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PETROGRAPHY AND PETROLOGY OF MT. BUNDEY GRANITE AND MT. GOYDER SYENITE, N.T.

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INTRODUCTION

Mt. Bundey is situated in the northern part of the Northern Territory and is 55 miles south-west of Darwin. Mt. Bundey Granite and Mt. Goyder Syenites occupy an area of about 45 square miles and have an intrusive relationship with the Lower Proterozoic, Burrell Creek, Golden Dyke, and Masson Formations. The contact is invariably sharp. The surrounding sediments show little effect of metamorphism, apart from the fact that, in the north-eastern margin of the mass, hornfelses have been formed.

MT. BUNDEY GRANITE

Petrography

Mt. Bundey Granite is a pale pinkish medium- to coarse-grained leucocratic rock. The pink colour is due to potash-feldspar, which is a major constituent of this rock. The potash feldspars are quite large, and crystals measuring up to 2 x 1.5 cm. have been noticed. The grain-size of the rock ranges between 0.5 mm. and 2.5 mm. The rock shows little sign of deformation, apart from slight undulose extinction in quartz and, in rare cases, bent biotite flakes. The constituent minerals nowhere follow any set pattern, and thus there is no foliation seen in the hand specimen. It is a massive granite, without any directional features whatsoever.

Under the microscope the rock shows typical granitoid texture. The essential minerals are potash feldspar, plagioclase, quartz, hornblende, and biotite; iron ores, sphene, apatite, zircon, and allanite are the accessories. Muscovite and chlorite have also been noticed, and one section also contains crystals of pyrite.

The potash feldspar in all slides examined is microperthite. It occurs as medium to large anhedral to subhedral crystals. The perthites are patch and vein type (Anderson, 1929). In most cases they are cloudy, as they are slightly kaolinised and sericitised. Inclusions of plagioclase, quartz, biotite, and the accessory minerals are quite common; in some places the potash feldspar shows a poikilitic relationship towards the inclusions. Usually where the microperthite is in contact with plagioclase myrmekitic intergrowth is noticed, in some cases microperthite has replaced plagioclase.

Plagioclase feldspars occur in subhedral to euhedral crystals of medium grainsize. Compared with potash feldspar they are usually much more cloudy due to alteration to kaolin and sericite. The plagioclase ranges in composition from An_{28-36} (oligoclase-andesine). As already mentioned above, the plagioclase has in some cases been replaced by microperthite. Zoning (oscillatory type) was noticed; the more calcic core usually alters to epidote, and the borders of the crystals are probably pure albite. The alteration in most cases is most intense in the central part of the crystal, thus leaving a fresh marginal zone. Inclusions of quartz and the accessory minerals are quite common.

Quartz occurs in large- to medium-sized anhedral grains which are usually fresh. They show slight undulose extinction. Cracks are also noticed in some of these grains. Inclusions of feldspars and the accessory minerals are common.

Hornblende occurs as medium to large subhedral to euhedral crystals whose size ranges from 0.5 x 0.1 mm. to 1.6 x 0.5 mm. It is greenish and remarkably fresh, and is strongly pleochroic from yellow green to dark green with X = yellow green; Y = olive green; and Z = dark green. Occasionally colour zoning is also seen. Simple twinning is quite common. The hornblende has been partly replaced by biotite. Inclusions of sphene, magnetite, apatite, zircon, etc., are common.

Biotite occurs as subhedral flakes ranging in size from 0.3 x 0.1 mm. to 1.4 x 0.45 mm. It is strongly pleochroic from pale yellow to dark dirty brown. Pleochroic haloes are quite common. Partial alteration to green chlorite has taken place. Inclusions of zircon, apatite, iron ores, and feldspars are seen.

Sphene is the most prominent mineral among the accessories. It occurs usually in irregular grains, but some good lozenge-shaped crystals are also present. Crystals as long as 1.2 x 0.4 mm. have been noticed. It is pale orange and is distinctly pleochroic. Apatite is another common accessory, which occurs in irregular grains as well as in well-formed crystals. Some of these crystals measure up to 0.9 x 0.3 mm. Small, well-formed crystals of zircon are also quite common.

Iron ores occur mainly as irregular grains and masses. Magnetite and ilmenite are the most common ores, though hematite and leucoxene have also been observed.

Modal Analysis

Six thin sections of the Mt. Bundey granite were selected for modal analysis, and the results are given in Table 1 (Nos. 6-11). Under "opaque accessories" are included magnetite, hematite, ilmenite, and leucoxene, and "non-opaque accessories" include sphene, apatite, zircon, muscovite, chlorite, and allanite. Modal analysis has been used here to classify these rocks on the basis of Johannnsen's (1939) classification. The granitic rocks of Mt. Bundey were found to range in composition from ordinary granites to adamellite.

The granites are essentially biotite-hornblende granite, where biotite is subordinate to hornblende. Among the major constituents potash feldspar is predominant, and forms between 36 and 53% of the bulk. Plagioclase is invariably subordinate to potash feldspar. An average composition based on the mean of the six analyses is given below:

Quartz	-	27.15
Potash feldspar	-	43.39
Plagioclase	-	21.17
Biotite	-	2.67
Hornblende	-	3.89
Op. Acc.	-	0.74
Non-Op. Acc.	-	1.00
Total	-	100.01
Colour Index	-	8.30

TABLE I - MODAL ANALYSIS

Serial No.	1	2	3	4	5	6	7	8	9	10	11
Sp. No.	4214	3285	4220	4809	4222	4235	4234	3286	4260	4819	3290
Total distance traversed.	816.72	638.12	671.86	713.76	595.46	516.37	575.40	513.30	509.60	639.14	557.42
Colour Index	22.33	24.80	14.54	20.45	26.31	9.72	13.06	7.02	9.36	5.20	5.44
Symbol	231	231	231	231	231	231	231	231	213	213	213
Quartz	8.07	8.24	8.70	10.23	12.56	20.99	23.79	24.06	31.96	35.20	26.91
Pot. Feld.	61.03	56.20	63.57	57.39	38.78	46.95	36.25	42.20	42.05	39.40	53.46
Plagioclase	8.57	10.76	13.18	11.93	22.33	22.34	26.89	26.72	16.68	20.19	14.18
Biotite	1.86	p.	p.	2.65	5.56	3.47	3.25	2.42	2.46	3.06	1.33
Hornblende	16.17	19.31	8.84	15.75	15.72	4.62	7.72	3.37	4.69	0.63	2.32
Non Op. Acc.	2.80	3.20	2.58	0.88	2.02	0.56	0.89	0.73	0.89	0.44	0.94
Op. Acc.	1.50	2.29	3.12	1.17	3.01	1.07	1.20	0.50	1.32	1.07	0.85
Total	100.00	100.00	99.99	100.00	99.98	100.00	99.99	100.00	100.00	100.00	99.99
Name	Syenite	Sy.	Sy.	Qtz.Sy.	Qtz.Sy.	Gr.	Adm.	Adm.	Gr.	Gr.	Gr.

----Mt.Goyder Syenite---　　　　---Mt. Bundey Granite---

(p = present in small amount)

MT. GOYDER SYENITE

Petrography

The rocks of Mt. Goyder range in composition from syenite to quartz-syenite. These are medium-grained melanocratic rocks, having a dark pinkish grey colour. In some cases large crystals of potash feldspar are seen in handspecimen, and they give a porphyritic texture to the rock. These phenocrysts do not show any distinct orientation, but faint parallelism is, in places, apparent.

These syenitic rocks are very similar to the granitic rocks from Mt. Bundey. Under the microscope they show a hypidiomorphic texture. The essential minerals are potash feldspar, plagioclase feldspar, amphibole, quartz and biotite; sphene, apatite, iron ores, and zircon are the accessories. Allanite and fluorite have also been noticed in some of the sections.

Potash feldspar is invariably microperthite, like the potash feldspar in the Mt. Bundey rocks. The microperthite is of the vein type, and occurs in large- to medium-sized subhedral to anhedral crystals. Occasionally traces of oscillatory zoning are seen in the perthites, this suggests that they were originally plagioclase feldspars which have been subsequently replaced by potash feldspars. This may explain the high percentage of potash feldspar with respect to plagioclase in these rocks. The potash feldspars are usually slightly cloudy due to alteration to kaolin and sericite. Inclusions of plagioclase, quartz, hornblende, etc., are quite common.

Plagioclase feldspars occur in medium to small grains, and are usually subhedral to anhedral in form. These feldspars are usually oligoclase, with anorthite content in the range of 12-30; they give a biaxial negative figure. They are much more altered than the potash feldspars; the alteration products are mainly kaolin and sericite. Polysynthetic twinning is quite common, but in some places, due to severe alteration, it is rather obscured. Traces of zoning are also noticeable. Inclusions of quartz and accessory minerals are common.

Both green and brown hornblende are present. The green hornblende is the more common, but in some places brown hornblende which has been partly replaced by green hornblende was noticed. It is probable that most of the brown hornblende which was present originally has now been completely replaced by green. The hornblendes occur usually as subhedral to euhedral crystals of medium grain size; occasionally large euhedral crystals are also seen. Most commonly the hornblende occur as clusters of a few euhedral crystals. The mineral is strongly pleochroic from pale yellow green to dark green, and also shows simple twinning. The hornblende is remarkably fresh; inclusions of feldspars, sphene, apatite, and iron ores are common. In some cases hornblende has been partly replaced by biotite.

Quartz occurs in subhedral to anhedral grains of medium size. Slight undulose extinction is common. Inclusions of feldspars and other accessories are also common.

Biotite occurs in flakes of medium size. These are strongly pleochroic from pale yellow to dark rose-red. Pleochroic haloes are also present round highly refracting inclusions. Inclusions of zircon, apatite, and iron ores are quite common.

Sphene occurs in large subhedral to euhedral crystals of pale orange or deep honey colour. They are slightly pleochroic. The mineral occurs in association with amphibole, sometimes filling the interspaces between the crystals. Inclusions of iron ore may be present. Apatite occurs in medium to large subhedral to euhedral crystals. Some of these crystals measure up to 1.7 x 1.05 mm. It usually occurs as inclusions in amphibole and biotite. Sphene and apatite are the most common among the accessories, and they are very similar in their form and mode of occurrence to those found in the Mt. Bundey granites.

Magnetite and ilmenite occur in irregular grains and masses, usually as inclusions in, or in association with, amphiboles. Other minor accessories are allanite and zircon, which are much the same as those described in connection with the Mt. Bundey granites. In one section fluorite was observed.

Modal Analysis

Five thin sections of these rocks were selected for modal analysis, and the results are given in Table 1 (1-5). The essential minerals are potash feldspar, plagioclase, amphibole, quartz, and biotite, and the main accessories are sphene, apatite, iron ores, and zircon. The pattern here is much the same as that of Mt. Bundey granite. Potash feldspar is the predominant mineral, and plagioclase is subordinate to it. Amphiboles become an important constituent here. An average composition based on the mean of five modal analyses is given below:

Quartz	- 9.56
Potash feldspar	- 55.39
Plagioclase	- 13.35
Biotite	- 2.01
Amphibole	- 15.16
Op. Acc.	- 2.22
Non-Op. Acc.	- 2.30
Total	- 99.99
Colour Index	- 21.69

CHEMICAL DATA

Two samples from Mt. Goyder Syenite and two samples from Mt. Bundey Granite were selected for chemical analysis; the results, together with their modes, are given in Table II.

It is evident from the analyses that these rocks are rich in potash, which is explained by the high potash-feldspar content in the mode. The high percentage of magnesia and lime in the syenites, as compared with the granites, is due to the greater abundance of hornblende in the syenites.

In Table III, the mean of the two analyses of the syenites from Mt. Goyder and the two analyses of the "granites" from Mt. Bundey are compared with Daly's average analysis for syenites and average analysis for Precambrian granites. It is apparent that the syenites from Mt. Goyder compare well with the Daly's average syenite. The high soda and potash content of Mt. Goyder syenite is due to high percentage of potash feldspar in the mode.

TABLE 2.

	1.	2.	3.	4.
Specimen	4220	3285	3286	3290
SiO_2	59.76	60.40	70.40	71.16
Al_2O_3	16.56	17.21	15.18	13.82
Fe_2O_3	5.38	1.99	1.57	1.59
FeO	1.52	2.84	1.36	1.09
MgO	2.44	3.60	1.16	1.23
CaO	2.14	4.02	1.53	1.45
Na_2O	4.98	3.24	3.39	3.71
K_2O	5.52	4.70	3.84	5.05
H_2O+	0.94	0.92	0.63	0.58
H_2O-	Nil	0.04	0.03	Nil
TiO_2	0.15	0.35	0.34	0.09
P_2O_5	0.10	0.08	0.16	0.07
MnO	0.09	0.04	0.05	0.03
Total	99.58	99.43	99.64	99.83
Modes				
Quartz	8.70	8.24	24.06	26.91
Pot. Feldspar	63.57	56.20	42.20	53.46
Plagioclase	13.18	10.76	26.72	14.18
Biotite	Present	Present	2.42	1.33
Hornblende	8.84	19.31	3.37	2.32
Non-Op. Acc.	2.58	3.20	0.73	0.94
Op. Acc.	3.12	2.29	0.50	0.85
Total	99.99	100.00	100.00	99.99

1. Mt. Goyder Syenite, 2 miles S.S.E. of Mt. Bundey Homestead, Mt. Bundey 1-mile sheet. Analyst, S. Baker.
2. Mt. Goyder Syenite, ½ mile east of Mt. Goyder, Mt. Bundey 1-mile sheet. Analyst, S. Baker.
3. Mt. Bundey Granite (Adamellite), 3¾ miles N.E. of Old Battery in Mt. Bundey Creek, Mt. Bundey 1-mile sheet. Analyst, S. Baker.
4. Mt. Bundey Granite, 3 miles north-east of Old Battery in Mt. Bundey Creek, Mt. Bundey 1-mile sheet. Analyst, S. Baker.

TABLE III.

	Daly's Average of 50 analyses of syenites.	Mean of two analyses of Mt. Goyder Syenite.	Daly's Average of 47 analyses of Precambrian granite	Mean of two analyses of Mt. Bundey "Granite"
SiO_2	60.19	60.08	71.06	70.78
Al_2O_3	16.28	16.88	14.10	14.50
Fe_2O_3	2.74	3.68	1.46	1.58
FeO	3.28	2.18	1.63	1.22
MgO	2.49	3.02	0.59	1.19
CaO	4.30	3.08	1.97	1.49
Na_2O	3.98	4.11	3.24	3.55
K_2O	4.49	5.11	4.50	4.44
H_2O+	1.16	0.93	0.69	0.60
H_2O-		0.02		0.01
TiO_2	0.67	0.25	0.48	0.22
P_2O_5	0.28	0.09	0.10	0.11
MnO	0.14	0.07	0.18	0.04
TOTAL	100.00	99.50	100.00	99.73

With respect to the granitic rocks from Mt. Bundey, and Daly's average of Precambrian granites, the similarity as shown in the analyses, is remarkable.

PETROGENESIS

It is apparent from the above that the Mt. Bundey granites and Mt. Goyder syenites have much in common. Several important points of similarity may be noted:

a) The occurrence of the same type of microperthite (vein type) in both the granites and the syenites.

b) The occurrence of the same type of sphene and apatite in both; these minerals are quite unusual in their shape and large size.

c) The preponderance of potash feldspar over plagioclase.

Fig. 2 shows the relationship which exists between the quartz content of these rocks and the content of mafic minerals. It is apparent from the curves in Fig. 2 that with the increase in the percentage of quartz the percentage of mafic minerals decreases. The mafic mineral content is fairly high in the syenites, but in the granitic rocks the proportion of quartz is high, and the total mafic content decreases.

The results of the modal analyses have also been plotted in triangular diagrams. Fig. 3 is the M.F.Q. (M = total mafic, F = total feldspar, and Q = quartz); and Fig. 4 is the Q.Pl.Or. (Q = quartz, Pl = plagioclase, and Or = potash feldspars). In Fig. 3 all the eleven analyses lie in one corner of the triangle. In Fig. 4 the concentration shown is not as pronounced as in Fig. 3; nevertheless, here also all the analyses except Nos. 9, 10 and 11, fall in one triangle (231), and the other three which fall in the triangle (213) are not far away.

All this evidence tends to suggest that the syenites and the granites are comagmatic, and that there is a gradational change from the former to the latter. Apparently this view also conforms with the field evidence.

ORIGIN AND MODE OF EMPLACEMENT

It has been noticed in the field that the syenites and the granites show a concordant relationship with the sediments in which they are emplaced. The boundary of the igneous rocks follows the general trend of the strike of the sediments, and the boundary is always sharp; there is no gradational change from sediments to igneous rocks. It was also noted that the hornfelsic contact zone is narrow, and that xenoliths are present along the borders or very near to them. Some of these xenoliths were found to contain chiastolite, which suggests a moderately high temperature condition.

The above evidence, taken in conjunction with the prevalence of oscillatory zoning and twinning in plagioclase and the euhedral form and twinning in the amphiboles, at least suggests a magmatic condition. The general geological setting is completely incompatible with the idea of granitisation in situ. The sharp contact and lack of gradational change from sedimentary to igneous rocks, together with the rather narrow contact zone, are in keeping with a magmatic mode of origin. The presence of discontinuous reaction series (Bowen, 1922) in the form of brown hornblende-green hornblende-biotite also suggests a magmatic origin of these rocks.

Therefore it is concluded that the syenites and the granites are of magmatic origin, and that the original magma was a quartz-syenite magma which was intruded first rather near to the surface (as evident from the medium grain size of the syenites); and subsequently to this, and due to differentiation and possibly assimilation of the sediments, the granitic rocks were formed and emplaced probably largely at a deeper level than the syenites. Thus the granitic rocks are younger than the syenites, which also conforms with the field evidence.

Regarding the mode of emplacement of these rocks the ideas are still hazy and vague. From the available field evidence it is suggested that these rocks were emplaced by doming the sediments and by a process of magmatic stopping. The presence of xenoliths in the margin is very strong evidence in favour of this hypothesis, as the freezing of magma towards the margin stops further movement of the xenoliths and also puts a stop to the complete dissolution of them, it is for these reasons that xenoliths occur only in the marginal zone. Any xenoliths which reached the deeper and hotter parts of the magma have, apparently, been completely assimilated. However, much more detailed field work is required in order to confirm the postulated hypothesis.

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Daly, R.A., 1933 - Igneous Rocks and the Depths of the Earth.

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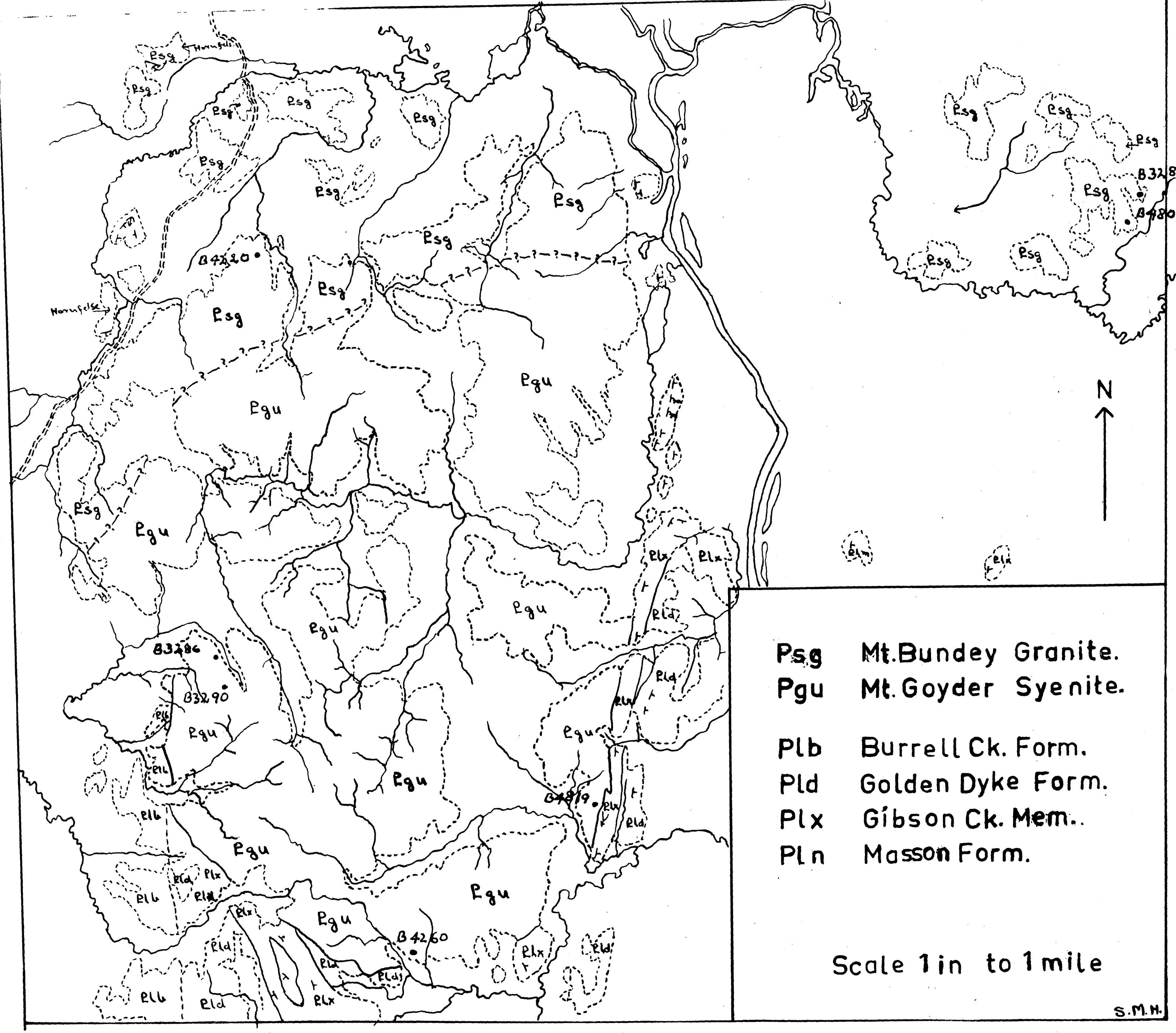
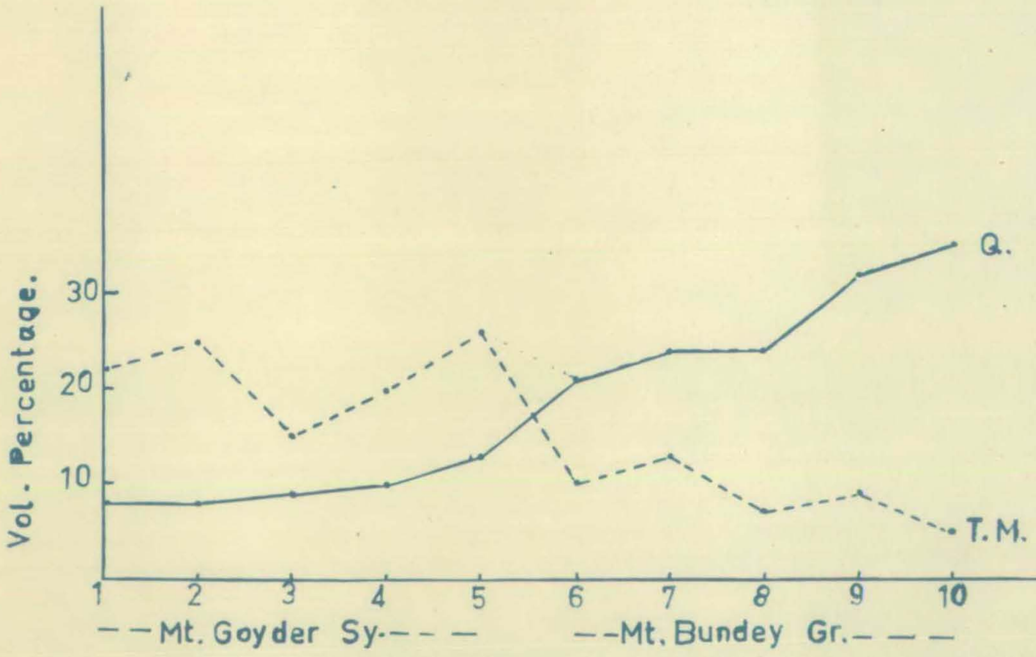

Psg Mt. Bundey Granite.
Pgu Mt. Goyder Syenite.
Plb Burrell Ck. Form.
Pld Golden Dyke Form.
Plx Gibson Ck. Mem.
Pln Masson Form.
Scale 1 in to 1 mile
N
B3285
B4809
B4220
B3286
B3290
B4819
B4260
S.M.H.

Fig.1



Vol. Percentage.
30
20
10
Q.
T.M.
1
2
3
4
5
6
7
8
9
10
- - Mt. Goyder Sy.- - -
- -Mt. Bundey Gr.- - -

Fig. 2

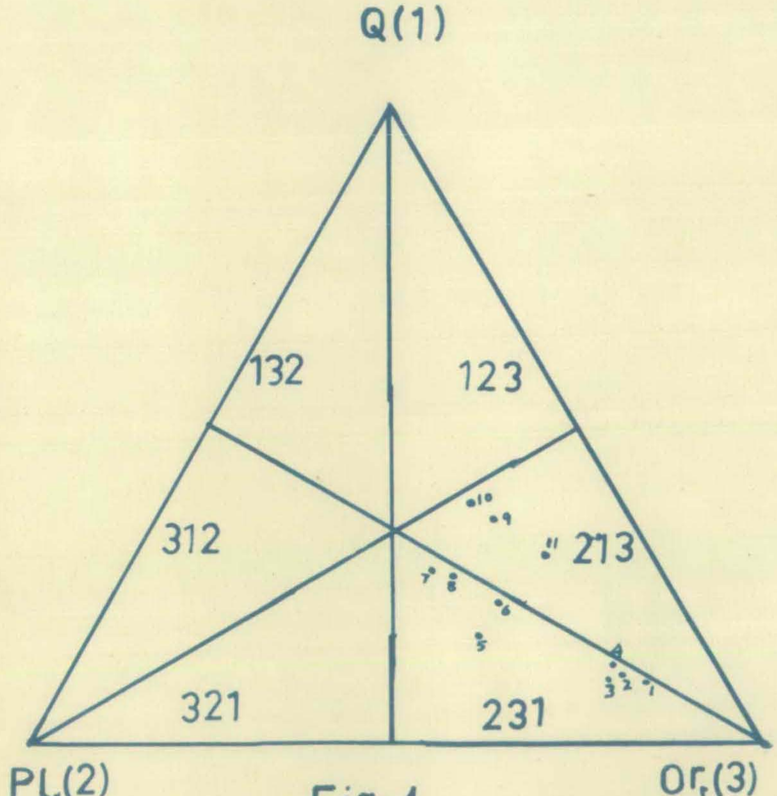


Fig. 4

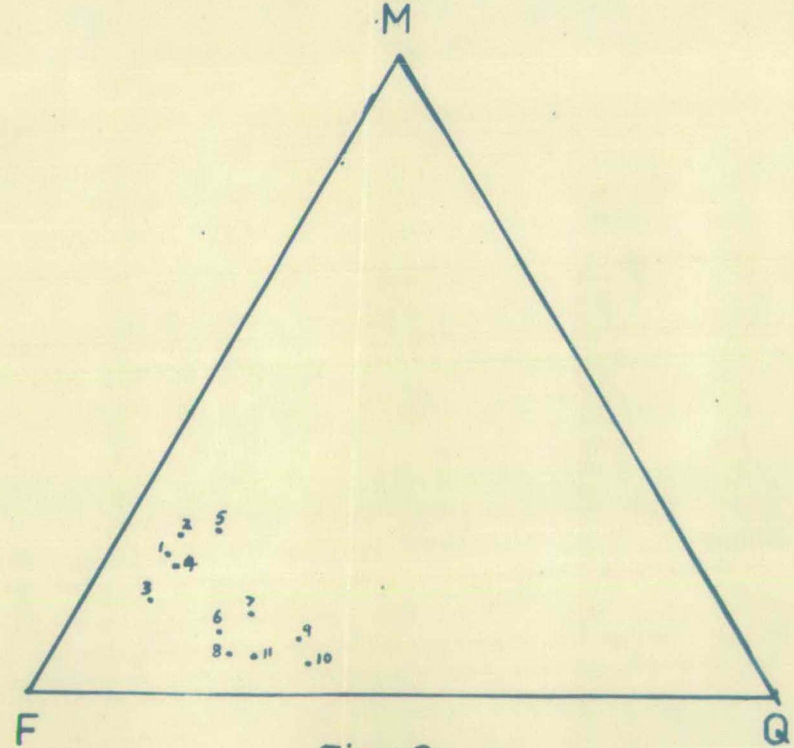


Fig. 3