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Gardar dykes north of the Igaliko Syenite Complex, southern Greenland

by

B. G. J. Upton and J. G. Fitton

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No. 127 Gardar dykes north of the Igaliko Syenite Complex, southern Greenland. 1985 *by* B. G. J. Upton & J. G. Fitton.

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Gardar dykes north of the Igaliko Syenite Complex, southern Greenland

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Abstract

An ENE–WSW trending swarm of Gardar dykes, traversing Mellemlandet and G. F. Holm Nunataq is principally composed of a 'main series' with compositions ranging from alkali olivine basalt to trachyte and rhyolite, and scarcer phonolitic trachyte associates.

The most basic 'main series' magmas were emplaced as several giant dykes up to 650 m wide. Synformally layered gabbroic and anorthositic cumulates are locally developed within these. At Syenitknold internal differentiation within a giant dyke gave rise to syenogabbros, layered syenite cumulates and peralkaline nepheline syenite pegmatites. A large xenolithic mass of exotic feldspathic gabbro within the syenites is ascribed to the foundering of feldspar-rich roofing facies into the underlying magma chamber. Less extreme differentiation in the same giant dyke east of Syenitknold produced syenogabbroic cumulates containing evidence for vigorous convective flow having developed in the cooling intrusion.

Smaller (< 40 m wide) and younger dykes are almost invariably of more differentiated character. The commonest dykes (< 15 m wide) are of benmoreite and trachyte. Dykes with their interiors crowded with plagioclase xenocrysts and anorthositic inclusions are referred to as 'big feldspar dykes' (B.F.D.s). While all compositions from basalt to benmoreite may be involved in the B.F.D.s, the B.F.D. character is typical of the hawaiites and mugearites.

Small (typically < 1 m), scarce dykes and sills of highly silica-undersaturated types range from ultramafic lamprophyres to carbonatites. These may be representative of a compositional continuum between 36 and 2 wt % SiO_2.

The main swarm is so closely similar to that seen to the WSW, extending through Tugtutôq and the Narssaq and Qagssiarssuk areas, that it is thought to be merely a faulted continuation of the latter. If so, this swarm, *c.* 15 km across, is at least 140 km long. The magnitude and extent of this alkaline swarm and its individual components, may well be unique: it differs from other swarms (e.g. that of the roughly contemporaneous Nunarssuit-Isortoq swarm) in the size and abundance of the salic dykes within it. It was almost certainly related to extensive fissure eruption of basic to salic lavas. A clockwise change of several degrees between the orientation of early giant dykes and later differentiated dykes is related to a change in the extensional stress direction during the development of the Gardar rift system.

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Introduction

The Gardar alkaline province (Emeleus & Upton, 1976) tends to show a biomodal distribution of rock-types, with salic rocks (syenites, granites, foyaites etc.) largely confined to central complexes and basic rocks (basalts, hawaiites and their coarser-grained equivalents) mainly restricted to dykes and to lavas of presumed fissure-volcano origin. Nevertheless, salic dykes are relatively plentiful in the neighbourhood of the large central complexes. (e.g. Grønnedal-Ika and Igaliko areas; Emeleus & Upton, 1976), where they may be attributed to lateral injections from large sub-volcanic magma chambers.

One distinctive swarm, however, plays a key role in any understanding of the genesis of Gardar magmatic evolution. This is the late Gardar (ENE–WSW) dyke-swarm that traverses the Tugtutôq archipelago and the peninsula extending between Narssaq and Qagssiarssuk (Upton, 1962; Macdonald, 1969; Upton & Blundell, 1978) (fig. 12). It is of critical importance because it involved a whole spectrum of magmas ranging from alkali olivine basalt to alkali rhyolites (together with some phonolitic trachytes and phonolites). The dykes too, are remarkable in their size and lateral persistence. Mugearite, benmoreite and trachyte dykes of 5–15 m width are commonplace and are traceable over tens of kilometres and in themselves constitute a remarkable phenomenon. They normally post-date dykes of hawaiitic and basaltic composition. These latter, up to 800 m wide and often internally differentiated, have been referred to as giant dykes (Upton, 1962).

This report covers preliminary investigation of Gardar dykes from the nunataq region some 25–60 km ENE of Qagssiarssuk. The dykes in this little-known area have much in common with those of Tugtutôq and, as will be argued, appear to be simply an ENE continuation of the extraordinary Tugtutôq swarm.

In 1982, a field investigation was made of the ENE–WSW dykes traversing (a) Mellemlandet, (b) the nunataq north of Motzfeldt Sø, and (c) G. F. Holm Nunataq in the region to the north-east of the Igaliko Syenite Complexes. The swarm is persistent over an outcrop length of *c.* 45 km from the Kiagtut sermiat (glacier) to the Inland Ice and appears unaffected by any post-Gardar faulting (fig. 1). While the whole swarm is diffuse over a total width of c. 15 km, the great majority of dykes are concentrated within an axial zone of less than half that width.

The swarm has been well mapped around Qagssiarssuk and in the southern part of Johan Dahl Land, as shown on the Narssarssuaq 1:100 000 geological map (Geological Survey of Greenland, sheet 61 V. 3 Syd). However, further east-north-east in Mellemlandet, the dykes are less well-known (Walton, 1965) and, in the region north of Motzfeldt Sø and in G. F. Holm Nunataq they have been known, hitherto, only in the sketchiest reconnaissance outline. The present study aims to lessen this deficiency and to relate the swarm in this relatively inaccessible terrain with that further to the west-south-west.

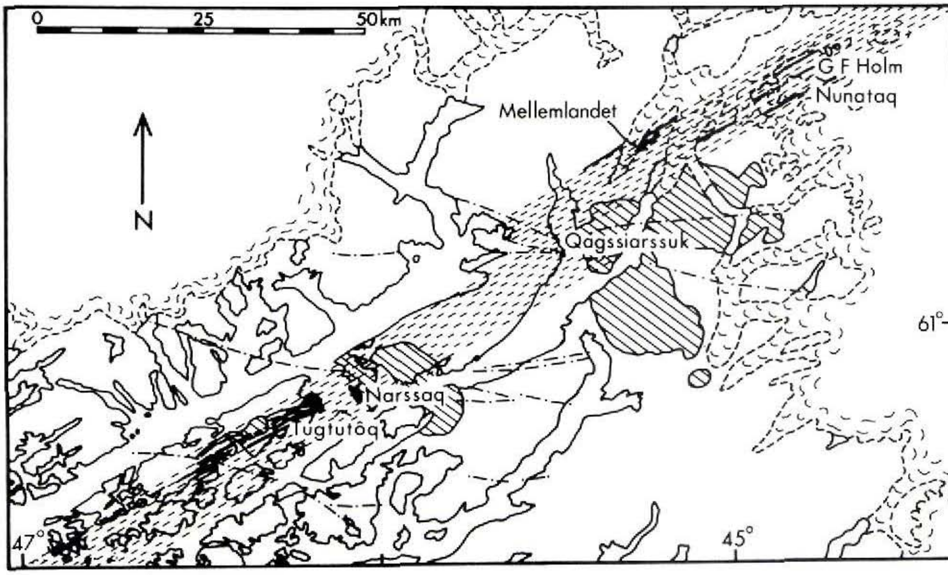

Fig. 1. Map of the Tugtutôq – G. F. Holm Nunataq region. Late Gardar alkaline complexes (Ilímaussaq and Igaliko) are outlined in the Narssaq and Qagssiarssuk areas respectively. The distribution of dykes composing the principal swarm of B. F. D.s, benmoreites, trachytes etc. is indicated by dashed ornament. The outcrop of giant dyke gabbros is indicated in black.

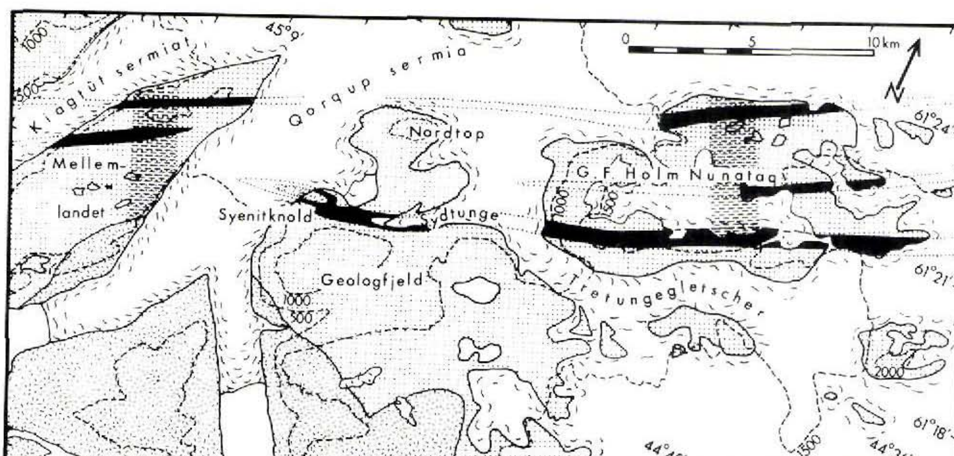

Fig. 2. Sketch map showing distribution of giant dykes (black) in the Mellemlandet – G. F. Holm Nunataq region. Stippled ornament; earlier Proterozoic country-rocks. Dashed ornament; syenites of the Motzfeld Complex and of Syenitknold. The ornamented bands across Mellemlandet and G. F. Holm Nunataq indicate the traverses across which the smaller dykes were collected.

Samples were systematically collected across a 10 km traverse of Mellemlandet (measured perpendicular to the swarm trend). Exposure is good and it is estimated that over 80% of all dykes exceeding 5 m width were recorded. By contrast, G. F. Holm Nunataq is largely covered with a regolith of frost-shattered rock, moraines and snow-fields and field-work was correspondingly more difficult. On the intervening ground (between Nordtop and Geologfjeld), because of difficult terrain, it was only possible to study relationships along and adjacent to the large gabbroic dyke (giant dyke) between Sydtunge and Syenitknold (fig. 2). Nevertheless, despite the limitations, broad conclusions can be drawn concerning the nature of the swarm along this 45 km exposed sector before its disappearance beneath the Inland Ice to the east-north-east.

The swarm is dominated by giant dykes of olivine gabbro up to 650 m across. In G. F. Holm Nunataq, three such parallel dykes occur spaced at 2–3 km intervals. Across Mellemlandet there are two giant dykes *c.* 1 km apart. With massive rectilinear joint patterns (and crumbly weathering on Mellemlandet) they are easily identified on aerial photographs. As noted by Walton (1965) the gabbro dykes on Mellemlandet are the earliest components of the swarm. Smaller (doleritic) dykes of similar composition are rare. The large number of smaller dykes, rarely exceeding 25 m and mostly less than 15 m across are composed of more differentiated materials (hawaiite, mugearite, benmoreite and trachyte). Dykes of benmoreite-trachyte composition are numerically dominant, typical examples being shown in fig. 3. These dykes, with SiO_2 contents in the range 55–69% and MgO < 1.5 wt% are generally

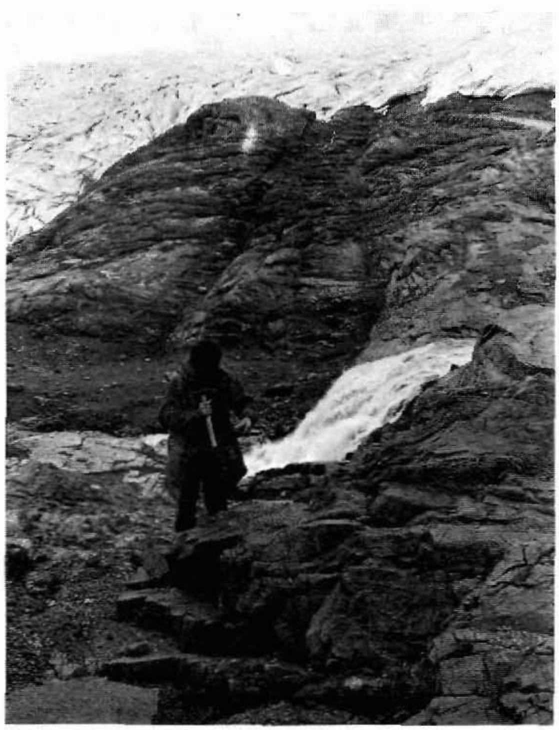

Fig. 3. ENE-trending benmoreitic dykes cutting Syenitknold syenite, beneath ice of Qorqup sermia.

alkali feldspar-phyric and tend to be brownish in their central facies with dark bluish black chilled margins. They are commonly 5–15 m wide and are observed cutting the gabbro giant dykes. With increasing basicity the trachydolerite (mugearite-hawaiite) dykes are greyer, generally plagioclase-phyric and lack the ophitic textures of the most basic (dolerite-gabbro) dykes. Many of these intermediate dykes are strikingly rich in large plagioclase phenocrysts and xenocrysts (up to 20 cm long) composing over 25% modally. These are typical 'big feldspar dykes' well known from the swarms further to the west-south-west (Upton, 1962). The 'big feldspar dykes' (B.F.D.s) range up to 30 m width. While most, in terms of an alkali-silica plot (fig. 4) fall into the mugearite-hawaiite fields (Cox *et al.*, 1979) some fall into the alkali olivine basalt (and very occasionally basanite) fields, whereas others extend into the benmoreite field.

Thus, the swarm comprises almost exclusively large basic dykes (dolerite and gabbro), smaller trachydolerite dykes and abundant, but generally still narrower, dykes of benmoreite and trachyte. While some rhyolitic dykes are noted, there appears to be none with > 70% SiO_2 and the dykes lack quartz phenocrysts. True phonolites with nepheline phenocrysts are also lacking although some of the dyke compositions plot in the phonolite field (fig. 4). The swarm appears mainly to have involved a suite of magmas ranging from critically undersaturated basalt to quartz-trachyte and scarcer phonolitic trachyte.

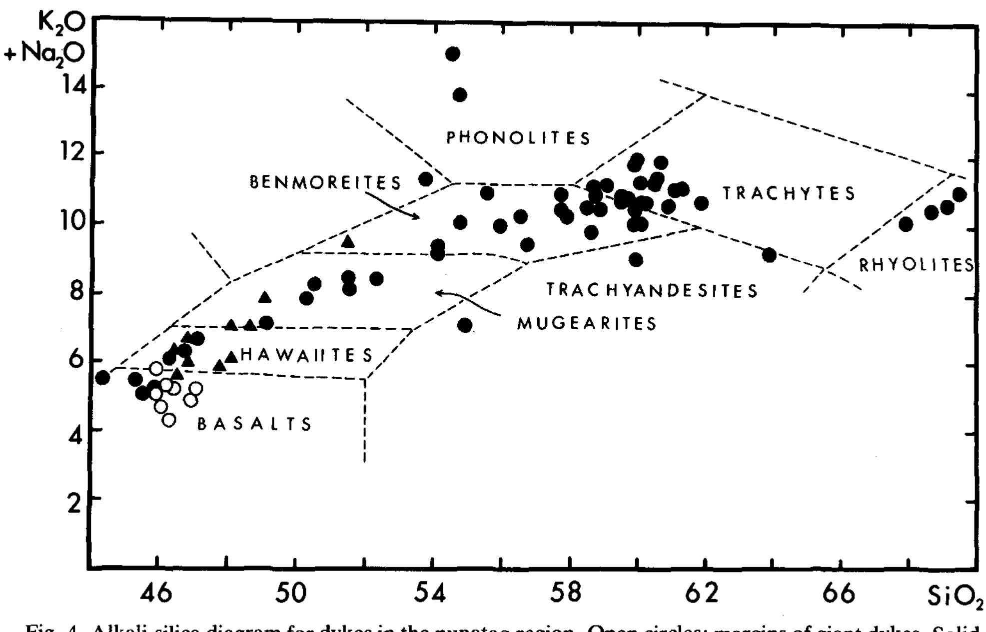

Fig. 4. Alkali-silica diagram for dykes in the nunataq region. Open circles; margins of giant dykes. Solid triangles; chilled margins of dykes conspicuously rich in plagioclase and anorthosite fragments (B.F.D.s). Solid circles; other dykes of the 'main series'.

Giant dykes

The large gabbroic dykes appear to be the earliest members of the swarm. They tend to be parallel-sided with more or less constant thicknesses of 300–650 m but they can attenuate to zero thickness over one or two kilometres as exemplified by the southern giant dyke on Mellemlandet which pinches out from WSW to ENE. It is inferred that this particular dyke reappears, with an *en echelon* offset to the south and east, as a major feature east of Qorqup sermia (glacier), whence it can be followed intermittently across G. F. Holm Nunataq (fig. 2). Continuations of the two giant dykes on Mellemlandet have not been mapped west of Kiagtût sermiat on Johan Dahl Land. While it is likely that the southern dyke diminishes to zero beneath this glacier, the northern dyke *does* extend through much of Johan Dahl Land but, as traced further west-south-west, it fails before reaching the fjord section north of Narssarssuaq.

The giant dykes appear to be true, vertical-sided, dilational dykes. Within 10 m of their contacts, they are usually well-chilled to relatively homogeneous medium-grained dolerite. The marginal 2–5 m, however, is commonly affected by back-veining from re-melted country rocks (granites and gneisses) and there is considerable evidence of hybridisation (fig. 5).

The central portions of the giant dykes are characteristically very coarse-grained (fig. 6). They are typically mesocratic troctolitic gabbros. Ovoid pegmatitic patches occur up to ½ m across. Plagioclase lamination and modal-layering may define, as in Mellemlandet, an

Fig. 5. Marginal facies of the giant dyke at Syenitknold. The rock is an intrusion breccia produced by anatexis of the granitic wall-rock and its subsequent 'back-veining' into the giant dyke. (Scale indicated by hammer).

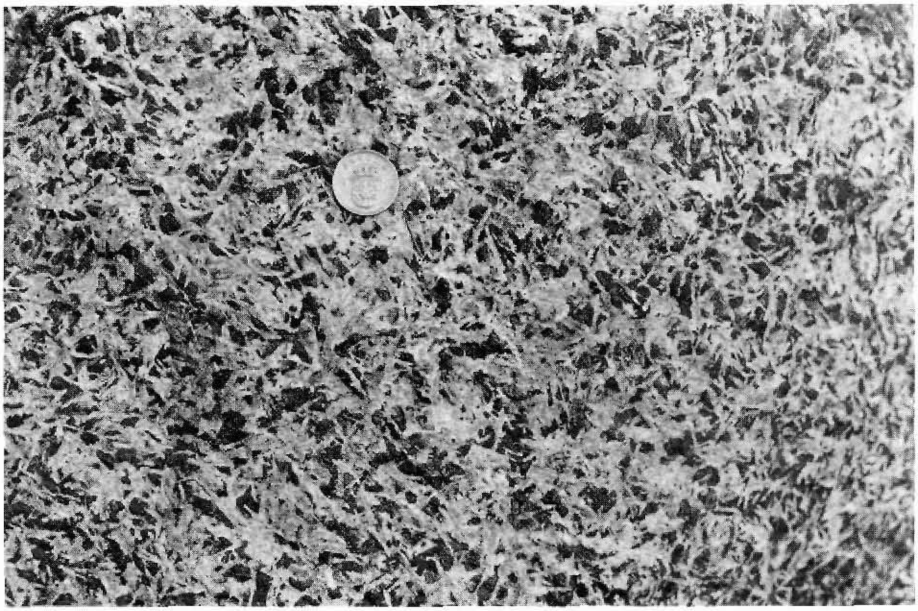

Fig. 6. Coarsely ophitic texture developed in troctolitic gabbro of the giant dyke north of Geologfjeld. The rock is principally composed of plagioclase and olivine, with subordinate interstitial augite.

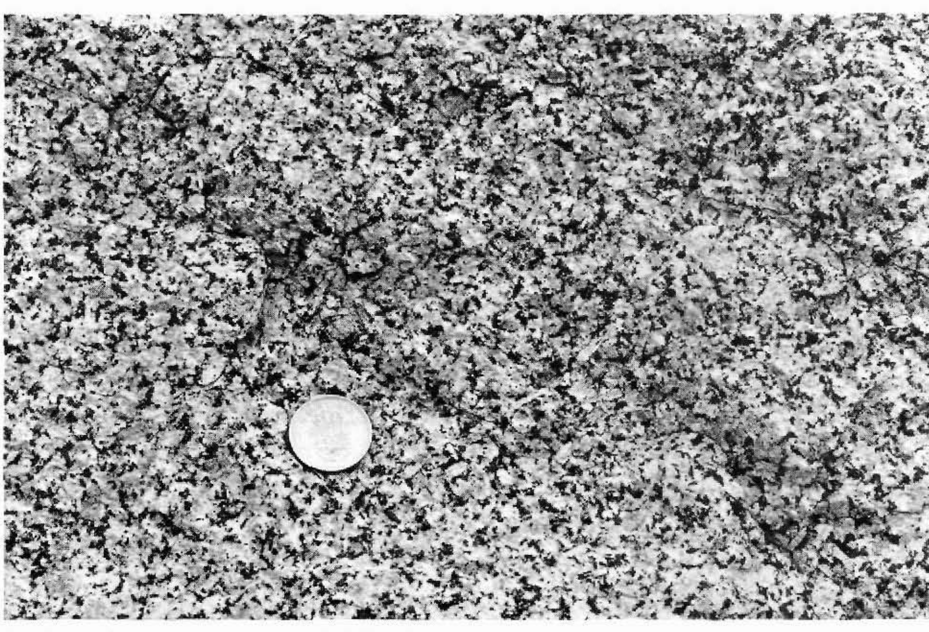

Fig. 7. Surface of mesocratic syenite at Syenitknold.

internal synformal structure where the layering changes from steeply (inwardly) inclined close to the wall-zones, to horizontal along the dyke axes (Walton, 1965). Well-laminated anorthositic units up to 1 m thick were noted in the southern dyke on Mellemlandet.

On the nunataq north of Motzfeldt Sø, between Syenitknold and Sydtunge (fig. 1), the giant dyke geometry is relatively complex and it is in this sector that more differentiated rocks make their appearance. Around Syenitknold syenite forms the central 300 m of the dyke immediately east of the Qorqup sermia, where it appears as a 'pod' ensheathed in gabbro and with an abrupt closure to the east. The junction of mesocratic augite syenite (fig. 7) with the ophitic gabbro is marked by a boundary zone, 20–30 m broad, of rusty brown weathering ferrosyenite and ferrosyenogabbro, rich in fayalitic olivine. No internal chilled margins are seen. The syenite itself shows some well-defined modal layering with inwardly directed dips (fig. 8).

The augite-syenite, ferrosyenite and ferrosyenogabbro all appear to be *in situ* differentiates within the main gabbroic intrusion.

Within the middle of the syenite outcrop is a sharply bounded tabular mass of gabbro some 50 m thick and c. 100 m across (fig. 9). The lower surface of this slab dips N at c. 45° comformably with the layering in the surrounding syenite. Although the upper contact has been lost by erosion it is thought that syenite also overlay the gabbro mass and that the latter constitutes a massive xenolith. It is highly feldspathic and contains an abundance of large (up to 20 cm) anhedral plagioclase crystals surrounded by darker olivine (fig. 10). Texturally it most closely resembles the gabbros at Narssaq 67 km to the west-south-west although unlike the latter, it has not been hydrothermally altered. The Narssaq gabbro is a roofing facies of

Fig. 8. Rhythmic layering in syenite in the differentiated giant dyke interior at Syenitknold.

Fig. 9. View of giant dyke on the west side of Syenitknold, showing large xenolith of feldspathic gabbro (presumed giant dyke roofing facies) forming the dark crags, *c.* 50 m high, in the mid distance. In the foreground, and beyond the dark crags, are crumbly outcrops of syenite. Gabbro, forming the northern part of the enclosing sheath around the syenite, forms the high ground seen in the left background.

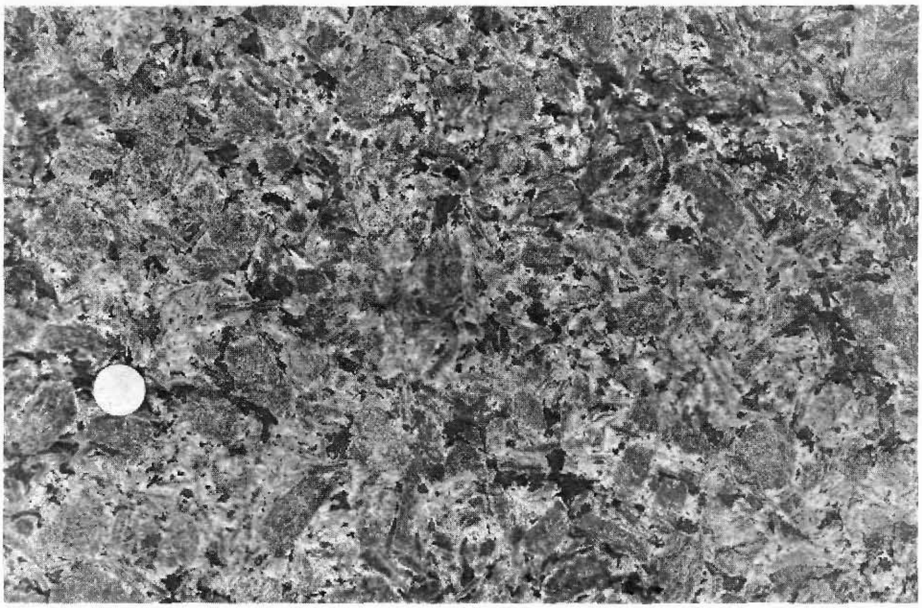

Fig. 10. Coarsely feldspathic (anorthositic) gabbro composing the xenolith of presumed roofing-facies at Syenitknold. The clouded appearance of the feldspar is attributed to thermal metamorphism by the syenite.

the Tugtutôq giant dykes where the latter spread out at the unconformity between older Proterozoic granite (Julianehåb Granite) and the overlying sediments of the Eriksfjord Formation. It contains much anorthositic xenolithic material that is thought to have accumulated in the roof zone through flotation. It is concluded that a very similar roofing facies overlay the giant dykes in the nunataqs and that, when the composition of the underlying magma had evolved to a sufficiently low density benmoreitic or trachytic composition (parental to the Syenitknold syenite), a large mass of solid roof collapsed and settled into the magma body beneath (fig. 11). Such behaviour was common in the larger Gardar complexes (e.g. Klokken; Parsons, 1979).

Some 3–4 km east of Syenitknold, towards the Sydtunge of the Tretungegletscher, there appears to be a second differentiated pod within the gabbro giant dyke (fig. 2). The differentiates at this locality are syenogabbros (with idiomorphic prismatic pyroxene in contrast to the ophitic pyroxene of the gabbros), showing strongly developed graded layering with

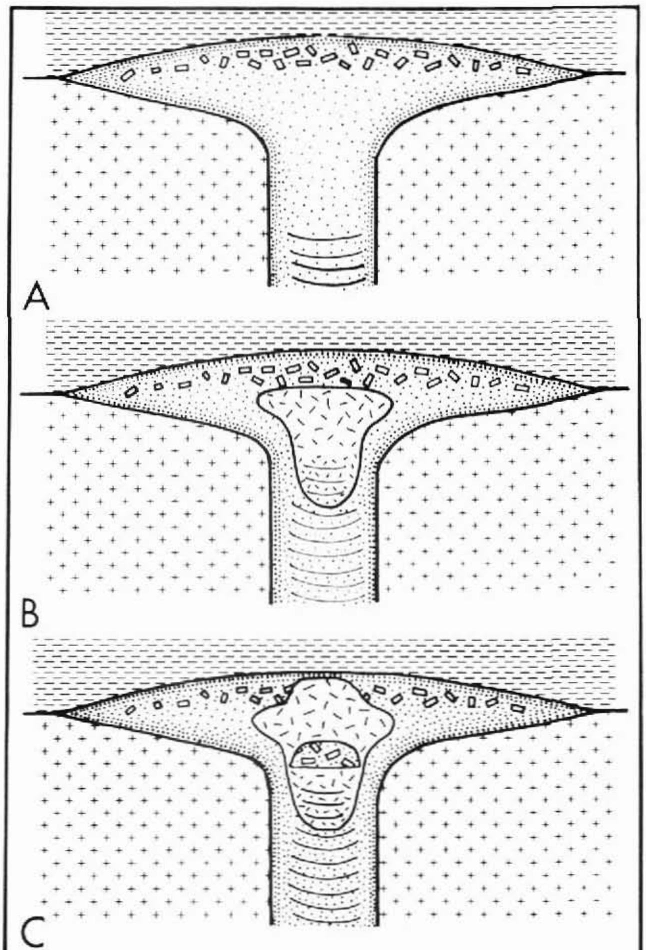

Fig. 11. Diagrams showing hypothetical evolution of the giant dyke relationships at Syenitknold. A: giant dyke composed of olivine basalt has a sill-like upper termination at the unconformity between the Eriksfjord Formation (lavas and sediments) and earlier Proterozoic granitoids. Synformally layered cumulates develop in the lower parts of the dyke. Plagioclase xenocrysts and anorthositic xenoliths acquired as accidental inclusions (in the lower crust?) form a flotation cumulate below the roof. B: Low density alkaline residual magma collects in the upper, interior part of the giant dyke, with further production of synformally-layered cumulates. C: A large coherent mass of roofing facies detaches and sinks into the lower density alkalic (benmoreitic?) magma.

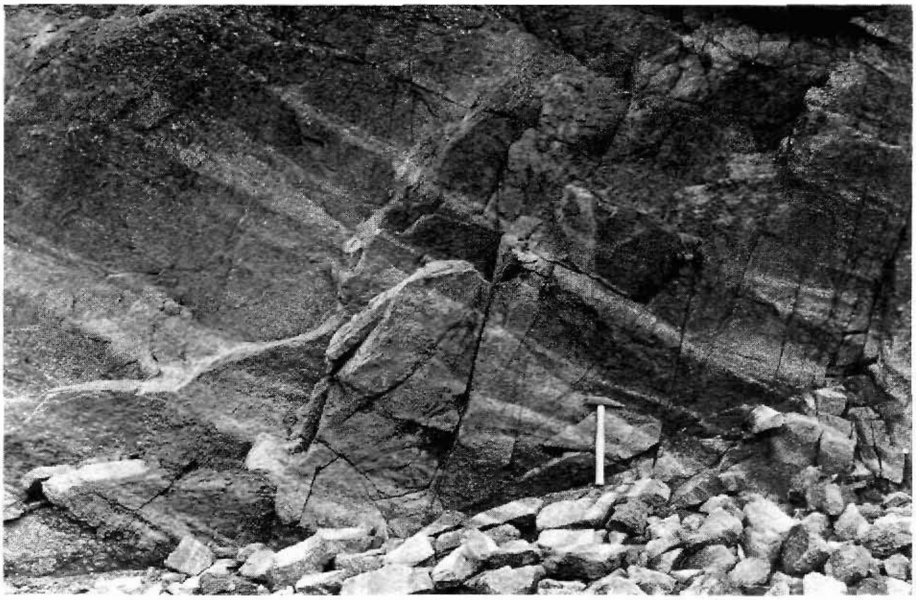

Fig. 12. Layering in syenogabbroic cumulates south-west of Sydtunge.

melanocratic units rich in olivine and pyroxene composing the bulk of the outcrops (fig. 12). Cross-beds and trough effects suggest 'cut and fill' structures produced by alternating current erosion and crystal deposition. It appears likely that, at least at this locality, there was vigorous convective overturn in the crystallising magma.

The giant dykes across and east-south-east of Mellemlandet resemble those in Tugtutôq in size, geometry, internal structure, texture and composition. The syenite pod at Syenitknold is similar in size and overall relationship to its gabbro host as that at Assorutit on Tugtutôq (Upton, 1962; Upton & Thomas, 1980). However, whereas the Syenitknold syenite developed feldspathoidal residues, that at Assorutit is silica-oversaturated and gave rise to alkali granite differentiates.

Petrography of giant dyke lithologies

The giant dykes are dominantly composed of troctolitic gabbro (fig. 6), with idomorphic plagioclase, olivine, magnetite and apatite and interstitial augite and biotite. The latter is generally seen as reaction zones around the magnetite. In the ferrogabbros and ferrosyenogabbros the ophitic texture is lost with increasing differentiation: the modal contents of augite, magnetite and apatite increase, while olivine decreases. Plagioclase cores of andesine-oligoclase are surrounded by micro- or crypto-perthite. With loss of the plagioclase cores to the feldspars these rocks grade into ferrosyenite. The syenites, in which the modal ratio of augitic clinopyroxene to olivine is distinctly higher than in the gabbroic components, generally lack feldspathoids. However, in some of the more differentiated inner facies at Syenitknold, interstitial nepheline is present, together with interstitial amphibole (pleochroism brown to blue-green) and accessory fluorite.

The most extreme differentiates are nepheline syenite pegmatites, forming sheets up to 30 cm thick, cutting the marginal gabbros. These consist of coarsely crystalline perthite, nepheline and aegirine. Interstitial areas containing calcite, fluorite and zircon suggest fluid residues rich in CO_2, F and large-ion lithophile elements.

Carbonatites and lamprophyres

An interesting, but volumetrically insignificant part of the swarm is composed of feldspar-free, highly silica-undersaturated, hypabyssal intrusions in which carbonates play an important role. While they encompass rock-types as diverse as (a) pale coloured carbonatites with minor contents of apatite, oxides and micas and (b) dark-grey, fine-grained dense lamprophyres with only minor carbonate, they are grouped together here as a single suite. Generally seen as dykes with the same (ENE) trend as the 'main series' feldspathic dykes, some sill developments were also noted. The carbonatite-lamprophyre dykes are characteristically thin, rarely exceeding 1 m in width.

In Mellemlandet, and near Syenitknold, carbonatitic dykes were seen cutting benmoreitic or trachytic dykes of the 'main series'. The lamprophyric dykes are similar to those seen west-south-west of Mellemlandet in the region north of Narssarssuaq. However, the latter are cut by dolerites and trachytic dykes: there thus appears to be a considerable time-spread in the intrusion of the carbonatite-lamprophyre suite which must be regarded as essentially contemporaneous with the 'main series' dyke swarm.

Detailed petrography of the suite awaits investigation. The lamprophyres tend to be highly altered and are composed of a fine-grained assemblage of opaque oxides, biotite and carbonate, with possible pseudomorphs after olivine and pyroxene. It is inferred that, despite rapid cooling, the magmas were so rich in volatiles (especially CO_2) that extensive deuteric alteration of early silicate minerals occurred during crystallisation.

Continuity of the dyke-swarm from the inland ice to the Tugtutôq archipelago

The total widths of giant dykes and satellite differentiated dykes in the nunataq and Tugtutôq areas are similar. In both areas the smaller dykes lie close to, or to the south of, the giant dykes. Small dykes north of the giant dykes are scarce. In both areas the most magnesian magmas formed the earliest, and most voluminous intrusions, i.e. the giant dykes.

In Mellemlandet an aggregate width of 1044 m of dykes was recorded (344 m of smaller dykes and 700 m of giant dykes) amounting to 22.7% dilation across the 400–600 m traverse. In G. F. Holm Nunataq, where exposure is much inferior, an aggregate of 1814 m of giant dykes gives a 25% dilation across the 6200 m traverse. On Tugtutôq there is 1500 m aggregate width giving 18.7% dilation across 8000 m. The dyke swarm in the Tugtutôq area very clearly attenuates towards the west-south-west. The whole swarm appears to be expanding in both aggregate width and dyke numbers as traced east-north-east across to G. F. Holm Nunataq. The likelihood is that the swarm persists beneath the Inland Ice, probably for tens of kilometres further towards the east-north-east.

Whereas the swarms seen in Tugtutôq and on the nunataqs are so similar that they must be regarded as a single phenomenon, they are not colinear. Either the nunataq swarm is simply offset in an *en echelon* left lateral fashion or it has been displaced by repeated left-lateral faulting. Since such left-lateral faults demonstrably affect the swarm in the Tugtutôq and Qagssiarssuk regions it is reasonable to conclude that the whole offset is due to such faulting and that a gross displacement of *c.* 23 km is involved. The quasi E–W fault passing a little north of Narssaq (fig. 1) and pre-dating the Ilímaussaq complex, is believed to have played a major role in the displacement of the whole swarm.

Having stressed the similarities between the nunataq and Tugtutôq swarms, some of the differences also require comment. The highly siliceous comenditic dykes of the Tugtutôq-Narssaq area (Macdonald, 1969) are apparently absent from the nunataqs. They thus appear to be a local phenomenon genetically associated with the central Tugtutôq and Dyrnæs-Narssaq complexes.

A late set of trachydolerite dykes in the Tugtutôq region distinguished by strong flow-layering, xenocryst and xenolith content and epidote-calcite-bearing amygdales (or ocelli), is known as far east as Qagssiarssuk but is apparently absent from the nunataqs.

Compositions and genetic relationships within the Gardar dykes

The magma compositions are presumed to be reflected in the relatively aphyric, fine-grained facies of the intrusions. These fall into two classes: (a) the feldspathic main series ranging from basalt to rhyolites and, more rarely, phonolitic trachytes and (b) the feldspar-free silica-poor lamprophyre-carbonatite series. Representative compositions from these two series are presented in Tables 1 and 2.

In terms of MgO% the compositions (other than those of the carbonatites and lamprophyres) range from about 8% downwards. Dykes identified in the field as 'big feldspar dykes' (B.F.D.s) occupy the silica range 46–54% and fall mainly into the categories of hawaiite and mugearite (fig. 4). However, some of the more mafic B.F.D. chills have compositions overlapping with those of the giant dykes. The latter include the most magnesian (basaltic)

Table 1. Compositions of selected fast-cooled dyke rocks from the 'main series' in the nunataq region

Weight %	1	2	3	4	5	6	7	8
SiO_2	46.34	46.57	48.15	57.70	59.64	67.85	69.46	44.79
Al_2O_3	18.26	14.68	15.70	14.79	15.14	15.72	15.61	20.14
Fe_2O_3*	13.17	13.94	12.94	9.80	8.90	2.31	2.22	5.26
MgO	7.18	4.31	3.53	0.93	0.72	0.51	0.23	0.24
CaO	8.27	8.01	6.26	3.04	2.42	1.02	0.42	1.28
Na_2O	3.23	3.81	3.90	4.85	5.26	5.15	5.02	8.07
K_2O	1.05	1.80	3.24	5.68	5.73	5.17	5.98	5.78
TiO_2	1.67	3.09	3.29	1.34	1.13	0.45	0.44	0.29
MnO	0.16	0.22	0.20	0.22	0.20	0.07	0.06	0.21
P_2O_5	0.47	1.86	1.64	0.39	0.30	0.06	0.06	0.06
	99.79	98.30	98.35	98.90	99.43	98.30	99.50	96.14
ppm								
Ni	82	16	13	4	4	4	4	4
Cr	57	9	6	3	4	4	5	5
V	138	174	132	–	–	3	1	–
Sc	13	22	18	17	16	8	7	–
Cu	32	32	32	10	9	–	2	–
Zn	81	138	112	165	151	85	52	180
Sr	980	872	983	114	130	88	61	48
Rb	17	36	79	135	96	39	48	192
Zr	97	199	209	522	350	271	278	979
Nb	14	34	34	62	45	16	14	212
Ba	789	1537	2761	605	301	1379	1165	25
Pb	2	7	7	22	20	32	22	20
Th	–	1	1	5	4	14	13	13
La	16	65	60	89	69	53	56	121
Ce	37	146	138	195	147	114	120	251
Nd	18	73	68	82	64	48	52	88
Y	18	37	36	51	40	26	25	51
C I P W norms								
$Fe_2O_3/FeO = 0.15$								
Q	–	–	–	–	–	14.54	15.35	–
or	6.27	10.97	19.69	34.20	34.32	31.14	35.61	35.69
ab	25.28	33.19	32.15	41.83	45.06	44.44	42.80	30.07
an	32.67	18.13	16.15	2.38	0.79	4.57	1.65	1.73
ne	1.13	–	0.97	–	–	–	–	22.38
di	4.78	8.54	3.97	9.03	8.20	0.11	–	3.95
co	–	–	–	–	–	–	0.27	–
ol	22.57	14.32	14.98	5.96	2.96	–	–	4.36
hy	–	1.43	–	1.09	3.97	3.71	2.88	–
mt	2.65	2.85	2.64	1.98	1.79	0.47	0.44	1.09
il	3.22	6.04	5.45	2.59	2.18	0.87	0.86	0.58
ap	1.12	4.54	3.99	0.94	0.72	0.16	0.16	0.16

(Fe_2O_3* = total Fe as Fe_2O_3).
1. 212177: Chill of central giant dyke, G.F. Holm Nunataq.
2. 212159: Hawaiite dyke (B.F.D.) margin. G. F. Holm Nunataq.
3. 212118: Mugearite dyke (B.F.D.) margin. G. F. Holm Nunataq.
4. 212140: Benmoreite dyke, Mellemlandet.
5. 212153: Trachyte dyke, Mellemlandet.
6. 212112: Quartz trachyte dyke, Mellemlandet.
7. 212119: Rhyolite dyke, Mellemlandet.
8. 212191: Phonolitic trachyte dyke, G. F. Holm Nunataq.

(Sample numbers relate to the collection of the Geological Survey of Greenland).

compositions with MgO from 5 to 8%. Thus the earliest, and the largest, intrusions in the swarm are the most magnesian.

Of the nunataq giant dykes, the average chilled margin MgO and MgO/(MgO+FeO*) values are:

	MgO%	*MgO/(MgO+FeO*)*
Mellemlandet		
Southern giant dyke	5.97	0.34
Mellemlandet		
Northern giant dyke (and its G. F. Holm Nunataq extension)	5.48	0.30
G. F. Holm Nunataq		
Southern giant dyke (and its extension to Syenitknold)	5.89	0.31
G. F. Holm Nunataq		
Central giant dyke	7.18	0.38

(FeO* = total Fe as FeO)

Thus the giant dykes themselves appear to have been supplied with distinctly differing magmas varying from the most primitive (G. F. Holm Nunataq central giant dyke) to the most evolved which intruded as the northern dyke across Mellemlandet and G. F. Holm Nunataq. However, the average composition of chilled margin samples from the giant dykes of the nunataq area is virtually identical to that of the younger giant dyke complex of Tugtutôq (Table 3).

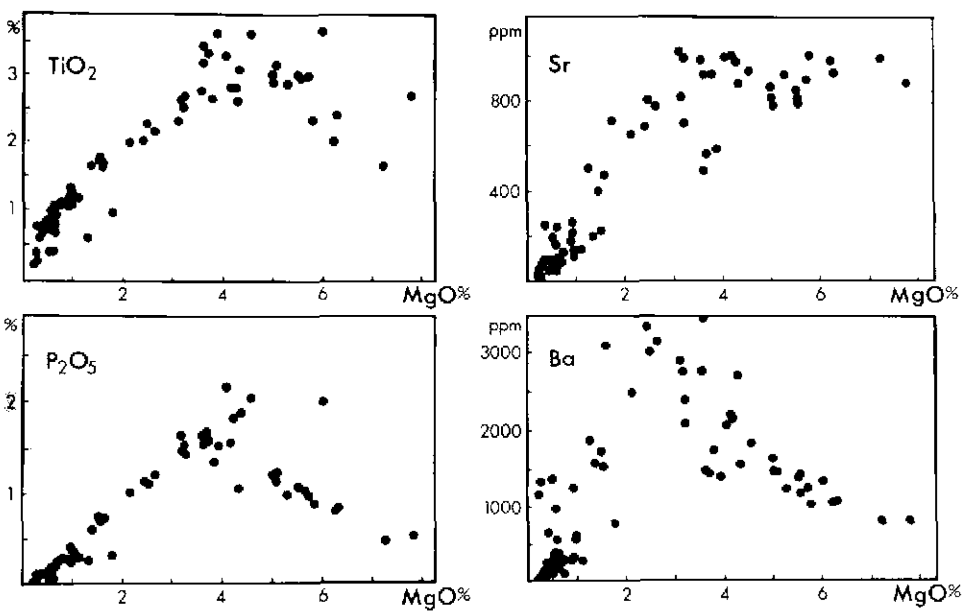

Fig. 13. Variation diagrams, TiO_2, P_2O_5, Sr and Ba *vs.* MgO wt% for fast-cooled dyke rocks of the nunataq area.

Table 2. Compositions of giant dyke lithologies in the Syenitknold area

Weight %	1	2	3	4	5	6
SiO2	45.52	43.87	51.55	52.12	49.57	49.07
Al_2O_3	16.49	11.32	13.57	13.71	6.53	23.26
Fe_2O_3*	15.09	19.92	15.41	14.84	19.78	6.85
MgO	5.52	3.27	1.95	1.33	1.74	2.45
CaO	8.35	9.20	5.80	5.16	10.24	9.69
Na_2O	3.55	3.65	4.41	4.44	6.38	3.90
K_2O	1.44	2.08	3.65	4.24	1.16	1.47
TiO_2	3.02	4.34	2.38	2.31	1.01	1.21
MnO	0.02	0.29	0.28	0.25	0.50	0.09
P_2O_5	1.05	2.33	0.84	0.71	0.32	0.37
	100.13	100.26	99.85	99.12	97.19	98.36
ppm						
Ni	54	6	6	5	12	18
Cr	41	5	5	5	12	18
V	203	24	1	–	51	106
Sc	23	42	33	22	5	7
Cu	60	63	30	31	8	22
Zn	103	147	127	133	284	45
Sr	794	598	476	336	710	1487
Rb	23	29	42	55	30	15
Zr	176	238	248	317	2400	62
Nb	28	42	40	58	126	10
Ba	1151	2227	4126	3338	766	900
Pb	3	–	3	3	35	2
Th	–	–	–	1	1	–
La	29	71	51	58	351	10
Ce	74	170	119	144	603	30
Nd	40	94	65	74	189	16
Y	33	64	47	52	111	12
C I P W norms						
$Fe_2O_3/FeO = 0.15$						
or	8.58	12.44	21.87	25.62	7.19	8.90
ab	25.57	24.77	34.55	34.06	21.71	29.29
an	25.10	8.46	6.53	5.07	–	42.56
ne	2.61	3.56	1.93	2.33	3.63	2.41
di	8.19	19.05	14.71	14.20	44.47	3.46
ac	–	–	–	–	8.21	–
ns	–	–	–	–	4.27	–
ol	18.61	13.77	10.90	9.50	7.70	8.75
mt	3.03	4.01	3.11	3.01	–	1.39
il	5.81	8.36	4.59	4.48	2.02	2.35
ap	2.51	5.59	2.02	1.72	0.80	0.89

(Fe_2O_3* = total Fe as Fe_2O_3).
1. 216607: Gabbro: Chilled margin.
2. 216621: Ferrogabbro.
3. 216623: Syenite.
4. 212198: Syenite.
5. 216603: Syenite pegmatite sheet.
6. 216618: Feldspathic gabbro from the large central xenolith.

Although there is a marked superabundance of small dykes having the most differentiated compositions (trachytes) there is no clear evidence for any volumetric deficiency of intermediate compositions, i.e. no obvious 'Daly Gap' emerges from this study.

That the composition of the dyke swarm magma was dominantly controlled by crystal fractionation and not, for example, by hybridisation between basaltic and trachytic magmas, is stongly suggested by the tendency for some elements (e.g. Ti, P and Ba) to rise to peaks in the mid-range at around 4.5% MgO (fig. 13). From 7.5 to 4% MgO silica concentration rises steadily with the tend steepening at lower MgO contents. CaO declines slightly until *c.* 4.5% MgO beyond which it falls relatively steeply.

Table 3. Mean compositions of giant dyke chills (4–8% MgO)

Weight %	1	2
SiO_2	46.06	46.00
Al_2O_3	17.13	16.71
Fe_2O_3	14.21	14.91
MgO	6.12	5.93
CaO	7.96	7.78
Na_2O	3.43	3.55
K_2O	1.41	1.45
TiO_2	2.51	2.63
MnO	0.18	0.19
P_2O_5	0.83	0.83
	99.84	100.01
ppm		
Ni	63	52
Cr	42	30
V	168	160
Sc	17	17
Cu	44	39
Zn	90	91
Sr	922	901
Rb	25	23
Zr	141	150
Nb	21	22
Ba	1052	1120
La	27	27
Ce	63	64
Nd	32	34
Y	26	27

(Fe_2O_3* = total Fe as Fe_2O_3).
1. Mean giant dyke chilled margin (nunataq region, 9 samples).
2. Mean giant dyke chilled margin (Tugtutôq – Narssaq Younger Giant Dyke Complex, 9 samples).

Table 4. Compositions of some carbonatite-lamprophyre hypabyssal intrusions from the nunataq area

Weight %	1	2	3	4	5	6	7	8
SiO_2	2.25	4.36	7.08	21.84	23.25	30.74	30.95	34.12
Al_2O_3	0.54	1.20	0.88	5.27	3.86	3.66	5.40	7.18
Fe_2O_3*	1.72	2.91	3.22	14.48	14.30	20.92	15.35	17.51
MgO	0.34	1.15	1.00	8.43	6.99	6.02	12.23	10.85
CaO	51.03	48.68	47.47	23.46	25.68	15.65	8.33	10.26
Na_2O	–	–	0.13	0.56	0.15	–	0.16	0.19
K_2O	0.04	0.07	0.11	1.35	1.16	2.84	3.97	3.20
TiO_2	0.04	0.04	0.04	2.89	1.99	2.12	4.07	5.88
MnO	1.05	1.31	1.18	0.35	0.67	0.79	0.25	0.24
P_2O_5	2.52	2.75	2.25	2.30	5.99	2.01	1.64	0.88
l.o.i.*	37.82	35.83	35.09	16.79	14.82	13.80	16.62	9.08
	97.35	98.30	98.45	97.72	98.86	98.55	98.97	99.39
ppm								
Ni	–	–	–	199	48	262	250	313
Cr	–	–	–	228	35	259	283	242
V	–	–	–	142	96	152	276	289
Sc	–	–	–	–	–	12	28	22
Cu	6	7	17	42	8	75	101	91
Zn	68	59	40	232	253	695	173	191
Sr	14500	8570	7970	4210	3740	2300	1905	945
Rb	11	9	18	35	96	192	139	154
Zr	6	4	7	226	358	271	838	470
Nb	1	178	107	160	232	524	243	104
Ba	1770	768	1120	1840	801	641	1910	1640
Pb	68	108	30	17	59	33	29	19
Th	10	15	16	33	101	171	31	7
La	1390	1380	1240	343	859	1090	180	72
Ce	3340	3170	2860	808	1890	2110	380	167
Nd	1550	1425	1310	377	793	776	162	80
Y	346	278	245	90	192	144	65	31

(Fe_2O_3* = total Fe as Fe_2O_3).
*l.o.i. = loss on ignition.
N.B. Na_2O is below detection limit in analyses 1, 2 and 6.

1. 216610: Carbonatite sheet cutting trachyte dyke near Syenitknold.
2. 212127: Carbonatite dyke cutting trachytic dyke. Mellemlandet.
3. 212128: Carbonatite dyke cutting trachytic dyke. Mellemlandet.
4. 212195: (Loose block). Carbonatitic lamprophyre. G. F. Holm Nunataq.
5. 212168: Carbonatitic lamprophyre dyke. G. F. Holm Nunataq.
6. 212156: Lamprophyre sheet. Mellemlandet.
7. 212166: Lamprophyre dyke, G. F. Holm Nunataq.
8. 212167: Lamprophyre dyke, G. F. Holm Nunataq.

It is inferred that FeTi oxide and apatite crystallisation commenced when MgO in the liquid fell to *c.* 4.5%. The CaO behaviour may indicate that augite precipitation also began at much the same temperature. Furthermore it appears that olivine-plagioclase fractionation occurred during the higher temperature stages (MgO > 4.5%); Al_2O_3 contents show virtually no change over most of the range suggesting that the bulk crystal extract retained a more or less fixed Al_2O_3 content at *c.* 15%.

While it has been assumed (in the above) that there is a continuous liquid line of descent from the giant dyke (basalt) magmas to the trachyte residues, the giant dyke chills are distinctive in their persistently high Al_2O_3 contents of 16–18%. This distinguishes them from even the most basic B.F.D. chills with similar MgO contents but which have Al_2O_3 in the range 14–16%. The 'direct' parental relationship of the giant dyke magmas to the younger, generally more differentiated magmas, is therefore in some doubt.

The carbonatitic-lamprophyric compositions differ strikingly from those of the 'main series' e.g. in their lower SiO_2 and Al_2O_3/CaO and their higher K_2O/Na_2O values.

Analyses of eight samples are presented in Table 4. Silica contents range from *c.* 2 to 34 wt% and the rocks may fall into two categories: (1) those with < 10% SiO_2 (carbonatites), with compositions of apatite søvites and (2) those with 20–34% SiO_2. The ultramafic lamprophyres, apparently lacking both melilite and leucite, are perhaps best designated as aillikites (Rock, 1986). The carbonatites are clearly rich in Sr, Ba, REE and Y. The lamprophyres also tend to be Sr- and Ba-rich although less extreme in terms of REE and Y contents. They differ from the carbonatites in their relatively high contents of Ni, Cr and V. Zn, Rb, Zr, Nb, Pb and Th also tend to reach high contents (relative to basaltic compositions) in these ultramafic rocks. They thus show the simultaneous richness in both 'compatible' and 'incompatible' trace elements that characterises such rocks as potassic ultramafic lavas and kimberlites. The potassic character of the lamprophyres is manifest in their high modal content of biotite.

Whether there is a compositional hiatus or continuum in the carbonatite-lamprophyre series requires further investigation. Two possibilities for this mutual relationship may be considered: (a) that there is an immiscible relationship between the relatively carbonate-rich and silicate-rich magmas or (b) that the carbonatites merely represent still smaller percent extracts from the mantle, derived principally from breakdown of phlogopite, apatite and (?fluor-) carbonates in the source rocks.

Despite the close spatial (and presumed temporal) relationship with the feldspathic 'main series' dykes, there appears to be a major compositional hiatus between the lamprophyres and the very distinctly more siliceous and aluminous basaltic dykes.

Concluding comments

The tendency for dyke trends to show a counter-clockwise rotation with decreasing age has been commented upon by Berthelsen & Henriksen (1975). It is clearly seen in the Nunarssuit area and it is also discernible in the relationship between older and younger giant dyke intrusions on Tugtutôq. Again, in the region between Qagssiarssuk and G. F. Holm Nunataq the same relationship is seen with respect to (a) the giant dykes which trend at 063° (± 2°) and (b) the younger trachytic-trachydoleritic swarm which has a trend of 057° (± 2°). This implies that the direction of extensional stress changed during the development of the Gardar rift system.

The main trachyte to trachydolerite dykes together with their large basic (giant dyke) precursors thus form a major swarm extending from the western part of the Tugtutôq archipelago to G. F. Holm Nunataq – over 140 km long and *c.* 15 km broad. It has no counterpart elsewhere in the Gardar province and is, so far as we are aware, unique on a global scale. (The roughly contemporaneous major dyke swarm in the Nunarssuit-Isortoq area further north (Emeleus & Upton, 1976), while containing comparable giant dykes, is predominantly composed of dykes of basic composition). It is unlikely that so intense a swarm did not feed surface volcanism. This being so we envisage accumulation of fissure-fed basalts, trachytes and phonolites on a scale probably surpassing that described for flood trachytes and phonolites in Kenya (King & Chapman, 1972).

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References

Berthelsen, A. & Henriksen, N. 1975: Geological map of Greenland 1:100 000. Ivigtut 61 V. 1 Syd. The orogenic and cratogenic geology of a Precambrian shield area. (Descriptive text), 169 pp. Copenhagen: Geol. Surv. Greenland.

Cox, K. G., Bell, J. D. & Pankhurst, R. J. 1979: *The interpretation of igneous rocks.* London: Allen & Unwin.

Emeleus, C. H. & Upton, B. G. J. 1976: The Gardar period in southern Greenland. *In* Escher, A. and Watt, W. S. (edit) *Geology of Greenland,* 153–181. Copenhagen: Geol. Surv. Greenland.

King, B. C. & Chapman, G. R. 1972: Volcanism of the Kenya Rift Valley. *Phil. Trans. R. Soc. Lond.* **A 271**, 185–208.

Macdonald, R. 1969: The petrology of alkaline dykes from the Tugtutôq area, South Greenland. *Meddr. dansk geol. Foren.* **19**, 257–282.

Parsons, I. 1979: The Klokken gabbro-syenite complex, South Greenland: cryptic variation and origin of inversely graded layering. *J. Petrology* **20**, 653–694.

Rock, N. M. S. 1986: The nature and origin of lamprophyres: Alnöites and allied rocks (ultramafic lamprophyres). *J. Petrology* **27** (in press).

Upton, B. G. J. 1962: Geology of Tugtutôq and neighbouring islands, South Greenland I. *Bull. Grønlands geol. Unders.* **34** (also *Meddr Grønland* **169**, 8), 60 pp.
Upton, B. G. J. & Thomas, J. E. 1980: The Tugtutôq younger giant dyke complex, South Greenland: fractional crystallization of transitional olivine basalt magma. *J. Petrology* **21**, 167–198.
Walton, B. J. 1965: Sanerutian appinitic rocks and Gardar dykes and diatremes north of Narssarssuaq, South Greenland. *Bull. Grønlands geol. Unders.* **57** (also *Meddr Grønland* **179**, 9), 66 pp.

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