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Geology of the Nunataks — Littlewood, Bertrab and Moltke in Weddell Sea Area, West Antarctica

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Introduction

A number of rock outcrops of varying dimensions — Nunataks — crop out within the polar ice cap, at the head of Vahsel Bay, Weddell Sea, Antarctica (Fig.l). Seven of these are spread in two clusters viz. Littlewood and Bertrab Nunataks. These are exposed within the valley into which the confluencing Schweitzer, Larchenfeld and Penck glaciers debouch. The Littlewood Nunataks — a group of four outcrops at the he'ad of the valley, is exposed along the frontal portion of intermediary ice slopes between Schweitzer and Larchenfeld glaciers. The Bertrab group, comprising one large and two small outcrops, is exposed along the western wall of this valley; the Argentinian base of General Belgrano II is located over the largest outcrop. The third group named as Moltke Nunatak, known to the visitors to this part of Antarctica much earlier than the other two, is at present, represented by two rock outcrops exposed along the northern ice front at the top of highly crevassed ice fall and are in turn overlooked by the polar ice overhang.

The Nunataks, hitherto, had been thought to be an extension of one body, now buried under thick ice cover. Present study has, however, revealed these Nunataks to be belonging to different stratigraphic levels representing either-uplifted fault blocks or eroded undulating coastal front. This would explain the absence of these rocks within the valley depression as well as in the adjacent valley of the Wiedenmann glacier. There is every possibility that the valleys, now occupied by the glaciers are antecedent in origin.

Moltke Nunataks

These are represented by two dark grey to light greyish brown rock outcrops — western one'being larger than the eastern outcrop (Fig. 2). Moltke Nunataks are exposed within the polar ice along coastal front at and around 78°S : 35°04' W in the Vahsel Bay of Weddell Sea. The two rock bodies are surrounded by overhangs of what appears to be a fast moving polar ice which cascades down the vertical slopes as highly fissured and crevassed ice fall. These Nunataks are practically inaccessible and to our knowledge have remained geologically unexplored till date. Only one of these, the eastern one, could be surveyed when the team was airlifted by helicopter and' it jumped onto the foot of the ice slope below the outcrop. The team, in fact, had to be retrieved with the help of a rope ladder hanging from the helicopter hovering overhead.

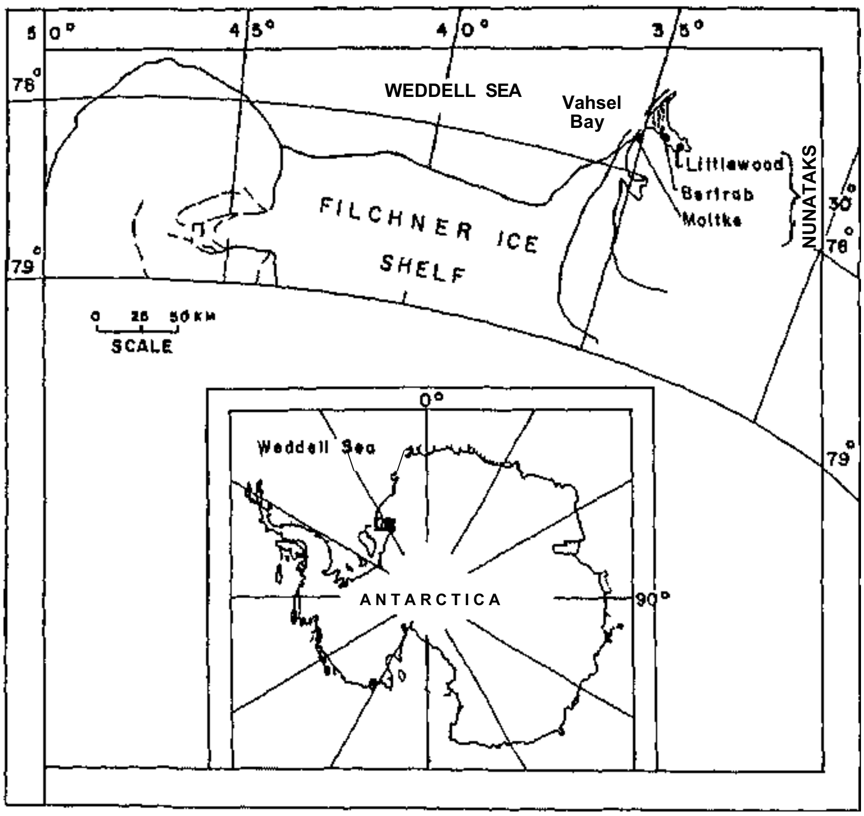


Fig 1 Location map showing the position of the Nunataki

Field examination has revealed that the eastern outcrop is mainly ot limestone mter-bedded with foliated lithic arkosic rock Limestone is slightly metamorphosed, but letains its sedimentary character like colour banding and bedding which shows almost N-S stnke with a moderate to steep westerly dip (Fig 3)

Megascopically, limestone is fine-grained cryptocrystalline and steel grey in colour The rock is highly jointed and fractured, the fracture plains being filled up with coarse-giamed calcite veins

Under the microscope, the rock shows a closely packed mosaic of the tme-grained calcite grains with subordinate quartz, fine flakes of chlorite and smectite and tine granular aggiegates of sphene Leucoxene, rutile, fine stumpy grains of plagioclase, tiny needles at muscovite and opaque oxides are accessory minerals present in the rock Calcite constitutes the bulk ot the rock and occurs as fine micntes, polygonal aggregates of spante calcite at places form recrystallized, interlocking, coarser aggregates within the tiner grained micrite mosaic Veins and lenses of coarse crystalline aggregates ot calcite (Fig 4) with matching walls are often present Calcite grains are mostly subhedral, slightly elongated parallel to the toliation and the grain interstices are filled up with quartz and rarely with plagioclase Quart/

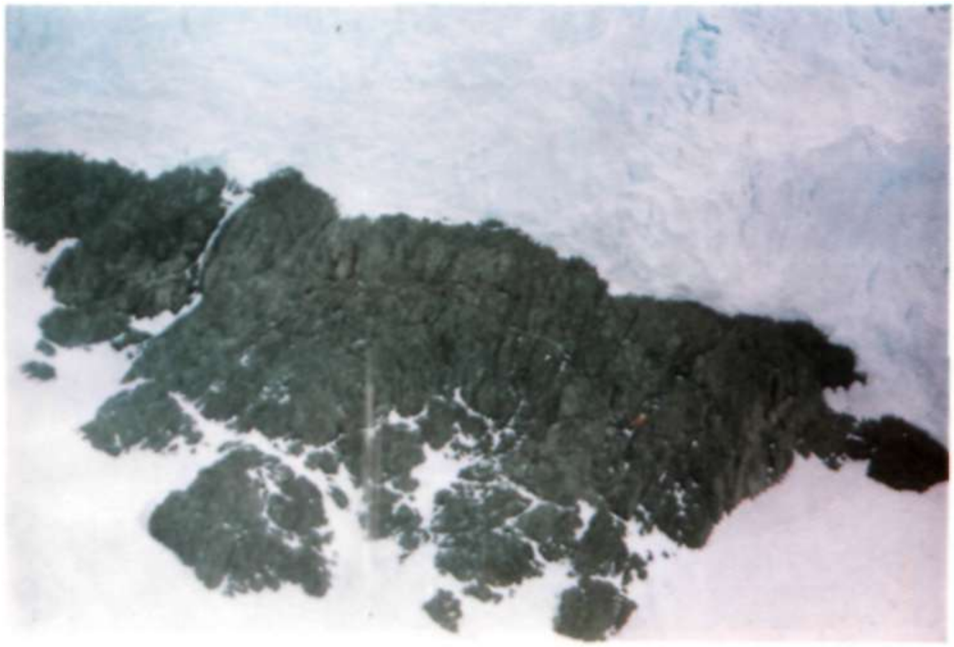


Fig. 2. Eastern Moltke Nunatak, Weddell Sea, exposing Lithic Arkose and Limestone.

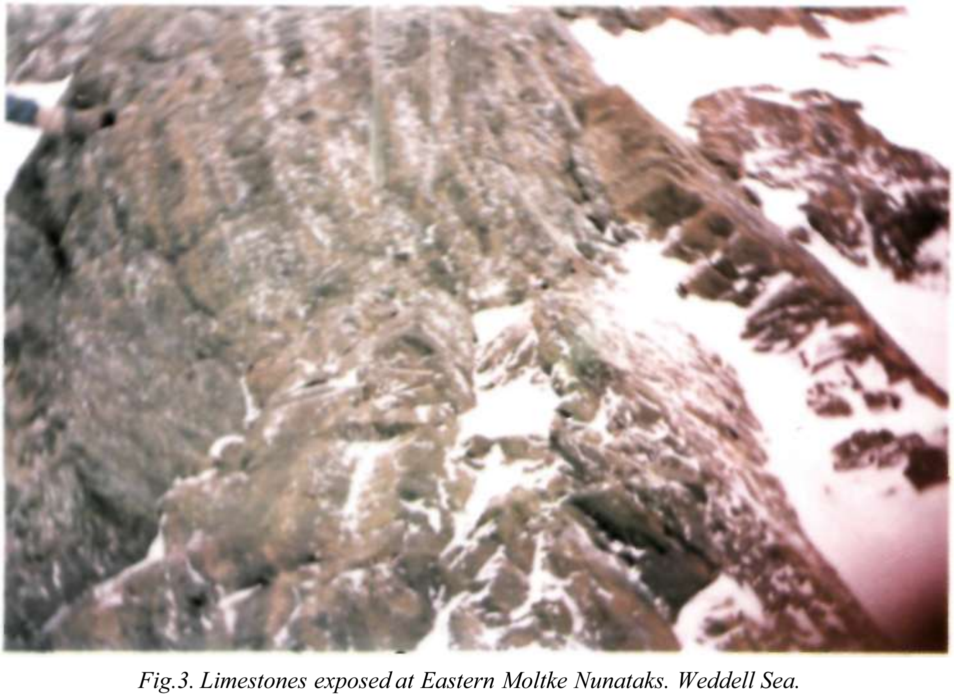


Fig.3. Limestones exposed at Eastern Moltke Nunataks. Weddell Sea.

Fig.4. Photomicrograph of limestone from Moltke Nunataks, Weddell Sea, coarse calcite vein cuts across the slide, x 20.

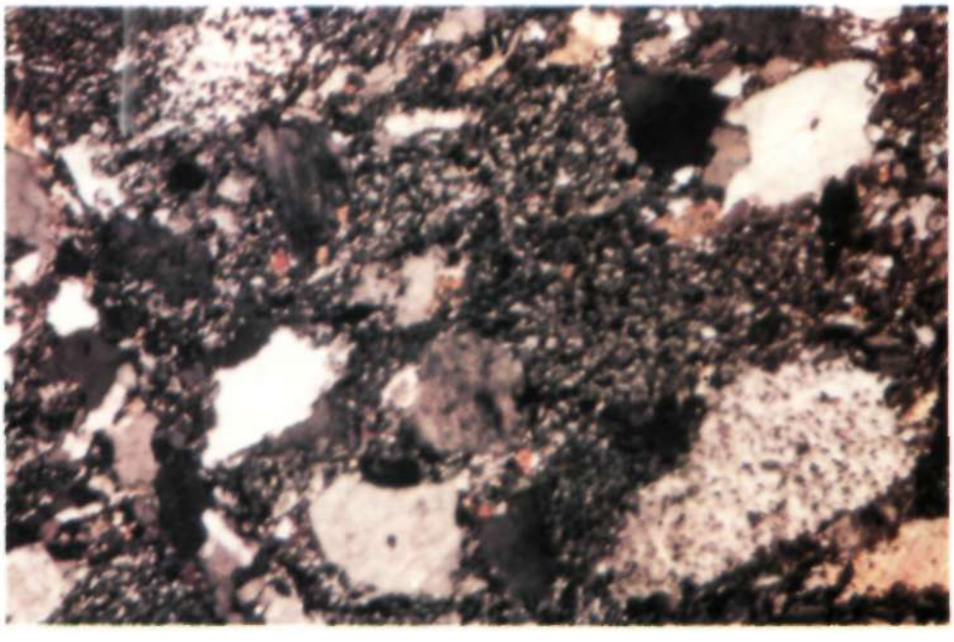


Fig.5. Photomicrograph of Lithic Arkose, Moltke Nunataks, Weddell Sea, x 20.

Table 1: Major Element Oxide (in wt%) Abundance in Limestone and Lithic Arkose of Moltke Nunataks

Sl. No.	1.	2.	3.	4.
Sample No.	MN-1	MN-2	MN-3	MN-4
Rock name	Lithic arkose	Limestone	Limestone	Limestone
$S1O^2$	72.22	15.87	45.41	34.24
AL^2O_3	11.79	3.01	9.67	7.37
Fe_2o_3	2.02	0. 54	—	1. .38
FeO	2 . 34	1. 62	2.36	2.79
MnO	0.05	0.14	0.05	0.08
MgO	0 .29	0.18	—	0,79
CaO	2.17	43.60	33.5S	28.18
Na_20	3 ..11	1.08	1.24	1.59
K_2o	3.83	0. 55	2.37	1.56
Tio_2	0.39	0. 22	0.31	0.58
P_2O_5	0.08	0 .10	0.26	0.15
LOI	1.40	33. 39	—	21.51
Total	99.69	100 .30	95.25	100.14
Fe_20_3(T)	4.59	2. 34	—	4.48

grains are largely anhedral, fractured and show undulose extinction; the grain margin is embayed and replaced by calcite. Chlorite grains are generally developed at the periphery of opaque oxides. The mineral shows very low birefringence with the following pleochroic scheme : X = straw yellow, Y = yellowish green, and Z = green.

Microscopic examination failed to reveal the presence of any microfossil or algal filament. Samples were also subjected to maceration but no palynological elements could be.detected.

The limestone beds are associated with compact, medium-grained, light greyish brown clastic rocks. Under the microscope the latter reveals a medium-grained nature (Fig. 5) with bimodal grain size distribution. It is composed of coarse, immature clasts of quartz, inicrocline and plagioclase in the order of abundance, with rare lithic clasts of quartzite, granodiorite and limestone, embedded in a very fine-grained matrix of quartz with subordinate chlorite, rare epidote, sphene and plagioclase; chlorite mostly occurs as thin laminal wrapping around bigger clasts. Limestone rock fragments are rather sparse compared to other types. The proportion of clasts to matrix is, roughly 1:1. The modal composition of the rock shows microcline 29.08%, quartz 12.45%, plagioclase 1.90%, and rock fragments 5.25% ; matrix component includes chlorite 14.60% and quartz plus rare plagioclase 36%. Sphene and epidote are in traces. The rock shows prominent directional fabric. Quartz, both

Table 2: Trace Element (in ppm) Abundance in Limestone and Lithic Arkose of Moltke Nunataks

SL No.	1.	2.	3.
Sample No.	MN-1	MN-2	MN-3
Rock Name	Lithic arkose	Limestone	Limestone
Cu	15	15	15
Pb	55	90	85
Zn	60	40	70
Ni	30	40	45
Co	30	40	45
Li	<10	<10	< 10
Rb	75	15	50
Cs	<10	<10	< 10
Ag	2	2	2
Cd	<10	<10	< 10
La	32	20	nd
Y	4.7	0.27	2.5
Zr	303	nd	nd
Sr	600	1400	880
V	75	40	95
Cr	60	40	55
Sc	<10	<10	< 10
Sn	20	<10	10
Ge	<10	<10	< 10
Ga	10	<10	< 10
Bi	<20	<20	<20
Hf	<50	<50	<50
B	<20	<20	<20
W	< 100	< 100	< 100
Ba	>1000	<10	500
Th	<50	<500	< 500
Nb	<30	<30	<30

as clasts and in the matrix shows undulose extinction. The margins of clasts are generally highly irregular, showing protoclastic granulation. The fine-grained component of the matrix probably represents pulverised rock flour. There are a few carbonate veins transecting the rock. Based on mineralogical composition, the rock could be designated as arkose to lithic arkose. The rare lithic clasts of limestone, found in the rock, may have been derived from the underlying and associated limestone beds.

Chemical analyses along with trace element abundances of the limestone and associated lithic arkose are cited in Tables 1 and 2. Limestone is arenaceous with CaO varying (in weight per cent) from 28.12 to 43.60; SiO_2 15.87 to 45.41; A12O3 3.01 to 9.67; $Fe_{2O}3$ 0.54 to 1.38; FeO 1.62 to 2.79; MgO 0.18 to 0.79; P2O5 0.10 to 0.26 and TiO_2 0.22 to 0.58. K2O+Na2O varies from 1.63 to 3.61. The lithic arkose analysis shows (in weight per cent) $Si0_2$ 72.22; Al2O3 11.79; CaO 2.17 and Na_2 O+K_2O6.94. Fe_2O_3, FeO, MgO, TiO_2, P2O5 and MnO contents are largely comparable with those in limestone. Trace element abundances in both the varieties of rocks are more or less comparable excepting Sr, Pb and Rb. Limestone shows higher values for Pb and Sr but is appreciably depleted in Rb compared to lithic arkose. Higher Rb abundance in the latter may be attributed to higher content of phyllosilicates. Extremely high abundance of Ba in arkosic rocks would indicate their granitic provenance. Significantly high values of Ba in siliceous limestone (limestone 10 ppm while in siliceous limestone 500 ppm) compared to the high CaO variety, also indicate that the impurities are largely derived from the washed granitic material.

The association with lithic arkose and the mineralogical characteristics, particularly the presence of epiclastic quartz and plagioclase grains indicate that the limestone sediment was not accumulated on deep sea floor but in a shallow water environment, probably in the low energy area of the shallow shelf seas. The nature of the rock fragments plus the predominance of sub-angular clasts of microcline, quartz and plagioclase point towards a granitoid provenance for lithic arkose rather than an argillaceous assemblage. The rocks show a clear imprint of deformation and have undergone lower greenschist facies conditions of metamorphism.

Bertrab Nunataks

Bertrab Nunataks (77° 54'S: 34° 40' W) are represented by three rock outcrops of varying dimensions, which are exposed along the western valley wall. Largest of these outcrops forms an escarpment which is highly polished and striated in nature. The Argentinian station, General Belgrano II is located on this outcrop (Fig.4).

Megascopic examination revealed existence of as many as three rock types in the largest outcrop viz. reddish brown granitic rock, dark grey acid volcanic and dark grey basic rock invaded by dolerite dykes.

Under the microscope the granitic rock (Fig. 6) reveals a medium-grained porphyritic texture essentially composed of phenocrystal plagioclase with minor subhedral to anhedral quartz set in a fine-grained granophyric aggregate of quartz and potash feldspar almost in equal proportion. Plagioclase is largely euhedral to subhedral, prismatic in habit with an average grain size of 1.00 mm x 0.40 mm. The margins of the grains are commonly irregular, being mantled by a flange of potash feldspar inter-grown with quartz. The core of the plagioclase grains is markedly altered to sericite, zoisite and carbonates. This selective alteration may be due to hydrothermal action being active in the CaO rich core. The twinning is on albite law and normal zoning (Fig.7) is frequent. Symmetrical extinction on {010} measured from albite twin lamellae indicates plagioclase to be oligoclase in composition. Quartz in the groundmass forms small subrounded worm-like, wedge-shaped and elongated grains intergrown with potash feldspar forming various types of implication textures such as, cuneiform, graphic, radiating fringe and mottled fringe types (Leighton, 1954). The gradational nature of the implication texture from graphic to mottled fringe types through radiating fringe type in the scale of a thin section and the eutectic nature of crystallization of quartz and potash feldspar strongly suggest that the implication textures are of primary origin. Strongly pleochroic brown biotite and granular epidote plus irregular Fe-Ti oxides are the ubiquitous accessories. Biotite shows the following scheme of pleochroism with X=pale reddish yellow, Y=yellow, and Z=brownish yellow. The mineral is occasionally altered to chlorite. The modal composition of the rock shows potash feldspars including perthite - 48.60 %, quartz - 24.04 %, plagioclase - 18.76 %, biotite - 6.35 %, chlorite - 1.07 %, and opaque oxides - 1.18%. From the mineralogical and textural point of view the rock could be designated as a medium-grained granophyre. Presence of prominent normal zoning in plagioclase phenocrysts and widespread granophyric eutectic intergrowth indicate that the granophyre may be the shallow level intrusive equivalent of the rhyolites.

Thin section studies on the dark grey acidic rock reveal a porphyritic texture with phenocrysts of potash feldspar, quartz and plagioclase (in order of abundance), set in a very fine- grained groundmass (Fig. 8) made up of needle shaped microlites of K-feldspar, tiny xenomorphic quartz, saussuritised and rare Fe-Ti oxides. Inter-granular spaces of microlites and potash feldspar are occupied by tiny grains of quartz. Quartz also occurs in clusters, mostly anhedral and shows undulose extinction. K-feldspar phenocrysts are largely subhedral and rarely show perthitic intergrowth. The modal composition of the rock indicates that the phenocrystal components comprise only 15 % and the rest is groundmass. The phenocrysts include K-feldspar - 70 %, plagioclase - 3.90 %, and quartz - 4.10 %. The rock shows rare fluidal texture and can be designated as a rhyolite.

The dark grey medium-grained basic rock shows a sub-ophitic texture. The dominant mineral constituents are tabular grains of saussuritised plagioclase, anhydrous fibrous actinolite and quartz with subordinate sphene and Fe-Ti oxides. The modal composition of the rock indicates presence of plagioclase 53.82 %, actinolite - 34.20 %, quartz - 3.36 %, Fe-Ti oxides - 6.17 % and sphene - 1.91 % with traces of calcite and chlorite. Excepting plagioclase, minor quartz and opaque all seem to be secondary minerals. Actinolite is partly altered to chlorite along the periphery. Its pleochroic scheme is X= greenish yellow, Y = yellowish green, Z = green. $Z^{A}C = 15°$ and the elongate sections are length slow. Although there is a pervasive mineralogical transformation, the original sub-ophitic texture of the rock is largely retained. Actinolite is probably altered form of clinopyroxene and the rock was primarily a medium-grained gabbro. Based on present mineralogical composition it can be designated as epidiorite (Fig.9). The rock has been metamorphosed to greenschist facies.

The dark grey dyke rock in the area is a fine-grained porphyritic rock. Phenocrysts consist of large plagioclase grains either occurring singly or as glomeroporphyritic aggregates with minor amount of mafic minerals (Fig.10). Latter are possibly pyroxenes, now altered to an aggregate of biotite and chlorite, set in a fine-grained groundmass consisting of plagioclase

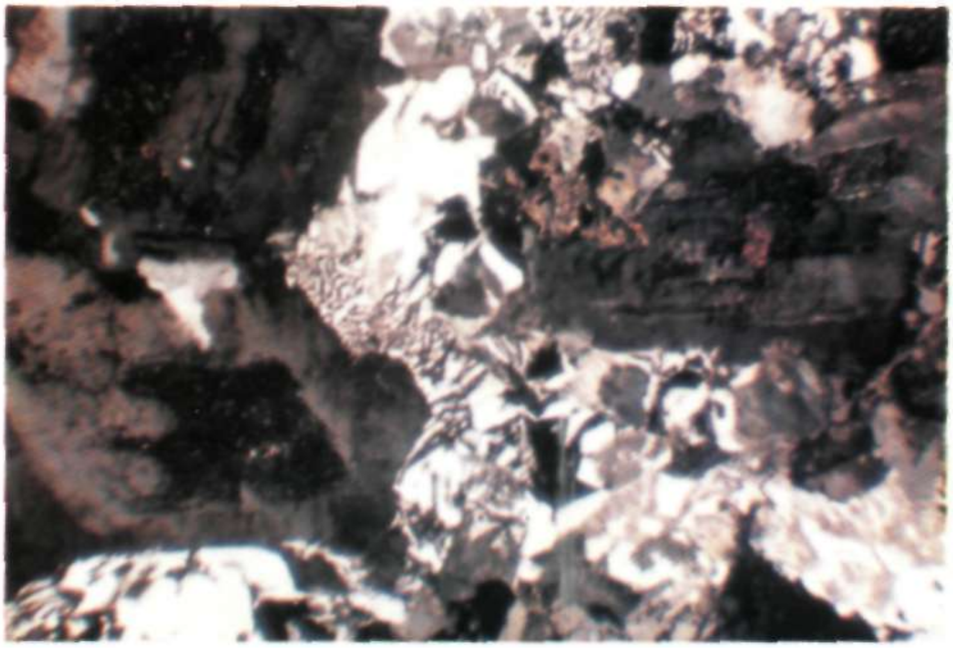


Fig.6. Photomicrograph of Granophyre, Bertrab Nunatak Weddell Sea, X *20. showing granophyric texture and altered feldspar.*

Fig.7. Photomicrograph of Granophyric rock from Bertrab Nunatak, Weddell Sea. showing zoned plagioclase and granophyric texture, x *20.*

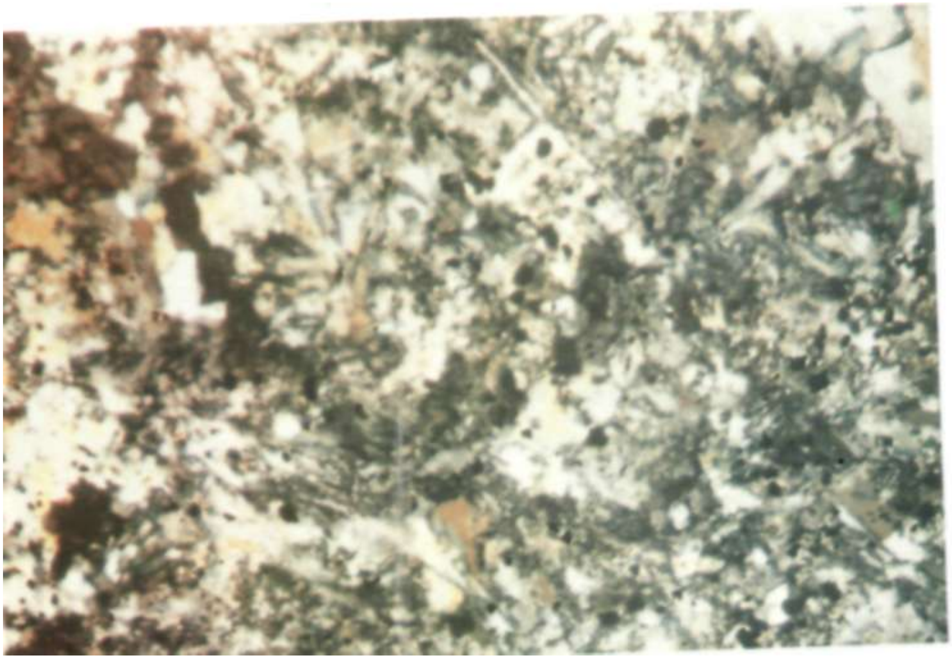


***Fig 8. Photomicrograph** of Rhyolite eith lath shaped alkali feldspar,* x *20. Bertrab Nunatak Weddell Sea.*

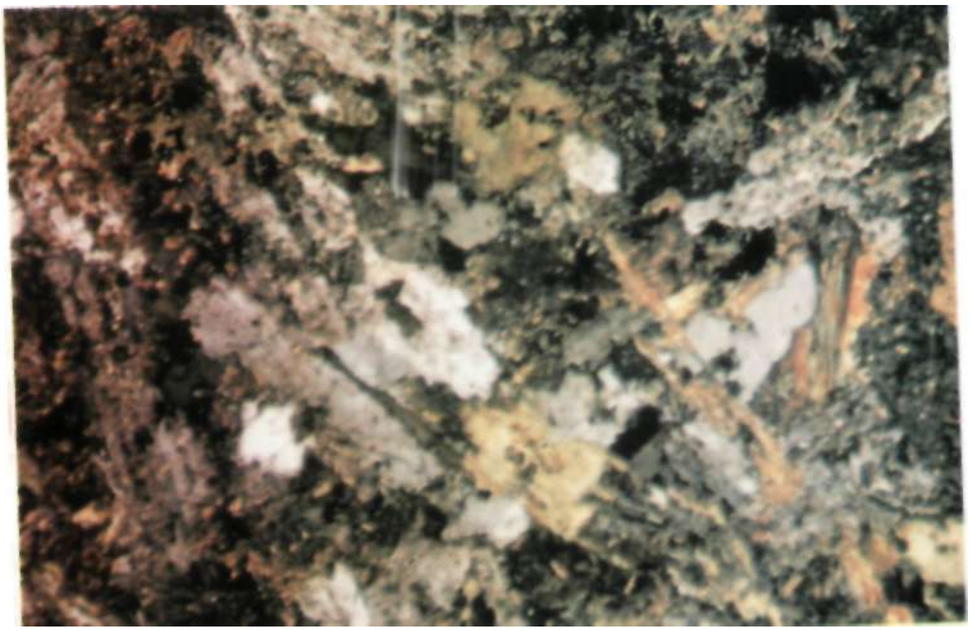


Fig.9. Photomicrograph of Epidiorite showing (White) feldspar and (Coloured) hornblende, x *20. Bertrab Nunatak, Weddell Sea.*

laths, intergranular spaces of which are filled up with fine-grained feathery aggregates of biotite, chlorite and minor rutile. The plagioclase mega-phenocrysts are labradorite in composition, largely saussuritised and show relict albite twinning; normal zoning is also not infrequent. Plagioclase grains in the groundmass are also saussuritised, tabular in shape and often fringed by a thin rim of clear feldspar. The groundmass texture of the rock is intergranular. The modal composition of the rock shows presence of 47.11 % plagioclase (including 16.60 % of oegaphenocrysts); 32.71 % biotite; 17.97% chlorite; 0,79 %sphene; 0.29 % rutile and 1.13 % Fe-Ti oxides. Biotite shows the following pleochroic scheme: X=pale yellow, Y=yeIlow and Z=straw yellow, while that of chlorite is X=pale green, Y=green and Z=deep green. The latter shows very low birefringence. On the basis of mineralogical composition the rock is identified as an altered fine-grained dolerite. The rock is also affected'by greenschist facies of metamorphism.

Chemical analyses along with the CIPW norm calculated for the rocks of Bertrab Nunataks show a broad spectrum of acid and basic compositions (Table 3). The normative total feldspar in granophyre is An-6.52, Ab-47.31, Or-46.17, while from the optical measurements phenocrystal plagioclase ranges from An-12 to An-15.

The normative composition of total feldspar in rhyolites of Bertrab Nunataks is An-2. 76, Ab-49.43, Or-47.81. This is slightly less anorthitic compared to the feldspars of granophyre from the same Nunataks. Rhyolite also shows slightly higher differentiation index. Otherwise both the varieties of rocks show strikingly similar major element chemistry indicating their common genetic parentage.

The major element chemistry of epidiorite and that of altered dolerite are largely comparable. Epidiorite shows slightly higher SiO2 content but depletion in MgO, CaO and K2O as compared to dolerite. Both the compositions are hypersthene-quartz normative and may have been derived from tholeiitic magma.

As regards trace element distribution (Table 4), granophyre shows higher abundances for Ba (rhyolite 900 ppm; granophyre > 1000 ppm) and Sr (rhyolite 15 ppm; granophyre 65 ppm), which may be due to the higher plagioclase content in granophyre.

On the other hand dolerite and epidiorite display similar pattern of trace element distribution. However, dolerite shows slightly higher abundances for Zn, Ni, Co, Cr, Rb and Sc and depletion in La, Ba, and V compared to epidiorite. Other elements exhibit largely comparable values. Thus from the major and trace element chemistry it may be suggested that the basic rocks of Bertrab Nunataks are genetically related and are derivatives of tholeiitic basalt magma.

Littlewood Nunataks

Four rock outcrops which form the easternmost of the group of Nunataks in the region, go under the name of Littlewood Nunataks (77° 53' 30" S: 34° 10'W) (Fig. 11). These were first reported by (Aughenbaugh *et al.,* 1965) and are exposed in three levels, the topmost one being the largest. The rocks are highly jointed, fine-grained, reddish brown in colour which have been identified megascopicafly as rhyolites. Aughenbaugh (op.cit.) has assigned them younger Proterozoic age of 840+30 Ma.

Table 3 : Major Element Oxides (in wt%) and CEPW Norms of Acid and Basic Rocks from Bertrab Nunataks

Sample No.	BN-1	BN-2	BN-5	BN-8(6)
Rock Name	Epidiorite	Rhyolite	GranoDhvre	Dolerite
Si02	53.81	74. 30	73.00	46.91
Al_2O_3	15. 23	12.77	14 .00	16 .32
Fe_2o_3	4.65	1.72	2.12	5.10
FeO	8.28	1.71	1.62	7.74
MnO	0.36	0.04	0.06	0.21
MgO	3.91	<0.15	<0.15	5.96
CaO	5.21	0.37	0.81	7.13
Na_2O	2.23	3.61	3. 22	2.45
K_2O	2.21	5.00	4. 50	3.08
Tio_2	1.89	0.14	0.31	1.93
P_2O_5	0.38	0.02	0.04	0.26
LOI	1.55	Tr	0. 58	2.79
Total	99.71	99.68	100. 26	99.88
Fe_2O_3	13.75	3.60	3.90	13.61
Na_2O/K_2O	1.17	0.72	0.715	0.80
Q	12. 63	32 .64	34 .98	3.96
C	0.62	0.80	2.46	—
O r	13. 34	29.61	26. 65	18.75
Ab	19. 22	30. 62	27 .31	21.35
An	23. 81	1.71	3.77	25.17
Di	—	—	—	—
Hy	19.00	1.82	1.07	18.99
Mt	6.87	2.50	3.08	7.62
Il	3.66	0.27	0.59	3.78
Ht	—	—	—	—
Ap	0.92	0.05	0.09	0.63
D.I.	45.16	92. 87	88.94	36.14
Or	23.62	47 .81	46.17	28.72
Ab	34.12	49.43	47.31	32.71
An	42.26	2.76	6.52	38. 56
Na2O+K2O)	4.44	8.61	7.72	5 .53
$Na._2 O+K_2 OVAl_2O_3$	0.29	0.67	0.55	0.34

Table 4 : Trace Element (in ppm) Abundance in Acid and Basic Rocks of Bertrab Nunataks

Sl. No.	1	2	3	4
Sample No.	BN-1	BN-2	BN-5	BN-8(6)
Rock Name	Epidiorite	Rhyolite	Granophyre	Dolerite
Cu	10	< 10	<10	<10
Pb	65	55	50	60
Zn	300	10	50	440
Ni	35	15	15	75
Co	65	25	30	80
Li	30	<10	<10	30
Rb	85	130	100	185
Cs	<10	<10	<10	<10
Ag	2	1	3	3
Cd	<10	<10	<10	<10
La	–	25	29	-
Y	27	28	22	30
Zr	139	200	264	137
Mo	<10	<10	<10	< 10
Sr	245	15	65	245
V	345	15	15	250
Cr	25	15	25	40
Sc	10	<10	<10	20
Sn	20	20	15	15
Ge	<10	<10	<10	<10
Ga	10	10	10	10
Bi	<20	<20	<20	<20
Hf	<50	<50	<50	<50
B	<20	<20	<20	<20
W	<100	< 100	< 100	<100
Ba	>1000	900	>1000	800
Th	<500	<500	<500	<500
Nb	<30	30	<30	<30

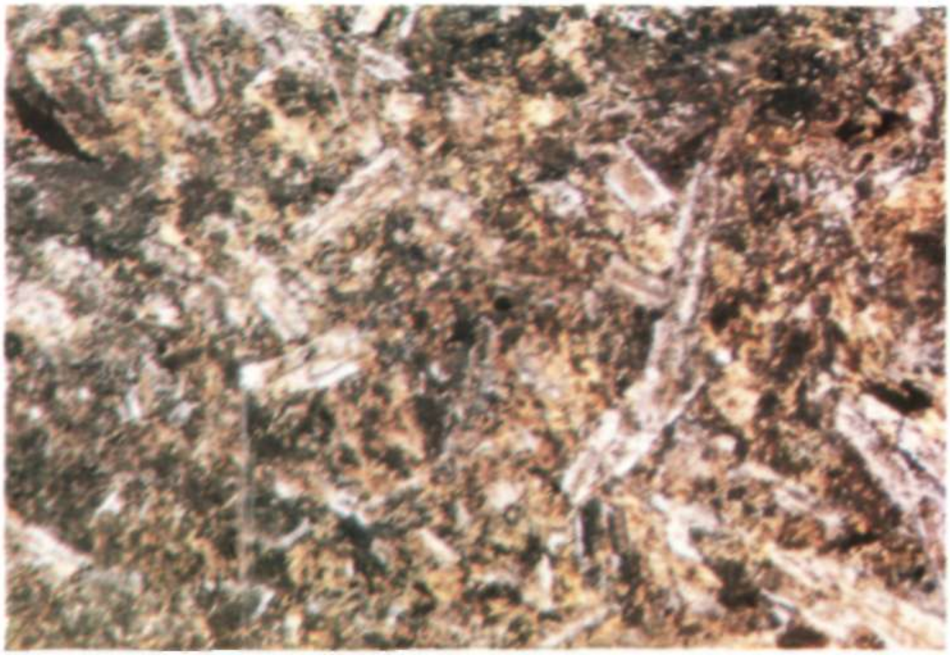


Fig.10. Photomicrograph of Dolerite showing typical ophitic texture, x *20. Bertrab Nunatak. Weddell Sea.*

Fig. I1. IMllewood Nunatuks. Weddell Sea.

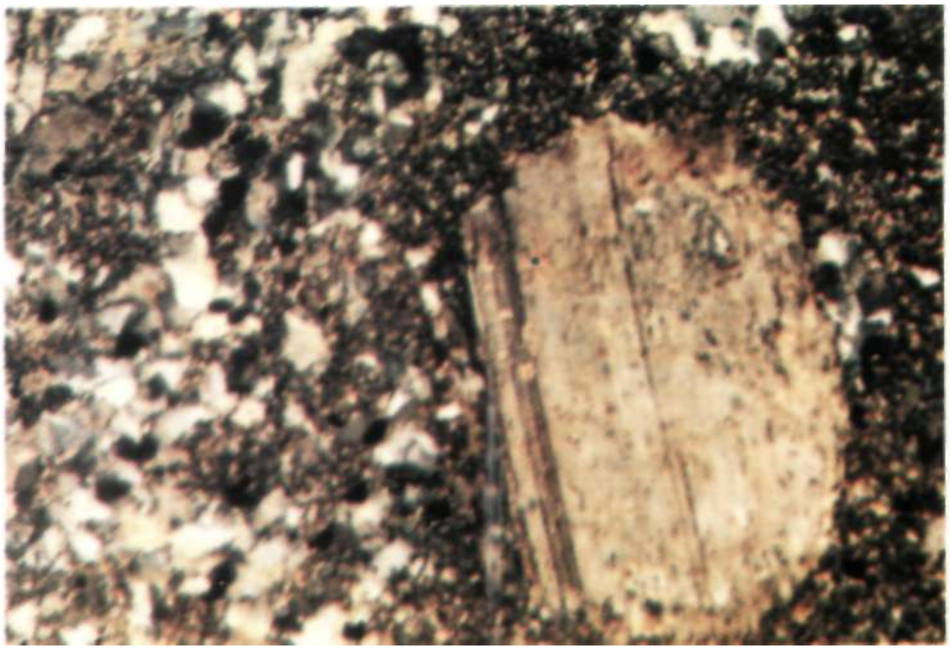


Fig 12. Photomicrograph of Rhyolite showing fine grained ash, plagioclase clasts and acid flow, Littlewood Nunatak, Weddell Sea.

*Fig. 13. Photomicrograph showing Plagioclase Porphyroclast in acid **tf** x 10, Littlewood Nunatak, Weddell Sea.*

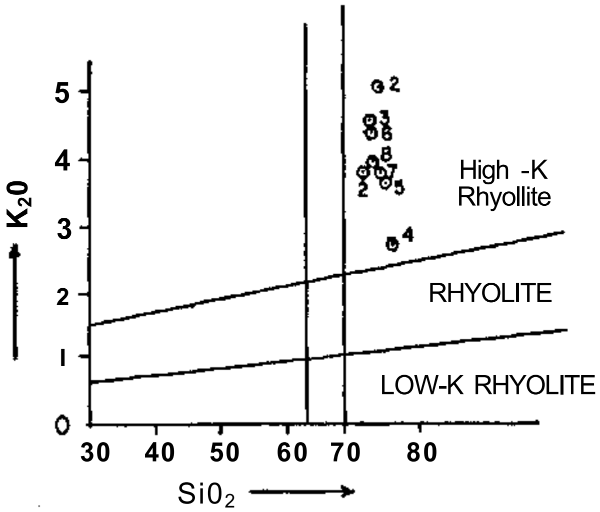


Fig. 14. Classification of acid rock assemblage by K2O and Sio_2 contents of Littlewood and Bertrab Nunataks (Sample details: 1, BN-2-Rhyolite; 2, BN-5-Granophyre; 3, LWN-1-Rhyolite; 4, LWN-3- Rhyolite; 5, LWN-7-Rhyolite; 6, LWN-10 - Rhyolite; 7, LWN - 13 - Rhyolite and; 8, LWN-U-Rhyolite).

Under the microscope the rocks show a porphyritic texture with fragmental appearances (Fig. 12). The groundmass is devitrified, often showing two distinct colour components : one colourless and the other light brown. The colourless component is relatively coarser-grained and forms aggregates of xenomorphic quartz with serrated outlines and minor K-feldspar at places displaying an indistinct granophyric texture. Quartz contains dusty hematite inclusions. The coloured component which is a quartzofeldspathic aggregate, is relatively finer in grain size and shows cryptocrystalline mosaic, where quartz and K-feld - spar occur in almost equal proportion showing sutured grain boundaries. K-feldspar assumes a cloudy appearance due to hydrothermal alteration. The alteration of K-feldspar to carbonate and clay minerals along with -fine impregnation of iron hydroxides and very thin phyllosilicates impart the light brown colour to the rock. The phyllosilicates appear to be non-pleochroic. The brown portion sometimes exhibits fluidal texture displayed by tiny hair like laths of K-feldspar. The phenocrysts include large euhedral to subhedral grains of plagioclase (Fig. 13) intensely saussuritised K-feldspar (may be sanidine) and rarely occur - ring grains of quartz. A few prismatic grains of mafic mineral now altered to-biotite, also occur as phenocrysts. In some sections fine-grained cognate fragments of same rhyolite material are found caught up within the groundmass along with the phenocrysts. Plagioclase phenocrysts are faintly zoned, partly corroded and show twinning on albite and carlsbad laws. They are occurring as single grain or forming aggregates showing glomeroporphyritic habit. The mineral assumes a turbid appearance due to its intense transformation into sericite, clay and calcite and carries a thin rim of slightly darker brown material intimately associated with the groundmass. Extinction angle measured on {010} from albite twin lamellae varies between 20° and 25° which indicates that the plagioclase phenocrysts are oligoclase to acid andesine in composition. Dissemination of tiny opaque oxides are common. The average modal composition of the rock shows that the phenocrysts form 27.80% of the rock. Of this K-feldspar constitutes 4.60%, plagioclase 11.20% and quartz 12.00%. On the basis of modal composition the rock can be *sensu stricto* described as rhyodacite, rather than a rhyolite.

Chemical analyses of six samples along with their CIPW norms and trace element abundances are given in Tables 5 and 6. All the compositions show normative corundum. The rock being significantly poor in mafic minerals, MgO content is very low. The normative An and Ab contents of feldspars vary from An - 0.13 to 2.18 and Ab - 53.89 to 61,15. The felsic nature of the rocks is reflected in their high differentiation index, which ranges from 89.14 to 91.65.

Major element chemistry

The major oxides of the acid and basic igneous rocks of Bertrab and Littlewood Nunataks are furnished in Tables 3 and 5. The acid volcanic rocks of both the areas are peraluminous (Shand, 1951) and they are all corundum normative, whereas the basic rocks of Bertrab Nunataks are hypersthene-quartz normative. A few variation diagrams have been drawn to unravel their geochemical characteristics :

1) Wt.% K_2O vs. Si02 (Fig.14). It is found that acid volcanics are all high-K rhyolites (Ewart, 1979) and in this regard they are significantly different from the low-K rhyolites of the island arcs (Ewart and Bryan, 1972). These rhyolites are largely comparable with the continental rhyolites (Barker, 1981).

2) Wt.% of AI2O3, CaO, FeO, Na_20, Ti02 and P2O5 vs. $Si0_2$ (Fig.15). Most of the plots indicate clustering of values for acid volcanics while basic rocks fall distinctly apart. Among acid rocks a distinct variation is noticed with respect to AI2O3 and K2O where a linear decrease is apparent with increasing silica content. Trend of FeO shows reverse pattern i.e. an increase with increasing silica content.

3) Mol% CaO (xlOO) plotted against $(Na_20+K_20)/Al_20_3$ (Fig.16). A linear trend can be traced from this binary diagram, which indicates a decrease in CaO mol % with increasing Na_20+K_20/Al_20_3 ratio. This probably indicates the degree of differentiation.

4) In Na_20 vs. K_2O diagram (Fig. 17) a clustering of plots is noticed in case of acid volcanics indicating that their ratio does not show significant variation with respect to differentiation. This observation is further corroborated by the binary diagram of Na_20/K_20 vs. $Si0_2$(Fi.18).

5) Normative Q| Ab and Or plotted in a ternary diagram (Fig. 19). Clustering of plots, excepting one value, around centre of the field, indicates a largely homogeneous composition of the acid igneous rocks.

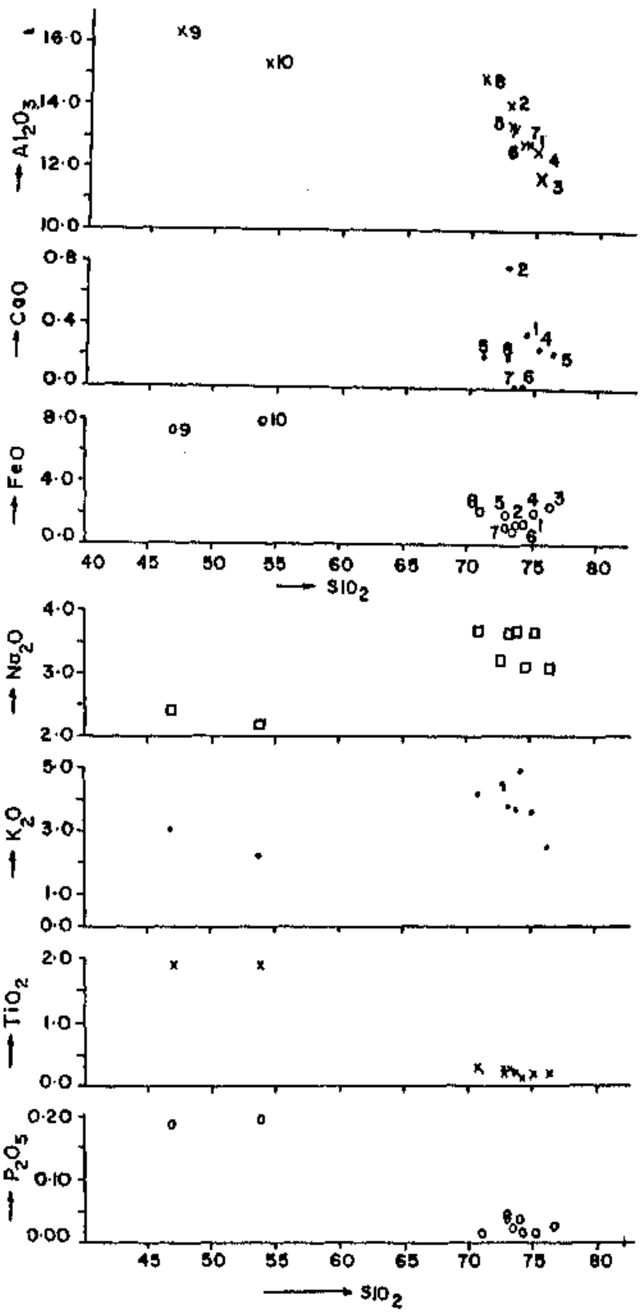
6) Similar clustering of plots is noticed in case of acid volcanics in the ternary diagram of normative Ab - An - Or (Fig.20). The plots 9 and 10 being of the basic rocks are significantly away from the acidic field. Acid rocks plot very close to Ab - Or line indicating very low CaO content in these rocks. This also signifies i) two distinct geochemical domains for acid and basic rocks in the Bertrab Nunataks and ii) the acid rocks of Bertrab Nunataks are strikingly similar in geochemical attributes to those of Littlewood Nunataks.

Table 5: Major Element Oxide Abundances (in wt %) in Rhyolites with Their CIPW Norms from Littlewood Nunataks

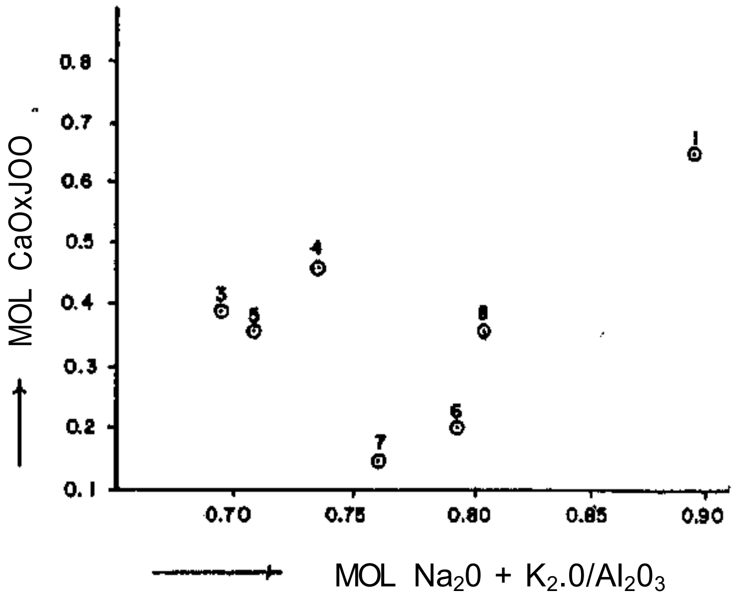
Sample No.	LWN-1	LWN-3	LWN-7	LWN-10	LWN-11	LWN-13
SiO_2	76.49	75.37	72.91	73.84	70.84	73.42
Al_2O3	11.61	12.53	13.37	12.85	14.81	13.31
Fe_2O_3	2.18	2.55	2.44	2.87	2.88	3.04
FeO	2.43	2.16	2.07	1.71	2.07	1.44
MnO	0.06	0.06	0.05	0.05	0.07	0.06
MgO	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15
CaO	0.22	0.26	0.20	0.11	0.20	0.08
Na_2O	3.09	3.60	3.70	3.70	3.72	3.66
K_2O	2.66	3.66	4.41	3.77	4.21	3.87
TiO_2	0.19	0.21	0.25	0.27	0.29	0.28
P_2O_5	0.03	0.02	0.04	0.04	0.02	0.05
LOI	0.50	0.15	0.27	0.50	0.57	0.39
Total	99.46	100.59	99.71	99.71	99.68	99.60
Fe_2O_3 (T)	4.85	4.92	4.71	4.75	5.15	4.62
Na_2O/K_2O	1.16	0.98	0.84	0.98	0.88	0.95
Q	47.12	38.83	33.53	37.69	32.33	37.40
C	3.35	2.21	2.25	2.60	3.85	3.10
Or	15.87	21.52	26.18	22.43	25.08	23.03
Ab	26.40	30.31	31.45	31.53	31.71	31.19
An	0.90	1.51	0.73	0.29	0.87	0.07
Di						
Hy	2.73	1.86	1.72	0.67	1.33	0.25
Mt	3.19	3.68	3.55	4.19	4.21	4.05
1l	0.36	0.40	0.48	0.52	0.56	0.54
Ht	—	—	—	—	—	0.27
Ap	0.07	0.05	0.10	0.10	0.05	0.12
D.I.	89.39	90.65	91.17	91.65	89.14	91.61
Or	36.76	40.62	44.85	41.36	43.48	42.42
Ab	61.15	57.21	53.89	58.12	55.01	57.45
An	2.09	2.18	1.26	0.53	1.51	0.13
Na_2O+K_2O	5.75	7.26	8.11	7.47	7.93	7.53
$(Na_2O+K_2O)/Al_2O_3$	0.47	0.58	0.61	0.58	0.54	0.57

Table 6: Trace Element Abundance in Acid Volcanic Rocks of Littlewood Nunataks (ppm)

Sample No.	LWN-1	LWN-3	LWN-7	LWN-10	LWN-11	LWN-13
Cu	10	10	<10	<10	10	<10
Pb	50	35	50	40	50	60
Zn	50	25	40	40	60	45
Ni	20	15	20	15	20	20
Co	25	25	25	25	30	30
Li	<10	<10	<10	<10	<10	<10
Rb	55	80	105	95	110	100
Cs	<10	<10	<10	<10	<10	<10
Ag	2	2	2	2	2	2
Cd	<10	<10	<10	<10	<10	<10
La	34	30	24	23	nd	26
Y	32	34	49	47	58	44
Zr	178	211	330	331	375	294
Mo	< 10	<10	<10	<10	<10	<10
Sr	30	30	30	30	30	30
V	15	40	15	40	40	40
Cr	20	20	25	10	20	20
Sc	<10	<10	10	<10	10	10
Sn	15	30	30	30	20	20
Ge	<10	<10	<10	<10	<10	<10
Ga	<10	<10	10	10	10	10
Bi	<20	<20	<20	<20	<20	<20
Hf	<50	<50	<50	<50	<50	<50
B	<20	<20	<20	<20	<20	<20
W	< 100	<.100	<100	<100	<100	< 100
Ba	>1000	>1000	>1000	>1000	>1000	> 1000
Th	<500	<500	<500	<500	<500	<500
Nb	30	30	30	30	30	30



*F*ig. 15. SiO_2 vs Al_2O_3 CaO, FeO, Na_2O, K_2O, T_2 & P_2O_5. Variation diagram for acid and basic rock compositions of Littlewood Nunataks and Bertrab Nunataks (Sample details:9, BN-8(6)-Dolerite; 10, BN-1 -Epidbrite, for other details see Fig. 14).



*F*ig. 16. Mol ecular CaO values vs peralkalinity indices (Mol. Na_2O+ K_2O/Al_2O_3) for acid rock compositions of Littlewood Nunataks and Bertrab Nunataks (Sample details as given in *F*ig. 14).

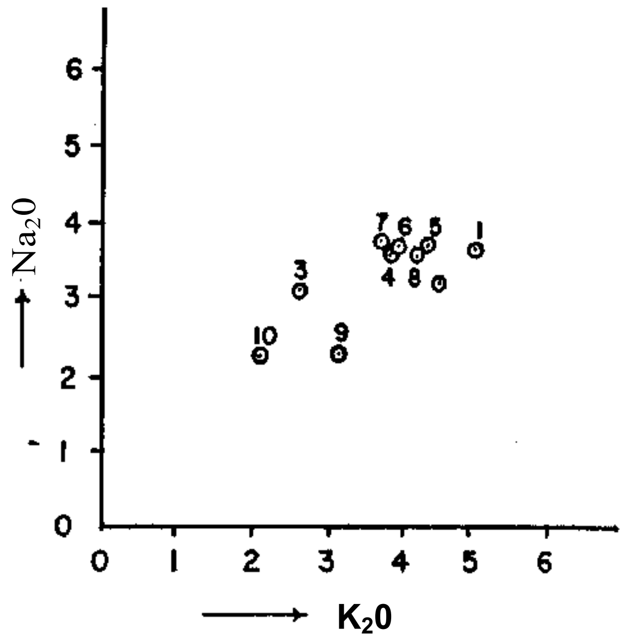


Fig.17. Na_2O vs K_2O variation diagram for acid and basic rocks of Littlewood and Bertrab Nunataks (Sample details as given in Fig. 14).

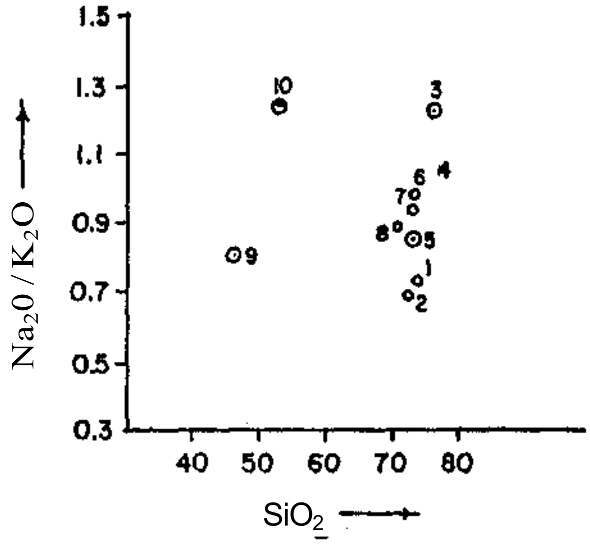


Fig. 18. Na_2O/K_2O vs SiO_2 variation diagram for acid and basic rock compositions of Littlewood and Bertrab Nunataks (Sample details as given in Fig. 14).

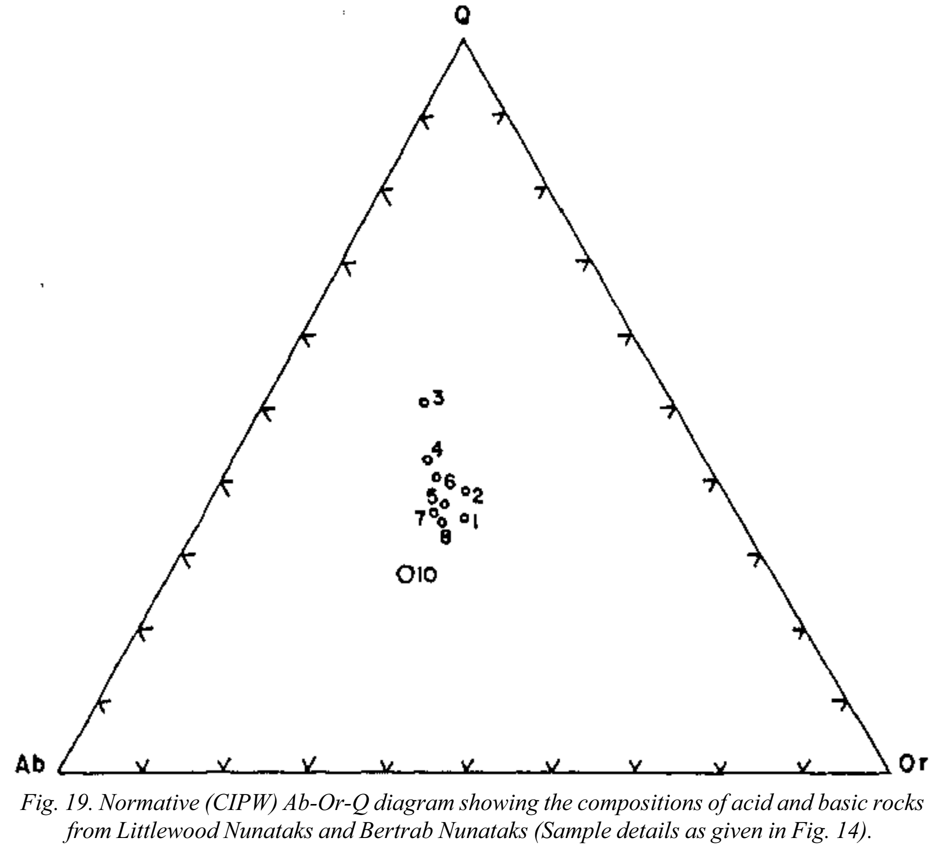


Fig. 19. Normative (CIPW) Ab-Or-Q diagram showing the compositions of acid and basic rocks from Littlewood Nunataks and Bertrab Nunataks (Sample details as given in Fig. 14).

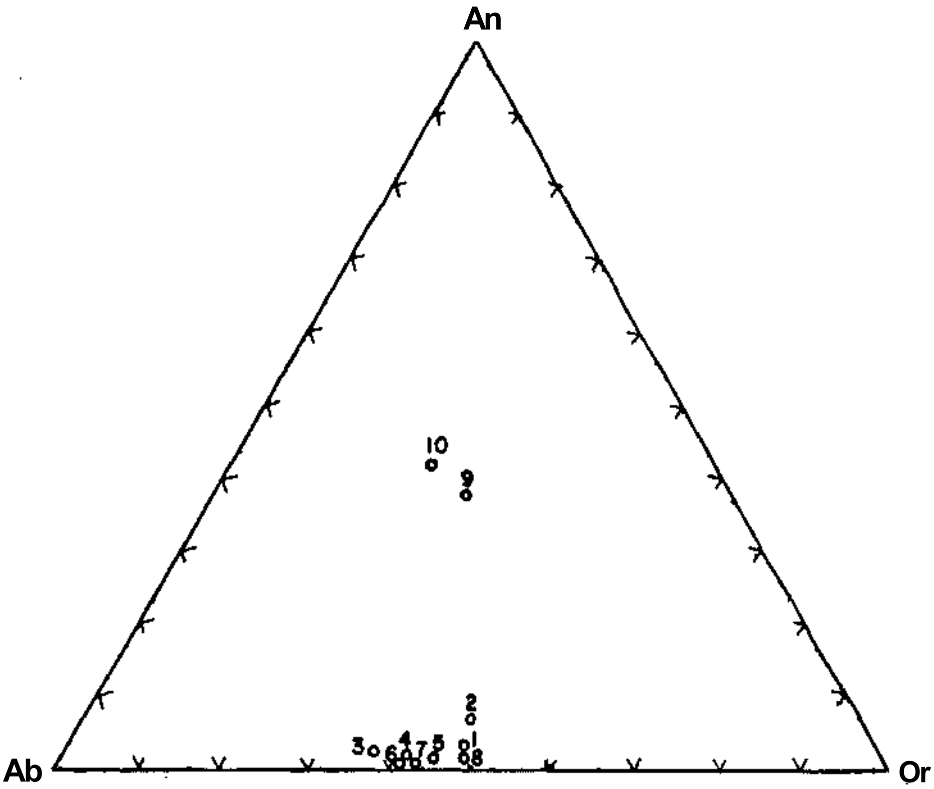


Fig.20. Normative (CIPW) Ab-An-Or diagram showing compositions of acid and basic rocks of Littlewood and Bertrab Nunataks (Sample details as given in Fig. 14).

7) A distinct linear variation is observed in AFM diagram (Fig. 21) in case of acid volcanics. An iron enrichment with respect to alkalies and magnesium is evident. The basic rocks of the Bertrab Nunataks fall markedly away from the field of acid rocks. Yet again indicating that the two are unrelated.

Summing up to the observations it can be said that:

i) clustering of plots in case of acid igneous rocks in both binary and ternary variation diagrams suggest that these rocks have reached a certain degree of homogeneity.

ii) a distinct iron enrichment is noticed in acidic assemblages.

iii) the acid rocks of Bertrab and Littlewood Nunataks are strikingly similar in their major element chemistry. They are peraluminous, high potash, corundum normative rhyolites. Gxanophyre of Bertrab Nunataks is related to the rhyolites. These rhyolites show attributes similar to those of continental rhyolites rather than the rhyolites in an oceanic environment. The basic rocks are genetically unrelated with the acid assemblages.

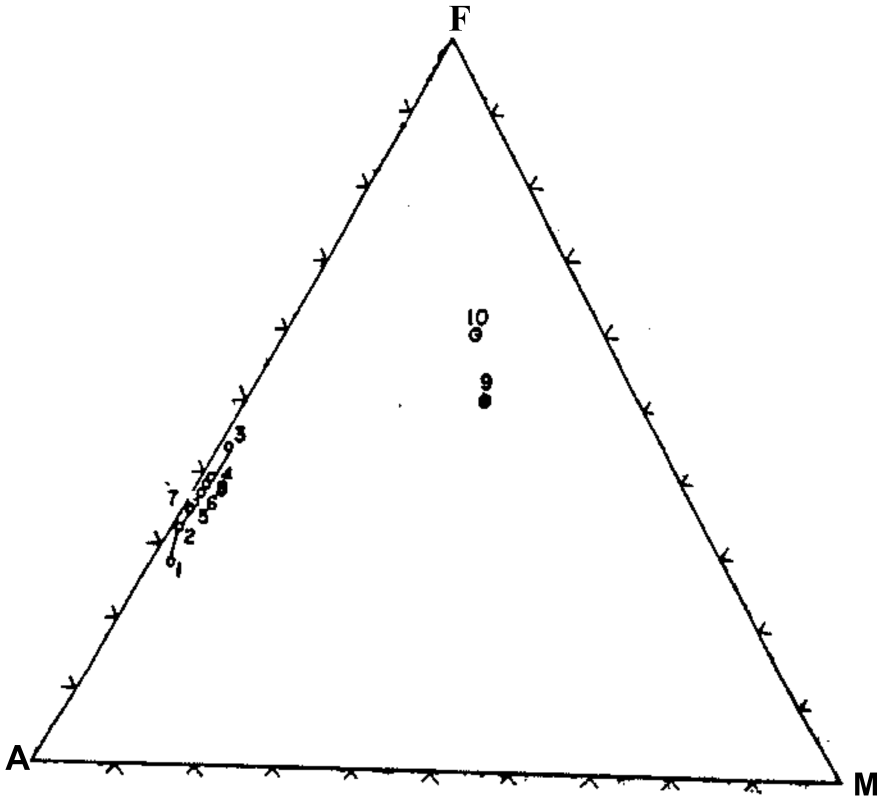


Fig.21. Plot of acid and basic rock compositions of Littlewood and Bertrab Nunataks in A-F-M diagram (Sample details as given in Fig 14).

Trace element distribution

Two distinct patterns of trace element behaviour are recognisable in the acid and basic rocks of Bertrab Nunataks (Table 4). The acidic rocks of Littlewood Nunataks (Table 6) are strikingly analogous to those of Bertrab Nunataks in their trace element distribution pattern. Acidic rocks are enriched in Zr and Ba and depleted in Cr, V, Zn, Ni, and Co as compared to basic rocks. The acid volcanic rocks largely show a homogeneous composition; no significant pattern of behaviour in trace elements could be established within the acidic suite.

REE distribution

Basic and acidic rocks from Bertrab Nunataks and rhyolites from the Littlewood Nunataks (Table 7) show good EREE fractionation trends (LREE/HREE > 4) and the light and heavy rare earths are well fractionated. XREE is very similar in the acid volcanics (80.33, 86.82 in Bertrab and Littlewood Nunataks respectively) and the fractionated nature of source is also confirmed by CeN/Yb_N ratios.

Table 7: Rare Earth Element Data for Acid and Basic Rocks from the Littlewood Nunataks and Bertrab Nunataks [ppm *(g/g)]*

Locality — Littlewood Nunataks (All Rhyolite Samples)

Sample No.	LWN-1	LWN-3	LWN-7	LWN-101	LWN-13	LWN-11
La	19	18	12	20	14	26
Ce	45	40	31	48	32	64
Pr	6.1	6.2	4.3	6.8	4.5	8.2
Nd	31	30	20	30	21	36
Sm	8.6	8.0	6.5	7.8	6.2	8.6
Eu	0.84	0.84	0.90	1.0	0.81	1.1
Gd	5.5	4.6	4.2	5.2	3.9	5.5
Tb	0.82	0.80	0.75	0.82	0.68	0.92
Dy	4.6	4.5	4.5	5.0	3.9	4.4
Ho	0.80	0.78	0.96	0.95	0.78	0.80
Er	2.2	2.2	2.8	2.5	2.2	2.0
Tm	0.26	0.24	0.38	0.32	0.30	0.24
Yb	1.7	1.5	2.2	1.8	1.6	1.5
Lu	0.19	0.17	0.31	0.24	0.23	0.18

Locality — Bertrab Nunataks

Sample No. Rock name	BN-1 Epidiotite	BN-8(6) Dolerite	BN-5 Granophyre	BN-2 Rhyolite
La	16	20	17	16
Ce	29	48	38	28
Pr	5.8	6.2	5.3	5.9
Nd	27	30	24	26
Sm	8.6	7.8	6.2	8.0
Eu	2.0	2.0	0.89	0.42
Gd	5.7	5.6	4.0	5.5
Tb	0.94	0.94	0.67	0.94
Dy	5.6	5.8	3.8	5.5
Ho	1.1	1.1	0.77	1.0
Er	3.0	3.1	3.1	2.0
Tm	0.40	0.38	0.25	0.40
Yb	2.0	2.1	1.5	1.9
Lu	0.15	0.30	0.18	0.20

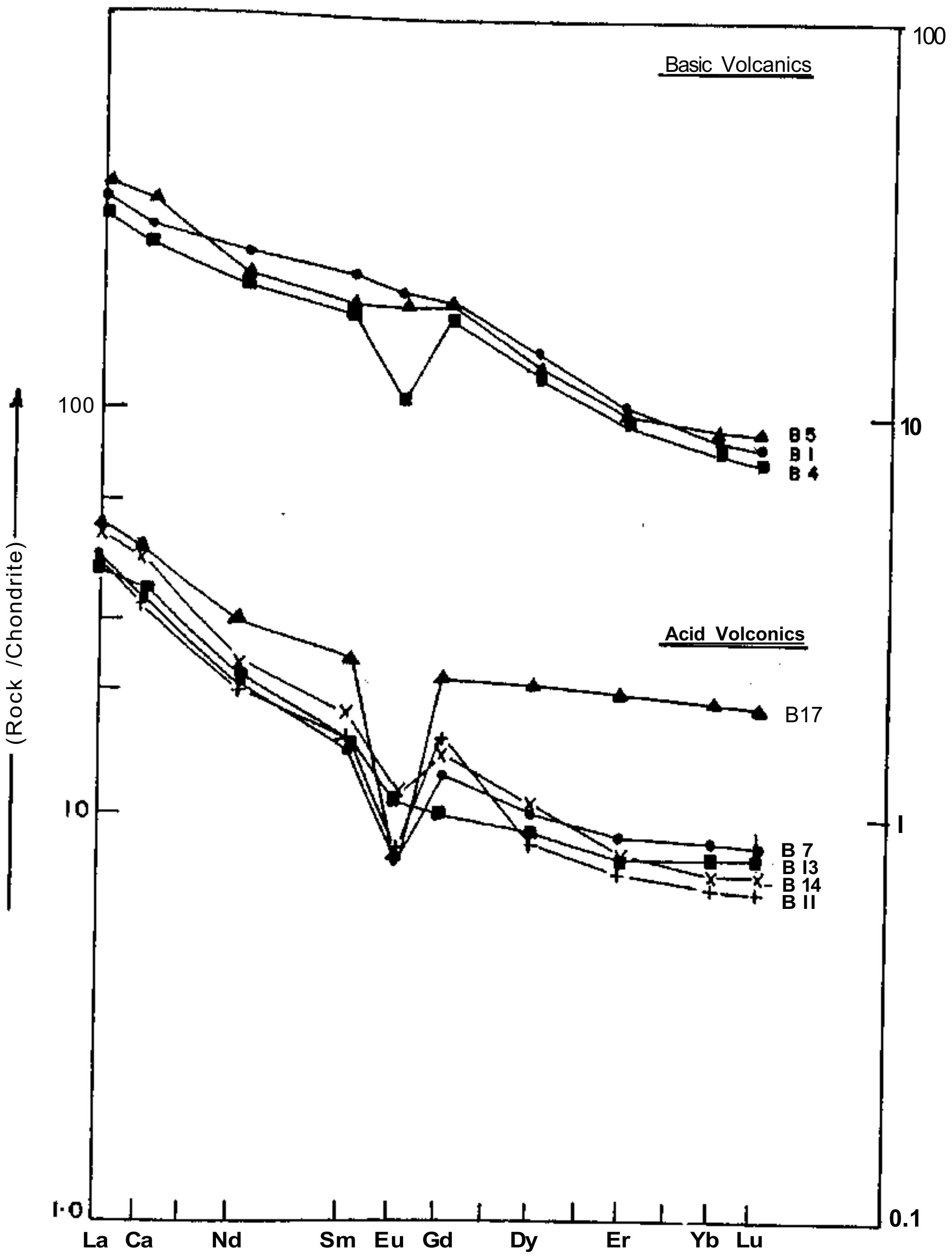


Fig.22. Chondrite normalised REE patterns (Bertrab Nunatak).

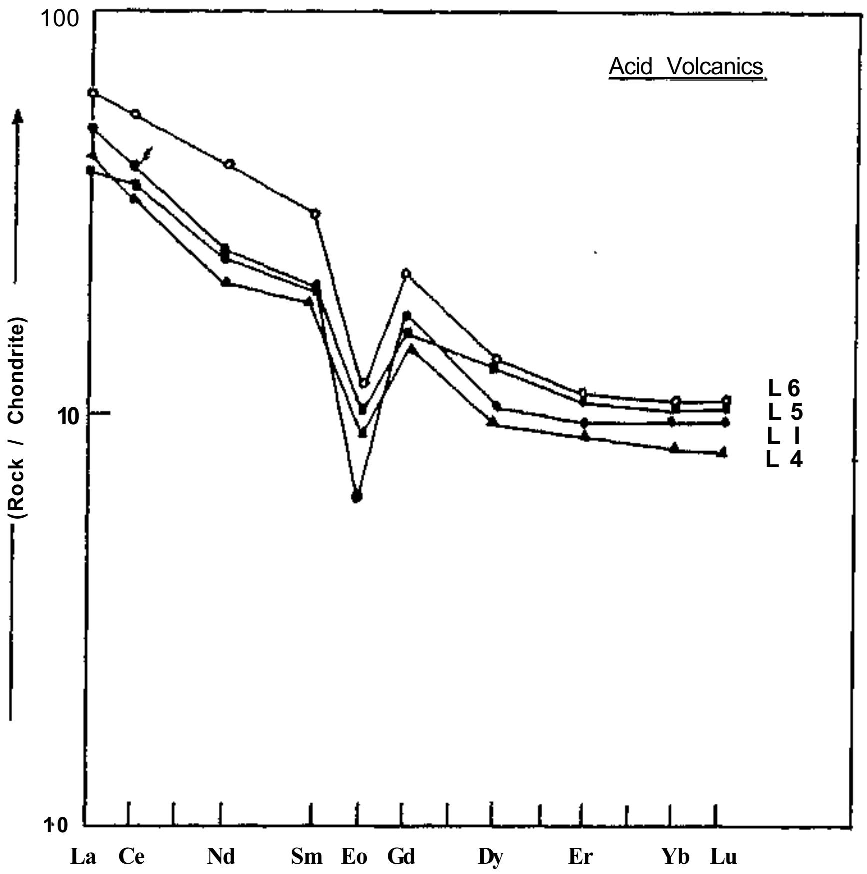


Fig.23. Chondrite normalised REE patterns (Littlewood Nunatak).

DREE distribution in basic volcanics from Bertrab differs from that of the acid volcanics with lower EREE, low Ce_N/Yb_N and low LREE/HREE ratios.

Synthesis

The major, trace and EREE abundances and the mineralogical similarities observed in the acidic rock assemblages from the two Nunataks — Bertrab and Littlewood clearly show their common mode and source of origin. The basic and acid volcanics from Bertrab Nunataks appear to have genetically evolved from a common mantle source as is evident from low negative Eu anomaly in the basic rock (Fig.22) and less fractionation of LREE and HRLE as. compared to high negative Eu anomaly in acid volcanics.

The Littlewood acid volcanics have high negative Eu anomalies (Fig.23) though the LREE/HREE fractionation is almost the same as in Bertrab suggesting fractionation of plagioclase and hydroxyl bearing mineral phases. The overall patterns however, support a common source of origin for these acid volcanic rocks,

Conclusion

Nunataks of the Vahsel Bay expose an interesting geological section. Acidic variants, rhyolites of Littlewood as well as those of Bertrab show strikingly similar major element chemistry and the geochemical attributes are similar to those of continental rhyolites rather than of an oceanic environment. Presence of igneous rocks of both deep seated and shallow nature in Bertrab viz. granite, granophyre, rhyolite, epidiorite, basalt, dolerite indicate an active margin. On the other hand, limestone and particularly the presence of epiclastic quartz and plagioclase grains in arkose of Moltke Nunataks, indicate deposition in a shallow water environment, probably in the low energy areas of shallow shelf region.

Rhyolites are commonly fragmented in nature and often contain fragments of the same material indicating that extrusion of acid volcanics was punctuated by explosive volcanism; porphyritic nature of the rhyolites would indicate a high volatile pressure in the melt. Presence of dolerite intrusives within the rhyolite of Bertrab Nunataks and their absence from other Nunataks is apparently because of it being a local activity. Time relation between the rhyolite and granophyre could not be established in field.

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