\circ}$.

QUARTZ: About 15 %. Large grains up to 3mm show strong undulose extinction. Recrystallized aggregates are common.

YELLOW BROWN MATERIAL: About 4 %. Small irregularly shaped grains. Poikiloblastic structure. Probably limonite but could be staurolite.

ZIRCON: About 1 %. Grains are well rounded. Size average 0.05mm.

ACCESSORIES: Limonite.

375/84 **IGNEOUS AMPHIBOLITE.**

MACRO: Dark green, amphibole rich, fine grained, amphibolite.

MICRO: Fine even textured, igneous rock with no preferred mineral orientation.

HORNBLENDE: About 70 %. Grainsize <0.5mm. Sub euhedral elongate grains. Strongly pleochroic, α = cream, β = darl green. γ = bright green.

PLAGIOCLASE: About 15 %. Grainsize <0.5mm. Anhedral grains showing undulose extinction. Multiple twinning rare. Ab_{55} (Michel Levy).

QUARTZ: About 5 %. Small rounded equidimensional anhedral grains.

EPIDOTE: About 5 %. Grainsize <0.2mm. Slightly pleochroic, light green yellow.

OPAQUES: About 5 %. Highly irregular shape and size. Evenly distributed on a micro scale.

375/88 **FELDSPAR QUARTZ IRON OXIDE GNEISS.**

MACRO: Hard fine grained grey felsic rock with a rough fissility produced by muscovite.

MICRO: Sub granoblastic texture. Grainsize is variable and boundaries have sericite and biotite which also forms rough layers. Quartz veins (0.6mm) are also parallel to this layering.

PLAGIOCLASE: About 60 %. Grainsize <2mm. Ab_{83} (Michel Levy).

QUARTZ: About 30 %. Mainly present as thin continuous veins showing strong undulose extinction. Extensive recrystalization has occured. Grainsize in aggregates is 0.1mm.

MUSCOVITE: About 5 %.

OPAQUES: About 3 %. Size average 0.2mm. Grains are strongly elongated in the layering plane.

BIOTITE: About 2 %. Size average 0.2mm. Strongly pleochroic, α = dark olive green, $\beta = \gamma$ = straw yellow.

ACCESSORIES: Apatite, Zircon (small grains 0.1mm., well rounded).

375/89A **FELDSPAR QUARTZ IRON OXIDE GRANITIC ROCK.**

MACRO: A medium grained granitic rock with orange pink feldspar (90 %), fine opaques and quartz.

MICRO: Sub granoblastic fine grained (0.3mm average) felsic rock with no layering on a micro scale.

PLAGIOCLASE: About 65 %. Grainsize <2mm. Multiple twinning rare. Ab_{87} (Michel Levy).

MICROCLINE: About 15 %. Size average 0.4mm. Cross hatched.

QUARTZ: About 10 %. Usually occurs as rounded grains (0.2mm) within larger feldspar grains (2D view).

OPAQUES: About 10 %. Irregular in size and shape.

375/85 (2 slides) FINE GRAINED GREY 'HOUGHTON DIORITE' TYPE.

MACRO: Massive green grey amphibolite. A fine grained rock with a relatively high quartz content. Some mineral orientation is present.

MICRO: Granoblastic. Grainsize and distribution are even. Quartz grains are small and rounded.

AMPHIBOLE: About 55 %. Size average 0.3mm. Pleochroic. α = cream, β = bright green, γ = green. Biaxial (-). $2V = 90^{o}$ (Kamb) $z\hat{}c = 18^{o}$

PLAGIOCLASE: About 25 %. Size average 0.5mm. Sericitized grains. Multiple twinning rare.

QUARTZ: About 10 %. Size average 0.2mm and rounded. Grains are clear and unstrained.

OPAQUE: About 7 %. Irregular size and shape generally but many grains have square outline.

APATITE: About 20 %. Size average 0.3mm.

EPIDOTE: About 1 %. Small grains which often form stringers between plagioclase and amphibole grains.

ACCESSORIES: Sphene (as coronas around opaques), Zircon (well rounded small grains <0.1mm).

375/100B STREAKY 'HOUGHTON DIORITE' TYPE.

MACRO: A rock containing quartz, epidote and hornblende in approximately equal ratios. Grainsize varies from 1mm to 3mm. A layering exists and is distinguished by grainsize and amphibole content.

MICRO: Sub granoblastic feldspar and amphibole with quartz veins.

AMPHIBOLE: About 25 %. Size average 1.5mm. Pleochroic, α =cream, β = pale green, γ = green. Biaxial (-), z^c = 20°.

EPIDOTE: About 20 %. Yellow green; pleochroic.

PLAGIOCLASE: About 30 %. Multiple twinning common. Twins are sometimes bent. Ab_{87} (Michel Levy).

QUARTZ: About 25 %. As very large grains and veins with irregular boundaries. Strong undulose extinction.

ACCESSORIES: Opaques, Apatite, Zircon (as large grains with approximate square outline (0.1 X 0.1mm) or with elongate shape 0.4mm long. They are concentrated in quartz grains.).

375/100C **LAYERED STREAKY 'HOUGHTON DIORITE' TYPE.**

MACRO: A strongly layered medium grained amphibolitic rock with dark green amphibole and light green epidote forming layers in salmon pink quartzo feldspathic rock.

MICRO: Granoblastic. Feldspar forms polygonal grains (0.5mm) and is covered by a haze of sericite and epidote.

AMPHIBOLE: About 40 %. Size average 0.5mm. Biaxial (-). $2V = 65^{o}$, $z \wedge c = 18^{o}$.

PLAGIOCLASE: About 50 %. Size average 0.5mm. Multiple twinning common. Some are bent and broken. Ab_{57} (Michel Levy).

EPIDOTE: About 8 %. Forms thick boundaries of small grains(average 0.1mm) between plagioclase and amphibole grains.

OPAQUE: About 1 %.

SPHENE: About 1 %. As very small grains (<0.1mm) in aggregates around opaques and in stringers.

ACCESSORIES: Apatite, Zircon (small grains <0.1mm., well rounded).

375/100g   COARSE GRAINED PYROXENE FELDSPAR PEGMATITE.

MACRO: Pegmatitic rock with very large crystals of grey green pyroxene (3cms X 4cms). Small blebs and streaks of dark green amphibole are present within these crystals as remnants (Plate 1B). Large crystals of pink and white feldspar (1cm) are also present (may be up to 6 cm). Opaque is also common in thick veins (5mm thick).

MICRO: Pegmatitic igneous texture with many sub euhedral grains. Plagioclase grains are usually tabular and broken or fractured at the point of contact with similar grains.

PLAGIOCLASE: About 35 %. Grainsize large and variable. Grains are hazy with sericite inclusions. 'Islands' of microcline are present in the larger plagioclase grains. Multiple twinning is common. Ab_{92} (Michel Levy).

CLINOPYROXENE: About 35 %. Very large crystals. Biaxial (+). $2V = 80^{\circ}$. $z^c = 38^{\circ}$. Length fast.

MICROCLINE: About 10 %. As diffuse areas in plagioclase. Cross hatching common. Secondary to plagioclase.

HORNBLENDE: About 5 %. Weak pleochroism - light greens. Secondary to pyroxene. Biaxial (-), $2V = 75^{\circ}$, $z^c = 25^{\circ}$.

EPIDOTE: About 5 %. Occasionally as larger grains up to 1mm.

OPAQUE: About 5 %. In vein form (consists of magnetite and hematite. see polished section description).

QUARTZ: About 5 %. As veins; undulose extinction.

ACCESSORIES: Zircon (poorly rounded grains <0.1mm).

375/118 SPECKLED AMPHIBOLITE.

MACRO: Dark medium grained amphibolite.

MICRO: Granoblastic feldspar and hornblende in about equal quantities.

HORNBLENDE: About 25 %. Size average 0.3mm. Strongly pleochroic, α = yellow brown, β = dark brown, γ = dark green. Biaxial (-). $2V = 70^{o}$, $z\hat{}c = 20^{o}$.

CLINOPYROXENE: About 20 %. Size average 0.3mm. Biaxial (+). High 2V.

K FELDSPAR: About 38 %. Size average 0.4mm. Grains are clear and untwinned.

OPAQUES: About 5 %. Irregular in shape and size.

QUARTZ: About 10 %. Show undulose extinction.

APATITE: About 2 %. Size average 0.2mm and oval shaped.

ACCESSORIES: Zircon (small well rounded grains.)

375/141 SPECKLED AMPHIBOLITE:

MACRO: Amphibolite of medium, even grainsize which has 65 % dark green amphibole and 35 % plagioclase. A rough lineation is present.

MICRO: Essentially granoblastic. Some plagioclase grains have a preferred orientation.

HORNBLENDE: About 35 %. Size average 0.5mm. Strongly pleochroic, α = straw yellow, β = dark olive green, γ = green. Biaxial (-), $2V = 80^{\circ}$, $z \wedge c = 15^{\circ}$.

ACTINOLITE: About 30 %. Size average 0.5mm. Most grains show evidence of uralitization. Slightly pleochroic, α = pale green, β = light green, γ = bright green.

PLAGIOCLASE: About 33 %. Size average 0.5mm. Ab_{85} (Michel Levy). Clear grains, multiple twinning rare.

EPIDOTE: About 1 %. Size average <0.1mm.

OPAQUES: About 1 %. Size average 0.2mm.

ACCESSORIES: Sphene (as haloes around opaques).

375/150 BLACK SPECKLED AMPHIBOLITE.

MACRO: Very dark, igneous looking, medium grained amphibolite.

MICRO: Sub interlocking grains with irregular shapes but a similar overall size.

HORNBLENDE: About 25 %. Size average 0.5mm. Strongly pleochroic. α = yellow, β = dark brown, γ = dark olive green. Biaxial (-). High 2V. $z \wedge c = 24^{\circ}$.

ACTINOLITE: About 35 %. Size average 0.7mm. Uneven light green colouring, moderately pleochroic. Fibrous uralitized grains.

PLAGIOCLASE: About 37 %. Size average 0.8mm. Most grains are clear and untwinned.

OPAQUES: About 2 %. Size average 0.2mm.

EPIDOTE: About 1 %.

ACCESSORIES: Apatite, Sphene (from alteration of opaques).

375/150D **STREAKY 'HOUGHTON DIORITE' TYPE.**

MACRO: Medium grained quartzo feldspathic rock with considerable hornblende and epidote. The green minerals and quartz form a rough layering in salmon pink feldspar.

MICRO: A rough layering in of actinolite occurs in equigranular and equidimensional feldspar grains, often rimmed with epidote.

PLAGIOCLASE: About 20 %. Size average 1.0mm. Usually clouded with ~~sericit~~ sericite and epidote. Multiple twinning rare. Ab_{85} (Michel Levy).

HORNBLENDE: About 30 %. Size average 0.3mm. Weakly pleochroic, α = white, β = light green, γ = green. $z \wedge c = 34^{o}$.

QUARTZ: About 20 %. Size average 2mm. Shows strong undulose extinction some recrystallization is evident.

MICROCLINE: About 10 %. Cross hatched. Occurs as irregular wavy intergrowths (worm like) in plagioclase.

EPIDOTE: About 20 %. Size average 0.1mm. Chiefly as small grains on plagioclase-~~actinolite~~ actinolite boundaries.

ACCESSORIES: Opaque, Zircon, Sphene (around opaque).

375/150F **STREAKY 'HOUGHTON DIORITE' TYPE.**

MACRO: Consists of feldspar, quartz and amphibole. The amphibole is streaky giving a rough layering. This could be the result of shearing.

MICRO: Granoblastic to nematoblastic. Sphene and amphibole occurs in layers of elongated grains. Feldspar grains are granoblastic. There are no opaques (converted to sphene?).

PLAGIOCLASE: About 60 %. Size average 1.5mm. Ghost twinning is common. Good multiple twinning is rare. Biaxial (+). $2V = 75^{\circ}$, Ab_{90} (Michel Levy).

HORNBLENDE: About 20 %. Moderately pleochroic, $z\hat{}c = 28^{\circ}$.

SPHENE: About 15 %. Grains up to 6mm long. Biaxial (+). $2V = 20^{\circ}$. Moderate pleochroism.

EPIDOTE: About 5 %. Chiefly along amphibole - plagioclase boundaries

ACCESSORIES: Zircon, Opaque.

375/150G A GRANITIC VARIETY OF BIOTITE FELDSPAR GNEISS.

MACRO: Pink quartzo feldspathic fine grained rock with biotite books (= 2mm) scattered at 1cm intervals evenly throughout the rock. Cracks in the rock have a fine grained green material in them. This could be a Cu salt or epidote.

MICRO: Irregular grainsize and shape of feldspar with quartz grains often rounded. Biotite occurs as sporadic porphyroblasts.

PERTHITE: About 60 %. Grainsize 0.5-1mm. Exolved plagioclase is present as long stringers. Cross hatching is rare.

QUARTZ: About 37 %. Size average 0.6mm but up to 2mm. Undulose extinction, commonly recrystallized.

BIOTITE: About 3 %. Strongly pleochroic, α = dark green, $\beta = \gamma$ = light green.

ACCESSORIES: Sphene (~0.5mm), Epidote (as thin veins ~0.1mm), Opaque, Apatite, Zircon.

375/165 BIOTITE FELDSPAR GNEISS.

MACRO: Fine grained grey quartzo feldspathic rock with occasional quartz grains several mm. across.

MICRO: Granoblastic feldspar interlayered with lepidoblastic lenses of muscovite and biotite. Opaques are randomly distributed throughout the rock.

PLAGIOCLASE: About 70 %. Size average 0.3mm. Multiple twinning is common and is dislocated in some grains. Ab_{90} (Michel Levy).

QUARTZ: About 10 %. Variable grainsize. Shows undulose extinction and recrystallized aggregates.

OPAQUE: About 10 %. Grainsize and shape is irregular.

MUSCOVITE: About 7 %. As a matrix around some grain boundaries and as lenses.

BIOTITE: About 2 %. Size average 0.3mm. They have a rough orientation. Strongly pleochroic, green.

APATITE: About 1 %.

375/174 QUARTZ RICH MUSCOVITE BIOTITE GNEISS.

MACRO: Consists of clear Quartz grains (~ 1mm) between schistose green or white micaceous layers. The quartz grains are lense shaped.

MICRO: A gneiss with oriented quartz grains and very thin continuous quartz veins parallel to muscovite and limonite layers.

QUARTZ: About 30 %. Grains about 3mm but may be up to 5mm. Show strong undulose extinction and some recrystalization. Some grains show strong fracturing.

MICACEOUS MINERALS: About 69 %. Chiefly muscovite with some biotite in small grains.

TOURMALINE: About 1 %. Dark green, slightly pleochroic.

ACCESSORIES: Apatite.

375/198 **SPECKLED AMPHIBOLITE.**

MACRO: A fine grained green grey rock with a slight schistosity given by fine green biotite.

MICRO: Granoblastic eqmigranular fine grained (0.3mm) amphibolite rock with rutile forming distinct layers about 10mm apart. These may represent original bedding.

PLAGIOCLASE: About 45 %. Size average 0.4mm. Multiple twinning is rare. Grains are cloudy with inclusions of biotite and epidote. Ab_{90}.

AMPHIBOLE: About 43 %. Size average 0.3mm. Pleochroic, α = light green, β = green, γ = blue green. Biaxial (-). High 2V, z^c = 15°.

BIOTITE: About 5 %. Size average 0.2mm. Pleochroic, α = yellow brown, β = γ = yellow.

EPIDOTE: About 4 %. Size average <0.1mm.

RUTILE: About 1 %. Size average 0.2mm. Grains have a square or subrounded outline. They are deep red or golden yellow with extreme relief. Sphene reaction rims are common.

ACCESSORIES: Apatite, Sphene (some grains show pleochroism orange colours), Quartz.

375/212F **IGNEOUS AMPHIBOLITE.**

MACRO: A medium grained green, black, amphibole rich, amphibolite.

MICRO: Strongly interlocking laths of plagioclase and prismatic euhedral amphibole crystals.

AMPHIBOLE: About 59 %. Size average 0.5mm. Pleochroic, α = pale yellow, β = green, γ = blue green. Biaxial (-). 2V = 65°, z^c = 18°.

PLAGIOCLASE: About 40 %. Laths up to 2mm long. Grains are a pinkish colour with small euhedral crystals of amphibole throughout. Multiple twinning is common. Ab_{37} (Michel Levy).

OPAQUES: About 1 %. Size and shape is highly irregular.

ACCESSORIES: Apatite, Quartz (as small aggregates of polygonal grains).

375/230 FINE GRAINED FELDSPAR QUARTZ OPAQUE ROCK.

MACRO: Massive quartzo feldspathic rock with medium to fine grains of evenly distributed quartz, opaque, and salmon pink feldspar.

MICRO: Sub granoblastic microcline is predominant with well rounded quartz and opaque also present.

MICROCLINE: About 50 %. Size average 0.9mm. Cross hatching is common. Most grains are perthitic. Many grains are sericitised.

QUARTZ: About 40 %. Size average 0.5mm. Grains are rounded and show slightly undulose extinction.

OPAQUE: About 5 %. Size average 0.5mm. Some grains have a square outline.

MUSCOVITE: About 1 %.

ACCESSORIES: Zircon (large grains up to 0.3mm which are angular or poorly rounded).

375/233 BLACK SPECKLED AMPHIBOLITE WITH UNUSUAL WHITE 'PEBBLES'.

MACRO: Medium grained black amphibolite which contains interesting small 'nodules' or 'pebbles' of white fine grained material.

MICRO: Granoblastic medium grained rock.

HORNBLENDE: About 30 %. Size average 0.5mm. Strongly pleochroic, α = straw yellow, β = light brownish green, γ = dark olive green. Biaxial (-). 2V = 85^{o}, z^c = 30^{o}.

PLAGIOCLASE: About 30 %. Size average 0.5mm.Grains are clear and free from inclusions and twinning. Biaxial (+). 2V = 90^{o}.

CLINOPYROXENE: About 15 %. Size average 0.5mm. Biaxial (+). 2V = 50^{o}. Transparent to light green in thin section.

ACTINOLITE: About 10 %. Light green, weakly pleochroic. Biaxial (-). 2V = 90^{o}.

OPAQUE: About 15 %. Size average 0.4mm.

ACCESSORIES: Sphene, Apatite.

'PEBBLES': Very fine grained lightly birefringent material; could be sericite.

375/313B **LAYERED 'HOUGHTON DIORITE' TYPE.**

MACRO: A strongly layered amphibole feldspar gneiss with dark green amphibole layers (~ 4mm) in pink feldspar.

MICRO: Granoblastic texture of equidimensional plagioclase grains. Layering is indicated by elongated amphibole grains of variable size.

PLAGIOCLASE: About 75 %. Size average 0.7mm. Multiple twinning is common. Ab_{62} (Michel Levy).

URALITE: (A fibrous variety of hornblende after pyroxene). About 20 %. Size varies up to 1mm. Pale green colours; Weakly pleochroic, Biaxial (-). $2V = 85^{\circ}$, $z \wedge c = 27^{\circ}$.

EPIDOTE: About 4 %. Grainsize = 0.2mm. Yellow. Weakly pleochroic.

OPAQUE: About 1 %. Irregular size up to 0.5mm. Generally elongated parallel to layering.

ACCESSORIES: Biotite, Zircon (size average 0.1mm, irregular shape).

375/313D FINE, MASSIVE GREY 'HOUGHTON DIORITE' TYPE.

MACRO: Fine-medium grained, massive, grey-green quartzo feldspathic rock with some amphibole.

MICRO: Sub interlocking grains with quartz having smooth boundaries. Microcline is present as irregular 'islands' with diffuse boundaries within plagioclase. Grainsize is irregular and commonly up to 1.5mm.

PLAGIOCLASE: About 45 %. Size average 1mm. Often hazy with inclusions. Ab_{64} (Michel Levy).

QUARTZ: About 30 %. Grains sometimes greater than 1mm. May show undulose extinction.

MICROCLINE: About 15 %. Forms within plagioclase grains. Cross hatching is common.

AMPHIBOLE: About 10 %. Size average 0.7mm. Pleochroic, α = pale green, β = blue green, γ = green.

ACCESSORIES: Sphene, Zircon (common, rounded grains 0.2mm), Opaque, Amber mineral (Rutile ?, Monazite ?).

375/321 MASSIVE AMPHIBOLE.

MACRO: Medium to coarse grained olive green amphibolite composed almost entirely of 'fibrous looking' amphibole. Some specimens show iron oxide in addition. Xenoliths which have been largely amphibolitized can be seen in many specimens. Their average size is 4cms. (Plate 1A). Grainsize is noticeably finer around xenoliths.

MICRO: Sub interlocking. Grains are usually elongated and vary in size up to 1.5mm. Some small equidimensional quartz grains are also present.

AMPHIBOLE: About 95 %. Grainsize up to 3.5mm. Slightly pleochroic, α = cream, β = light green, γ = light blue green. Biaxial (-). $2V = 90^{o}$, $z \wedge c = 19^{o}$.

QUARTZ: About 3 %. Size average 0.2mm. Shows strong undulose extinction

SERICITE: About 2 %. Could be a country rock xenolith. Individual grains are <0.1mm.

375/400 BIOTITE FELDSPAR GNEISS.

MACRO: Grey biotite and sericite surround cream feldspar in rough gneissic layers. There is a slight mylonitic appearance.

MICRO: Some crude gneissic layering still remains after disruption (shearing?). Garnet grains are badly shattered and broken apart.

SERICITE - MUSCOVITE - QUARTZ: Groundmass, about 40 %.

QUARTZ: About 40 %. Grains up to 0.4mm. Shape irregular. strongly undulose extinction.

PLAGIOCLASE: About 8 %. Size average 0.5mm. Grains are difficult to recognise because of abundant sericite inclusions. Ab_{90}.

BIOTITE: About 5 %. Size average 0.1mm. Pleochroic, α = straw yellow, $\beta = \gamma$ = dark green brown.

SILLIMANITE: About 3 %. Size average for cross sections 0.1mm.

GARNET: About 3 %. Skeletal porphyroblasts up to 1mm. across. Colourless; isotropic.

OPAQUE: About 1 %. Size average 0.2mm.

ACCESSORIES: Zircon (up to 0.1mm. Usually well rounded).

375/431 SERICITE NODULE FROM PEGMATITE LAYERS.

MACRO: Equidimensional pebbles about 3cm., grey in colour are scattered throughout a feldspar pegmatite layer. The fine grained material is prol probably sericite. (Plate 3B).

MICRO: Zircon clusters and quartz and/or rutile are commonly together and surrounded by large biotite grains. These in turn may have a chloritic halo.

SERICITE AND CHLORITE: Form the bulk of the slide and are very fine grained.

BIOTITE: Fairly common around yellow grains. Size average 4mm. Strongly pleochroic, α = green brown, $\beta = \gamma$ = white.

MUSCOVITE: Occasionally found around yellow grains in place of biotite.

QUARTZ: Present in rare, small, highly strained grains.

ZIRCON: Small grains (<0.1mm) rounded and in clusters or lines of 10 or so. They are chiefly associated with biotite grains (Plate 3B).

YELLOW GRAINS: Grainsize up to 1mm. They are golden in colour, show high relief and are uniaxial. It is present in quartz as thin needles which show definite orientation. Single grains show a strong cleavage. Possibilities are monazite, alanite or rutile.

TOURMALINE: As rare blue grains.

375/453 PHLOGOPITE SCHIST WITH CHLORITE SAPPHIRINE PORPHYROBLASTS.

MACRO: A grey green schistose rock with flakes of phlogopite (1mm). Green blue porphyroblasts (~ 1cm) are scattered throughout the schist. Some hand specimens show small black needle like tourmaline crystals.

MICRO: Lepidoblastic with porphyroblasts of chlorite which contain very small blue grey sapphirine grains. (Plate 3C)

PHLOGOPITE: About 90 %. Size average 1.2mm. Slightly pleochroic, α = light yellow, β = γ = yellow brown. Uniaxial (-), (sometimes biaxial with a low 2V). Parallel extinction, length slow.

SAPPHIRINE: About 3 %. Size average 0.1mm. Grains are full of inclusions (opaque?) and may be quite black. Usual colour is an uneven royal blue to transparent. Relief high. Slight pleochroism. Final identification from an Xray powder photograph. (see AppendixII).

CHLORITE: About 7 %. Size average 0.1mm. Colourless, non pleochroic, parallel extinction, final identification by Xray powder photograph.

ACCESSORIES: Opaque (The close association with sapphirine suggests it may be a spinel).

375/480 PINK FELDSPAR 'GRANITE'.

MACRO: Massive coarse grained pink feldspar with thin quartz veins and quartz blebs, and a light green amphibole (in some specimens) in 2mm grains. Iron oxide is present in veins and blebs.

MICRO: Partially interlocking grains, especially elongate irregularly shaped quartz grains (worm like). The quartz grains have smooth outlines while the feldspar have irregular boundaries. Feldspar crystals severalcms long are common.

K FELDSPAR: About 60 %. Many grains are perthitic. The exolved plagioclase occurs as irregular 'islands'. Ab_{88} (Michel Levy). Cross hatching is not found. The pink macroscopic colour is the K feldspar is due to very small (<0.1mm) idioblastic red brown inclusions. These are invariably hexagonal in outline and could be either biotite or hematite. A similar occurrence is described by Segnit (1965). (Plate 4A)

QUARTZ: About 40 %. Undulose extinction.

375/484 **STREAKY 'HOUGHTON DIORITE' TYPE.**

MACRO: A grey pink quartzo feldspathic rock with faint streaks of green amphibolite giving a faint layering.

MICRO: Amphibole and sphene form layers. The interlocking feldspar is sub granoblastic.

PLAGIOCLASE: About 75 %. Size average 0.5mm. Multiple twinning is common. Ab_{48} (Michel Levy). Biaxial (+). 2V = 85^{o} (Kamb).

AMPHIBOLE: (Uralite). About 20 %. Size average 0.8mm. Pale green colour. Slightly pleochroic. Biaxial (-), 2v = 70^{o}, z^c = 20^{o}.

EPIDOTE: About 2 %. Largish masses (0.5mm) closely associated with actinolite.

SPHENE: About 2 %. Oval shaped grains up to 0.5mm.

QUARTZ: About 1 %. (as aggregates of small polygonal grains).

ACCESSORIES: Opaque, Zircon (grainsize 0.2 - 0.4mm, well rounded).

375/516 FINE GRAINED GREY 'HOUGHTON DIORITE' TYPE.

MACRO: Grey, massive, fine grained feldspathic rock containing a small amount of amphibole. A small fold is also visible in hand specimen.

MICRO: Interlocking to granoblastic texture with tabular amphibole and equidimensional feldspar grains. Antiperthite is common.

PLAGIOCLASE: About 30 %. Size average 0.5mm. Ab_{37}. Multiple twinning is common.

MICROCLINE: About 20 %. As irregularly shaped and sized exolved islands.

HORNBLENDE: About 45 %. Size average 0.4mm. Many grains appear uralitised. Pleochroic, α = transparent, β = pale green, γ = pale blue green. Biaxial (-), $2V = 70^{\circ}$, $z\wedge c = 33^{\circ}$.

OPAQUE: About 5 %. Grains irregular in size and shape.

ACCESSORIES: Chlorite (basal section is yellow), Apatite, Zircon (small rounded grains <0.1mm).

375/521 SILLIMANITE GNEISS.

MACRO: A cream coloured porous rock resembling mylonite. A very rough layering is depicted by brown iron oxide. minerals and quartz grains.

MICRO: Mylonitic. Quartz occurs as irregularly scattered grains many of which have a sub rounded outline. Quartz occurs also as fine stringers 0.1mm wide, alternating with muscovite. Limonite occurs in grains up to 2mm which are commonly irregularly divided so as to resemble boxworks. Opaques are also associated with these.

MUSCOVITE: (could possibly be Paragonite) About 50 %. Grainsize is fine but may be up to 0.2mm. Biaxial (-). 2V = 17°. Colourless.

QUARTZ: About 35 %. Size variable(2mm). Grains usually rounded in outline with strong undulose extinction.

LIMONITE: About 10 %. As individual grains and as a dark brown staining.

OPAQUE: About 2 %. Associated closely with limonite.

SILLIMANITE: About 3 %. Square cross section with a strong diagonal cleavage.

ACCESSORIES: Zircon.

375/532 FELDSPAR OPAQUE GNEISS.

MACRO: Quartz and opaque form rough layers and lenses (~ 1mm) wide through a yellow micaceous mineral.

MICRO: Gneissic texture of large fractured quartz and opaque grains in fine grained muscovite.

MUSCOVITE: About 45 %. Grains generally very small but may be 1mm in size.

QUARTZ: About 40 %. Grains range in size up to several mm and may be sericitized. Most grains show strong undulose extinction but some of the larger grains show little strain. (recrystallized?).

PLAGIOCLASE: About 5 %. Some multiple twinning is faintly visible. Grains are strongly sericitized and stained with limonite. Biaxial (+), High 2V.

ORTHOCLASE: About 5 %. Only present as small grains in the micaceous groundmass.

OPAQUES: About 5 %. Associated with muscovite as small grains but also as larger grains (0.5mm) with irregular outline.

ACCESSORIES: Xenotime (length slow, parallel extinction, Uniaxial (+), High birefringence.).

POLISHED SECTIONS.

375/321 Hematite.

Reflectivity ; 28.1

Vicker's Hardness ; 922

MICRO: White or cream mineral

: isotropic

375/100 Magnetite and Hematite.

Magnetite (primary mineral).

Reflectivity ; 19.5 , 20.0

Vicker's Hardness ; 495

MICRO: light pinkish grey brown mineral

: isotropic

Hematite (predominant but secondary).

Reflectivity ; 28.9 , 30.0

Vicker's Hardness ; 912 , 956

MICRO: White cream mineral

: anisotropic

: forms secondary radiating 'needles' from cracks and fissures in the primary oxide. (Widmanstatten texture). This is an example of martitization.

POLISHED SECTIONS (cont.)

375/519 Hematite.

Reflectivity ; 28.3

Vicker's Hardness ; 1017

MICRO: cream colour

: isotropic

: grains may be altemately pitted or clear (bimodal)

375/452 Maghemite and Ilmenite.

Maghemite (forms the bulk of the oxide).

Reflectivity ; 26.3 , 26.0

Vicker's Hardness ; 962

MICRO: white or cream colour

: forms the bulk of the slide but is probably secondary.

Ilmenite

Reflectivity ; 17.9 ,

Vickers Hardness ;1580 , 1289

MICRO: Grey colour

: isotropic

: probably primary; exists as small but regular hair like craze over the white mineral.

: also present in the iron oxide are cigar shaped bodies 0.5mm long of spinel. They are oriented parallel to the Ilmenite streaks.

APPENDIX II.

Phlogopite schist with Sapphirine Chlorite porphyroblasts, is the interesting rock. An Xray powder photograph of the porphyroblasts gave lines in the following positions.

FILM NO.	:	12934
RADIATION	:	Cu
FILTER	:	Ni
KV / mA	:	40/24

2 θ	d Å	mineral causing peak
1.26	7.025	c*
1.88	4.720	c
3.03	2.950	c
3.17	2.823	s c
3.32	2.698	c
3.55	2.529	s^γ
3.69	2.436	c
3.78	2.380	s c
4.34	2.055	s
4.54	1.998	s c
5.26	1.740	c
5.75	1.603	c

*c = chlorite.

γs = sapphirine.

(Where both occur together it is probable they overlap.)

APPENDIX III.

DIGESTION AND ANALYSIS OF SAMPLES:

ROCK DIGESTION:

In order to obtain complete trace element removal from the silicate lattice it was decided to use HF. digestion. It was necessary to digest 1 gm. of sample since:

(a) The A.A.S. has a minumum detection limit of 1ppm.

(b) We wish to determine concentrations as low (or lower) than 50 ppm in the rock.

(c) The smallest easily workable volume of solution is 50cc.

and so

$$\text{ppm (rock)} = \frac{\text{Y (ppm soln.)} \times \text{Volume (cc)}}{\text{WT. sample (gm)}}$$

$$\text{ie.} \quad 50 = \frac{1 \times 50}{\text{wt. (gm)}}$$

$$\text{ie. wt. (gm)} = 1.$$

Thus it was necessary to digest the sample in relatively large containers and since platinum beakers were scarce, new plastic beakers were used. These could not be used on a sand bath so were placed on a steam bath. Only minor discolouration of the plastic occurred and this was shown, by the use of blanks and standards to have no effect on trace element readings.

The following method was found to be satisfactory and completely dissolved the rock in 36 hours.

50cc. HF were added to aplastic beaker containing 1gm. (exactly weighed to 3 decimal places) of sample. This was covered and left to heat on a steam bath for 12 hours. The plastic lid was removed and the sample evaporated to a sludge. 8cc. of $HClO_4$ were added and evaporated again to a sludge. 2cc. of $HClO_4$ were added and made up to 50cc in a volumetric flask. Sometimes it was necessary to dissolve the residue by heating on the steam bath. Solutions were then stored in plastic bottles.

A.A.S.:

An idea of the precision may be gauged by the reproduceability of results. As checks in the variation of trace element results some samples had duplicates or triplicates run from the beginning. In addition some A.A.S. runs were redone. Eg. The following are the results for samples 321, 212 and 457 for Ni.

	Run 1.	Run 2.	Run 3.
375/321	132	135	133
321 (check)	126	126	128
212	92	90	83
457	75	66	66

In this way it could be seen that reproduceability would give readings for values about 50ppm. of 50 ± 10ppm. Results become less variable as the sensitivity of the A.A.S. instrument increased. ie. for readings > 100ppm. for most elements.

STANDARDS:

Standards were difficult to find since the well known U.S.G.S. standards were too precious to be used for this purpose. Mr. Sumataro from the Geology department kindly loaned his standard, Sa. 1.

FeO DETERMINATION:

Method based on notes of Dr. R.L. Oliver, University of Adelaide:

Reagents: Conc. Sulphuric Acid.
Hydrofluoric Acid.
Potassium Permanganate of known normality.
Boric Acid.

Proceedure: The potassium permanganate was first accurately standardised against sodium oxalate solution (Method from Vogel p.284). 0.1 - 0.5gm of sample was accurately weighed into a crucible with a close fitting lid. 5cc. of distilled water were added and the crucible heated to boiling. 5cc. of HF and 5cc of conc. H_2SO_4 were then added rapidly from another crucible and the lid replaced. This was simmered for 5 - 10 minutes until the sample was completely dissolved and then the crucible and lid were plunged into a 600 cc. beaker half full of a solution of H_2O, 10cc 1:1 H_2SO_4, 10cc. saturated boric acid solution. This was titrated immediately and rapidly to present oxidation of Fe^{2+} by air. The end point was faint pink.

Calculation:

$$\% \ FeO = \frac{\text{titration (cc.)} \times 0.07184 \times 100 \times \text{normality } KMnO_4}{\text{wt. sample.}}$$

B.C.R. 1 and B.H.N. were used as standards to check results. Accuracy can be gauged by their accepted standard values.

	THIS THESIS:	STD. VALUE:
B.C.R. 1.	8.98 %	8.91 % (ave. from Flannagan 1968)
B.H.N.	6.37 %	7.55 % (ave. from Amdel)

Rubidium and Strontium: Were analysed on the Xray Fluoresence Spectrograph (X.R.F.). Background was found by measuring Compton scattering. NBS 70 A was used as the standard since this has a well known ppm. range and mass absorption (μ) factor.

Counting error was estimated using the method of Norrich and Chappel (1967).

Counting error (99.7 % Confidence limit) = $\frac{6}{m}\sqrt{\frac{Cb}{T}}$

Where m = number of counts / sec / ppm.

T = total analytical count time.

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

Sr in NBS 70 A gave a 1.2 ppm max count error.
Sr in G.S.P. 1 gave a 4.6 ppm max count error.
Rb in NBS.70.A gave a 8.1 ppm max count error.
Rb in G.S.P. 1 gave a o.1 ppm max count error.

This only gives a very rough indication of error since the lower detection limit is actually determined by machine drift and background slope.

Lanthanum and Cerium: Were analysed using X.R.F. The background slope factor was found by measuring Ultrasil on both sides of the peak.
A Lanthanum standard was made up to 860γ using La_2O_3 and quartz powder.
A Cerium 1000γ standard was made from CeO2 and quartz (CeO_2 was obtained by heating white ceric nitrate at 800°C until it turned yellow).

Barium was analysed on the X.R.F. with background measured as in La and Ce

Vanadium, Nickel, Cobalt, Chromium and Copper were analysed with the Atomic Absorption Spectrometer (A.A.S.). An air acetylene flame was used for all elements except V which required the higher temperature nitrous oxide flame.

Sodium was measured using the Flame Photometer.

Weight Change was calculated by heating an accurately weighed sample for several hours in a furnace at 1000°C. Results were checked using the Penfield method and found to be unchanged.

ELEMENT ASSOCIATIONS AND PROPERTIES:

Vanadium occurs chiefly as V^{3+} and as such has very similar chemical properties with Cr^{3+}. Since it is chiefly associates with magnetite and ilmenite which could be either sedimentary or igneous, one would expect little balue as a discriminating element. It is , however, used to good effect by Rivalenti and Siginolfi (1969) in a plot of V vs. TiO_2. V may be weathered from igneous rock and depositted in clays so that some sediments have very high V content. (Hawks and Webb 1962).

Chromium is identical in size with Fe^{3+} and so preferentially enters Fe^{3+} positions. The absolute concentration of Cr is a useful indicator of rock parentage (Taylor 1955). Evans and Leake (1960) relied heavily on Cr to establish the origin of the Connemara amphibolites. Hawks and Webb (1962) note that mobility in weathering solutions is low so that evaporites and oxidates are low in Cr. It is probably the most useful single element.

Cobalt and Nickel have similar chemical properties and the same valency (2+). The Ni/Co ratio makes a good indicator of rock parentage.

Copper was introduced soley because Walker et al (1960) found it had useful discriminating properties for their Queensland amphibolites.

Rubidium is similar in size and chemical character to K with which it forms a close association. Thus Rb enrichment is confined to acid rocks.

Strontium is intermediate in size between Ca^{2+} and K^{+} but due to its 2+ valence state forms a close assiciation with Ca^{2+}. Sr^{2+} should increase relative to Ca^{2+} during fractionation where it enters feldspar lattice positions (Taylor 1964). Sr^{2+} also substitutes for Ca^{2+} in chemical sediments where its proportion is said to be controlled by salinity.

Barium has similar chemical properties with Sr^{2+}, K^{+}, and Rb^{+} and so should be useful when used in conjunction with these elements.

Lanthanum and Cerium are potentially very useful but little work has been done on them because of past difficulties with their analysis. 60 % of the rare earths are contained in monazite with the rest predominantly in apatite. Haskin and Gehl (1962) comment that while they are fractionated in igneous rocks, they tend to be invariant in sediments.

APPENDIX IV

The following example is submitted to show on what basis variables (trace elements) can be deleated from a computor program. Program four has 5 variables but from PRCT. ADDED three of these are of doubtful use. The effect of dropping them (Program 5 ; 2 variables) can be seen by using the following equation from Rao (1965).

$$F = \frac{N_1+N_2-p-1}{p-q} \cdot \frac{N_1N_2(D_p^2 - D_q^2)}{(N_1+N_2)(N1+N_2-2)+N_1N_2D_q^2}$$

on p-q and (N_1+N_2-p-1) degrees of freedom.

Where N_1 = ortho control population.

N_2 = para control population.

q = degrees of freedom in program 5

p = degrees of freedom in program 4

D^2 = Mahalanobis Distance.

Program 5	Program 4
-0.55log Cr+4.52logCo	-0.64logCr - 1.50logV - 0.67logNi + 6.69logCu + 0.87logSr.
D_2^2 = 2.36	D_5^2 = 3.13
N_1 = 20	N_1 = 20
N_2 = 20	N_2 = 20
q = 2	p = 5

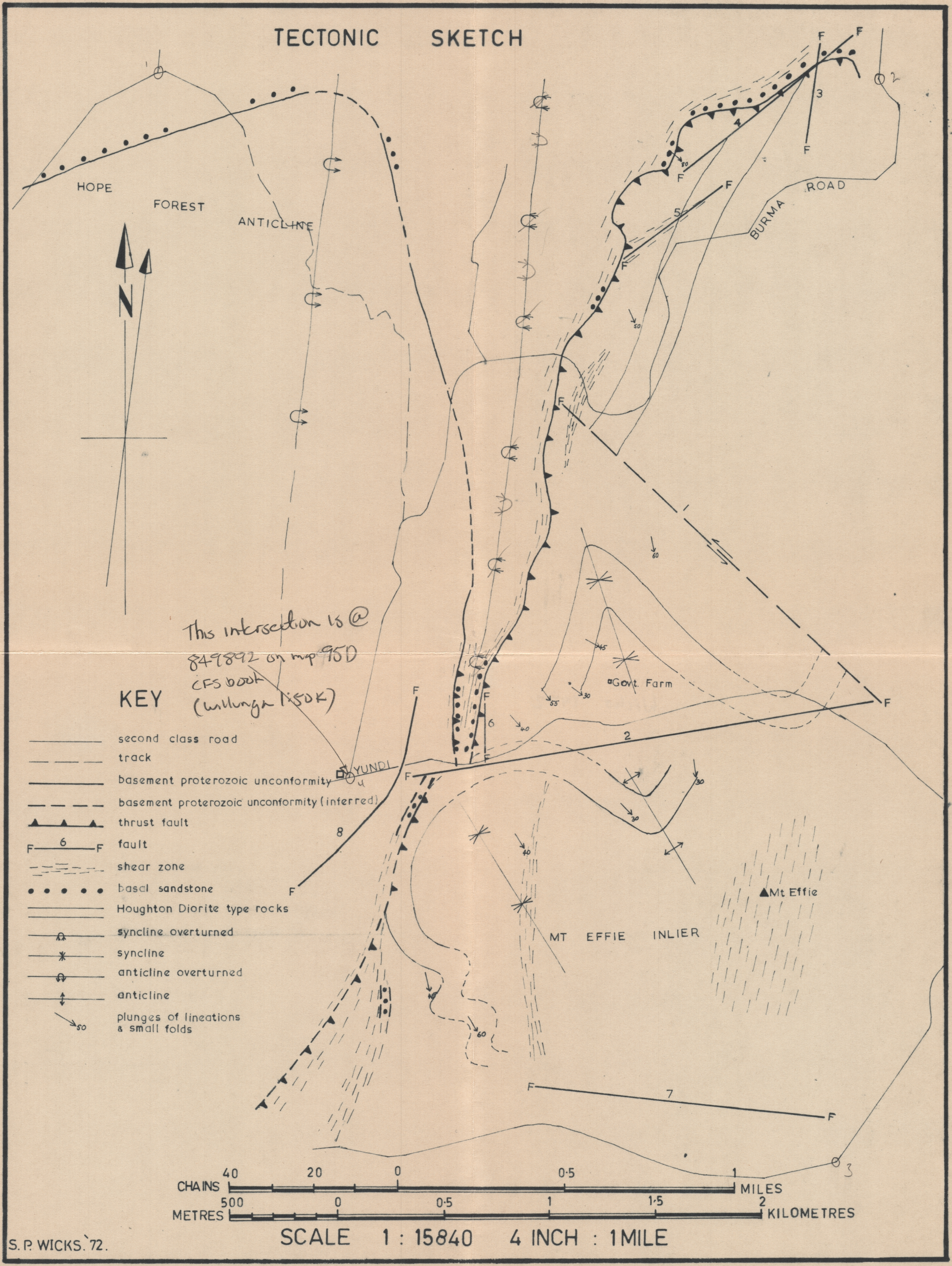
Thus F = 1.60 on 3 and 37 degrees of freedom.

From tables at the 95 % probability level, F is 3.08 so that the probability of the 3 discarded variables contributing to the discrimination is much less than 95 %.

APPENDIX V.

Different diagrams were used because the following authors found them successful.

FIGS.	
6A	Gomes et al (1964)
6B	Leake (1963)
6D	Mistra (1971)
6E	Van de Kamp (1968)
7A & C	Leake (1963) who referes to them as conclusive in deciding the origin of amphibolites.
7B & G	Gomes et al (1964)
7D, E, & F	Leake (1963)
7H	Mistra (1971)
8A	Billings et al (1966)
8B	Used because Ni and Cr were shown to be good discriminators by Discriminant Function Analysis
8C, D, & E	Walker et al (1960)


TECTONIC SKETCH
HOPE FOREST ANTICLINE
BURMA ROAD
N
This intersection is @ 849892 on map 95D CFS book (Willunga 1:50K)
YUNDI
Govt. Farm
Mt Effie
MT EFFIE INLIER
KEY
second class road
track
basement proterozoic unconformity
basement proterozoic unconformity (inferred)
thrust fault
fault
shear zone
basal sandstone
Houghton Diorite type rocks
syncline overturned
syncline
anticline overturned
anticline
plunges of lineations & small folds
CHAINS 40 20 0 0·5 1 MILES
METRES 500 0 0·5 1 1·5 2 KILOMETRES
SCALE 1 : 15840 4 INCH : 1 MILE
S. P. WICKS. 72.