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The petrology and age of alkaline mafic lavas from
the nunatak zone of central East Greenland

by

C. K. Brooks, A. K. Pedersen and D. C. Rex

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Abstract

Alkaline basic lavas occurring as outcrops of limited extent in the nunatak zone of East Greenland beyond the head of Kejser Franz Josephs Fjord have been examined in detail on the basis of new collections. These rocks show considerable diversity and include highly magnesian, perovskite-bearing nephelinites, slightly less magnesian nephelinites, basanitoids and nepheline hawaiites. Phonolite, reported earlier, is absent from the new collection. Apart from the perovskite-bearing nephelinites, probably primary magmas derived by small degrees of partial melting of normal mantle, these rock types have evolved in a complicated way and do not appear to be related by low pressure processes. While it is possible that alkaline basaltic magmas have been a widespread feature in the late stages of volcanism in this part of East Greenland, the nephelinites appear to be restricted to intracontinental areas. They represent small-scale flank activity possibly related to the prolongation of the Jan Mayen fracture zone.

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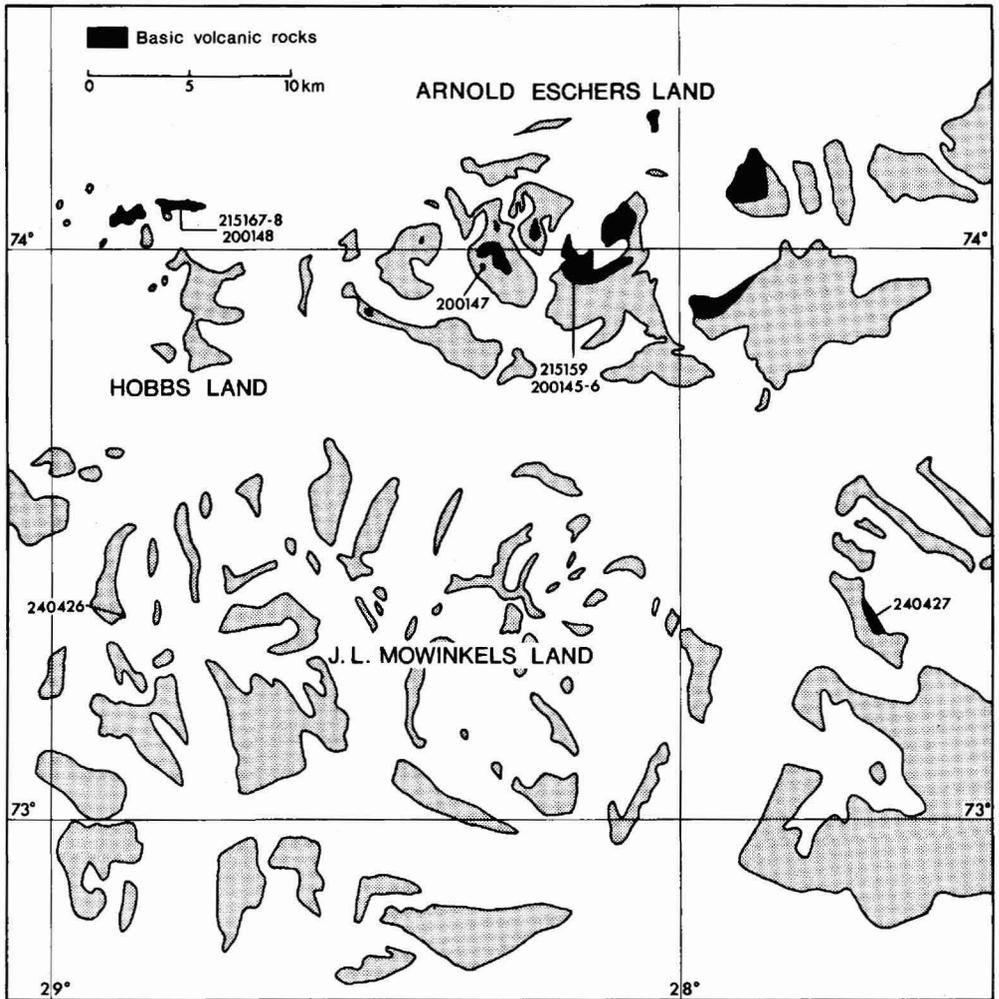


Fig. 1. Map of the nunatak zone at around 74°N in East Greenland showing main outcrops of volcanic rocks and the localities of the present samples.

Introduction

Tholeiitic plateau basalts of lower Tertiary age are a prominent feature of the geology of East Greenland (e.g. Brooks *et al.*, 1976; Deer, 1976; Noe-Nygaard, 1976). Strongly alkaline basic volcanic rocks have long been known from certain inland areas, notably overlying the plateau basalts in the Prinsen af Wales Bjerge, inland from Kangerdlugssuaq at about 69°N (Anwar, 1955; Brooks & Rucklidge, 1974) and in isolated exposures in the nunatak zone inland from Kejser Franz Josephs Fjord at about 74°N (Katz, 1952 a & b, see also Haller, 1956). More recently alkaline basaltic and hawaiitic lavas have been found overlying the tholeiitic plateau basalts in northeast Greenland from 73°N to 74°30'N although their extension inland is at present very imperfectly known (Upton & Emeleus, 1977; Hald, 1978; Noe-Nygaard & Pedersen, in prep.).

It is possibly significant that the more strongly alkaline rock types are situated in inland areas, 150 to 200 km from the present coast whereas the more voluminous tholeiitic rocks reach their greatest development along the coast. Brooks (1973) suggested that this distribution in the Kangerdlugssuaq district might be related to the formation of rift structures during continental break-up.

The alkaline rocks of the nunatak zone in central East Greenland at c. 74°N are very inaccessible and previous work has been meagre, being based on samples taken on an extended sledge journey (Katz, 1952 a). During recent reconnaissance work on the Caledonian rocks of the area by the Geological Survey of Greenland new samples have been collected, and we report here on their petrography, petrochemistry and age with a view to accurately characterizing these rocks and attempting to elucidate their relationships to other Tertiary rocks in this area.

Field occurrence

Due to the reconnaissance nature of the field work during which the samples were collected, it is not possible to add much to the descriptions given by Katz (1952 a) and Haller (1956).

These rocks are found in a terrain, which is extensively covered by ice and has an extreme arctic climate. They are found at high elevations, capping the tops of nunataks and at no place form any considerable continuous outcrop (fig. 1). It is therefore uncertain just how extensive these rocks originally were: they may be the remnants of an originally continuous lava field extending inwards under the inland



Fig. 2. View looking from the west to the nunatak in Arnold Eschers Land from which sample GGU 200147 was collected. The sampling locality is indicated by an arrow and the nature of the terrain and the individual volcanic rock outcrops are clearly seen.

ice (Wenk (1961) estimated their area to be in excess of 2000 km²), or they may have been isolated occurrences not much more extensive than their present known outcrop area. The latter is more likely because such highly alkaline basic lavas commonly form relatively scattered volcanic structures, and there is little evidence for any great thickness or original continuity.

The volcanic rocks are flat-lying and overlie peneplained schists and gneisses of the Caledonian and possibly older age (fig. 2). In the area covered by fig. 1, the peneplain rises from around 2000 m elevation to around 2300 m in a southwesterly direction. At one point lava was seen filling a valley incised into this peneplain (Higgins, pers. comm.). Apart from the localities sampled in Hobbs Land, Arnold Eschers Land and J. L. Mowinckels Land, further isolated occurrences were observed which are too small to be shown in fig. 1. Further exposures of these rocks are known from Wilkins Nunatakker, about 10 km due north of the most easterly land in fig. 1, but an occurrence previously reported from Hvidbjørns Nunatakker (20 km southwest of fig. 1) was found to consist of schists (Friderichsen, pers. comm.). The scattered land areas of the nunatak zone are often covered by extensive areas of semi-permanent snow, and much of the exposed surface is composed of blocks formed by intense frost-shattering. It is, however, believed that such blocks are approximately *in situ* and representative of the underlying material.



Fig. 3. Columnar jointed neck (?), Arnold Eschers Land. Samples GGU 200145 and 200146 were collected at this locality.

The limited time available prevented a detailed investigation of the field relations, but it appears that flows predominate. It is estimated that the volcanic remnants occupying depressions in the peneplained surface have a thickness of the order of 30–40 m but otherwise decrease rapidly in thickness. At one point, columnar jointed basalt which may possibly be a volcanic neck was seen (fig. 3). No dykes were observed although Katz (1952 a) reported them to be abundant in Hobbs Land, and he assumed that they represented feeder channels as they resemble the lavas petrographically.

Age relationships

Geologically, it can only be stated with certainty that these rocks are post-Caledonian, but it has long been assumed that they are lower Tertiary like the basalts on the coast. Detailed biostratigraphical studies by Soper *et al.* (1976 a & b) place the age of commencement of volcanism in the area to the south of Scoresby Sund as uppermost Palaeocene (corresponding to an age of perhaps 55 m.y.). Radiometric determination in the same area broadly confirms this assignment (Beckinsale *et al.*, 1970; Brooks & Gleadow, 1977).

To confirm the age of volcanism, K-Ar dating has been carried out on five rocks from the area and results are shown in table 1. These results show a spread of ages from 44 to 58 m.y., which is probably related to argon loss from the common interstitial potassic zeolites. It is possible that the three higher ages, which lie within the experimental error of each other, represent an approximation to the age of

Table 1. K-Ar age determinations on volcanic rocks from the nunatak zone

Sample no.	% K	vol. ^{40}Ar rad. ($\text{cc/g} \times 10^{-5}$)	% Ar rad.	Age (m.y.)
GGU 240426	0.570	0.09922	52.6	44 \pm 2
GGU 240427	1.00	0.19627	77.6	50 \pm 2
GGU 200145	0.780	0.17144	76.1	56 \pm 2
GGU 200148	0.426	0.09525	57.0	57 \pm 2
GGU 200147	0.714	0.16274	66.1	56 \pm 2

rad. = radiogenic

For locations of these samples see fig. 1.

Decay constants used as recommended by IUGS Subcommittee on Geochronology (Steiger & Jäger, 1977).

extrusion, and we tentatively conclude that the average of these, 56 ± 1 m.y. (1σ), is the best estimate of the time of this event.

Therefore the volcanism here was contemporaneous with voluminous tholeiitic activity in the East Greenland coastal regions. A similar age was obtained by fission track dating of apatite from the highly alkaline Gardiner intrusion (Brooks & Gleadow, unpubl.) which is petrologically comparable with the magma types represented in the nunatak zone. On the other hand, the salic alkaline rocks of East Greenland are appreciably younger (Beckinsale *et al.*, 1970; Pankhurst *et al.*, 1976).

Petrography

The rocks are characterized by phenocrysts of olivine and clinopyroxene set in a pyroxene-rich groundmass which is often glass-rich. Early chromite is included in some olivines, and xenocrysts (largely clinopyroxene) may be abundant in some samples. All samples are porphyritic although the mode of phenocrysts and probable xenocrysts ranges from 50 per cent down to a few per cent. Table 2 gives a qualitative summary of the phenocryst and groundmass mineralogy of these rocks.

Rocks of nephelinitic affinity

These vary considerably, from picritic rocks dominated by phenocrysts of olivine to strongly clinopyroxene-phyric types and others poor in phenocrysts. The less mafic are basanitoids, the others nephelinites (see under Petrochemistry). Crystal aggregates, possibly representing early cognate cumulates, are occasionally pre-

Table 2. Petrographic summary of volcanic rock samples from the nunatak zone

GGU no.	Phenocrysts	Inclusions	Groundmass	Alteration
240426 nephelinite	ol (abundant) + cpx (minor)	none observed	largely acicular cpx with mt + pf + analcime + mica (trace)	negligible
200147 nephelinite	ol (with cr inclusions) + cpx	green, spongy-cored cpx	cpx+mt+trace mica + interstitial ne	negligible
200146 nephelinite	ol (with cr inclusions)	none observed	fine-grained, but similar to previous – mica more abundant + ne+ mt+ il+ pf	phillipsite infills cavities
240427 nephelinite	ol+ cpx	none observed	cpx + mt + mica + interstitial ne + analcime.	negligible
200148 nephelinite	ol + cpx	some cpx cores	cpx + mt + mica + pf	minor alteration of ol, natrolite developing in groundmass
200145 basanitoid	cpx (abundant) + ol (minor)	cpx cores, ol + cpx aggregates	cpx + mt + abundant purplish glass + il	minor, apart from devitrification of glass to mt + plag
215159 basanitoid	cpx (very abundant) + ol (minor)	cpx cores	cpx + mt + plag + glass + analcime + il	glass devitrified
215167 ne hawaiiite	cpx (very sparse) + ol (pseud.)	green, spongy-cored cpx	fine-grained – largely cpx + mt + feldspar/feldspathoid (?)	yellowish sheet silicate + analcime in vesicles
215168 ne hawaiiite	essentially similar to previous except for occasional dehydrated kaersutites now composed of cpx + rhönite + yellowish sheet silicate. Analcime and zeolite (in part thompsonite) in groundmass.			

Abbreviations: cpx, clinopyroxene; ol, olivine; cr, chromite; mt, titanomagnetite; pf, perovskite; il, ilmenite; ne, nepheline; plag, plagioclase.

Mineral identifications are by microprobe.

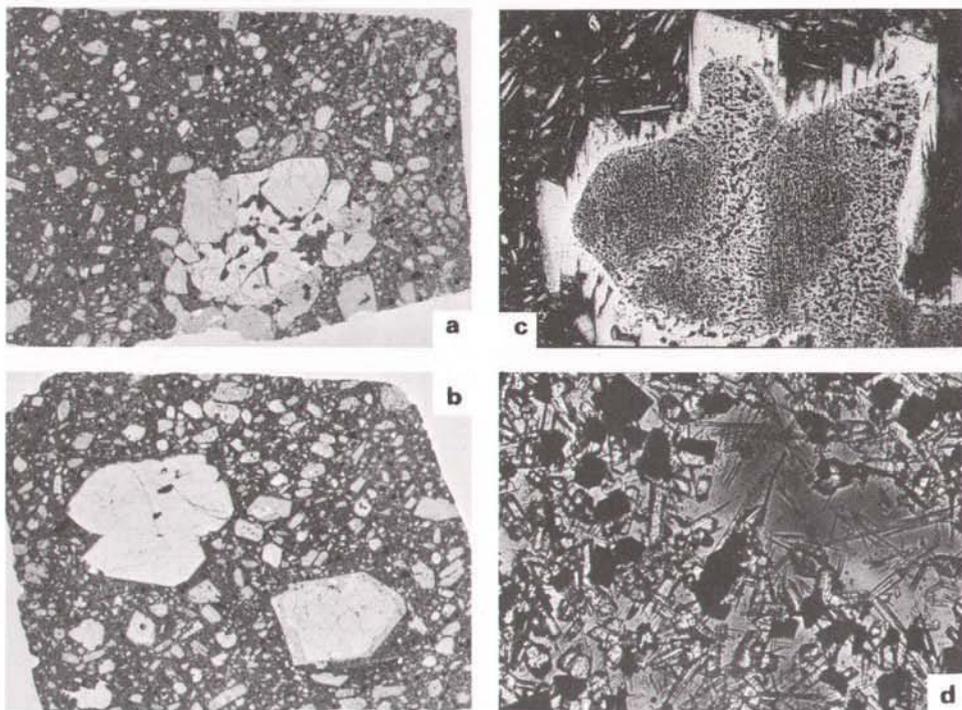


Fig. 4. a & b. Photographs in plane polarized light of two entire thin sections (*c.* 2.5×4 cm) of GGU 200145. A presumed cognate inclusion of olivine and clinopyroxene may be seen in (a), while (b) shows the typical large clinopyroxenes with xenocrystic cores of chromian diopside which are regarded as mantle fragments. c. A large (3 mm across) partially resorbed core of clinopyroxene in GGU 200147. Such cores were originally more acmitic and provide evidence for hybridization. d. Detail of the groundmass, which is rich in pyroxene and opaque oxides, in GGU 200145. Also seen is the residual glass which has a phonolitic composition (field of view *c.* 0.5 mm across). Apatite needles are present in the glass.

sent. In addition to the obvious phenocrysts, some samples contain larger crystals which are strongly out of equilibrium with the groundmass. These occur either as corroded cores inside a euhedral overgrowth or as resorbed and spongy crystals. Typical examples of some of these relationships are shown in fig. 4.

The groundmass is composed of euhedral clinopyroxene, opaque Fe–Ti oxides and occasionally perovskite – all of which are euhedral or nearly so – in a matrix of one or more of the following: glass, feldspathoids, zeolites and poikilitic brown mica. The texture, which resembles many lamprophyres is panidiomorphic (fig. 4d). Plagioclase is observed in only two samples (GGU 215159 and 200145) in small amounts, and ocelli composed largely of feldspathoids sometimes occur. Ilmenite from such ocelli has been analysed (see below).

Nepheline hawaiites

These rocks are slightly porphyritic with phenocrysts of olivine (now pseudomorphed) and clinopyroxene. In addition, they contain spongy-cored xenocrystic clinopyroxene and megacrysts of kaersutite now replaced by an aggregate of rhönite and clinopyroxene. Their extensively altered and very fine-grained groundmass consists of euhedral clinopyroxenes, opaque oxides, dark mica and masses of what is believed to be altered plagioclase or glassy residuum. Original vesicles are lined by euhedral alkali feldspar and filled with analcime and zeolites.

The chemistry of the minerals and glasses is described below based on about 150 analyses made on the TPD microprobe at the Research School of Earth Sciences, Canberra, applying the procedure described by Reed & Ware (1975).

Mineralogy

Olivines. About 20 analyses, representing all types of olivine, have been made, but in contrast to the pyroxenes, variation is small and most have a composition lying within the range Fo₈₀₋₉₀. Very limited zoning has been observed, up to about Fo₅. A weak correlation between the forsterite content and the Mg/Mg+Fe^{total} ratio of the host rock can be seen: GGU 240426 (Mg/Mg+Fe^{total} = 0.72) has olivine phenocrysts with composition 90.2% Fo while GGU 200145 (Mg/Mg+Fe^{total} = 0.54) has phenocrysts with cores of 77.8% Fo and rims of 75% Fo. In the two most FeO-rich rocks olivine phenocrysts are very scarce. It appears therefore that these olivine crystals are generally true phenocrysts.

Three selected olivine analyses are shown in table 3.

Pyroxenes. Clinopyroxene is the dominant modal and normative constituent in these rocks and several distinct types may be distinguished in thin section. The compositions of representative examples from a total of over 40 individual analyses are shown in table 4 and plotted in fig. 5.

(a) Pyroxenes in the nephelinites (table 4, no. 1). The phenocrysts, which range in size up to about half a centimetre, have compositions lying close to the diopside/salite boundary (i.e. 10% hedenbergite) and tend to reflect the compositions of the host rock. Thus rocks with high Fe/Mg ratios tend to have pyroxenes with high Fe and Ti and low Cr contents. Although the correlation is not perfect (the pyroxenes in GGU 200145 have anomalously high Fe/Mg and low Cr), it does tend to confirm the petrographic interpretation that the euhedral form indicates that they are cognate. Judging by the Al (VI) contents of these phenocrysts, they crystallized at upper crustal levels.

The clinopyroxene phenocrysts are rimmed by pyroxene similar to that of the groundmass. The boundary between the colourless cores of the phenocrysts and the lilac rims is sharp, and fine-scaled oscillatory bands, similar to those described by Brooks & Rucklidge (1973), may be present in the rims. These late pyroxenes are, as is commonly the case in alkaline rocks, strongly enriched in Ti and Al and are more Fe-rich. They are also depleted relative to the phenocrysts in Cr₂O₃ which has presumably been removed from the liquid by the earlier crystallization of the phenocryst generation.

Table 3. Selected olivine analyses from volcanic rocks of the nunatak zone

	1	2	3
SiO ₂	40.84	39.22	37.52
ΣFeO.....	10.33	16.60	23.21
MnO.....	—	—	0.26
MgO.....	49.23	44.16	39.05
CaO.....	0.11	0.19	0.15
	<u>100.51</u>	<u>100.17</u>	<u>100.17</u>
% Fo.....	84.5	82.6	75.0
Basis: 4 oxygens			
Si.....	0.997	0.991	0.981
Fe.....	0.211	0.351	0.507
Mn.....	—	—	0.006
Mg.....	1.792	1.663	1.521
Ca.....	0.003	0.005	0.004
Cations.....	<u>3.003</u>	<u>3.010</u>	<u>3.019</u>

1. Core of large olivine crystal in GGU 240426.
2. Core of olivine phenocryst in GGU 200148.
3. Rim in olivine in an olivine-clinopyroxene cognate inclusion in GGU 200145.

If the orientation of the tie lines between the phenocryst and groundmass pyroxenes indicates the direction of evolution of these clinopyroxenes at low pressure, then the trend exhibited by the phenocrysts, which is approximately parallel to the Ca-Fe side of the triangle in fig. 5, indicates a quite different process. Such a trend could be explained by the high pressure separation of a highly diopsidic pyroxene of the type found by Brooks & Rucklidge (1973) as megacrysts in an alkaline dyke from Wiedemanns Fjord, East Greenland.

Deep green pyroxene crystals are present in sample GGU 200147 (table 4, no. 5). These may be several millimetres in size and appear strongly corroded. Some cores are homogeneous and are enriched in Fe compared to the other pyroxenes in the same rock (e.g. 30% Hd as against 11% in the groundmass pyroxenes) and are also rich in Na and Mn. Calculation shows that they are also rich in Fe³⁺. Some green pyroxenes have partially resorbed cores (fig. 4c) and appear to be in an advanced state of breakdown from compositions similar to the homogeneous green cores. The spongy-cored green pyroxenes are not so rich in Fe as the homogeneous ones and contain glassy inclusions with zeolites, apatite and a titanomagnetite which is much richer in magnetite than groundmass Fe-Ti oxide. Such green pyroxenes are common in basanitic and related rocks (Brooks & Printzlau, 1978). These authors suggest that they indicate mixing of magmas with very different concentrations of Fe and alkalis.

Table 4. Selected clinopyroxene analyses from volcanic rocks of the nunatak zone

	1	2	3	4	5	6
SiO ₂	51.54	50.96	45.11	53.97	50.15	43.15
Al ₂ O ₃	1.76	3.88	7.63	0.41	1.59	10.26
TiO ₂	1.44	0.99	3.71	0.32	0.52	3.67
Cr ₂ O ₃	0.61	0.42	0.23	0.87	0.24	0.18
ΣFeO	4.92	5.23	9.07	3.42	16.83	7.12
MgO	15.72	15.35	12.09	17.83	7.57	11.67
CaO	23.47	22.07	22.43	22.62	19.40	22.23
Na ₂ O	0.23	0.54	0.61	0.17	2.79	0.93
	99.69	99.44	100.92*	99.61	99.41**	99.27***
Fe ₂ O ₃	0.00	1.71	5.45	0.00	8.39	6.46
FeO	4.92	3.69	4.16	3.42	9.28	1.31
new sum	99.69	99.61	101.46*	99.61	100.23**	99.91***

- * total includes 0.03% K₂O (= 0.001K)
 ** total includes 0.30% MnO (= 0.010 Mn)
 *** total includes 0.06% K₂O (= 0.003K)
 New sum by method of Papike *et al.* (1974)
1. Phenocrysts in nephelinite, GGU 200146.
 2. Phenocrysts in nepheline hawaiite, GGU 215167.
 3. Groundmass and rim pyroxenes in GGU 215167.
 4. Diopsidic cores rich in Cr₂O₃ in GGU 200145.
 5. Green acmitic cores in GGU 200147.
 6. Pyroxene in aggregates with rhönite and serpentine(?) after kaersutite in GGU 215168.
- All analyses are averages of several point analyses.

Cations calculated by the method of Papike *et al.* (1974)

	1	2	3	4	5	6
Si	1.909	1.878	1.672	1.974	1.927	1.611
Al ^{IV}	0.077	0.122	0.328	0.018	0.072	0.389
TET	1.986	2.000	2.000	1.992	1.999	2.000
Al ^{VI}	0.00	0.046	0.006	0.000	0.000	0.063
Ti	0.040	0.027	0.103	0.009	0.015	0.103
Cr	0.018	0.012	0.007	0.025	0.007	0.005
Fe ³⁺	0.000	0.047	0.152	0.000	0.242	0.182
Fe ²⁺	0.152	0.114	0.129	0.105	0.298	0.041
OCT	1.078	1.090	1.065	1.111	0.996	1.043
Ca	0.931	0.871	0.891	0.887	0.799	0.889
Na	0.017	0.039	0.044	0.012	0.208	0.067
M2	1.026	1.000	1.000	1.009	1.006	1.000
QUAD	92.31	86.66	67.23	96.60	73.52	61.13
OTHERS	7.69	13.34	32.77	3.40	26.48	38.87
QUAD						
Wo	47.73	47.67	52.78	45.16	52.19	56.31
En	44.46	46.11	39.57	49.51	28.32	41.11
Fs	7.81	6.22	7.65	5.33	19.49	2.58
OTHERS						
Ti	30.05	14.57	21.78	22.84	5.10	18.43
NAM 2	12.37	20.49	9.23	31.28	70.48	12.04
Al4	57.57	64.94	68.99	45.88	24.42	69.52
X _{Fe} ²⁺	0.15	0.12	0.16	0.10	0.41	0.06
best name for others	CaMg TAL	CaFe3 CATS	CaMg TAL	NATAL	ACMITE	CaMg TAL

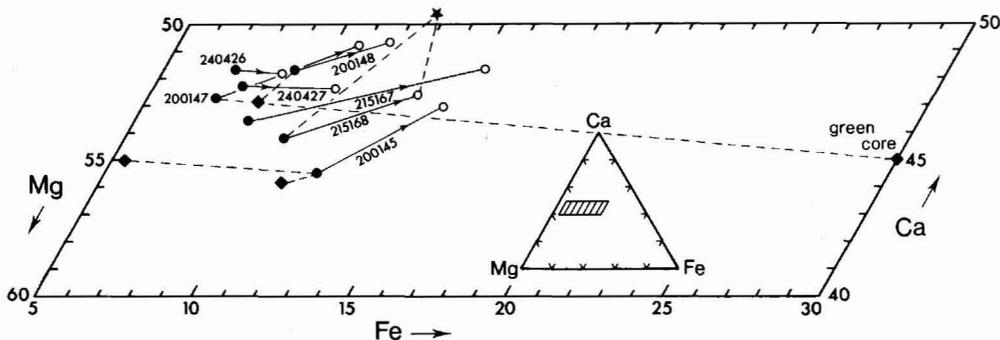


Fig. 5. Average clinopyroxene analyses plotted in terms of Ca-Mg-Fe. Open circles: rims, filled circles: phenocryst cores, rhombs: xenocrystic cores and the olivine-clinopyroxene inclusion, and star: clinopyroxene in aggregate after kaersutite.

Strongly corroded diopsidic cores are present in GGU 200145 (table 4, no. 4). These have a high Mg/Mg+Fe ratio and high Cr contents and in this respect resemble clinopyroxenes in lherzolite nodules in alkali basalts (Ross *et al.*, 1954) and alpine peridotites (e.g. Green, 1964). They may therefore be fragments derived from mantle lherzolites except that they have a low Al(VI) content which does not support this interpretation. Corroded cores in sample GGU 200148 are of different type and more Fe- and Ti-rich and more Cr-poor. They are most probably accidentally acquired phenocrysts from a related magma such as GGU 215167 and, as with the green cores discussed above, suggest some hybridization.

In addition to the diopsidic cores, sample GGU 200145 contains apparently cognate aggregates of olivine and clinopyroxene. The pyroxene in these has a composition which is entirely consistent with this interpretation.

(b) Pyroxenes in the nepheline hawaiites. The pyroxenes in these rocks (table 4, no. 2) do not differ greatly from those in the nephelinitic rocks in terms of Ca-Mg-Fe but are much richer in alumina and ferric iron and generally poorer in Cr. A gradual increase in Al_2O_3 from about 4% in the phenocrysts to about 7.5% in the groundmass grains is observed within the nepheline hawaiites, and this is correlated with an increase in TiO_2 (from 1% to 3.8%). Such clinopyroxenes are typical products of low pressure crystallization from alkali basaltic and hawaiitic magmas with a moderately low silica activity (Carmichael *et al.*, 1974).

Sample GGU 215168 contains in addition pseudomorphs after an earlier phenocryst phase, which broke down to a mixture of clinopyroxene (table 4, no. 6), rhönite and a yellow, serpentine-like mineral (see below under rhönite). This assemblage, together with the morphology of the pseudomorphs, suggests that the original phase was kaersutitic amphibole. The pyroxene in this intergrowth is quite distinct from the other clinopyroxenes, being rich in CaO, Al_2O_3 and poor in SiO_2 and Cr_2O_3 . Calculation shows that much of the Fe is present as Fe^{3+} , and that the breakdown of kaersutite was accompanied by oxidation.

In summary, this interesting assemblage of clinopyroxenes cannot be unambiguously interpreted, but indicates a complicated history for these magmas. The magmas have undergone a period of crystallization prior to eruption during which the phenocrysts formed and in some cases aggregated to form olivine-clinopyroxene rocks. Mixing with more evolved but probably co-genetic magmas also occurred and, in some cases, crystals were acquired from

extraneous sources. These relationships are likely to complicate any attempt to put forward a simple petrogenetic scheme for these magmas.

Micas. A brown mica occurs in the groundmass of many of the rocks. It tends to form plates which poikilitically enclose the other constituents and is presumably of late-stage origin. However, the four rocks with the highest FeO/MgO ratios do not appear to have this phase. Analysis shows that this mica is a titaniferous phlogopite which does not show great variation from the analysis shown in table 5. Ti, which is the element showing most variation, lies in the range 5 to 11% and is exceptionally high, those at the upper end of this range being the most Ti-rich micas known to us, although a minor part of this may be caused by interfering Ba not adequately accounted for in the correction procedure.

These micas contrast strongly with those reported in the groundmass of the nephelinite from Kangerdlugssuaq described by Brooks & Rucklidge (1974). These latter micas were Ti-poor and required some Fe³⁺ to make the Z positions up to 8.00. Similar micas to those reported here are found in lamproites, e.g. those from Holsteinsborg in West Greenland described by Brooks *et al.* (1978) or Smoky Butte, Montana (Velde, 1975), but these have Fe³⁺ in the Z position once again due to the fact that Al lies below 2.00 atoms per formula unit. Perhaps the best comparison is with a phlogopite from an alkali basalt from Jan Mayen (Flower, 1971) but this has only a little over half the TiO₂ of the most titaniferous of the nunatak samples. It is clear that much information must be acquired on this mineral group before the observed variations can be understood.

Table 5. A typical mica analysis from the volcanic rocks of the nunatak zone together with comparisons

	Wt. %			Basis: see below		
	1	2	3	1	2	3
SiO ₂	37.11	42.0	40.10	5.403	6.088	5.885
Al ₂ O ₃	12.24	8.07	12.02	2.101	1.379	2.075
TiO ₂	10.79	2.36	6.15	1.181	0.258	0.678
ΣFeO	8.29	12.46	9.41	1.009	1.503	1.150
MnO	0.14	0.06	0.82	0.017	0.007	0.101
MgO	17.46	20.2	17.40	3.788	4.362	3.831
CaO	0.23	0.17	0.00	0.036	0.026	—
Na ₂ O	0.57	1.01	1.00	0.161	0.284	0.284
K ₂ O	8.07	10.1	8.36	1.499	1.867	1.566
	<u>94.90</u>	<u>96.43</u>	<u>95.26</u>	<u>15.195</u>	<u>15.774</u>	<u>15.570</u>

1. Titaniferous phlogopite from sample GGU 240427 with cations on basis of 22 oxygens.
2. Phlogopite with reversed pleochroism (due to tetrahedral Fe³⁺) from nephelinite, Kangerdlugssuaq (Brooks & Rucklidge, 1974). Cations on basis of 22 oxygens.
3. Titanium-rich phlogopite, Jan Mayen (Flower, 1971). This is a standard chemical analysis with oxidation state and (OH) reported; calculated on basis of 24 (O, OH). Fe³⁺ has been combined with Fe²⁺ for comparative purposes.

Table 6. Rhönite from the volcanic rocks of the nunatak zone together with a comparison

Wt. %			Basis: 28 cations and 40 oxygens		
	1	2		1	2
SiO ₂	26.54	28.58	Si	7.056	7.664
Al ₂ O ₃	15.14	13.35	Al	4.746	4.221
TiO ₂	10.70	10.70	Ti	2.140	2.158
ΣFeO	21.25	22.49	Fe	4.725	5.044
MnO	0.17	0.17	Mn	0.038	0.039
MgO	12.85	12.09	Mg	5.092	4.832
CaO	11.01	10.23	Ca	3.137	2.939
Na ₂ O	2.07	2.11	Na	1.067	1.097
K ₂ O	0.00	0.02	K	—	0.007
	<u>99.73</u>	<u>99.74</u>			
Fe ₂ O ₃	9.65	6.14	Fe ³⁺	1.930	1.240
FeO	<u>12.57</u>	<u>16.96</u>	Fe ²⁺	2.795	3.804
new sum	100.70	100.35			

Oxidation state calculated from stoichiometry.

1. Rhönite in aggregate with clinopyroxene (table 6, col. 5) and yellow serpentine (?) replacing kaersutite in sample GGU 215168.
2. Rhönite in alteration rim on kaersutite, Otago Harbour, New Zealand (Kyle & Price, 1975).

Perovskite. This mineral has been identified in the groundmass of three samples and indicates the markedly undersaturated nature of these rocks (Carmichael *et al.*, 1974, p. 53). Several analyses confirm its identity but have low totals, possibly due to the presence of Nb₂O₅ and Ce₂O₃ which have not been quantitatively determined.

Rhönite. The literature reports rhönite in nephelinites, basanites and related rocks both as a primary phase, either as microphenocrysts or in the groundmass, and as a breakdown product of kaersutite. It does not apparently vary much in composition, and the rhönite analyses made in this work (table 6) do not deviate significantly from rhönite analyses published previously (Kyle & Price, 1975; Magonthier & Velde, 1976).

The rhönite in sample GGU 215168 forms aggregates with clinopyroxene and a yellowish, serpentine-like mineral. These aggregates have a euhedral form and this, together with their composition and the known occurrence of rhönite after kaersutite, indicates that they formed by the breakdown of kaersutite phenocrysts which ceased to be stable when the lava was erupted at the surface. Diffuse patches with a similar mineralogy may also be found in sample GGU 215167 and these are apparently also after kaersutite where resorption has progressed even further. The rhönite is almost opaque and pleochroic from purple-brown to deep green; and its composition is consistent with the ideal formula, which is $X_4Y_{12}Z_{12}O_{40}$,

The variation is apparently continuous over this range. These spinels are closely similar to those described from other mafic alkaline rocks such as the nepheline from Kangerdlugssuaq (Brooks & Rucklidge, 1974) and the rocks of East Island in the Crozet Group, Indian Ocean, described by Gunn *et al.* (1970).

Apart from the chromite grains included in and preserved by olivine phenocrysts and the titanomagnetites of the groundmass, occasional large crystals of titanomagnetite are also present in some samples. However, these do not appear to differ in composition from the groundmass grains. A magnetite is also present in the spongy centres of some clinopyroxenes which apparently represent xenocrysts in an advanced state of resorption. Those in the spongy green pyroxene cores have been commented on above.

In sample GGU 200146, occasional ocelli composed largely of nepheline are found and these contain blades of ferrian ilmenite (table 7). If this ilmenite crystallized in equilibrium with the magnetites of the accompanying groundmass, it indicates a temperature of around 930°C and an oxygen fugacity of around 10^{-12} (Buddington & Lindsley, 1964). When calculated using the procedure of Anderson (1968) the magnetite has 55.4% ulvöspinel and the ilmenite has 7.4% hematite. Within the probable error, this point lies on the FMQ buffer curve.

Ilmenite also occurs in the basanitoids, GGU 200145 and 215159, where it is confined to glass inclusions and large glassy embayments in silicate crystals. It shows a tendency for epitaxial relations towards the host crystal as described by Roedder & Weiblen (1971). Apparently co-equilibrated magnetite and ilmenite from a glass inclusion in GGU 215159 gives a temperature around 985°C and f_{O_2} around $10^{-11.4}$, which is again on the FMQ buffer curve.

Felsic minerals. Nepheline occurs in the groundmass of several rocks, either interstitially or in ocelli or late-stage segregation patches. Its composition, which does not vary very widely, is reported in table 8 (no. 1) and corresponds to $Ne_{75.92}Ks_{20.36}Qz_{3.72}$. According to the work of Hamilton (1961), this nepheline crystallized around 600°C which is entirely compatible with its occurrence.

Plagioclase is now found only in the groundmass of basanitoids GGU 200145 and 215159. Analysis 2 (table 8) corresponds to $An_{16.5}Ab_{68.9}Or_{14.5}$. Plagioclase was probably originally also present in the extensively altered groundmass of the nepheline hawaiites GGU 215167 and 215168 but has not been preserved. In GGU 215168 alkali feldspar occurs (table 8, no. 5) lining analcime-filled vesicles. This has a composition of $Or_{48.7}Ab_{47.4}An_{3.9}$.

Several rocks contain analcime, usually filling vesicles, although occasionally as a groundmass phase. It varies little in composition and, when calculated on the basis of 4 cations, shows a reasonable agreement with the ideal formula.

Sample GGU 240427, which is one of the most potassic rocks in bulk composition, contains a homogeneous mineral in the groundmass whose composition (table 8, no. 4) closely resembles many published analyses of pseudoleucite. However, it shows no tendency to break down as do pseudoleucites. On the other hand it is much richer in K_2O than potassic analcimes (Wilkinson, 1968) and has perhaps formed by subsolidus cation exchange from analcime.

Other zeolites are found filling vesicles in some samples. Thus GGU 215167 and 215168 are particularly rich in such vesicles and were probably collected from flow tops. In these two

Table 8. Selected analyses of light minerals in the volcanic rocks of the nunatak zone

	1	2	3	4	5	6	7
SiO ₂	44.22	62.46	54.43	54.19	65.73	46.56	45.45
Al ₂ O ₃	32.77	23.09	23.79	22.45	19.80	28.28	25.45
ΣFe ₂ O ₃	1.15	0.60	1.77	0.65	0.31	—	1.52
MgO	0.15	—	—	—	—	—	—
CaO	0.13	3.45	0.39	0.36	0.53	0.93	7.30
Na ₂ O	16.53	7.94	12.77	3.45	5.61	15.40	1.19
K ₂ O	6.05	2.54	0.50	12.95	8.75	0.12	7.49
	101.00	100.08	93.65	94.05	100.73	91.29	88.40
Basis:	32(0)	32(0)	4 cat.	4 cat.	32(0)	56 cat.	32(0)
Si	8.426	11.138	1.979	2.071	11.789	23.536	9.608
Al	7.362	4.854	1.037	1.009	4.187	16.833	6.343
Fe	0.165	0.081	0.048	0.018	0.042	—	0.242
Mg	0.043	—	—	—	—	—	—
Ca	0.027	0.659	0.015	0.014	0.102	0.516	1.654
Na	6.107	2.745	0.898	0.257	1.951	15.044	0.488
K	1.471	0.578	0.023	0.631	2.002	0.061	2.020
Z*	15.95	16.073	3.004	3.10	16.018	40.37	16.193
R**	7.65	3.982	0.936	0.90	4.055	15.62	4.162

1. Nepheline, average of 6 closely similar analyses in GGU 200146 and 240427.
2. Plagioclase in GGU 200145 (Ba present but not measured).
3. Analcime, average of 6 analyses from GGU 240426, 215167 and 215168.
4. Postassic analcime(?) occupying centre of segregation patch and crystallized after accompanying nepheline, GGU 240427.
5. Alkali feldspar rimming vesicle in GGU 215168.
6. Natrolite included in pyroxene in GGU 200148. Average of 3 similar analyses.
7. Calcic phillipsite (selected analysis) in GGU 200146.

* Z = Si, Al, Fe^{III}

**R = Mg, Ca, Na, K.

samples the vesicles seem to be largely filled with analcime but in other samples natrolite (included in clinopyroxene in GGU 200148 – composition shown in table 8, no. 6) or phillipsite (as radiating aggregates in vesicles in GGU 200146 – table 8, no. 7) occur. These minerals have been indentified from their compositions as determined by microprobe; but in other cases the composition does not clearly correspond to any mineral and they may be aggregates of several minerals.

Table 9. Analysis of interstitial glass in basanitoid from the nunatak zone

	1	2	σ	CIPW weight norm		
				1	2	
SiO ₂	55.23	56.90	0.91	or	31.20	32.03
TiO ₂	1.30	0.59	0.16	ab	35.49	35.18
Al ₂ O ₃	19.90	20.17	0.30	an	1.05	—
Σ FeO	3.47	3.88	0.11	ne	19.24	20.80
MgO	0.83	0.58	0.21	ac	—	0.19
CaO	1.46	1.88	0.48	wo	—	0.91
Na ₂ O	8.39	8.72	0.29	di	3.41	4.93
K ₂ O	5.28	5.42	0.36	ol	0.34	—
				mt	—	3.18
	95.86	98.14		hm	3.07	—
				il	1.48	1.12
				pf	0.89	—

1. Interstitial glass in GGU 200145, average of 8 separate point analyses. Norm calculated using oxidation ratio of phonolite from Kangerdlugssuaq (Brooks & Rucklidge, 1974).

2. Average of 47 phonolite analyses (Nockolds, 1954, original analysis has P₂O₅, MnO, H₂O and Fe₂O₃).

σ Standard deviation of individual analyses used to calculate col. 1.

Glass. Brown interstitial glass occurs abundantly in the basanitoids GGU 200145 (fig. 4d) and 215159. The average of 8 microprobe analyses for GGU 200145 is shown in table 9. The variation in composition of this glass is minor, as shown by the standard deviations also reported in this table. The glass is a phonolite and is very similar in composition to a world average for phonolites published by Nockolds (1954) and to a residual glass from a basanite from New South Wales described by Wilkinson (1966). It is likely that differentiation of these lavas would give rise to phonolitic end products. Katz (1952 a) noted the presence of phonolite in the dykes of the area but there is no further information on this rock-type to allow a comparison with the interstitial glass. The phonolitic glass is slightly anorthite normative and lacks the strongly peralkaline character of the tinguaitic phonolites described by Brooks & Rucklidge (1974) from the Kangerdlugssuaq area, indicating that these have probably arisen by a different process. The presence of normative hematite and perovskite in the glass is not significant as these can be eliminated by altering the oxidation ratio, a parameter not known from the microprobe analyses. Furthermore, P₂O₅ has not been determined nor included in the norm calculations.

Petrochemistry

New analyses of rocks from the nunataks together with the older results from Katz (1952 a & b) are reproduced in table 10, where they have been arranged in order of decreasing 100 Mg/Mg+Fe^{total} ratios and the four analyses reported by

Table 10. Compositions and norms of volcanic rocks from the nunatak zone

GGU no.:	240426	200147	200146	240427	200148	200145	215159	215167	215168		13b	24	11a	901b
SiO ₂	40.80	41.63	39.27	40.55	38.64	43.36	42.69	44.74	44.57		37.82	40.40	41.48	38.30
Al ₂ O ₃	5.04	8.48	7.09	7.72	7.42	7.55	6.84	13.98	13.57		6.53	6.09	8.76	6.25
Fe ₂ O ₃	5.41	6.54	5.67	6.39	9.68	5.15	6.17	6.87	7.04		7.34	7.90	8.99	6.79
FeO	8.22	6.75	9.89	7.57	5.82	10.74	10.39	5.23	5.05		8.76	10.35	7.27	7.60
MgO	18.81	14.04	16.08	12.96	10.28	10.10	10.32	6.28	5.84		10.65	9.93	8.85	16.36
CaO	11.27	12.99	10.57	12.83	15.92	13.48	13.56	8.94	9.27		16.25	13.63	11.53	12.65
Na ₂ O	1.70	2.64	2.37	2.95	1.98	2.25	1.76	3.67	4.12		1.70	2.55	2.30	2.48
K ₂ O	0.71	0.93	0.96	1.26	0.58	1.22	0.99	2.01	1.86		0.86	0.82	2.61	1.49
MnO	0.25	0.26	0.26	0.31	0.26	0.22	n.d.	0.26	0.25		0.28	0.27	0.23	0.20
TiO ₂	4.62	3.55	5.14	4.40	5.57	4.94	5.21	3.07	3.07		5.74	5.53	4.48	4.70
P ₂ O ₅	0.47	0.78	0.66	1.01	1.39	0.52	0.47	1.14	1.12		0.83	0.53	0.69	1.32
l.o.i.	2.05	1.91	2.44	1.43	2.73	1.48	1.39	4.04	3.97		H ₂ O ⁺	2.66	1.60	2.53
	-	-	-	-	-	-	-	-	-		H ₂ O ⁻	0.52	0.42	0.49
	99.35	100.31	100.36	99.38	100.06	100.94	99.78	100.07	99.61		99.94	100.02	100.21	100.06
<u>Mg</u>														
Mg+Fe ^{tot}	71.90	66.43	65.65	63.42	55.77	53.94	53.57	49.51	47.74		47.95	50.55	50.87	68.22
<i>C. I. P. W. weight norm (100% dry basis)</i>														
or	4.31	5.57	5.79	7.60	3.51	7.24	5.95	12.35	11.48		-	4.05	15.44	-
ab	5.44	4.36	3.44	2.19	2.75	8.18	10.92	26.30	25.46		-	7.77	6.58	-
an	4.14	8.66	5.99	4.19	9.89	6.93	7.97	16.36	13.62		7.65	2.74	5.84	1.51
lc	-	-	-	-	-	-	-	-	-		3.99	-	-	6.91
ne	5.06	9.91	9.23	12.62	7.81	5.93	2.28	3.24	5.93		7.79	7.47	6.97	11.36
di	39.36	40.32	34.04	42.35	48.09	45.48	45.48	17.14	20.84		49.06	46.95	35.66	39.25
ol	23.49	12.88	21.59	10.67	2.77	8.10	7.15	5.83	3.87		3.33	4.64	3.93	16.58
hm	-	-	-	-	7.48	-	-	-	-		-	-	1.28	-
mt	8.06	9.62	8.39	9.46	3.55	7.50	9.09	9.16	8.56		10.64	11.45	11.19	9.85
il	9.02	6.84	9.97	8.53	10.85	9.43	10.06	6.06	6.09		10.90	10.51	8.51	8.93
ap	1.12	1.83	1.56	2.39	3.30	1.21	1.11	2.75	2.71		1.92	1.96	1.63	3.12
ln	-	-	-	-	-	-	-	-	-		1.49	-	-	0.71

First 9 columns are new analyses by the Geological Survey of Greenland using the techniques described by Sørensen (1975). 13b phlogopite-bearing olivine nephelinite, Hobbs Land (Katz, 1952a), 24 augite-rich basalt of ankaramite type, Arnold Eschers Land (Katz, 1952a), 11a limburgite, Hobbs Land (Katz, 1952a) and 901b olivine nephelinite from plug in Alpedal, Strindbergs Land (Katz, 1952b). The older analyses were also quoted by Haller (1956). l.o.i. = loss on ignition, n.d. = not determined

Katz (1952 a) have been reproduced for reference purposes. Evidence for the alkaline nature of these rocks is provided by the normative nepheline (up to 12.62%) and high values for K_2O , P_2O_5 and TiO_2 . Seven of the rocks are very mafic with Al_2O_3 less than 9 wt. % and are classified loosely as nephelinitic types. The remaining two samples (GGU 215167 and 215168) are less mafic, have higher Al_2O_3 contents and are nepheline hawaiites (Irvine & Baragar, 1971). The concentrations of compatible trace elements, Ni + Cr, are lower, in accordance with this classification.

(a) *Rocks with nephelinitic affinities.* These are characterized by high MgO (up to 18.8%), large amounts of normative and modal nepheline, high normative diopside and high normative colour index (reaching around 80). Three of the samples carry modal perovskite and these, together with two others, do not carry modal feldspar. Although the nomenclature of such rocks is poorly defined, they are chemically nephelinites (e.g. Irvine & Baragar, 1971). while two rocks with modal feldspar could be termed basanitoid as modal nepheline is not present (Wilkinson, 1974). The low alumina basic rocks represent a zone in silica activity – temperature space between the stability fields of feldspar and perovskite (e.g. Carmichael *et al.*, 1974). Katz's (1952 a) original terminology used names such as limburgite, auge-rich basalt and ankaramite, to classify these rocks, but such names, while descriptive, are not rigorously defined and are partially dependent on trivial factors such as cooling rate.

Green (1971) has argued that lavas with values of 100 Mg/Mg+Fe^{total} in the range 65 to 73 and Ni contents over 200 ppm could represent liquids which had been in equilibrium with the mantle. On the basis of this simple criterion, the first four samples in table 2 are possible primary liquids.

(b) *Nepheline hawaiites.* The two samples composing this group have a much lower colour index of around 40, are more Fe-rich (100 Mg/Mg+Fe^{total} ratio of 47–50) and are andesine-normative. This is the first record of such rocks from the nunatak zone; but they compare closely with some alkaline lavas from Jan Mayen (Hawkins & Roberts, 1972) and with the recently discovered alkaline lavas covering the plateau basalts in the coastal zone (Hald, 1978). This similarity might indicate a continuity of alkaline volcanism from the Atlantic margins in as far as the nunatak zone and calls for observations of the intermediate region.

Trace elements

These are reported in table 11, where the strongly alkaline character of the rocks is clearly seen. This table shows that the large ionic radius lithophile ('LIL') elements are strongly concentrated relative to, for example, the East Greenland tholeiites (Brooks *et al.*, 1976; Noe-Nygaard & Pedersen, 1974). These elements are enriched up to twenty times their values in the nearby tholeiites (as reported for

Table 11. Trace elements and strontium isotopes in volcanic rocks from the nunatak zone

GGU no.	240426	200147	200146	240427	200148	200145	215167	215168
Cs	—	—	(0.32)	(0.54)	—	—	—	—
Rb	59.8	42.7	42.4	38.7	19.2	24.5	44.5	46.7
Ba	—	622	673	(36)	745	(22)	797	776
Pb	—	27	14	(902)	13	(387)	8	14
Sr	1053	1313	1332	1979	2356	9	1262	1425
La	66	97	89	162	129	63	117	117
Ce	130	191	189	(167)	252	(54.4)	233	232
Nd	63	100	103	163	141	70	115	114
Sm	—	—	—	(29.0)	—	(11.5)	—	—
Eu	—	—	—	(7.50)	—	(3.07)	—	—
Tb	—	—	—	(2.36)	—	(0.86)	—	—
Yb	—	—	—	(3.63)	—	(1.79)	—	—
Lu	—	—	—	(0.44)	—	(0.24)	—	—
Y	27	32	31	61	47	24	35	37
Th	—	8	8	(15.8)	12	5	11	10
U	—	—	—	(5.42)	—	(1.71)	—	—
Zr	420	370	498	523	694	307	557	560
Hf	—	—	—	(12.6)	—	(7.1)	—	—
Nb	84	96	97	126	127	58	121	120
Ta	—	—	—	(3.93)	—	(0.59)	—	—
Sb	—	—	—	(0.57)	—	(0.21)	—	—
Zn	94	135	135	111	138	118	123	126
Cu	209	163	208	181	256	368	103	102
Co	—	—	—	—	—	78	—	—
Ni	610	335	544	259	157	175	53	48
Sc	—	32	31	(234)	35	(191)	14	14
V	286	327	355	(34)	425	(40)	237	231
Cr	—	1437	851	388	498	433	51	50
Ga	—	18	17	(1069)	23	(484)	23	22
⁸⁷ Sr/ ⁸⁶ Sr	0.70404	0.70427	—	0.70380	0.70398	0.70465	—	—
	±6	±6	—	±5	±6	±5	—	—

Bracketed values are determinations by instrumental neutron activation, all others by X-ray fluorescence on pressed powder pellets corrected for absorption from the major element concentrations.

Sr isotopes measured on an MM 30 mass spectrometer.

other nephelinites e.g. Kay & Gast, 1973). Ni and Cr are also enriched. Within the nephelinites, very substantial differences occur in some transition element ratios (e.g. Ni/Cr) as well as in the concentration of LIL elements, while others, such as

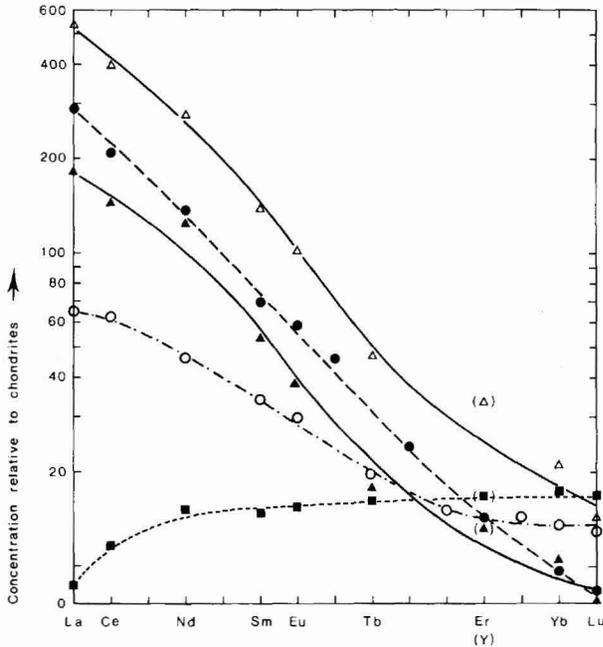


Fig. 6. Semi-logarithmic plot showing rare-earth element concentrations relative to chondrites (Schilling, 1971) in two nephelinites from the nunatak zone (GGU 240427, open triangles, and GGU 200145, filled triangles). For comparison are shown an average for nine nephelinites (Kay & Gast, 1974: filled circles), an average for tholeiitic plateau basalts from East Greenland (unpublished work of Brooks & Schilling: open circles) and an average for eighteen mid-ocean ridge basalts (Schilling, 1971: filled squares).

Sc, vary but slightly. These features cannot be explained using simplistic petrogenetic models. In fig. 6 the rare earth elements, normalized to chondritic values, are compared to those in nephelinites, East Greenland plateau basalts and mid-ocean ridge tholeiites. It is clear that the rare earth element content of the nunatak samples resembles closely that in the nephelinites analysed by Kay & Gast (1973) and are quite distinct from the other groups plotted. These authors interpreted their results to indicate that the nephelinites arose by small degrees of partial melting (*c.* 1%) at a rather deep level in the mantle. This would be consistent with the peripheral location of these rocks with respect to the areas of voluminous tholeiitic volcanism to the east as the zone of partial melting here would be expected to lie at a deeper level. However, other interpretations are possible, including mantle inhomogeneity (e.g. Beswick, 1976) as possibly suggested by the Sr isotopic compositions (see below). A thorough discussion of the origin of nephelinites is, however, beyond the scope of this investigation.

Sr isotopes are also reported for some of the nephelinite samples in table 11. They are variable and somewhat higher than values reported for fresh basalts from oceanic areas, but within the range of values found in mantle-derived rocks. The variability, which is well outside analytical error, may possibly be caused by crustal contamination but may also reflect variability in the source regions of the magmas. Similar results have been obtained by Bell & Powell (1969) for African nephelinites.

The nepheline hawaiites differ strongly from the nephelinites in their much lower contents of transition elements, suggesting that they have experienced fractionation of ferromagnesian phases. In terms of LIL elements, they do not differ greatly from the nephelinites.

Summary and conclusions

On the nunataks beyond the head of Kejsers Franz Josephs Fjord are exposed the remnants of a suite of highly alkaline basic lavas which are approximately contemporaneous with the voluminous tholeiitic plateau basalts of the coastal region. Recent discoveries, cited earlier, of alkaline lavas overlying the tholeiites in the coastal region and compositional similarities between these upper lavas and the least basic volcanics of the nunatak region suggest that a more or less continuous alkaline volcanism once extended from the continental margin several hundred kilometres inland to the nunataks along the inland ice. Nephelinites, however, have not been found nearer to the coast than about 100 km, and the same is true of the Kangerdlugssuaq district about 600 km to the south. It therefore appears probable that the nephelinites constitute a small volume, highly undersaturated flank activity such as that around the swell structures of the African rift (e.g. Williams, 1971) or the late stage nephelinites found on certain volcanic islands, notably the Hawaiian archipelago (e.g. Macdonald & Katsura, 1964).

Another factor which should be considered is the relationship to the present Jan Mayen centre. The island of Jan Mayen, situated about 10° to the east of the area treated here, lies on a major fracture zone (Johnson & Heezen, 1967) which, if prolonged, passes into Kejsers Franz Josephs Fjord, a major topographic feature. It is therefore possible that this fracture is somehow related to the volcanic activity in the inland area in the manner documented for many fracture zones including this one by Sykes (1978). This possibility gains some support from the fact that there is a broad petrological similarity between the nunatak lavas and those of the much more recent Jan Mayen (Hawkins & Roberts, 1972). On Jan Mayen ankaramites are abundant and, although generally much less undersaturated than the rocks described here, carry abundant xenocrystic material including chromian diopsides very similar in composition to that of the nunatak region. Similarly, the phenocrysts of brown salite are similar to the phenocrysts reported here. However, any connection between Jan Mayen and East Greenland nunatak region remains speculative.

More specifically, this new collection shows that the Tertiary nunatak rocks vary substantially in composition and include (a) highly undersaturated, perovskite-bearing nephelinites with MgO contents and other chemical features transitional towards kimberlites, (b) less magnesian, strongly undersaturated nephelinites, (c) less silica undersaturated, pyroxene-rich basanitoids which may

contain phonolitic residual glass, and (d) nepheline hawaiites with a much more evolved composition and containing pseudomorphs after kaersutite.

The perovskite-bearing nephelinites are devoid of cognate inclusions or obvious non-equilibrium phases and may be primary magmas. All other types include several non-equilibrium phases suggestive of a complicated history. Our observations are reinforced by those of Katz (1952 a) who reported, in addition to a similar variety of mafic rocks, highly differentiated phonolitic dykes.

It is not the purpose of this paper to speculate on the petrogenesis of these rocks; but a similar spectrum in which highly undersaturated mafic lavas are prominent is commonly observed in alkaline, intra-cratonic volcanic provinces, and the reader is referred to a recent paper by Brey (1978) for a summary of such occurrences and a discussion of their petrogenesis.

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