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Petrology of the coastal dykes at Tugtilik, southern East Greenland

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Petrology of the coastal dykes at Tugtilik, southern East Greenland

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Dolerite and lamprophyre dikes from Tugtilik in the southern part of the onshore exposure of the East Greenland coastal dike swarm are described. The dolerites, which are earlier, are similar to other tholeiites from the dike swarm and the plateau basalts and also to many Icelandic tholeiites. Transitional varieties have been identified from the Angmagssalik district. The lamprophyres have a nephelinitic composition and are rich in phenocrysts and xenocrysts. In one case, abundant low pressure inclusions occur. Rocks identical to these lamprophyres have not previously been described from Greenland but are well known, for instance, in the African Rift.

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The East Greenland coastal dike swarm is a major geological feature originally described by Wager & Deer (1938) and recently delineated using aeromagnetic methods by Larsen (1978), who demonstrated a considerable offshore extension and suggested its relationship to sea floor spreading in the North Atlantic. However, apart from two papers of rather limited scope (Vincent 1950, 1953) and our own studies (see Nielsen 1978) there are effectively no petrological studies of this swarm, which is hundreds of kilometres long and frequently comprises more than 50% of the total exposure. This paper is a continuation of our work on the dikes of East Greenland which has hitherto been concentrated in the Kangerdlugssuaq district, an area of particularly complex dike injection. The present work, which deals mainly with the Tugtilik area about 220 km south of Kangerdlugssuaq, is intended to investigate the homogeneity of the coastal swarm along its strike. The samples were collected during a brief visit to Tugtilik in 1973 and the study is reconnaissance in nature, as it was not possible with the time and means available to study the field relations in any detail; this is especially true on the outer coast where the swarm becomes intense. The Tugtilik collection has been supplemented by a few specimens from the Angmagssalik district even farther to the south in order to gain an impression of possible changes in the character of the swarm in this direction. The study shows important petrological differences from the dikes in the outer parts of Kangerdlugssuaq.

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Geological relationships

According to Bridgwater et al. (1978), the coastal dike swarm in this area is composed of a number of en echelon sub-swarms and Tugtilik lies just to the south of the largest of these, which has the Kialineq intrusive complex at its centre (Fig. 1). Our collection was made from around the head of Tugtilik Fjord, with additional samples being taken on the outer coast. It thus comes largely from an area to the west or inland (about 10 km) from the main concentration of dikes. In accordance with this, a distinct increase in the intensity of the dikes was observed towards the outer coast. The country rock in this area is Precambrian gneiss.

Two broad petrographic types of dike-rock were distinguished in the field. The first of these is a brown-weathering, usually aphyric, massive dolerite. When occasionally porphyritic, only phenocrysts of plagioclase may be seen. The other type, termed "lamprophyre", is dark-coloured and clinopyroxene-phyric, often very strongly so. Of the 22 analysed samples, 12 dolerites have a strike of 35°, while 8 lamprophyres have a strike of 30° (one sample comes from a sheet of low dip and one sample is a loose block). This difference is not significant in view of the variability (Fig. 2) and we conclude that both types strike approximately parallel to the general trend of the coast here (i.e. about 40°). A wide variation in thickness of the dikes was observed; the analysed samples come from dikes var-

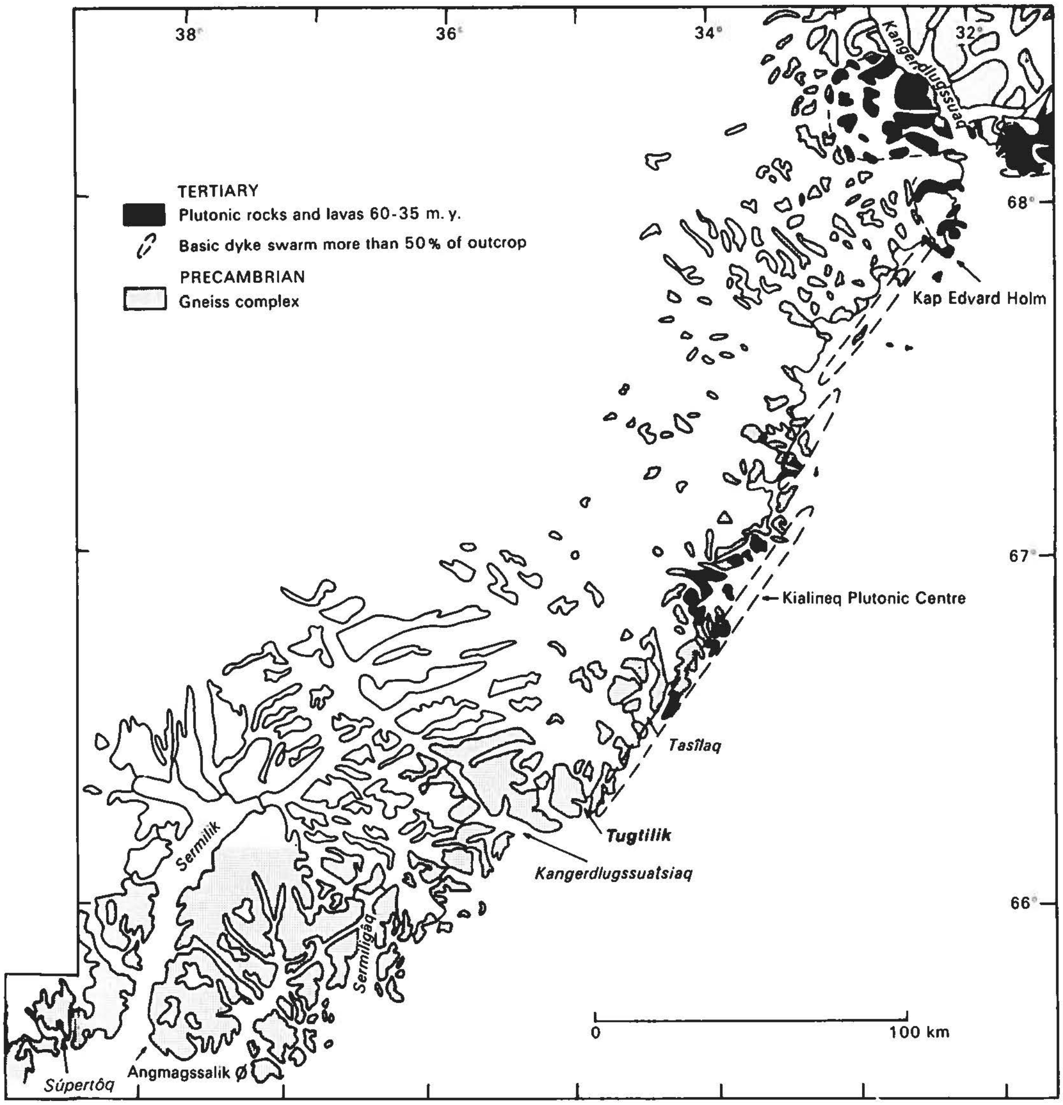

Fig. 1. Distribution of Tertiary igneous rocks between Angmagssalik and Kangerdlugssuaq showing location of Tugtilik and Sermiligâq. After Bridgwater et al. (1978).

ying from 30 cm up to 25 m but the dolerites are invariably much thicker than the lamprophyres (Fig. 2) and for this reason, only the dolerites are visible from a short distance offshore. The lamprophyres were mainly encountered by us towards the head of the fjord. In all eight cases where intersections between the two types was observed, the lamprophyres are later and are sometimes intruded (with chilled margins) along the dolerites.

More detailed field observations were made by Williams (1974) at Tasîlaq, which lies about 40 km to the north in a similar position to Tugtilik with respect to the dike swarm, i.e. about 10 km inland from the area where dikes comprise more than 50% of the outcrop. He found that (a) the dikes tend to tilt more on approaching the outer coast (as originally observed by Wager & Deer 1938), (b) there is a distinct tendency for a bimodal distribution of dips as found by Nielsen in the Kangerdlugssuaq area, (c) the dykes have an average strike of about 45° (similar to that found here), and (d) the amount of crustal extension in this area was of the order to 20–30%, falling rapidly on going inland (also similar to Wager & Deer's and our observations). Williams did not make any petrographic distinctions, although he noted that the later dikes were porphyritic and thus probably correspond to our clinopyroxene-phyric lamprophyres. We believe that the situation at Tugtilik and that at Tasîlaq are very similar. These areas differ from Kangerdlugssuaq in that only coast-parallel dikes are present whereas at Kangerdlugssuaq swarms

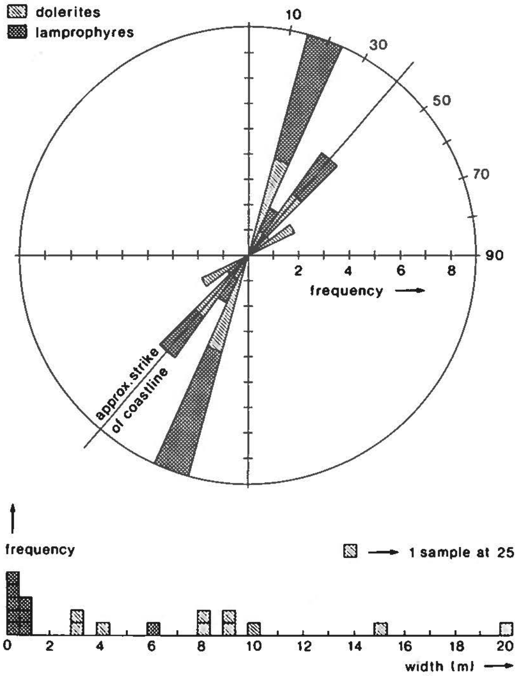

Fig. 2. Orientations and thicknesses of dikes at Tugtilik divided according to petrographic type.

of many different orientations are present, some of them radial (Nielsen 1978). However, in both areas early dikes were doleritic and later dikes were lamprophyric (highly alkaline). The difference may be related to the crustal doming which has taken place at Kangerdlugssuaq (Brooks 1973).

It is clear that very large volumes of magma have been involved in the coast-parallel dike swarm. If we assume that the amount of crustal extension over the entire 800 km of the known length of the dike swarm (Larsen 1978) is the same as that observed at Tasîlaq, and its width is assumed 10 km, this would amount to c. 5×10^4 km^3 to a depth of 20 km. As the intensity of diking is often very much higher than the 20–30% observed at Tasîlaq, reaching 99% in places, this is clearly a minimum estimate. The impressive plateau basalts of East Greenland are believed to have a volume of around 2×10^5 km^3 (Brooks et al. 1976, Soper et al. 1976) so it would appear that comparable volumes of magma have been retained in the crust during the volcanic episode. A similar conclusion was reached by Larsen (1978) on the basis of his aeromagnetic work.

Petrology

In thin section, the differences observed in the field between dolerites and lamprophyres are clearly seen. The dolerites are essentially olivine-clinopyroxene-plagioclase rocks, often with an ophitic texture and typically aphyric, whereas the lamprophyres are characteristically rich in ferromagnesian phenocrysts set in a panidiomorphic groundmass which is feldspar-free. The lamprophyres typically contain corroded cores to the clinopyroxene phenocrysts and sometimes have ultramafic nodules as described below. Their petrography is summarized in Table 1. The broad division of the collection is confirmed by chemical analysis (Table 2). Dolerites are relatively alkali-poor and hypersthene-normative while the lamprophyres are alkali-rich and nepheline-normative, often strongly so. On an alkali-silica diagram (Fig. 3) the dolerites tend to overlap the Hawaiian division line of MacDonald & Katsura (1964) but the lamprophyres plot clearly in the alkaline field. Samples from farther to the south at Súpertôq in the Angmagssalik district are weakly hypersthene normative but also plot in the alkaline field; they are typical transitional basalts. A single sample (GM 20750) from Ailsa Ø off the mouth of Tugtilik is weakly nepheline normative and appears to be intermediate in many ways

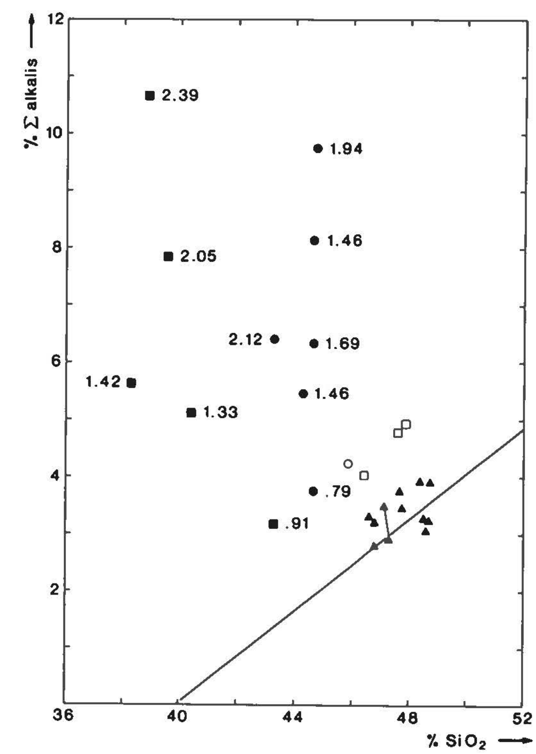

Fig. 3. Alkali-silica diagram for dike rocks largely from Tugtilik. Lamprophyres are shown by filled circles and filled squares, the latter denoting the *leucite-* and *larnite-*normative group. Numbers besides these points are FeO^{tot}/MgO ratios. Tholeiitic dolerites are shown by filled triangles (tie line connects chill to centre of a single dike) and transitional dikes from Súpertoq, Angmagssalik district, by open squares. A single *nepheline-*normative transitional sample is denoted by an open circle. The line is the Hawaiian division line between alkali basalts and tholeiites of MacDonald & Katsura (1964).

Table 1. Petrographic summary of the Tugtilik dikes

Specimen No.	rock type	phenocrysts	xenocrysts	groundmass, late stage
20729 A	dolerite-centre	plag (up to 2 mm)	none seen	sub-ophitic olivine dolerite with plag up to 3 mm.
B	dolerite-chill	ol, cpx	none seen	very fine-grained.
20730	lamprophyre	cpx, ox	resorbed cpx cores and included brown amph	titaniferrous cpx with aegirine overgrowths, ox, foid, biot.
20731	dolerite similar to 20729 B			
20732	lamprophyre	cpx (abundant) ol (minor, altered)	resorbed cpx cores	very fine-grained with ocelli containing pale brown amph and foid.
20733	dolerite similar to 20729 B			
20735 A	lamprophyre-centre similar to 20730 but lacks ol			
B	lamprophyre-chill	cpx, ol (altered) conc. within 1 cm of contact		very fine-grained, only cpx needles identified.
20736	lamprophyre	cpx, ol (altered)	brown, rounded amph	too fine-grained to resolve.
20737	dolerite similar to 20729 A but ol-free			
20738 A	lamprophyre (loose blocks)	cpx, minor ol (fresh)	none seen	cpx-rich, foid, Ti-garnet, sphene, ocelli.
20738 B		large cpx (abundant, up to ½ cm) + minor ol (altered)	none identified certainly but some rounded cpx cores may be xenocrysts	pale brown amph, cpx, ox, foid.
20739 A	lamprophyre (cuts along middle of B)	cpx, ol	possibly cpx cores, rounded brown amph	fine-grained rich in cpx, ol, acicular amph, ox, foid, ocelli.
20739 B	dolerite	aphyric	none seen	plag, cpx, ox, brown and green amph.
20740	lamprophyre	cpx	rounded cpx cores	ol (altered), cpx, K-spar, brown amph, ox.
20741	lamprophyre	cpx, ol (small and sparse)	none seen	cpx, ol (altered), biot, ox, much ap, calcite, ocelli with calcite.
20742	dolerite	none	none seen	cpx, ol (sparse and altered), plag, ox, glass (now chlorite?).
20743	lamprophyre	sparse cpx	none seen	cpx (with aegirine overgrowths), ox, biot, ap, foid, calcite.
20744 A	dolerite-centre very similar to 20729 A			
B	dolerite-chill very similar to 20729 B			
20745	lamprophyre	cpx, ol	resorbed cpx cores	cpx, ox, amph, K-spar, calcite, ocelli.
20746	dolerite similar to 20729 B			
20747	lamprophyre (believed to be equivalent to 20745	cpx, ol	cpx megacrysts	cpx, amph, ox, foid. Rich in inclusions of clinopyroxenite, wehrlite, etc.
20728	lamprophyre	sparse cpx	corroded cpx cores	cpx (with aegirine rims), ox, biot, foid, zeol, sphene, perovskite, Ti-garnet.
20749	dolerite similar to 20729 A			
20750	dolerite (altered)			
20751	dolerite	none	none seen	very fine-grained.
20752	dolerite	none	none seen	ol (altered), cpx rimmed by brown amph, plag, ox.
20753	dolerite	none	none seen	ol-free, cpx, plag, ox.
20754 A	lamprophyre-centre	cpx, ol	resorbed cores	ol (altered), cpx, ox, K-spar (sericitized).
B	lamprophyre-chill	aphyric	none seen	very fine-grained.
20755	dolerite (Sermiligâq-Ikâteq)			
A	chill	cpx, ol, plag	none seen	very fine-grained.
B	brown weathering, major part	aphyric	none seen	ophitic ol, dolerite, similar to 20729.
C	more leucocratic zone at center	aphyric		little visible difference from B in thin section.
20756, 20757, 20058	dolerites (Súpertôq)	aphyric	none seen	ol, cpx (very purple), plag, ox. Very fresh.

Key: plag = plagioclase, K-spar = alkali feldspar, foid = feldspathoids (nepheline, sodalite, analcime), zeol = unidentified zeolites, ol = olivine, cpx = clinopyroxene, amph = amphibole, biot = dark mica, ox = Fe-Ti oxides (or sulphides), ap = apatite.

Sample numbers are prefixed by GM (Geologisk Museum, København).

Table 2. Selected analyses from the southern part of the East Greenland coastal dike swarm

	1	2	3	4	5	6	7
SiO_2	48.69	47.93	44.64	44.63	44.67	43.27	38.88
Al_2O_3	13.45	14.17	9.35	14.71	14.65	9.79	14.35
Fe_2O_3	2.33	3.92	4.27	5.64	6.42	5.07	3.46
FeO	11.64	9.74	4.56	4.86	4.44	5.17	7.06
MgO	5.84	5.20	10.70	6.79	5.26	10.76	4.26
CaO	10.95	8.51	15.02	10.35	10.14	16.45	10.91
Na_2O	2.72	3.20	2.54	6.18	7.88	2.72	8.50
K_2O	0.51	1.65	1.22	1.93	1.83	0.46	2.13
MnO	0.23	0.21	0.12	0.19	0.20	0.20	0.28
TiO_2	2.68	3.66	1.41	1.84	1.67	1.52	2.33
P_2O_5	0.32	0.71	0.52	0.52	0.59	0.55	1.16
H_2O^+	0.59	0.66	2.48	2.32	2.35	3.09	4.27
CO_2	–	–	3.20	–	–	1.14	1.89
sum	99.95	99.56	100.03	99.96	100.10	100.19	99.48
FeO^{tot}/MgO	2.35	2.55	0.79	1.46	1.94	0.91	2.39
CIPW weight norm[1]							
Or	3.03	9.88	7.67	11.73	11.12	–	–
Ab	23.18	27.44	1.13	2.56	0.04	–	–
An	23.15	19.69	11.18	6.89	–	13.75	–
Lc	–	–	–	–	–	2.23	10.60
Ne	–	–	11.77	27.76	36.28	13.04	36.05
Ac	–	–	–	–	1.37	–	4.18
Ns	–	–	–	–	–	–	1.39
Di	24.49	15.28	51.87	34.75	39.56	51.89	22.36
Hy	12.93	6.12	–	–	–	–	–
Ol	4.71	10.31	10.54	9.52	5.63	11.64	10.62
Ln	–	–	–	–	–	1.13	7.17
Mt	2.65	2.57	1.71	1.96	1.33	1.96	–
Il	5.13	7.04	2.85	3.60	3.26	3.02	4.75
Ap	0.75	1.66	1.28	1.24	2.41	1.33	2.89
Trace elements (ppm)							
Rb	9.2	–	19	28	23	16	36
Sr	278	–	673	641	936	879	1330
Ba	102	–	670	920	820	871	911
Zr	150	–	70	220	127	116	200
Cr	85	–	470	175	85	606	12
Ni	56	–	150	71	44	125	10
V	360	–	230	210	285	334	390
Sc	62	–	47	41	25	48	0

[1]volatile-free basis with Fe_2O_3/FeO set to 0.15 (Brooks 1976).

1. chilled margin of tholeiitic dolerite (GM 20729).
2. transitional dolerite, Súpertôq Fjord, Angmagssalik district (GM 27056).
3. 30 cm thick lamprophyre with large green clinopyroxenes (GM 20732).
4. lamprophyre dike rich in megacrysts, etc. (GM 20747).
5. 6 m thick lamprophyre with prominent acmitic rims on clinopyroxenes (GM 20730).
6. Lamprophyre loose block: contains sphene and melanite (GM 20738/A).
7. Lamprophyre dike with very nobbly-weathering centre. Sphene, melanite and perovskite in groundmass (GM 20748).

All samples except 2, from near head of Tugtilik below lake.

between the dolerites and lamprophyres. It is, however, rather altered.

On the alkali-silica diagram it is possible to divide the lamprophyres into two groups, one with rising alkalis and almost constant silica, the other with slightly falling silica as alkalis rise. This latter group also differs in that it is leucite and larnite normative with an absence of normative orthoclase and albite, i.e. it is appreciably more undersaturated. However, the small numbers of samples does not allow any great confidence to be attached to this division.

Lamprophyres and dolerites are also sharply distinguished on their trace elements, the lamprophyres being consistently high in Rb, Sr and Ba (by factors of 2–3, 2–3 and 7–8 respectively) in spite of their having lower FeO/MgO ratios and being generally richer in Cr by as much as 4–6 times in the more magnesian members (Table 2).

Dolerites

These rocks are typical tholeiites and call for little special comment. They have fine-grained chilled margins with microphenocrysts of olivine, augite and plagioclase (with compositions around Fo_{70}, $Ca_{44}Mg_{44}Fe_{15}$ and An_{67} respectively in sample GM 20729A) and holocrystalline centres with ophitic texture and which weather to a distinctive rusty red. These rocks are all very fresh with only olivine occasionally showing minor alteration; this also reflected in the rather low volatile content (around 1%) and low to very low Fe_2O_3/FeO ratio (cf. Brooks 1976). This rock type is found at least

Table 3. Comparison of Tugtilik lamprophyres with other nephelinites

	1	2	3	4	5	6
SiO_2	40.35	41.56	43.07	46.84	43.0	41.66
Al_2O_3	11.78	13.83	13.14	15.59	14.4	15.38
Fe_2O_3	5.26	5.68	7.99	5.44	5.6	3.71
FeO	8.24	5.42	6.56	5.68	8.9	7.57
MgO	12.49	7.43	6.73	6.65	5.2	4.56
CaO	12.91	16.01	12.36	10.88	10.5	11.69
Na_2O	3.51	4.89	4.80	4.57	7.6	9.11
K_2O	1.23	1.24	1.71	2.06	2.1	2.28
MnO	.20	.21	.19	.19	.30	.30
TiO_2	3.11	1.57	2.33	1.56	2.1	2.50
P_2O_5	.90	2.16	1.09	.54	.16	1.24
Sum*	100.00	100.00	100.00	100.00	100.0	100.00
FeO^{tot}/MgO	1.04	1.42	2.04	1.59	2.68	2.39
CIPW weight-norm (with Fe_2O_3/FeO set to 0.15)						
Or	–	–	8.78	12.17	–	–
Ab	–	–	–	8.61	–	–
An	12.76	12.13	9.26	15.94	–	–
Lc	5.70	5.75	1.04	–	9.73	10.57
Ne	16.09	22.42	22.00	16.29	33.79	35.98
Ac	–	–	–	–	1.70	4.17
Ns	–	–	–	–	–	1.38
Di	27.37	35.19	37.23	28.23	34.28	22.31
Ol	23.65	10.92	11.46	11.97	10.67	10.59
Ln	3.58	3.17	–	–	3.13	7.16
Mt	2.49	2.02	2.63	2.03	1.82	–
Il	5.91	2.98	4.43	2.96	3.99	4.75
Ap	2.09	5.00	2.53	1.25	37	2.87

* Recalculated volatile-free.
1. Average olivine nephelinite (39 analyses) quoted by Bailey (1974: Table 2, analysis 23).
2. Tugtilik lamprophyre, GM 29741.
3. Melanephelinite, Napak, Uganda (King 1965: 77, Table 2, analysis 8).
4. Tugtilik lamprophyre, GM 20736.
5. Olivine melanephelinite, Moroto, Uganda (Varne 1968: 175, Table 2, analysis 4).
6. Tugtilik lamprophyre, GM 20748.

as far south as the Angmagssalik district as sample GM 20755 was taken from a prominent dike which can be followed over 25 km south of Sermiligâq. Rocks of this composition are well known in East Greenland both as components of the coastal dike-swarm (cf. Nielsen 1978, THOL-1 compositions) and in the plateau lavas (Brooks et al. 1976) as well as in other parts of the North Atlantic province (Brooks & Jakobsson 1974). It is the most abundant magma type in this province and was apparently erupted at the time of continental breakup.

Transitional types

The single enigmatic transitional type from Ailsa Ø was noted above. It is rich in plagioclase and was apparently intruded at a rather early stage which probably accounts for its altered character. Its affinities are unknown.

Samples collected at Súpertôq fjord in the Angmagssalik district belong to a distinctive hypersthene normative transitional type which has lower normative hypersthene than the normal tholeiites and plots in the alkaline field on an alkali-silica diagram. The more alkaline nature is confirmed by the strongly purplish augite which reflects the high TiO_2 content of these rocks. Such rocks have also been found to the north (Nielsen 1978) and are found in Iceland, e.g. the Torfajökull area (Jakobsson 1972).

Lamprophyres

The rocks of this diverse group are all nephelinites. They are free of modal feldspar and in chemical composition resemble closely the well-known nephelinites of the African Rift (Table 3). Their mineralogy is complex and is summarized in Table 1. It will be treated in terms of the individual minerals based on reconnaissance microprobe analyses distributed as shown in Table 4.

Olivine occurs as phenocrysts in a number of samples but always in small amounts (< 5%) and is often altered. It also occurs occasionally as a groundmass phase. An analysis of such olivine in GM 20738A shows that it is homogeneous with a composition of Fo_{87} while in GM 20739A it is reversely-zoned from Fo_{80} to Fo_{84}.

Clinopyroxenes. These are the most important minerals in these rocks. They are not only present ubiquitously in large amounts but show a wide range of variations. Several distinct types are present, broadly designated as late-stage, groundmass, phenocrysts and

Table 4. Summary of analysed minerals

	29	30	32	38/A	39/A	43	45	47	48
Olivine	×			×	×				
Clinopyroxene	×	×	×	×	×	×	×		×
Amphibole		×			×		×	×	
Biotite		×				×			
Feldspar	×						×		
Nepheline						×		×	
Sodalite		×				×		×	×
Analcime						×	×	×	
"Zeolites"				×					×
Magnetite		×		×					×
Sphene				×					×
Ti-garnet				×					×

NB! Crosses indicate provenance of analysed minerals, *not* presence or absence of mineral in sample. Numbers at top of columns are last two digits of sample numbers in Table 1.

Table 5. Selected analyses of clinopyroxenes

	29	30 core	30 int.	32 core	32 int.	32 phen.	39/A rim	30 over
SiO_2	51.50	51.60	49.71	48.08	51.37	53.30	42.27	52.69
Al_2O_3	2.15	3.46	5.24	6.37	3.47	1.34	9.74	1.29
TiO_2	0.77	0.61	1.02	1.75	0.76	0.29	3.54	4.13
Cr_2O_3	0.16	0.05	0.08	–	0.12	0.03	0.02	–
FeO	8.86	5.11	6.33	8.53	5.25	3.19	9.90	25.96
MgO	16.04	15.36	13.07	12.25	15.45	16.99	10.32	–
MnO	0.10	0.10	0.07	0.16	0.15	0.08	0.02	0.07
CaO	20.67	23.65	23.71	22.23	23.87	25.08	23.23	0.98
Na_2O	–	0.20	0.28	0.75	0.17	–	0.29	13.87
	100.25	100.14	99.51	100.12	100.61	100.30	99.33	98.99
Cations on basis of 6 oxygens								
Si	1.909	1.898	1.855	1.800	1.885	1.944	1.628	1.999
Al	0.093	0.150	.228	0.281	0.150	0.057	0.416	0.057
Ti	0.022	0.018	.029	0.049	0.020	0.009	0.101	0.118
Cr	0.004	–	.002	–	0.002	–	–	–
Fe	0.274	0.157	0.197	0.265	0.161	0.096	0.316	1.136
Mg	0.892	0.847	0.732	0.687	0.850	0.930	0.596	–
Mn	0.002	0.002	0.002	0.004	0.004	0.002	–	0.002
Ca	0.821	0.931	0.947	0.892	0.938	0.981	0.958	0.039
Na	–	0.013	0.020	0.054	0.011	–	0.011	1.018
Σ cations	4.017	4.016	4.012	4.032	4.021	4.019	4.026	4.369

29. Microphenocryst in dolerite GM 20729/B.
30 core: Rounded core of large pyroxene in GM 29730.
30 int: Zone intermediate between core and rim of large pyroxene in GM 20730.
32 core: Rounded core of large pyroxene in GM 20732.
32 int: Intermediate spongy, resorbed zone in large pyroxene (same as previous) in GM 20732.
32 phen: Phenocryst core, GM 20732.
39A rim: Typical composition of rim and groundmass compositions in GM 20739/A.
30 over: Green, aegirine-rich overgrowths on pyroxenes in GM 20730.

xenocrysts. Analyses of typical examples are reported in Table 5, which is based on about 80 point analyses.

As xenocrysts are classified all types are apparently out of equilibrium with the enclosing groundmass judged by the presence of resorption (i.e. rounded, embayed outlines and/or spongy texture). Out of 13 lamprophyres examined in thin section 8 contained easily identifiable xenocryst cores. Such cores are generally diopsides and resemble the probable phenocryst cores except that they have higher Al_2O_3 (see Table 5). Occasionally, these corroded cores are rather Fe-rich, being enclosed by much more Mg-rich mantles. However, this effect is by no means as extreme as has been reported in other instances, even in East Greenland (Brooks & Rucklidge 1973, Brooks & Platt 1975, Brooks et al. 1979). Such pyroxenes were argued by Brooks & Printzlau (1978) as being evidence for magma mixing prior to growth of the phenocryst generation.

Rims on these pyroxenes are titaniferous augites such as are commonly found in this type of rock. They are overgrown in places by ragged margins of sodic pyroxene (Fig. 4) which have an abrupt boundary to the titaniferous rims and zone outwards to almost pure aegirine. Such sodic pyroxene overgrowths are especially well developed adjacent to areas of mesostasis rich in zeolites and feldspathoids, and are apparently of very late stage. Unfortunately, insufficient analyses of these rims are available to delineate their trend in the system Mg-Fe^{2+}-Na. Such sodic rims have not previously been observed in East Greenland nephelinites, and their presence in these rocks clearly reflects the very high alkali-contents of the magmas.

The pyroxenes in the lamprophyres, which are diopsides or salites, differ markedly from those in the dolerites which are augites, a difference which is well known (Carmichael et al. 1974: 272).

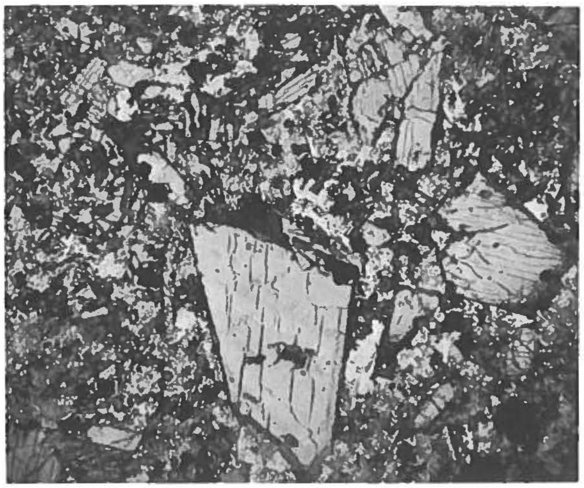

Fig. 4. Typical lamprophyre (GM 20730) showing clinopyroxene phenocrysts in a pyroxene-rich groundmass with a feldspathoidal mesostasis. Aegirine overgrowths are present on the Mg-, Ca- and Ti-rich earlier pyroxenes (Field of view c. 4 mm across).

Amphibole. Brown amphibole occurs as a groundmass phase in a number of lamprophyres and occasionally also as a xenocryst, identified as such by its rounded form showing that it has been resorbed. An analysis (Table 6) shows that in this case the amphibole is titanian pargasite (Leake 1978) and very similar compositions were found in GM 20739A. These xenocrysts are completely unzoned.

Some samples contain groundmass amphibole, although this is by no means ubiquitous. It has a very similar composition to the large xenocrysts but appears

Table 6. Selected analyses of amphibole and biotite

	30 amph.	45 amph.	47 amph.	43 biot.
SiO_2	40.39	37.91	40.24	38.02
Al_2O_3	12.46	15.02	13.51	9.84
TiO_2	3.93	3.71	4.23	2.49
Cr_2O_3	0.04	–	–	–
FeO[1]	11.99	16.19	10.99	24.06
MgO	13.04	9.49	13.80	12.55
MnO	0.06	0.31	0.10	0.93
CaO	12.38	12.01	12.66	0.11
Na_2O	2.87	2.78	2.26	–
K_2O	0.99	0.76	0.94	9.15
	98.15	98.18	98.73	97.15
basis	23 oxygens		22 oxygens	
Si	5.997	5.741	5.901	5.865
Al	2.174	2.680	2.331	1.785
Ti	0.437	0.418	0.466	0.287
Cr	–	–	–	–
Fe	1.479	2.044	1.346	3.090
Mg	2.905	2.153	3.034	2.905
Mn	0.009	0.036	0.009	0.120
Ca	1.969	1.944	1.988	0.019
Na	0.811	0.917	0.642	–
K	0.187	0.145	0.176	1.804
Σ cations	15.968	16.078	15.893	15.875
100 Mg/Mg+Fe	66.26	51.29	69.27	48.46

[1]total Fe as FeO.

30 amph.: Pale brown amphibole occurring as inclusion in xenocrystic clinopyroxene core in GM 20730.
45 amph.: Amphibole in ocelli with alkali feldspar in GM 20745. Pale brown needles.
47 amph.: Groundmass amphibole in GM 20745.
43 biot.: Groundmass biotite in GM 20743.

to be slightly more magnesian. It also occurs in an acicular habit as a component of ocelli in some samples where it is apparently more Fe-rich but not greatly different in character. Kaersutite was not found although it is common in other East Greenland lamprophyres (e.g. Brooks & Platt 1975).

Biotite occurs as a groundmass constituent in several samples but has little more the accessory status. A typical example is shown in Table 6. Ti is again relatively low and this feature both of the amphiboles and biotites is presumably a consequence of the low TiO_2 content of the magmas.

Feldspars, feldspathoids and zeolites. These rocks are designated nephelinites and feldspar is typically absent. Feldspar has however been identified in two samples which are therefore strictly basanites. The norms indicate that potential feldspar is present in many more and it may be occult (e.g. disguised as zeolite) in these. The two samples with modal alkali fedspar are GM 20740 and 20745, the latter with composition of Ab_{55} (Table 7) as an important constituent of the ocelli.

Typically the ferromagnesian minerals are set in an isotropic to low birefringent base which is not readily identified under the microscope. The microprobe shows this material to be nepheline, sodalite or analcime (see typical analyses in Table 7). In some cases (e.g. GM 20743) all these minerals have been identified coexisting. It would appear that the nepheline whose composition is reported in Table 7 is too rich in SiO_2 but whether this is due to analytical error or to loss of alkalis is unknown. However, similar compositions were obtained for both GM 20743 and 20745. Sodalite was an unexpected phase, as we are not familar with other occurrences in the groundmass of mafic rocks, and it was not discussed in the review by Wilkinson (1974), neither was it found in the nephelinites from the Nunatak zone to the north (Brooks et al. 1979). Its composition is close to the ideal and similar to those in standard compilations. The example in Table 7 has the highest Cl of the four sodalites from separate samples analysed but is otherwise typical. Analcime has a rather constant composition, typified by the analysis in Table 7.

Table 7. Selected feldspar, feldspathoid and prehnite analyses

	45 feld.	43 ne.	47 sod.	48 anal.	38 preh.
SiO_2	65.71	47.18	37.50	52.05	42.98
Al_2O_3	19.09	30.50	31.79	24.45	24.24
Fe_2O_3[1]	0.43	0.66	0.31	0.04	0.31
CaO	0.24	0.53	0.30	–	28.03
Na_2O	6.25	16.61	25.15	13.31	–
K_2O	7.82	3.78	–	0.49	–
Cl	–	–	7.04	–	–
	99.54	99.26	102.09	90.34	95.56
less O≡Cl			–1.59		
			100.59		
Basis:	8 oxy.	4 oxy.	21 oxy.	6 oxy.	11 oxy.
Si	2.974	1.123	6.009	1.945	2.972
Al	1.016	0.855	5.988	1.075	2.020
Fe^{3+}	0.016	0.011	0.030	–	0.017
Ca	0.011	0.013	0.048	–	2.075
Na	0.549	0.766	7.794	0.963	–
K	0.451	0.114	1.932	0.011	–
Σ cations	5.017	2.882	21.801	3.994	7.084

[1]all Fe as Fe_2O_3.

45 feld: Alkali feldspar in ocelli with amphibole in GM 20745.
43 ne: Nepheline in groundmass of GM 20743.
47 sod: Sodalite in groundmass of GM 20743.
48 anal: Analcime in groundmass of GM 20748.
38 preh: Prehnite in groundmass of GM 20738A.

No detailed survey has been made to determine the precise distribution of analcime and sodalite in the collection but neither appear to be limited to the more undersaturated samples. A zeolite in the groundmass of GM 20748 appears to be gonnardite although the analysis gave a rather low Na_2O content. According to Deer, Howie & Zusmann (1963) this zeolite is fairly well documented from basaltic rocks and may arise as an alteration product of the nepheline. GM 20738A contains prehnite in the groundmass, an analysis of which is reported in Table 7. It shows no evidence of being secondary.

Fe-Ti oxides. All investigated examples of these minerals, which occur as phenocrysts and groundmass constituents, proved to be magnetite. An example occurring in a large clinopyroxene in GM 20730 is also magnetite with a composition not essentially different from those shown in Table 8.

Ti-garnets, sphene, perovskite. These minerals occur as groundmass constituents in two specimens. Perovskite often forms a core to patches of sphene and/or Ti-garnet indicating that it formed earlier that the two latter minerals. Sphene and especially Ti-garnet form mossy aggregates and grains enclosing other

Table 8. Selected analyses of magnetites, sphenes and Ti-garnets

	39a mag.	43 mag.	48 sph.	48 gar.	48 gar.	48 gar.
SiO_2	–	–	29.39	28.58	29.71	33.35
ZrO_2	–	–	0.13	–	–	–
Al_2O_3	5.53	0.82	0.14	–	–	1.45
TiO_2	8.08	5.29	36.17	19.85	15.84	5.96
Cr_2O_3	0.09	–	–	–	–	–
FeO^1	75.48	84.48	3.31	17.22	19.39	20.91
V_2O_5	0.26	0.21	–	0.09	0.07	0.49
MgO	3.68	–	–	–	–	–
MnO	0.48	1.39	–	0.22	0.13	–
CaO	–	0.15	29.38	32.97	33.28	35.86
				–	–	
	93.60	92.34	98.52	98.93	98.42	98.02
$Fe_2O_3^2$	47.13	55.72		8.37	13.64	23.16
FeO^2	33.06	34.31		9.69	7.11	0.07
new sum	98.31	97.89*		99.77	99.78	100.34
Basis	24 cations 32 oxygens	24 cations 32 oxygens	20 oxygens	8 cations	12 oxygens	
Si	–	–	3.965	2.446	2.539	2.786
Zr	–	–	0.008	–	–	–
Al	1.906	0.300	0.022	–	–	0.143
Ti	1.782	1.238	3.671	1.277	1.017	0.374
Cr	0.035	–	–	–	–	–
Fe^{3+}	10.394	13.072	0.337	0.539	0.876	1.456
Fe^{2+}	8.101	8.939	–	0.694	0.508	0.005
V	0.035	0.037	–	0.005	0.004	0.027
Mg	1.623	–	–	–	–	–
Mn	0.123	0.357	–	0.016	0.010	–
Ca	–	0.056	4.246	3.023	3.096	3.209

[1]All iron as FeO.
[2]Fe_2O_3 and FeO calculated on basis shown below. Dash signifies that no X-ray peak was detected.

39A mag. Core of magnetite phenocrysts in GM 20739/A.
43 mag. Groundmass magnetite in GM 20743.
48 sph. Mossy patches of sphene in groundmass of GM 20748.
48 gar. Three analyses of deeply coloured Ti-garnet occurring a mossy patches in groundmass of GM20748. Dark isotopic core, light isotopic zone and birefringent rim (see text).

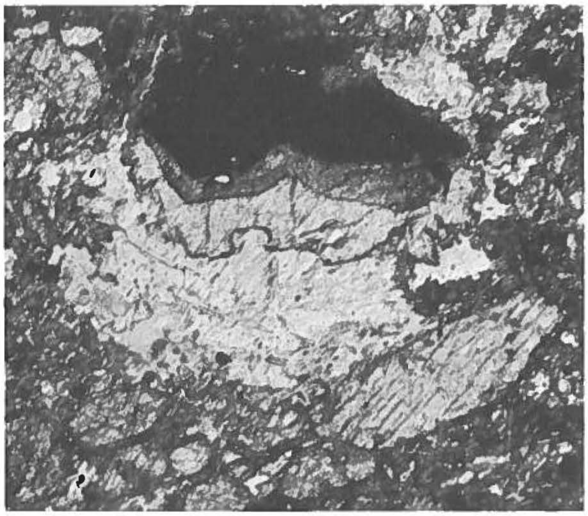

Fig. 5. Leucite-larnite normative nephelinitic lamprophyre (GM 20738A) showing successive mantling on early Ti-rich garnet cores adjacent to an area of carbonate. (Field of view c. 1 mm across).

groundmass constituents. Perovskite has not been analysed in the present study but analyses of sphene and Ti-garnet are presented in Table 8. Sphene in GM 20738A has a rather simple composition, that in GM 20748 is more complex with measurable Zr and rare earths. The latter could not be determined by means of the technique used but were observed qualitatively. Significant amounts of Nb may also be present. The more evolved nature of the sphene in this rock is presumably correlated with the more evolved nature of the rock itself (cf. Table 2). No corresponding compositional difference was apparent in the garnets but this may be masked by their strongly zoned character. They have a main inner part of dark brown to almost opaque material. This varies in composition as shown in Table 8. Where the garnet abuts onto an area of zeolite in an ocellus it is rimmed first by a honey yellow, isotropic garnet and subsequently by an almost colourless, weakly birefringent variety (Fig. 5). Analyses reported in Table 8, which have been calculated as recommended by Huggins et al. (1977) on the basis of 8 cations and 12 oxygens, show that the main substitution is $R^{2+} + R^{4+} = 2R^{3+}$ ($CaTi = 2Fe^{3+}$) with minor amounts of $R^{5+} + 2R^{2+} = 3R^{3+}$ ($VCa_2 = 3Fe^{3+}$).

Inclusions in lamprophyres

Innumerable inclusions were found in the dike GM 20747 at one locality and are probably quite common to judge by the ubiquitous presence of xenocrysts in the lamprophyres.

It is felt to be likely that a search would reveal many more nodule bearing localities. It should also be noted that GM 20747 is the only sample in the collections to show the blotchy texture ascribed by Brooks & Printzlau (1978) to magma mixing. Out of the large collection of nodules and megacrysts which were brought home, only the following samples have been examined in any detail:

a) Clinopyroxene megacrysts with rounded inclusions of olivine (Fo_{78}). The pyroxene is homogeneous except for a slight rise in Fe towards the interior (Table 9) and does not differ markedly from some of the pyroxenes in the dikes. These megacrysts are up to several centimetres in size.

b) Amphibole wehrlite with a hypidiomorphic texture (Fig. 6). The only example which has been examined in any detail has a very approximate mode of 60% olivine, 40% clinopyroxene and 10% amphibole. Mineral compositions are more magnesian than found for the megacrysts and are very homogeneous, i.e. olivine: 82.5% Fo (10 analyses $\sigma = 1.1$), clinopyroxene $Ca_{50.2}Mg_{40.3}Fe_{9.4}$ (17 analyses, for these figures σ = 0.5, 0.9 and 0.7, respectively). Only a few amphibole analyses have been made but these are in no way remarkable. The bulk of the amphibole is light brown and is similar to that in the dikes in being a titaniferous pargasite. It is however more magnesian (100 Mg/Mg+Fe = 75.0) than those of the dike groundmass or the analysed xenocrysts. In places, a darker amphibole is developed, most likely by reaction with the enclosing magma, and this is both more Fe- and Ti-rich, but is still not kaersutite. Selected analyses are reported in Table 9.

c) Strongly sheared monomineralic clinopyroxenite.

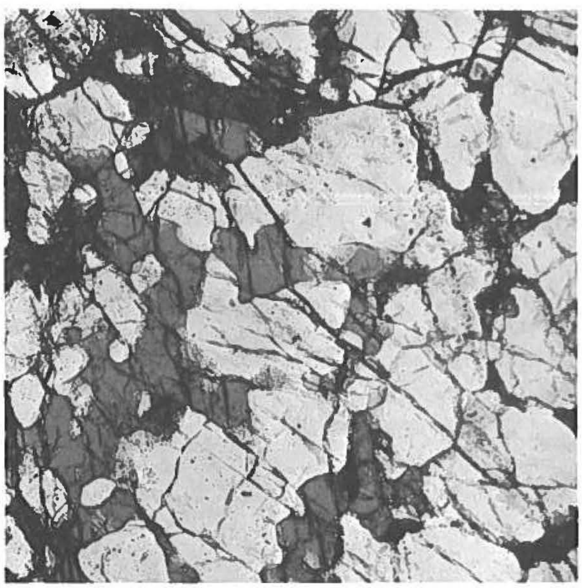

Fig. 6. Hypidiomorphic amphibole wehrlite inclusion in GM 20747. Amphibole of two colours is present, the darker arising by reaction with the enclosing magma. (Field of view c. 4 mm across).

Table 9. Selected analyses of minerals occurring as components of inclusions in GM 20747

	a		b			c	d	
	ol	cpx	ol	cpx	amph	cpx	ol	cpx
SiO_2	38.75	47.17	39.48	50.56	41.76	51.85	38.80	49.22
Al_2O_3	–	5.87	–	5.69	13.21	2.72	–	5.75
TiO_2	–	1.98	–	1.41	2.93	0.82	–	1.31
Cr_2O_3	–	0.07	–	0.04	–	0.04	–	0.11
FeO[1]	19.32	7.77	17.03	5.65	9.05	4.58	20.06	6.55
MgO	41.04	12.45	43.59	13.50	15.23	15.23	41.47	12.95
MnO	0.46	0.04	0.51	0.11	–	0.03	0.59	0.19
CaO	0.05	23.80	0.10	22.96	12.43	24.52	0.07	22.87
Na_2O	–	–	–	–	1.51	–	–	–
K_2O	–	–	–	–	0.99	–	–	–
	99.62	99.15	100.71	99.92	97.11	99.79	100.99	98.95
Basis:	4 oxy.	6 oxy.	4 oxy.	6 oxy.	23 oxy.	6 oxy.	4 oxy.	6 oxy.
Si	0.998	1.787	0.994	1.861	6.109	1.912	0.990	1.844
Al	–	0.262	–	0.247	2.279	0.118	–	0.254
Ti	–	0.056	–	0.039	0.322	0.023	–	0.037
Cr	–	0.002	–	0.001	–	0.001	–	0.003
Fe	0.417	0.246	0.359	0.174	1.108	0.141	0.428	0.205
Mg	1.575	0.703	1.637	0.741	3.323	0.837	1.577	0.723
Mn	0.010	0.001	0.011	0.003	–	0.001	–	–
Ca	0.001	0.966	0.003	0.906	1.949	0.969	0.002	0.918
Na	–	–	–	–	0.430	–	–	–
K	–	–	–	–	0.184	–	–	–
Σ cat.	3.001	4.023	3.004	3.972	15.704	4.002	2.997	3.984

[1]all Fe as FeO.

a) clinopyroxene megacryst (interior homogeneous part) with included olivine grains.
b) amphibole wehrlite inclusion.
c) strongly sheared clinopyroxenite.
d) wehrlite inclusion.

The pyroxenes of this rock are crossed by innumerable shear lamellae. They are homogeneous in composition and resemble some of the xenocryst cores in the dikes (Table 9).

d) Hypidiomorphic, amphibole-free wehrlite composed of about equal amounts of olivine and clinopyroxene (Fig. 7). Again compositions are unremarkable except that the minerals are rather more iron-rich than in the previous types.

It seems that these inclusions represent a rather complicated sequence of events at no great depth during which magmas, presumably isolated in pockets for rather long periods, underwent crystallization to form plutonic olivine-clinopyroxene-amphibole rocks. In other cases, the density contrast was apparently insufficient to cause crystal settling and clinopyroxenes grew to large size suspended in the magma. Thus it appears that several distinct pockets were tapped in the emplacement of the dike in which they are now found. It is not known under what conditions the intense shearing observed in some of the clinopyroxenites arose but these rocks on mineral-chemical grounds appear to belong to the same suite and not, for example, to the underlying Precambrian.

The general picture deduced from these inclusions, as well as from the wide spread in rock compositions, is in harmony with the results of fission track dating on the so-called "late dikes" which shows that they formed over a long period, i.e. 43–34 m.y. (Brooks & Gleadow 1979). There was thus ample time for the accumulation of crystals and evolution of a variable petrochemistry.

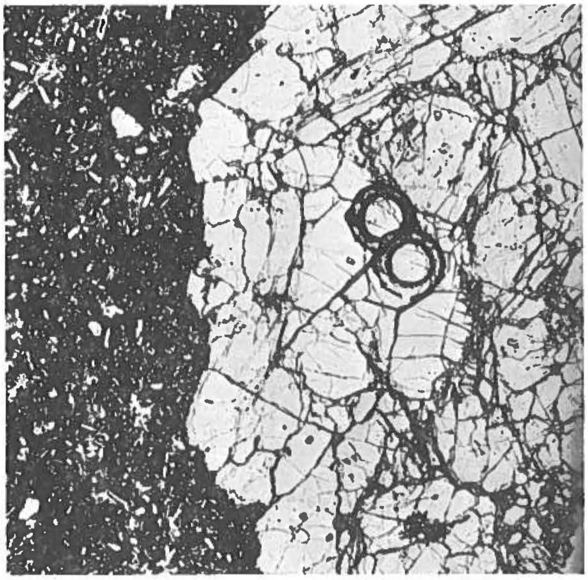

Fig. 7. Amphibole-free wehrlite inclusion in GM 20747. Clinopyroxene is slightly greyish, olivine completely white. (Field of view c. 4 mm across. The circles are analysed points in olivine).

Petrochemistry

Some general features of the petrochemistry of these dikes have been noted above. Thus, the dolerites were shown to be of a compositional type well known in the area and they will not be further discussed. However, the lamprophyres are more unusual and will be examined in a little more detail.

Selected samples of all the types discussed here are presented in Table 2. A complete table of analyses may be obtained from the authors.

Nephelinite rocks, similar to the Tugtilik lamprophyres and presumably formed under similar tectonic conditions, have also been recorded in the East Greenland Tertiary province from Kangerdlugssuaq (Brooks & Rucklidge 1974) and from the Nunatak zone over 900 km to the north (Katz 1952, Brooks et al. 1979). However, at Tugtilik the lamprophyres are much more strongly undersaturated and do not appear to be transitional to less undersaturated types. Indeed, exceptionally high alkali, particularly Na, contents are found at Tugtilik (sample no. GM 20748 has over 10 percent total alkalis). Another significant difference is the low TiO_2 content in the Tugtilik rocks, barely rising above 2 percent, whereas in the other East Greenland nephelinites it ranges from 3 to 6 percent. Similar TiO_2 contents were found by Brooks & Platt (1975) in the "late dikes" of Kangerdlugssuaq which are tentatively regarded as time equivalents of the Tugtilik dikes. However, the Kangerdlugssuaq late dikes are markedly less undersaturated and show a trend of differentiation to oversaturated intermediate types (see also Nielsen 1978). We conclude that the lamprophyres described here are not closely similar to any of the rock types previously described from East Greenland.

Table 3 shows some comparison between the Tugtilik lamprophyre compositions and nephelinitic rocks from Africa. This comparison shows that comparable compositions can be found elsewhere and suggests that a similar tectonic regime was operative under Tugtilik at the time of intrusion of the lamprophyres to that of the African rift. It is proposed that these nephelinites formed in a tensional environment which at this particular location did not successfully develop into a spreading axis. This conclusion is supported by the presence of basement on the continental shelf (Larsen 1978). It was earlier suggested that the lamprophyres fall into two groups on the basis of their relations in the alkalis-silica diagram (Fig. 3). While the sample collection is too small to state whether this is real or whether a continuum exists between the two, the more undersaturated group may also contain perovskite, Ti-garnet and sphene in the groundmass in spite of the low TiO_2 content common to the entire collection. However, other differences, i.e. in trace element content, have not been observed. The distribution of FeO^{tot}/MgO ratios with increasing alkalis, particularly in the more undersaturated group, suggests that crystal differentiation may have played a role in the development within the groups. However, this ratio for the other group is more irregular and the variation in trace elements, which also shows important irregularities, indicates that history of the lamprophyres is more complex and they may well stem from small independent magma batches.

Summary

The dikes at Tugtilik are regarded as being part of the East Greenland coast-parallel swarm and have a strike which is consistent with this. Thin lamprophyres and thicker dolerites were distinguished, the lamprophyres being more abundant inland.

The dolerites are typical olivine tholeiites having olivine, clinopyroxene and plagioclase on the liquidus. They are similar to the plateau basalts of the province and have been encountered at least as far south as the Angmagssalik district.

The lamprophyres are apparently later and have a nephelinitic composition although differing in important details (low TiO_2, higher alkalis) from other nephelinites so far described from East Greenland. These rocks contain abundant phenocrysts of clinopyroxene, often with xenocrystic cores and overgrowths of aegirine, and less abundant olivine and magnetite. The groundmass consists of clinopyroxene, ore and biotite set in a matrix of nepheline, sodalite, analcime, prehnite, zeolites and occasionally alkali feldspar. In the more undersaturated members, which may form a distinct leucite-larnite normative group, perovskite, Ti-garnet and sphene are found. Many of

these lamprophyres contain ocelli and diverse inclusions (wehrlites, clinopyroxenites, etc.) have been found.

A distinctly transitional type of hypersthene normative dike, characterized by titaniferous pyroxene and higher alkalis than the normal dolerites, has been found in the Angmagssalik district, but its distribution and abundance is at present unknown as is that of the lamprophyres described here.

It is believed that the dolerites were intruded at the time of continental break-up in the area, i.e. around 55 m.y. ago (Brooks 1979) but the lamprophyres probably were emplaced distinctly later during a protracted period of crustal tension. Hitherto, nephelinites have only been found in areas far removed from the continental margin. Their presence at Tugtilik is therefore rather unexpected. However, their increasing intensity in going inland and the location of Tugtilik on the inland side of the main coastal dike swarm, which passes out to sea a little to the north (Larsen 1978), may nevertheless be in accordance with the previously known nephelinite distribution. In this case, the hypothesis proposed for the north-east Greenland nephelinites, i.e. flank activity over deep-lying parts of the mid-ocean ridge anomaly (Brooks et al. 1979), may still be valid. However, in view of the fact that these lamprophyres are probably younger than the main magmatic activity, it is perhaps most reasonable to suppose that they are products of a waning stage of the magmatism. More detailed discussions of their petrogenesis must await a more comprehensive knowledge of their precise extent in both space and time.

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References

Bailey, D. K. 1974. Nephelinites and ijolites. – In: Sørensen, H. (ed.), The Alkaline Rocks: 53–66. – Wiley, New York: 622 pp.

Bridgwater, D., Davies, F. B., Gill, R. C. O., Gorman, B. E., Myers, J. S., Pedersen, S. & Taylor, P. 1978. Precambrian and Tertiary geology between Kangerdlugssuaq and Angmagssalik, East Greenland. – Rapp. Grønlands geol. Unders. 83: 17 pp.

Brooks, C. K. 1973. Rifting and doming in southern East Greenland. – Nature Phys. Sci. 244: 23–25.

Brooks, C. K. 1976. The Fe_2O_3/FeO ratio of basalt analyses: an appeal for a standardized procedure. – Bull. geol. Soc. Denmark 25: 117–120.

Brooks, C. K. & Gleadow, A. J. W. 1979. Fission track dating, thermal histories and tectonics of igneous intrusions in East Greenland. – Contrib. Mineral. Petrol. (in press).

Brooks, C. K. & Jakobsson, S. P. 1974. Petrochemistry of the volcanic rocks of the North Atlantic ridge system. – In: Kristjansson, L. (ed.), Geodynamics of Iceland and the North Atlantic Area: 139–154. – Reidel, Dordrecht: 323 pp.

Brooks, C. K. & Platt, R. G. 1975. Kaersutite-bearing gabbroic inclusions and the late dike swarm of Kangerdlugssuaq, East Greenland. – Min. Mag. 40: 259–283.

Brooks, C. K. & Printzlau, I. 1978. Magma mixing in mafic alkaline volcanic rocks: the evidence from relict phenocryst phases and other inclusions. – J. volcanol. geotherm. Res. 4: 315–331.

Brooks, C. K. & Rucklidge, J. C. 1973. A Tertiary lamprophyre dike with high pressure xenoliths and megacrysts from Wiedemanns Fjord, East Greenland. – Contrib. Mineral. Petrol. 42: 197–212.

Brooks, C. K. & Rucklidge, J. C. 1974. Strongly undersaturated Tertiary volcanic rocks from the Kangerdlugssuaq area, East Greenland. – Lithos 7: 239–248.

Brooks, C. K., Nielsen, T. F. D. & Petersen, T. S. 1976. The Blosseville Coast basalts of East Greenland: composition and temporal variations. – Contrib. Mineral. Petrol. 58: 279–292.

Brooks, C. K., Pedersen, A. K. & Rex, D. C. 1979. The petrology and age of alkaline mafic lavas from the nunatak zone of central East Greenland. – Bull. Grønlands geol. Unders. 133: 28 pp.

Carmichael, I. S. E., Turner, F. J. & Verhoogen, J. 1974. Igneous Petrology. – McGraw Hill, New York: 739 pp.

Deer, W. A., Howie, R. A. & Zussmann, J. 1963. Rock-forming minerals. Vol. 4. Framework silicates. – Longmans, London: 435 pp.

Huggins, F. E., Virgo, D. & Huckenholz, H. G. 1977. Titanium-containing silicate garnets. II. The crystal chemistry of melanites and schorlamites. – Amer. Mineral. 62: 646–665.

Jakobsson, S. P. 1972. Chemistry and distribution pattern of Recent basaltic rocks in Iceland. – Lithos 5: 365–386.

Katz, H. R. 1952. Ein Querschnitt durch die Nunatakzone Ostgrönlands (ca. 74°N.B.). – Meddr Grønland 144 (8): 65 pp.

King, B. C. 1965. Petrogenesis of the alkaline igneous rock suites of the volcanic and intrusive centres of E. Uganda. – Jour. Petrol. 6: 67–100.

Larsen, H. C. 1978. Offshore continuation of East Greenland dyke swarm and North Atlantic ocean formation. – Nature, Lond. 274: 220–223.

Leake, B. E. 1978. Nomenclature of amphiboles. – Min. Mag. 42: 533–563.

Macdonald, G. A. & Katsura, T. 1964. Chemical composition of Hawaiian lavas. – J. Petrology 5: 82–133.

Nielsen, T. F. D. 1978. The Tertiary dike swarms of the Kangerdlugssuaq area, East Greenland. An example of magmatic development during continental break-up. – Contrib. Mineral Petrol. 67: 63–78.

Soper, N. J., Downie, C., Higgins, A. C. & Costa, L. I. 1976. Biostratigraphic ages of Tertiary basalts on the East Greenland continental margin and their relationship to plate separation in the northeast Atlantic. – Earth planet. Sci. Letters 32: 149–157.

Varne, R. 1968. The petrology of Moroto mountain, Eastern Uganda, and the origin of nephelinites. – J. Petrology 9: 169–190.

Vincent, E. A. 1950. The chemical composition and physical properties of the residual glass of the Kap Daussy tholeiite dike, East Greenland. – Min. Mag. 29: 46–62.

Vincent, E. A. 1953. Hornblende-lamprophyre dykes of basaltic parentage from the Skaergaard area, East Greenland. – Q Jl Geol Soc. Lond. 190: 21–50.

Wager, L. R. & Deer, W. A. 1938. A dyke swarm and crustal flexure in East Greenland. – Geol. Mag. 75: 39–46.

Wilkinson, J. F. G. 1974. The mineralogy and petrography of alkali basaltic rocks. In: Sørensen, H. (ed.), The Alkaline Rocks: 67–95. – Wiley, New York: 622 pp.

Williams, M. I. 1974. Geology report. – In: Westminster East Greenland Expedition – 1974: 29 pp. (duplicated report).

Greenland Geoscience

1979.

1. C. K. Brooks:
   »Geomorphological observations at Kangerdlugssuaq, East Greenland«. 24 pp.

The Kangerdlugssuaq area is mainly comprised of two contrasting rock groups: on the one hand the easily-eroded lavas and sediments of late Mesozoic to early Tertiary age and on the other the highly resistant Precambrian gneisses. Intermediate between these two types in terms of behaviour with respect to erosion are the Tertiary plutonic complexes and the basaltic areas along the coast which have been intruded by intense dyke swarms.

In the late Mesozoic the area was a peneplain, and low relief apparently persisted throughout the volcanic episode as there is good evidence that the lava plateau subsided during its formation. During this period ocean-floor spreading gave rise to the embryonic Danmark Stræde. Shortly after the volcanic episode the Kangerdlugssuaq area became the centre of a massive domal upwarping which has been a dominant feature of the land-forms up to the present day. The original surface of the dome has been reconstructed on the basis of topographic and geological evidence to show that it was elliptical in form with a major axis of at least 300 km in length and a height above present sea-level of about 6.5 km. However, subsequent isostatic effects are not considered in deriving these figures. The updoming is estimated to have occurred about 50 m.y. ago.

Several kilometres thickness of sediments and lavas were eroded off this dome at an early stage exposing the gneissic core, which still stands in alpine peaks up to about 2.7 km altitude in the central part, and dumping ca. 50000 km^3 of sediment on the continental shelf. The erosion was effected by a radial, consequent drainage system, relicts of which can still be found. Kangerdlugssuaq itself may owe its origin to a tectonic line of weakness formed in response to doming, but there are also good arguments for its being purely erosional. The erosion of the dome was probably fluviatile but all trace of this stage has been obliterated by the subsequent glaciation.

In the period between the Eocene and the early Miocene, possibly around 35 m.y. ago, the entire area underwent epeirogenic uplift raising the undeformed parts of the original lava plateau to around 2.5 km above sea-level. At present this plateau is undergoing dissection from the seaward side, but considerable areas are still preserved under thin, horizontal ice-caps.

A brief description of the various types of glaciers, an impermanent, ice-dammed lake and the areas of ice-free land is given. In the Pleistocene, the Kangerdlugssuaq glacier was considerably thicker than at the present time and extended far out over the shelf, excavating a deep channel here. Finally some observations on the coastlines are presented.

2. Sven Karup-Møller and Hans Pauly:
   »Galena and associated ore minerals from the cryolite at Ivigtut, South Greenland«. 25 pp.

Silver- and bismuth-rich galena concentrates have been produced for more than 70 years as a byproduct in the dressing of the crude cryolite from Ivigtut, South Greenland.

Concentrates from the years 1937 to 1962 contained from 0.44 % Ag and 0.74 % Bi to 0.94 % Ag and 1.93 % Bi. Conspicuous increases in the content of these elements appeared twice within this time interval, namely in 1955 and in 1960. Thus it seems that crude cryolite from specific areas within the mine carried galena high in silver and bismuth. This promoted a detailed study of the common Ivigtut galena and associated sulphides.

An outline of the geological setting of the deposit is given. The deposit is divided into two main bodies – the cryolite body and the quartz body. Both ate subdivided into units characterized by their content of siderite and fluorite. Galena samples from these units and from rock types surrounding the deposit have been studied.

Galena from units characterized by siderite follows the compositional pattern found in the galena concentrated, whereas the sparse galena mineralizations from unirs characterized by fluorite contain much smaller amounts og silver and bismuth, less than 0.2 %. However, within the fluorite-bearing units, two peculiar parageneses reveal high contents of silver and bismuth wxpressed by the presence of particular minerals such as marildite-aikinite and gustavite.cosalite respectively.

Further trace element studies on selected galena samples emphasize Sn and Te as chemically characteristic og the galena and of the sulphide-carbonate phase of the deposit.

The temperature of formation of the main part of the deposit is placed at 550–400°C, and between 300 and 200°C certain parts of the fluorite cryolite and the fluorite zone.

1980

3. John C. Rucklidge, Charles Kent Brooks and Troels F. D. Nielsen: "Petrology of the coastal dykes at Tugtilik, southern East Greenland".

Greenland Bioscience

1979.

1. Erik L. B. Smidt:
»Annual cycles of primary production and of zooplankton at Southwest greenland«. 56 pp.

Annual hydrographic observations, measurements of primary production, and sampling of zooplankton were undertaken in Southwest Greenland waters in the 1950s and –60s. In the coastal area and at the entrance to Godthåbsfjord winter cooling normally extends to the bottom, resulting in a vertical mixing of the water and an effective replenishment of nutrients at the surface. The subsequent production rate is, therefore, high with an average annual gross production calculated to about 160 g C – m^2. In the inner fjord regions the stratification is normally much more stable with persisting warm bottom water, and the production is, therefore, lower here than in the coastal area. The seasonal variation in the relations between daylight, primary production, phosphate, and quantity of zooplankton is, presumably, representative of the coastal waters at SW Greenland. A maximum in primary production in spring is normally followed by another maximum in late summer. The number of animals in the microplankton samples from the upper 30 m (the productive layer) is at its maximum simultaneously with the second maximum of the primary production, while the maximum of the macroplankton biomass (taken by stramin net) extends until late autumn in the coastal and outer fjord regions.

A maximum of the macroplankton biomass during winter in the deep water layers in the inner Godthåbsfjord, caused by inflow of warm bottom water, stable stratification and cooled outflowing surface water acting as a barrier to the ascent of the animals, is assumed to be normal to the open, non-threshold, W Greenland fjords.

Seasonal vertical migration of the zooplankton is indicated by Hensen net hauls from different depths. There is a concentration of zooplankton in the upper water layers in April–September and a deeper concentration from autumn to spring.

Annual cycles of various animal groups are described for holoplankton and meroplankton, separately. Holoplankters are normally dominant, copepods being the most numerous group. Meroplankters, especially bottom invertebrate larvae, are relatively numerous in the microplankton in spring and summer with *Balanus* nauplii dominant in spring and lamellibranch larvae in the following months. In a special section on fish eggs and larvae it is shown *I.a.* that cod eggs and larvae are normally concentrated in the upper 50 m, where they are much exposed to temperature variations, while eggs and larvae of American plaice occur also in deeper water. This may partly explain why the cod stock is more vulnerable to low temperatures.

It is shown that the epipelagic plankton fauna in the survey area in terms of growth and mode of development is more similar to the arctic than to the boreal fauna. It could therefore be termed subarctic, which also corresponds to the environmental conditions in the area.

1980

2. Jean Just:
"Amphipoda (Crustacea) of the Thule area, Northwest Greenland: Faunistics and Taxonomy". 64 pp.

The material reported on was collected in the Thule area, NW Greenland, in 1968 and includes 105 species. Four of these, *Aceroides goesi, Bathymedon antennarius, Monoculodes vibei* and *Parametopa crassicornis,* are new to science. An additional 6 species are new to Greenland, while 9 species have previously been found in E Greenland but not in W Greenland. Four genera, *Lembos, Arrhinopsis, Arctopleustes* and *Parametopa,* are recorded from Greenland for the first time.

Specimens belonging to 15 additional taxa are for various reasons not referred to species. Major taxonomic problems, warranting broadly based revisions, are outlined in the genera *Byblis, Gitanopsis, Ischyrocerus, Tmetonyx, Monoculodes* and *Stenula.* Three different forms of *Paroediceros lynceus* are discussed.

All known amphipod species from the Thule area are included in an annotated list. Forty-nine taxa are discussed and figured.

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