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Myggbukta and Kap Broer Ruys: the most northerly of the East Greenland Tertiary igneous centres(?)

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ABSTRACT. The Myggbukta Complex is a shallowly dissected central volcano superimposed on the early Tertiary Plateau Basalts of NE Greenland. This, and the Kap Broer Ruys centre, 30 km to the east, appear to be the most northerly central complexes of the North Atlantic Tertiary Province. The Myggbukta Complex comprises a suite of extrusions and minor intrusions ranging from picritic basalt to potassic rhyolite: most of the suite appears related by relatively low pressure ($<$ 10 kbar) crystal fractionation. A small rise in initial $^{87}Sr/^{86}Sr$ (0.70593) with silica content is attributed to minor contamination through crustal anatexis. A basic dyke-swarm associated with the complex, precedes it and shows more limited differentiation. The basalts of the dyke-swarm and the Myggbukta Complex are genetically intimately related to the lavas forming the upper part of the earlier plateau basalt succession (UPLS). It is proposed that a large shield volcano developed some 100 km west of the developing spreading centre (Mohns/Aegir ridge), of which the UPLS, the dyke-swarm and the Myggbukta Complex represent three successive evolutionary stages. A generalized increase in differentiation through time can be recognized from one stage to the next. The acid intrusions of the Kap Broer Ruys area are probably also largely residues of basalt fractionation like their Myggbukta counterparts. However, higher initial $^{87}Sr/^{86}Sr$ ratios (0.70625-0.71034) imply a greater degree of crustal contamination.

IN the British Tertiary igneous province there is a generalized pattern whereby major, largely fissure-fed, lava fields tend to predate central complex development. Visible dykes post-date the main lava fields and tend to increase in abundance towards the central complexes (Emeleus, 1982; Speight *et al.*, 1982). The same overall pattern emerges from reconnaissance studies of the coast-marginal Early Tertiary volcanic province of Northern East Greenland in the Gauss Halvø–Hold with Hope region (fig. 1, Upton *et al.*, 1980) where initial volcanism built up a lava sequence *c.* 1 km thick. This has been subdivided into a lower division (LPLS), composed mainly of K-poor oversaturated tholeiitic basalts, and an upper division (UPLS) comprising a much more variable sequence of K-rich basalts which, while still including quartz tholeiites, tends to be mainly composed of olivine tholeiites with subordinate alkali olivine basalts. This plateau lava sequence is accompanied by a sill-swarm in the underlying sedimentary succession which is compositionally allied to the lower plateau lavas (Upton *et al.*, 1984).

The sills and plateau lavas are transected by a dyke swarm and an associated volcanic complex (Myggbukta Complex, fig. 2). The latter is the dissected remains of a large central volcano; while the extrusive and hypabyssal rocks which compose it range from picritic basalt to rhyolite, it was dominantly a basaltic volcano with intermediate and acid compositions playing a minor role. It represents, so far as is known, the latest phase in basaltic magmatism in the NE Greenland coast-marginal province. Near Kap Broer Ruys, some 30 km east of Myggukta a sub-circular area of

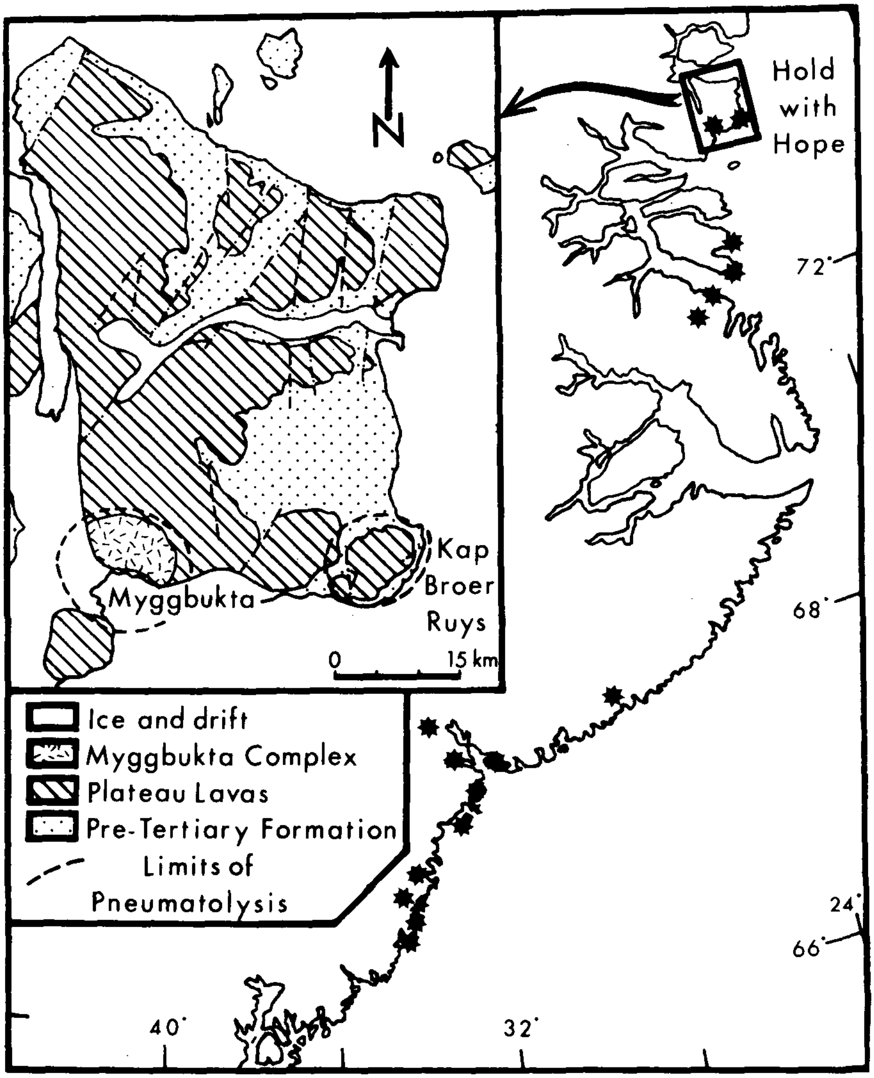

FIG. 1. Sketch map showing locations of principal Teritary igneous centres in East Greenland. Inset map of the Hold with Hope peninsula shows locations of the Myggbukta and Kap Broer Ruys centres.

plateau lavas and underlying sediments and sills, approximately 12 km in diameter has been affected by contact metamorphism and propylitization. Felsitic and granophyric intrusive rocks also crop out in this area (Upton *et al.*, 1980) and the metamorphism is believed to be caused by a large intrusion or intrusive complex at shallow depths of which the acidic intrusions are the only portions exposed. However, previous visitors to the Kap Broer Ruys area (Lenz, 1874; Nathorst, 1901) have also reported acid tuffs so that it is possible that a rhyolitic volcano developed at this locality.

Myggbukta Complex and the Hold with Hope dyke swarm

The plateau basalt succession in Hold with Hope and Gauss Halvø is believed to have been at least partially fed from fissure volcanoes lying east of the modern coastline (Noe-Nygaard, 1976; Upton *et al.*, 1980). While fissure eruption is presumed to have persisted in the more easterly sites during the early separation of Norway and Greenland, a later subordinate rifting episode occurred along the Greenland continental margin and gave rise to a

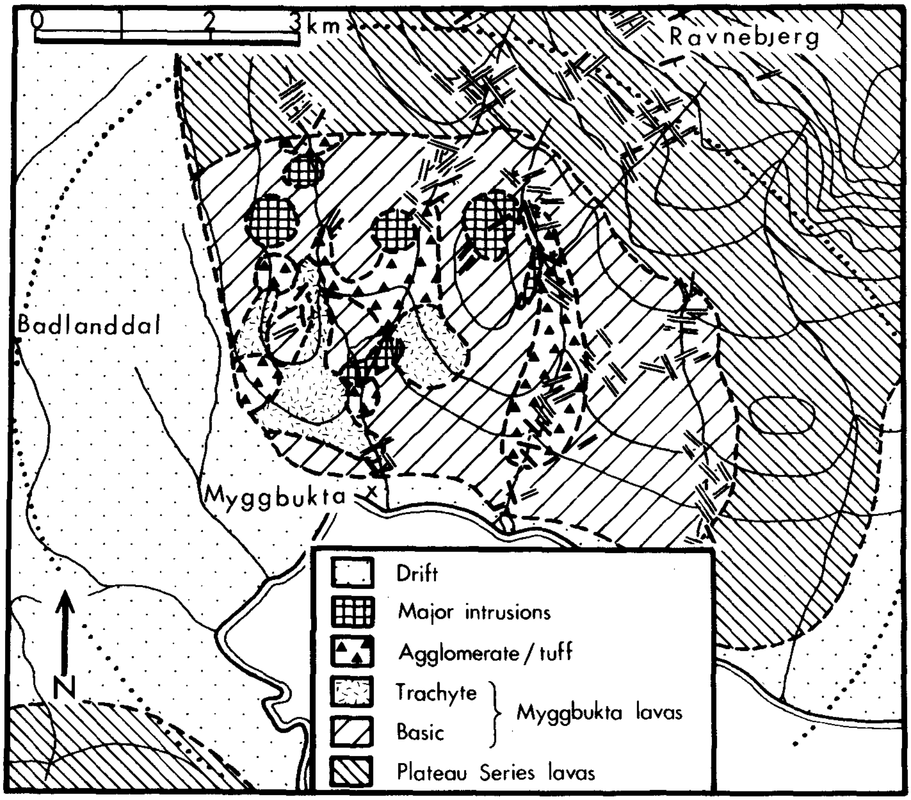

FIG. 2. Geological sketch-map of the Myggbukta Complex. Additional symbols: ×, abandoned radio station; ⟋, dip direction of lavas; \\, dykes and inclined sheets. 100 m contours shown as thin continous lines.

dyke swarm. This swarm, some 10–15 km broad, traverses Hold with Hope in a NE–SW trend but deflects to a NNE–SSW trend in the Gauss Halvø to west and south of Hold with Hope (Upton *et al.*, 1980). The Myggbukta volcanic complex developed as a major eruptive centre across the dykes swarm inflexion.

It has been proposed (Upton *et al.*, 1984) that the upper part of the plateau lava series (UPLS) may itself have been erupted from a vent or vents in the vicinity of Myggbukta so that there may have been a central-type shield volcano established before the dykes swarm was emplaced. However, in post-swarm activity the volcano appears to have been a collapse structure (caldera) superimposed on the early lava plateau. Although subordinate cones may have grown within this caldera, the Myggbukta volcano probably never formed a large positive topographic feature but may have developed by repeated eruption and concomitant collapse so that in the central area the plateau lavas are inferred to be down-faulted to a depth of several kilometres. The dyke swarm shows an increase in intensity towards the central volcano. As will be shown, while the dyke magmas are geochemically related to those of the subsequent Myggbukta volcano, they possess their own characteristics which distinguish them as a group from the Myggbukta basalts. Consequently they appear to represent a separate and distinct magmatic event. If they were supplied laterally from magma chambers underlying the Myggbukta volcano into adjacent crust (*cf.* Krafla Volcano; Sigurdsson and Sparks, 1978), this occurred prior to the generation of the Myggbukta lavas and intrusions. The Myggbukta volcano and its related dyke swarm were associated with a 'lateral rift' that may have lain at least 100 km west of the contemporary 'axial rifts' (Mohns and Aegir) along which new oceanic lithosphere was forming (Upton *et al.*, 1980). NW–SE trending dykes form a subordinate swarm localized close to the northern margin of the Myggbukta Complex. These post-date the NE–SW dykes and are grouped together with other Myggbukta intrusives in the following descriptions of petrography and petrochemistry.

Later Tertiary uplift of this section of the East Greenland margin appears to have been muted so that following Pleistocene–Recent glaciation, the Myggbukta volcano remained only shallowly eroded. Consequently, in contrast to most East Greenland Tertiary centres, the current erosion level reveals a succession of extrusive rocks penetrated by a profusion of hypabyssal intrusions and only very localized outcrops of coarse-grained intrusive rocks. It is possible that the low-relief may be due to (*a*) siting over thin attenuated crust, (*b*) a high-density core to the complex or (*c*) a combination of these factors.

In the northern part of the complex, down-faulted and inward dipping lavas of the UPLS are overlain by an indeterminate thickness of lavas and pyroclastic rocks (the Myggbukta Central Series) whose outcrop is wholly confined to the caldera. The Central Series and the underlying UPLS are cut by great numbers of dykes and inclined (commonly inward dipping) sheets and a small number of plugs up to 0.5 km across which may have fed eruptions within the caldera.

The Central Series and all but a minority of the intrusions are affected by intense propylitization. The complex is thus largely composed of greenstones with developments of epidote, chlorite, quartz, and calcite, most notably in veins and amygdales, with local development of pyrite, hematite, fluorite, and zeolites. One area of lavas has been almost wholly altered to clays and probably marks a hydrothermally active site.

The present study is based on a 10-day reconnaissance visit to Myggbukta in 1976 followed by laboratory study of some 74 samples. In view of the poor exposure of the complex, much of which is covered by drift and the waters of Mackenzie Bugt (the bay forming the south coast of Hold with Hope), and the intense frost shattering in much of the outcrop, the internal structures and chronological relationships are poorly known. Such dips as could be recorded from the Central Series extrusive rocks suggest a generally inward inclination (fig. 2). Whereas Myggbukta is predominately of basaltic composition there appears to be a continuum from basic rocks to salic rocks of trachytic and rhyolitic composition. Basaltic compositions are represented in the Central Series lavas and pyroclastic deposits, in the majority of the sheets and dykes and as coarser grained dolerites and gabbros in some of the plug-like intrusions. Trachytic lavas, ignimbrites and agglomerates occur abundantly within an area *c*. 3 km across, to the north of the abandoned Myggbukta Radio Station (fig. 2). Gabbro and quartz syenite intrusive rocks occur more or less centrally in the area of trachytes. The quartz syenite is compositionally equivalent to the trachytes and may show a (downward) gradation into the gabbros. Consequently the gabbro-syenite body is probably part of a feeder conduit that supplied the trachytic lavas. Judging by the relative scarcity of minor intrusions cutting the trachytes the trachytic volcano may have been a relatively late structure erupted within the Myggbukta caldera.

Whereas several of the larger intrusions appear to be essentially homogeneous dolerites, one body forming the highest ground in the caldera at *c*. 400 m, forming an area of low hills about 3–4 km NNE of Myggbukta termed the Barren Hills Complex, consists of a core of coarse ferrogabbro or ferrodiorite cut by thin sheets of intermediate to acid composition and surrounded by a partial ring of felsitic breccia cemented by calcite and hematite. However, true ring-dykes are not seen at Myggbukta at the present level of erosion and it should also be noted that no cumulitic rocks are exposed.

Apart from the instances cited above, acidic rocks occur sparingly as hypabyssal sheets. Highly altered rhyolitic pumice accumulations were also recorded at several localities and one rhyolite lava (? welded ashflow tuff) was also found. Fluviatile conglomerates containing silicified wood have been described from the Myggbukta Central Complex (Orvin, 1931; Upton *et al.*, 1980). The pebbles in these conglomerates consist of a range of feldspar-phyric (but otherwise very fine-grained) basic to intermediate compositions. Pebbles of plateau lavas are notably absent. While the pebbles cannot be matched with any known outcrops in Myggbukta they are nevertheless probably of local derivation from sources within the caldera.

Two basic rock units are fresh and unaffected by the otherwise pervasive propylitization. These are (i) a 6 m thick inclined sheet (sample no. 228139)* on the west side of a river gorge and (ii) a columnar jointed plug (or lava lake?) *c*. 0.5 km diameter within unbedded coarse agglomerate *c*. 3 km north of the Radio Station. (Sample no. 228127). Both are olivine-phyric and are uncut by younger intrusions Consequently these two units, which represent the most magnesian rocks found in Myggbukta, are regarded as the latest manifestations of basaltic magmatism in Hold with Hope.

Analytical techniques

Mineral analyses were made on electron probe microanalysers manufactured by Cambridge Scientific Instruments. Some were made on the

* All sample numbers relate to the collections at the Geological Survey of Greenland (GGU).

Geoscan 2 of Durham University but the majority were made on the Microscan 5 of Edinburgh University using either crystal spectrometry or energy dispersive methods. In all cases the standards used were of pure elements, oxides or simple silicate compositions. Corrections were made for dead-time, atomic number, absorption, and fluorescence, using computer programs based on the methods of Sweatman and Long (1969).

The rock analyses were made at Edinburgh University using XRF techniques. Major elements were determined on fused glass discs (Norrish and Hutton, 1969) with correction applied for inter-element mass absorption effects. Trace-elements were determined using pressed-powder discs and corrected for mass absorption effects with co-efficients calculated from the major element analyses. U.S.G.S. and C.R.P.G. rock standards (Abbey, 1977) were used in the calibration of both major and trace elements.

REE analyses were made using ICPAES techniques. The determinations were made on concentrated lanthanide solutions separated by cation exchange techniques (modified after Walsh *et al.*, 1981).

Sr-isotope analyses were carried out at the British Geological Survey, London (by R.D.B.) using a V.G. Micromass 30 automated spectrometer.

For the age determinations, potassium analyses were performed in triplicate by flame photometry on a Corning Eel (model 450) instrument employing sodium buffering and a lithium internal standard. Argon-40 was analysed statistically on an MS10 mass-spectrometer following isotope dilution with argon-38 tracer.

Petrography

With the exception of a few of the larger intrusions, including ophitic dolerites, gabbros, ferrogabbros and ferrodiorites and quartz syenites, the great majority of the Myggbukta components are sparsely porphyritic hypabyssal or extrusive rocks with fine-grained matrices. The latter commonly appear to have been originally glassy and often show fluidal disposition of quench feldspar and/or pyroxene microlites.

Apart from rare picritic (oceanitic) dykes containing over 30% modal olivine phenocrysts, the dyke swarm too is predominantly composed of sparsely porphyritic (< 5% phenocrysts) fine-grained dolerites.

The mainly silica-oversaturated character of the rocks is brought out (i) by their generally olivine-deficient nature and (ii) by the common presence of interstitial quartz in the dolerites and gabbros. In some of the acid hypabyssal sheets of the

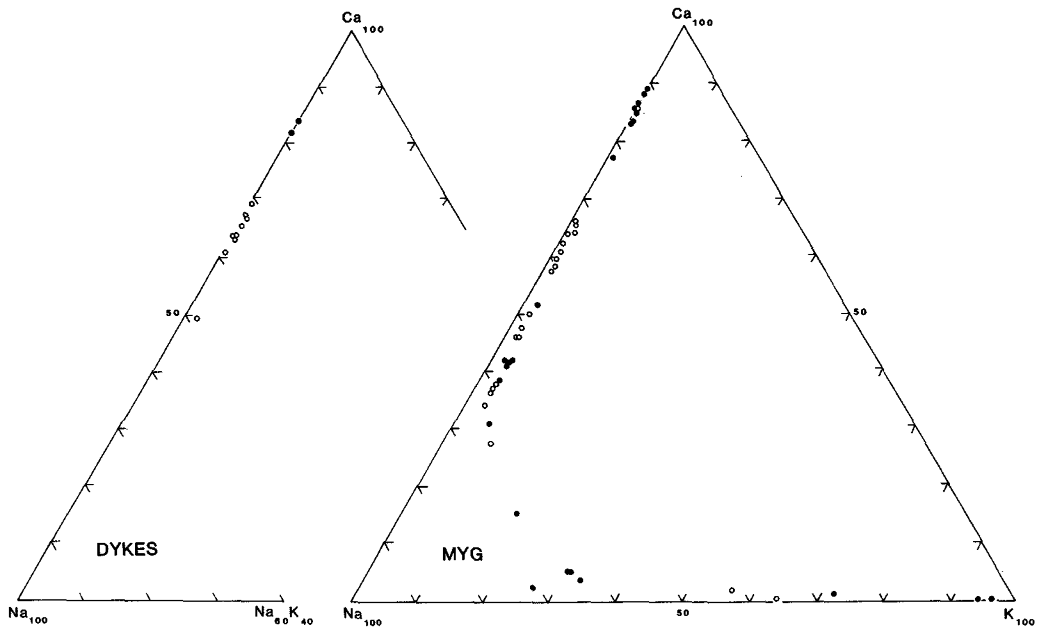

FIG. 3. Feldspar from the NE–SW Hold with Hope dyke-swarm and the Myggbukta Complex (MYG). Closed circles: phenocryst cores. Open circles: matrix feldspar compositions.

Myggbukta Complex elongate (?tabular) aggregates of quartz suggest paramorphs after tridymite. Subspherulitic sprays of quartz and feldspar in some of the more acid rocks imply some degree of supercooling. While quartz clusters are sometimes found in the more extreme differentiates, true quartz phenocrysts appear to be absent even from rocks with over 70% SiO_2.

The Myggbukta feldspar compositions range from calcic bytownite through anorthoclase (with moderate celsian content) to sanidine (fig. 3 and Table II). Commonly, however, the alkali feldspars are exsolved to orthoclase microperthites. Alkali feldspar phenocrysts may be present in any compositions more silicic than SiO_2 63 wt. %. A few intermediate compositions were noted containing both alkali feldspar and sodic plagioclase phenocrysts. Feldspars in the dykes show the range An_{84-50}, with matrix feldspars limited to An_{69-50} (fig. 3).

Olivine phenocrysts (or pseudomorphs thereafter) are confined to the most magnesian compositions (> 7 wt. % MgO). They commonly display strong zoning and are sometimes associated with orange-brown chrome-spinel microphenocrysts. The latter are common as inclusions within the olivines but also occur as discrete phenocrysts showing reaction relationships with development of opaque outer rims. In sample no. 228139, the most magnesian unit of the Myggbukta Complex, the olivine and spinel phenocrysts are accompanied by augite phenocrysts with up to 9 wt. % Al_2O_3 (Table I, col. 3). The phenocrysts assemblages ol + plag and ol + plag + augite have also been noted. However, the majority of the basic rocks (MgO wt. % 4–8) in both dyke swarm and central complex lack olivine and possess the phenocryst assemblage plag + aug, suggesting the operation of an olivine-liquid reaction relationship resulting in loss of olivine in the more differentiated compositions. The olivine compositional range (Fo_{89-65}) is essentially the same for both dykes and Myggbukta (fig. 4) and very similar to the range in the preceding UPLS lavas (Upton *et al.*, 1984).

TABLE I. Clinopyroxene compositions from some dykes and Myggbukta volcanic rocks

	1	2	3	4	5	6	7	8
SiO_2	49.62	50.41	47.58	50.18	50.66	49.74	49.99	52.85
TiO_2	0.73	0.41	1.36	1.42	1.22	1.51	1.12	0.63
Al_2O_3	0.98	0.76	9.04	3.02	2.54	5.03	4.12	1.57
Cr_2O_3	-	-	0.31	-	0.18	0.86	0.66	0.49
FeO*	23.09	20.97	6.70	7.74	9.66	5.08	6.43	6.55
MnO	0.66	0.54	0.12	0.26	0.24	0.23	0.17	0.13
NiO	-	-	-	-	-	0.18	-	-
MgO	5.81	8.64	13.86	14.35	14.41	15.05	15.13	16.99
CaO	19.51	18.47	21.02	22.19	20.95	22.20	21.62	20.34
Na_2O	-	-	-	-	-	-	-	-
	100.39	100.21	99.99	99.16	99.85	99.88	99.25	99.55

FeO*: Total iron as FeO

Cations to 6 Oxygens

	1	2	3	4	5	6	7	8
Si	1.966	1.972	1.758	1.886	1.900	1.843	1.864	1.949
Ti	0.022	0.012	0.038	0.041	0.035	0.033	0.032	0.018
Al	0.046	0.036	0.394	0.134	0.113	0.220	0.182	0.068
Cr	-	-	0.009	-	0.006	0.026	0.020	0.015
Fe″	0.765	0.686	0.207	0.244	0.303	0.158	0.201	0.203
Mn	0.023	0.018	0.004	0.008	0.008	0.007	0.006	0.005
Ni	-	-	-		-	0.006	-	-
Mg	0.344	0.504	0.764	0.804	0.806	0.832	0.841	0.934
Ca	0.828	0.774	0.832	0.894	0.842	0.882	0.864	0.804
Na	-	-	-	-	-	-	-	-
	3.996	4.005	4.006	4.011	4.013	4.007	4.011	3.996

1. 228131: Matrix pyroxene in icelanditic sheet. Myggbukta Complex
2. 228129: Marginal zone of augite in gabbro Myggbukta Complex
3. 228139: Core of phenocryst in picritic sheet. Myggbukta Complex
4. 228126: Augite in matrix of dolerite sheet. Myggbukta Complex
5. 228113: Core of phenocryst in dolerite dyke.
6. 228277: Core of phenocryst in potassic basalt lava. Myggbukta Complex.
7. 228154: Core of phenocryst in dolerite dyke.
8. 227973: Core of phenocryst in dolerite dyke.

TABLE II. Analyses of olivine, amphibole, biotite, alkali feldspar and opaque oxides from some NE dykes and rocks from the Myggbukta Complex.

	1	2	3	4	5	6	7	8
SiO_2	40.90	65.31	0.03	0.25	0.25	-	43.56	38.14
TiO_2	-	-	48.84	1.31	0.85	21.73	1.66	4.92
Al_2O_3	-	19.62	0.35	18.36	33.16	3.57	6.61	11.69
Cr_2O_3	-	-	0.09	42.00	28.96	2.43	-	-
V_2O_3	-	-	-	0.55	0.25	-	-	-
FeO*	10.95	0.22	46.16	26.75	23.40	64.33	25.68	18.73
MnO	0.14	-	0.36	0.48	0.28	0.48	0.33	0.68
NiO	0.37	-	-	-	-	-	-	-
MgO	47.99	-	3.22	10.95	13.29	2.75	6.94	12.38
CaO	0.32	1.03	-	-	-	0.22	10.34	-
Na_2O	-	7.32	0.03	-	-	0.16	2.02	-
K_2O	-	5.22	-	-	-	-	1.05	9.27
BaO	-	1.23	-	-	-	-	-	-
Cl	-	-	-	-	-	-	0.41	0.10
	100.67	99.95	99.08	100.65	100.44	95.67	98.61	95.91
FeO* Total iron as FeO.								
No. of oxygens to which cations are calculated.	(4)	(32)	(3)	(32)	(32)	(32)	(23)	(22)
Si	1.003	11.775	0.001	0.063	0.061	-	6.939	5.788
Ti	-	-	0.907	0.253	0.153	5.199	0.193	0.562
Al	-	4.169	0.010	5.554	9.281	1.340	1.041	2.092
Cr	-	-	0.002	8.516	5.435	0.610	-	-
V	-	-	(Fe") 0.174	0.094	0.039	-	-	-
Fe"	0.225	0.034	0.779	5.738	4.647	17.118	3.106	2.377
Mn"	0.003	-	0.008	0.105	0.057	0.130	0.059	0.087
Ni	0.007	-	-	-	-	-	-	-
Mg	1.753	-	0.119	4.186	4.702	1.304	1.891	2.800
Ca	0.008	0.199	0.000	-	-	0.076	1.736	-
Na	-	2.560	0.000	-	-	0.099	0.567	-
K	-	1.201	-	-	-	-	0.206	1.795
Ba	-	0.087	-	-	-	-	-	-
Cl	-	-	-	-	-	-	0.082	0.026
	2.999	20.026	2.000	24.509	24.375	25.876	15.823	15.527

1. 228055: Olivine; core of pheyocryst in oceanitic NE-SW dyke
2. 228279: Anorthoclase; core of phenocryst in trachytic lava. Myggbukta Complex.
3. 228113: Ilmenite; core of phenocryst in NE-SW dyke.
4. 227973: Spinel; microphenocryst in NE-SW dyke.
5. 228126: Spinel; microphenocryst in intrusive sheet. Myggbukta Complex.
6. 228139: Ti-magnetite; matrix of intrusive sheet. Myggbukta Complex.
7. 228135: Ferro-edenitic hornblende; matrix of (icelandic) intrusive sheet. Myggbukta Complex.
8. 228277: Biotite; matrix of potassic basalt lava. Myggbukta Complex.

Pyroxene in both the dyke swarm and Myggbukta are confined to a single high-Ca trend (fig. 4) from diopsidic to ferroaugitic compositions. The trend shows a pronounced fall and then rise in Ca with increasing Fe/Mg ratio. The dykes, lacking the more highly differentiated compositions of Myggbukta, have a pyroxene trend coincidental with that of the central complex but not extending to such iron-rich compositions.

The pyroxenes of the Myggbukta Complex rocks are broadly comparable in their Al_2O_3 contents to those of the tholeiitic LPLS lavas and associated sills (Upton *et al.*, 1984), showing a steady decrease in alumina with increased fractionation (fig. 5). The only marked exception is the late olivine- and spinel-phyric intrusive sheet (specimen no. 229139) which contains relatively sparse, corroded phenocrysts of diopsidic augite. The cores of these pyroxenes may be unusually aluminous (analysis 3, Table I). The variation of their Al_2O_3 content

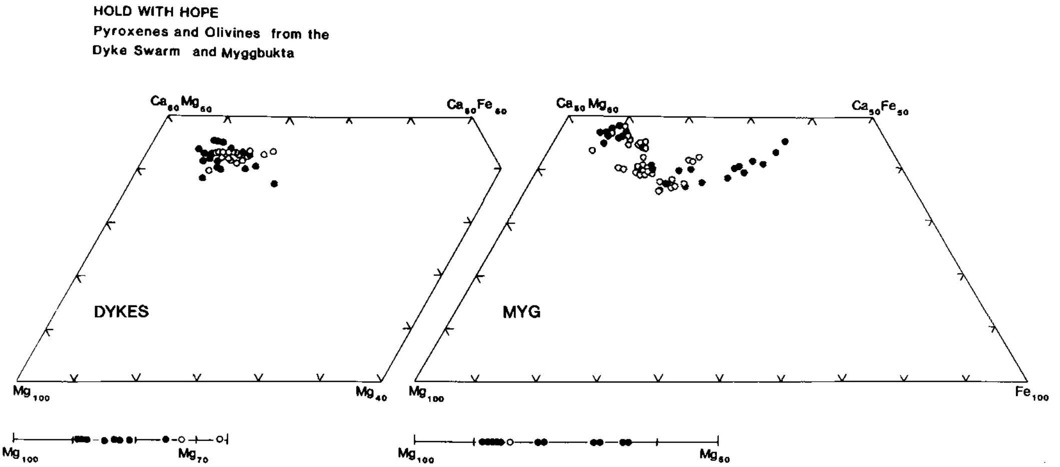

FIG. 4. Compositions of pyroxenes from the NE–SW dyke-swarm and the Myggbukta Complex (MYG). Olivine compositions also indicated on bars below the pyroxene projections. Closed circles: phenocryst cores. Open circles: matrix compositions.

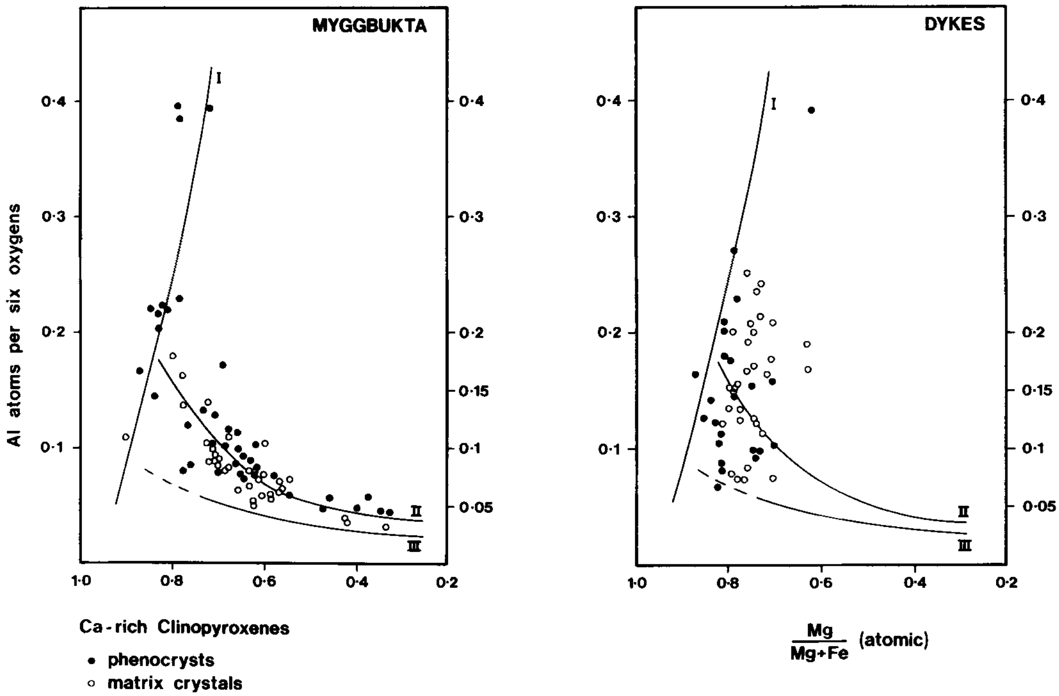

FIG. 5. Total aluminium (expressed as the number of Al atoms per 6 oxygens) in pyroxenes plotted against pyroxene $Mg/(Mg+Fe^{2+})$. The trends are based on data from pyroxenes in LPLS and UPLS lavas and the sills of Hold with Hope (Upton *et al.*, 1984). I = diopsidic augites from UPLS flows and the LPLS nehpelinite; II = tholeiitic lavas and sills: Ca-rich clinopyroxenes; III = tholeiitic lavas and sills: Ca-poor clinopyroxenes and orthopyroxenes.

closely follows the trend noted for some pyroxenes from UPLS lavas and the LPLS nephelinitic flow (fig. 5, trend 'I'; see also Upton *et al.*, 1984).

A rather different picture emerges from the relatively few analyses of dyke pyroxenes. Despite the somewhat limited variation in both pyroxenes and whole-rock compositions (fig. 4; Table III) there is a considerable range in the pyroxene alumina contents; furthermore, the range in matrix pyroxenes is almost as great as in phenocrysts despite the somewhat more diopsidic character of the latter (fig. 5). This somewhat independent behaviour of Al_2O_3 is illustrated by microphenocrysts from one tholeiitic dyke (sample no. 228154). Six of the crystals cover an Al/six oxygens range from 0.115 to 0.271 for an Mg/(Mg + Fe) variation of 0.811 to 0.782, although it should be noted that this sample also contains the most aluminous pyroxene measured from a dyke (Al_2O_3 8.86%, Mg/(Mg + Fe) 0.621).

TABLE III. Compositions of tholeiitic dykesfrom the NE–SW swarm. Hold with Hope.

	1	2	3	4	5	6
	228113	228171	228035	228155	228052	228055
SiO_2	53.66	52.94	48.67	49.00	48.75	45.22
TiO_2	2.38	2.46	3.01	2.03	2.17	1.31
Al_2O_3	17.27	13.61	15.70	15.03	14.07	9.79
FeO*	8.32	12.03	12.02	10.27	10.62	10.99
MnO	0.14	0.20	0.22	0.19	0.21	0.19
MgO	3.05	4.17	4.47	6.37	6.86	20.06
CaO	7.46	8.04	8.69	12.08	11.50	8.71
Na_2O	2.81	2.47	2.86	2.18	2.27	1.21
K_2O	3.12	1.39	1.61	0.60	0.53	0.28
P_2O_5	0.46	0.29	0.47	0.23	0.24	0.15
	97.84	97.60	97.72	97.98	97.22	97.91
$\frac{FeO^* + MgO}{MgO}$	2.73	3.88	2.69	2.61	2.55	0.55
(FeO*: Total Fe as FeO)						
		C.I.P.W. Norms: (Fe_2O_3/FeO = 0.15)				
qz	3.03	7.67	-	-	-	-
or	18.87	8.40	9.74	3.62	3.24	1.68
ab	24.32	21.36	24.70	18.80	19.73	10.42
an	25.85	22.46	25.79	30.01	27.33	20.89
ol	-	-	3.08	0.34	0.80	33.69
di	7.41	13.73	12.61	24.25	24.33	17.72
hy	13.15	18.56	14.77	16.89	17.67	10.57
mt	1.62	2.35	2.34	2.00	2.08	2.14
il	4.62	4.77	5.83	3.94	4.24	2.54
ap	1.12	0.70	1.13	0.56	0.57	0.36
			Trace elements			
Sr	743	317	588	347	288	204
Ba	1043	362	563	180	148	78
Rb	77	43	29	11	12	8
Th	7	7	7	12	2	3
Pb	0	13	10	9	7	7
La	65	31	45	18	13	6
Ce	147	69	99	43	35	10
Nd	66	36	49	23	21	7
Y	39	39	39	28	30	18
Zr	391	249	287	161	150	90
Nb	62	26	42	21	20	11
Sc	22	32	29	34	36	28
V	189	302	305	283	329	197
Zn	91	105	124	87	87	81
Cu	20	8	9	65	98	105
Cr	24	6	8	143	249	1476
Ni	18	8	10	76	105	786

Amphibole crystallized only in the most highly differentiated intrusions of Myggbukta. While generally pseudomorphed, blue-green hornblende is preserved, e.g. in the quartz syenite (sample no. 228273). Biotite occurs in the matrices of some remarkable potassic basalts (or trachybasalts) from within the trachyte-rich area, near the summit of the 230 m hill north of Myggbukta Radio-Station. (Table II, col. 8). This occurrence of trachybasaltic rocks is probably the same as that from which the sample described by Tyrrell (1932) was collected. Biotite is otherwise rare although found as relict phenocrysts in the most silicic extrusion (sample no. 228262) from Myggbukta.

The oxide phases have been little investigated: spinel microphenocrysts are recorded from both the more magnesian dykes and Myggbukta intrusions. Notably Cr-rich spinels, with up to 42 wt. % Cr_2O_3 occur in dyke samples no. 227973 and 228055 (Table II, col. 4) and highly aluminous but less chrome-rich spinels in Myggbukta basic intrusions, samples no. 228126 and 228139 (Cr_2O_3 *c.* 30–40 wt. % and Al_2O_3 25–30 wt. %). Many of the differentiated rocks contain microphenocrysts of magnetite and/or ilmenite. Apatite and zircon occur sparingly in the most fractionated Myggbukta rocks.

The acid rocks of Kap Broer Ruys present fine-grained matrices largely composed of quartz, feldspar, Fe-Ti oxides, and, occasionally, greenish hornblende. Phenocrysts of perthitic alkali feldspar and possible pseudomorphs after pyroxene are sparsely present. Granophyric textures are poorly represented and the rocks are regarded as having been initially obsidians which devitrified during late-stage hydrothermal activity.

The description of the Myggbukta magmas as predominantly silica-saturated to over-saturated tholeiites, with differentiation through basaltic andesite and icelandite intermediaries to trachyte and rhyolite, together with subordinate transitional and potassic alkali olivine basalts (Upton *et al.*, 1980) requires qualification since the rocks present something of a nomenclatural problem. With the exception of a very subordinate group of K-rich alkali olivine basalts and some gabbros of transitional affiliations, the Myggbukta and dyke swarm magmas were ol- hy- to hy-qz-normative (calculated on a $Fe_2O_3/FeO = 0.15$ basis). Modal olivine is confined to the most primitive compositions while interstitial quartz is a common component in the dolerites and gabbros.

The silica-saturated to oversaturated rocks of

Myggbukta form a relatively coherent trend inferred to define 'a line of liquid descent'. However, while the term trachyte is entirely apposite for the plagioclase-deficient felsic rocks with 63–68 wt. % SiO_2, the terms alkali olivine basalt–hawaiite–mugearite are clearly inappropriate for the more primitive members of the series. Conversely the terms tholeiitic basalt–tholeiitic andesite–icelandite are not wholly appropriate for a rock suite devoid of low-Ca pyroxenes. It is concluded that the relatively elevated K-contents (see below) of the Myggbukta magmas allowed crystallization of alkali feldspar from a comparatively primitive stage (alkali feldspar phenocrysts appear in samples with over 63 wt. % SiO_2) and, together with the dyke magmas, the silica activity did not rise to the level at which a separate low-Ca pyroxene could precipitate. In view of these considerations the following hybrid nomenclature scheme will be adopted for Myggbukta and the dyke swarm magmas: SiO_2 < 52%, tholeiitic basalt; SiO_2 52–58%, tholeiitic andesite; SiO_2 58–63%, icelandite; SiO_2 63–68%, trachyte; SiO_2 > 68% (potassic) rhyolite. In the dyke swarm the compositions span only the range tholeiitic basalt–tholeiitic andesite and, as is generally the case in the Hebridean and main East Greenland Tertiary Provinces and in Iceland, salic products are confined to the central volcano.

Petrochemistry

Fifty-four rocks from Myggbukta, 15 from the dyke warm and 4 from the Kap Broer Ruys intrusions were analysed.

Both the Myggbukta and dyke swarm basic (> 3% MgO) rocks are notably potassic (average K_2O/Na_2O for the Myggbukta rocks, 0.47 and for the dykes, 0.39). This potassic character is shared with the preceding UPLS and is in sharp contrast with the K-poor tholeiites copiously erupted in the early stages of the evolution of this volcanic province. (Upton *et al.*, 1984).

Myggbukta shows a trend with continuous silica enrichment (46–76 wt. %) with falling MgO (14.6–*c.* 0.0%) whereas the dykes show SiO_2 rising to *c.* 53% and MgO no lower than 3.5% (fig. 6). Myggbukta magmas with over 6.5% MgO were rare and tended to be erupted towards the close of the whole magmatic cycle. Mid-stage Fe and Ti enrichment is seen at Myggbukta (*c.* 14.5% total Fe as FeO and 3.6% TiO_2 at *c.* 4% MgO), whereas P_2O_5 attains a maximum (0.75% P_2O_5) at *c.* 2% MgO. Among the trace elements (fig. 7) in both Myggbukta and dyke

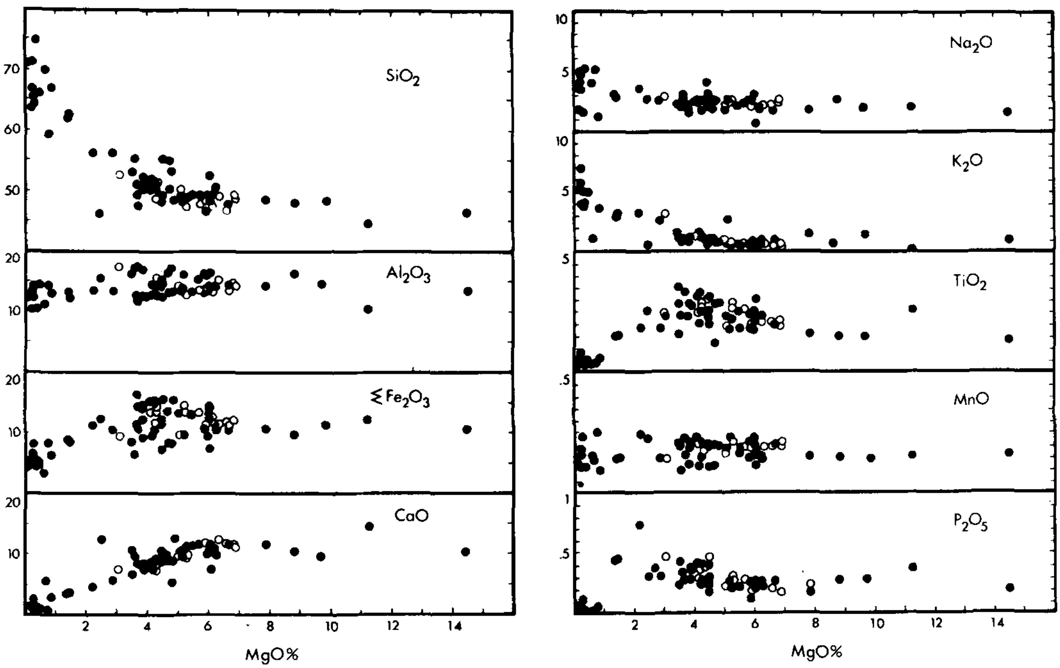

FIG. 6. Major-element variation plot *vs.* MgO% for NE–SW dykes (open circles) and Myggbukta samples (closed circles).

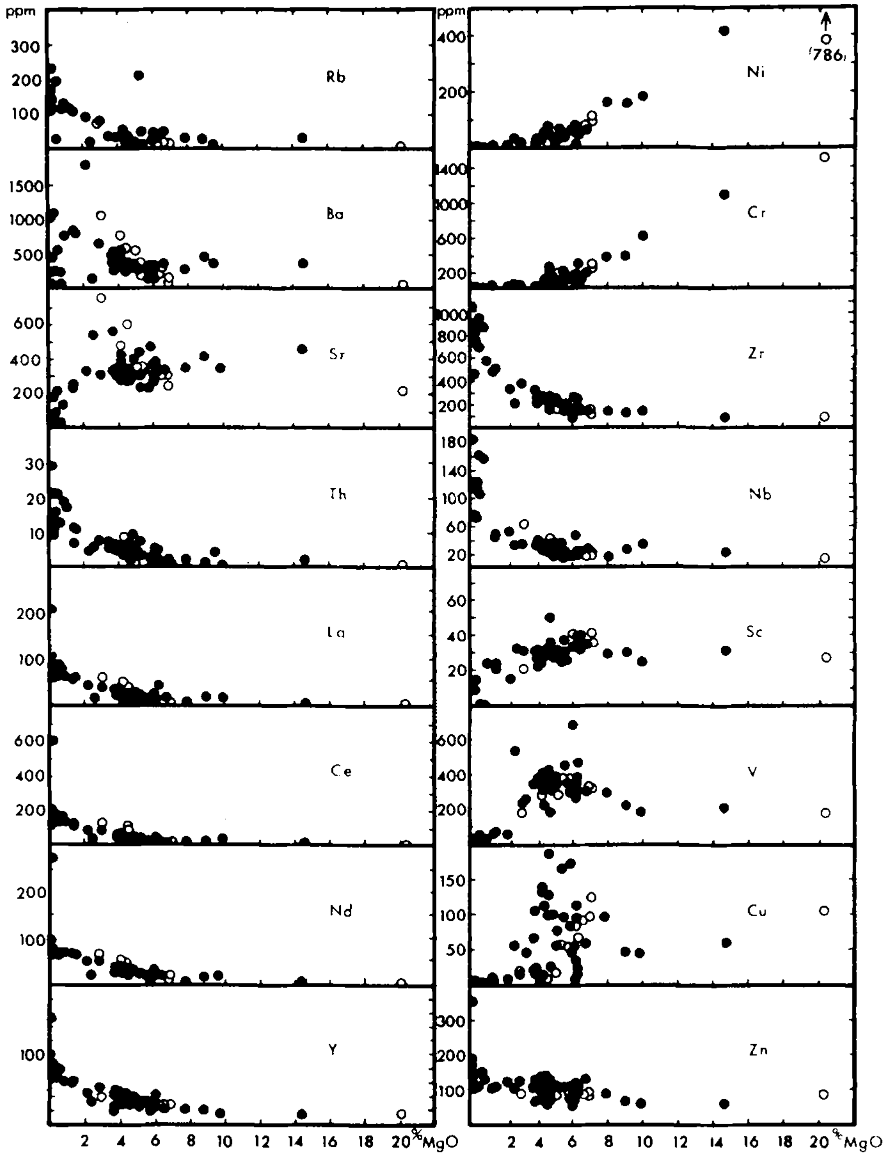

FIG. 7. Trace-element variation plot *vs.* Mg% for NE-SW dykes (open circles) and Myggbukta samples (closed circles).

magmas Ni and Cr fall rapidly with declining MgO, V rises to a maximum of nearly 700 ppm at *c.* 4% MgO while Th, Rb, La, Ce, Nd, Y, Nb, Zr, and Zn continue to rise with falling MgO throughout the series. Ba rises to over 300 ppm in Myggbukta salic rocks but appears to drop steeply in the most differentiated samples. Sc in Myggbukta remained roughly constant at *c.* 30 ppm until MgO reached around 4% MgO, below which figure Sc declined sharply. In the dykes a shallow decline in Sc from *c.* 40–30 ppm may be discerned. Rare-earth element (*REE*) patterns, chondrite-normalized, are similar for the basic rocks of both the dyke-swarm and Myggbukta. Patterns for five samples are shown in fig. 8. None display a negative Eu anomaly although some of the Myggbukta samples show a small positive Eu anomaly. The patterns for both the dyke-swarm and Myggbukta basic rocks tend to be somewhat flatter than those of the UPLS basalts (fig. 8).

TABLE IV. Compositions of some lavas and intrusions from the Myggbukta Complex.

	1	2	3	4	5	6	7	8
	228262	228254	228120	228132	228277	228270	228127	228139
SiO_2	75.04	71.95	63.07	55.63	46.22	48.28	48.14	46.10
TiO_2	0.41	0.46	1.64	2.27	1.85	3.22	1.60	1.48
Al_2O_3	10.76	10.61	12.76	15.71	16.24	13.03	16.04	13.43
FeO*	4.24	4.92	7.53	6.35	8.84	13.20	8.91	9.74
MnO	0.12	0.04	0.15	0.11	0.24	0.19	0.16	0.17
MgO	0.40	0.26	1.53	4.55	5.20	6.04	8.81	14.56
CaO	0.33	0.44	3.74	10.77	9.89	10.52	10.02	10.00
Na_2O	1.67	1.90	2.91	2.45	2.95	2.46	2.86	1.77
K_2O	5.28	5.95	3.38	0.52	2.85	0.81	0.85	1.06
P_2O_5	0.02	0.02	0.46	0.18	0.26	0.23	0.29	0.20
	98.29	96.55	97.17	98.54	96.54	97.98	97.68	98.43
$\frac{FeO^* + MgO}{MgO}$	10.60	19.92	5.92	2.40	2.70	3.19	2.01	1.66

(FeO*: total Fe as FeO)

C.I.P.W. Norms (Fe_2O_3/FeO = 0.15)

	1	2	3	4	5	6	7	8
qz	41.88	34.93	21.54	12.19	-	-	-	-
or	31.75	36.41	20.54	3.09	17.78	4.86	5.15	6.39
ab	14.38	16.68	25.35	21.03	12.68	21.20	24.72	14.44
an	1.49	2.15	12.06	30.77	23.96	22.56	29.06	25.95
co	1.79	0.29	-	-	-	-	-	-
ne	-	-	-	-	7.40	-	-	0.39
ol	-	-	-	-	10.61	1.88	17.19	29.12
di	-	-	3.31	18.04	21.44	24.09	16.04	18.51
hy	7.04	7.63	11.42	8.85	-	16.08	2.29	-
mt	0.82	0.97	1.48	1.23	1.78	2.57	1.74	1.87
il	0.80	0.90	3.20	4.37	3.72	6.22	3.10	2.86
ap	0.06	0.05	1.12	0.43	0.65	0.54	0.71	0.48

Trace elements

	1	2	3	4	5	6	7	8
Sr	41	14	243	359	420	354	409	462
Ba	67	26	830	237	287	317	470	394
Rb	141	224	106	14	205	24	23	27
Th	19	28	13	2	5	5	3	1
Pb	21	20	18	7	17	9	9	7
La	84	212	64	12	23	20	19	13
Ce	177	606	143	28	54	38	38	24
Nd	80	275	70	17	24	19	18	10
Y	89	154	63	20	28	29	23	17
Zr	735	1034	508	136	183	158	123	93
Nb	112	185	49	16	37	18	27	23
Sc	1	-	25	52	26	33	32	32
V	18	-	45	431	245	479	211	201
Zn	102	358	107	59	102	84	63	60
Cu	1	4	8	188	44	94	45	60
Cr	11	4	5	182	160	53	367	1086
Ni	3	11	5	51	75	45	158	418

The above features are all strongly indicative of magma suites controlled by crystal fractionation. Olivine and (minor) spinel fractionation occurred throughout the early stages as also, judging by the behaviour of Sc, did pyroxene. From the sporadic occurrence of high-Al diopsidic augite phenocrysts in both dykes and central complex, it is inferred that cotectic crystallization at relatively high pressures (? lower crustal levels) produced much of the observed basic compositions. Fe–Ti oxide separation at around the 4% MgO level controlled the later depletion in Fe, Ti, and V (and ? Sc), while apatite fractionation may have commenced somewhat later at *c.* 2% MgO. The late decline in Ba is attributed to fractionation of anorthoclase.

Some contrast between the dykes and Myggbukta is shown by Sr and Cu. In the dykes Sr increases with falling MgO but tends to remain approximately constant in the Myggbukta rocks until *c.* 4% MgO beyond which stage it falls sharply. The contrast is attributed to the earlier onset of plagioclase fractionation in the Myggbukta magmas than in the dyke magmas. Cu falls in the dykes from a maximum at *c.* 100 ppm in those samples with *c.* 7% MgO while it displays a generalized enrichment in Myggbukta to around 200 ppm by the time MgO

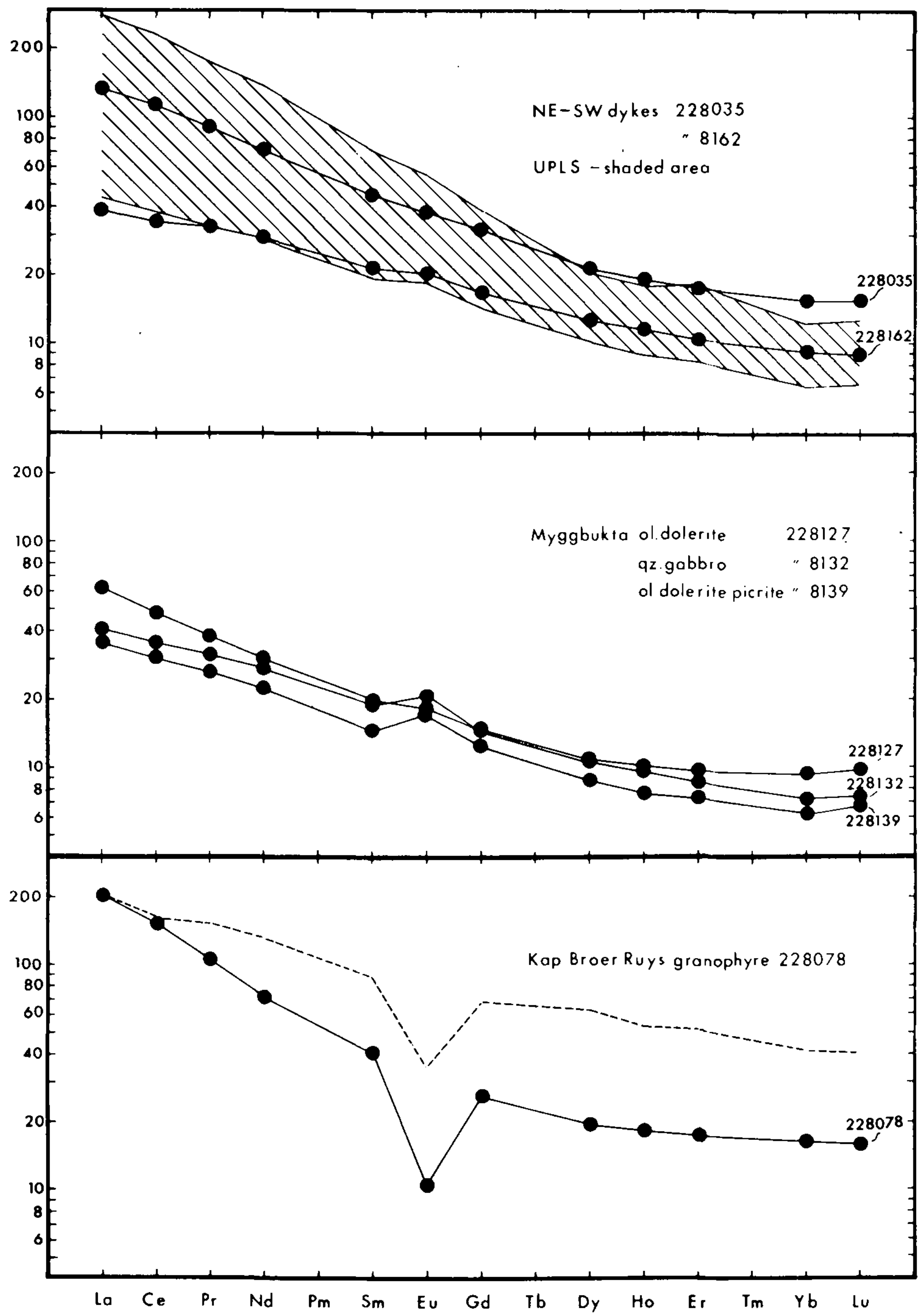

FIG. 8. Chondrite-normalised *REE* patterns for two NE dykes, three basic rocks from Myggbukta and a felsite from Kap Broer Ruys. *REE* range for UPLS also indicated. The dashed line relates to St Kilda granophyre (Sample QUB 73; data from Meighan, 1979).

was reduced to *c.* 5%. Beyond this point Cu was clearly effectively fractionated, possibly by separation of a Cu-rich sulphide liquid. Differences in sulphur-activity in the two magmas suites may account for this behavioural difference in Cu.

Zr/Y values for Myggbukta and the dykes are essentially identical and correspond closely to those of the UPLS. They are, however, higher than and quite distinct from the Zr/Y of the K-poor sill and LPLS tholeiites (fig. 9). Zr/Nb ratios too, show a broad correspondence for the dykes, Myggbukta and UPLS basalts. Like the Zr/Y data, the Zr/Nb values tend to be quite distinct from the relatively Nb-poor early tholeiites of the LPLS and associated sills (fig. 9).

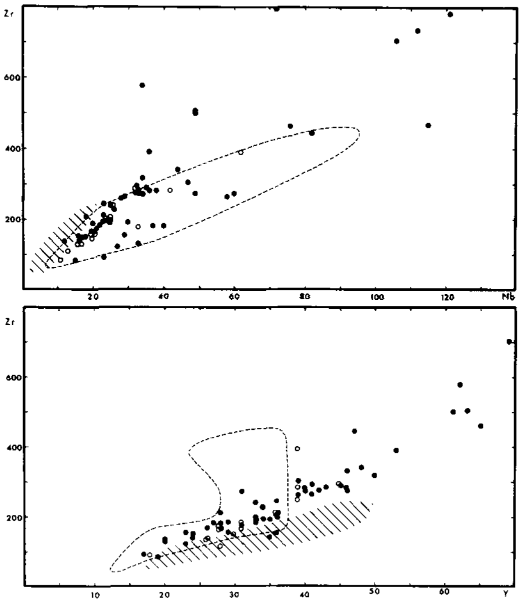

FIG. 9. Zr/Nb and Zr/Y plots for NE dykes (open circles) and Myggbukta samples (closed circles). Dashed lines encircle field for UPLS compositions and hatched areas indicate fields for LPLS sill compositions.

The Myggbukta and dyke magmas tended to be not only potassic but distinctly Rb rich. This enrichment is particularly pronounced in the Myggbukta Complex. Considering only the more primitive compositions (over 5% MgO) the mean K/Rb for the dykes (14 samples) is 387 while that for Myggbukta (18 samples) is 280. Whereas the dyke mean is almost identical to that of the UPLS (381, from 36 samples) the Myggbukta complex clearly shows the most Rb-enriched basalts in the Hold with Hope region. The general similarity between the dyke swarm and the Myggbukta eruptive rocks extends to their initial (50 Ma) $^{87}Sr/^{86}Sr$ ratios (Table VI). The dykes show a range of values from 0.70344 to 0.70589 while that for Myggbukta is 0.70353 to 0.70593. Although the lower end of the range coincides rather precisely with that shown by the UPLS, the upper end does not attain the extreme values (*c.* 0.708) of the UPLS. All tend to be high in relation to the LPLS tholeiite values (0.70321–0.70343). The $^{87}Sr/^{86}Sr_i$ values do not show any correlation with bulk Sr.

The Kap Broer Ruys acid rocks contrast with their Myggbukta counterparts: first they are extremely silicic (Table V) and are not part of any rock series linking them to a basaltic parentage.

TABLE V. Compositions of granophyres and felsites from the Kap Broer Ruys area, Hold with Hope.

	1 228032	2 228078	3 228077
SiO_2	76.07	74.22	73.36
TiO_2	0.06	0.19	0.10
Al_2O_3	13.14	12.79	12.51
FeO*	1.08	1.97	1.46
MnO	0.02	0.19	0.05
MgO	0.10	0.06	0.30
CaO	0.47	0.73	1.27
Na_2O	4.36	3.31	3.89
K_2O	4.46	5.54	5.37
P_2O_5	0.01	0.02	0.01
	99.77	99.02	98.32
$\frac{FeO^* + MgO}{MgO}$	11.80	33.83	5.87
	C.I.P.W. Norms (Fe_2O_3/FeO = 0.15)		
qz	31.87	31.01	27.74
or	26.42	33.05	33.30
ab	39.96	28.28	33.44
an	2.28	3.52	0.83
co	0.31	0.07	-
di	-	-	4.70
hy	1.82	3.28	0.49
mt	0.21	0.38	0.28
il	0.11	0.36	0.20
ap	0.02	0.05	0.02
	Trace elements		
Sr	17	48	43
Ba	70	465	227
Rb	216	239	200
Th	23	32	19
Pb	25	39	25
La	10	67	32
Ce	37	138	61
Nd	21	50	24
Y	50	42	23
Zr	135	251	130
Nb	84	31	14
Sc	-	3	1
V	2	0	1
Zn	95	212	129
Cu	1	6	1
Cr	4	4	4
Ni	4	5	3

1. 228032. 3m thick felsite sheet at base of of lava pile. Uglehøjene.
2. 228078. Porphyritic facies of granophyre. Corrie in hills inland from Kap Broer Ruys.
3. 228077. Granophyre. Locality as 2 above.

TABLE VI. *Initial $^{87}Sr/^{86}Sr$ ratios and Rb/Sb ratios: NE–SW dyke swarm. Myggbukta and Kap Broer Ruys*

	Sample no.	Rb/Sr§	Age correction*	Initial $^{87}Sr/^{86}Sr$‡
Dyke swarm				
Tholeiitic dolerite dyke	228026	0.0317	6	0.70367 ± 7
Tholeiitic dolerite dyke	228035	0.0499	10	0.70593 ± 7
Tholeiitic dolerite dyke	228052	0.0392	8	0.70344 ± 7
Tholeiitic dolerite dyke	228154	0.0254	5	0.70346 ± 7
Tholeiitic dolerite dyke	228155	0.0342	7	0.70427 ± 7
Tholeiitic dolerite dyke	228162	0.0344	7	0.70373 ± 7
Tholeiitic dolerite dyke	228171	0.1391	28	0.70589 ± 7
Myggbukta Complex				
Icelandic sheet	228120	0.4454	89	0.70593 ± 7
Tholeiitic dolerite sheet	228126	0.0837	17	0.70470 ± 7
Tholeiitic dolerite sheet	228127	0.0577	12	0.70465 ± 7
Icelanditic sheet	228130	0.6762	135	0.70497 ± 7
Tholeiitic gabbro	228132	0.0406	8	0.70467 ± 7
'Transitional' picritic sheet	228139	0.0585	12	0.70455 ± 7
'Transitional' gabbro	228253	0.0380	8	0.70360 ± 7
'Transitional' gabbro	228257	0.0553	11	0.70367 ± 7
Tholeiitic basalt lava	228261	0.03251	7	0.70353 ± 7
Rhyolitic lava	228262	3.5253	707	0.70536 ± 10†
Tholeiitic basalt lava	228269	0.1369	27	0.70483 ± 7
Quartz syenite	228273	2.3005	461	0.70410 ± 8†
Tholeiitic dolerite	228286	0.0749	15	0.70499 ± 7†
Kap Broer Ruys				
Felsite sheet	228032	14.9189	2998	0.70625 ± 31†
Porphyritic granophyre	228078	5.1041	1024	0.70786 ± 12†
Porphyritic granophyre	228082	0.5607	112	0.71034 ± 7

* Age correction applied to the fifth decimal place assuming an age of 50Ma (see text).
§ atomic ratio ± 1% (2σ) determined directly by XRF.
‡ Initial ratios quoted with 2σ errors calculated only from the errors in the age correction due to analytical uncertainty in Rb/Sr and mass spectrometric error of ± 0.01% (2σ). All quoted relative to a value of 0.070800 for the Eimer and Amend standard by subtracting 0.00005 to allow for a measured value for this standard of 0.70805 ± 1.

Whereas there is some evidence for hydrothermal alteration, for example of the ferromagnesian minerals, the highly siliceous character is regarded as a primary feature. Secondly, they are distinctly poorer in Mg, Fe, Ti, La, Ce, Nd, Y, Zr, and Nb than their Myggbukta counterparts (fig. 10) and richer in Th and Pb. K/Rb values for the 3 Kap Broer Ruys samples range 171–223 whereas acid rocks of Myggbukta (> 65% SiO_3) range from 221–485. Initial (50 Ma) $^{87}Sr/^{86}Sr$ ratios for Kap Broer Ruys, 0.70625–0.71034, are very distinctly higher than any from Myggbukta.

Fig. 11 displays chondrite-normalized incompatible element plots for average Myggbukta and dyke swarm basic rocks (4–8% MgO, Table VII). The abundance patterns are similar and lie approximately midway between the average traces for 'enriched MORB' and 'oceanic alkalic basalt' (Sun, 1980). The enrichment values are generally comparable to those of the average UPLS tholeiites but are quite distinct from those of the early 'depleted' tholeiites. The trace for sample no. 228277, the trachybasalt lava from Myggbukta, is also shown. This shows the most extreme values of the basic rocks described in this paper, with exceptional enrichment in Pb, Rb, Ba, Th, K, and Nb.

Geochronology

The similarities in the overall evolution of the coast-marginal volcanic province of northern East Greenland to the main Tertiary province south of

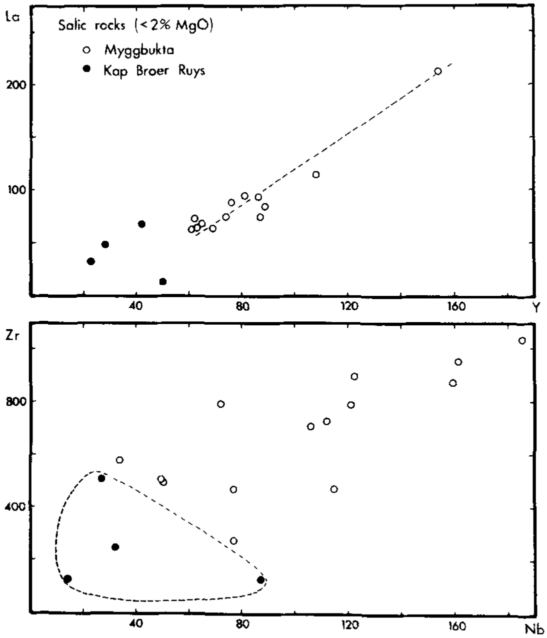

FIG. 10. La/Y and Zr/Nb plots for salic compositions from the Myggbukta (open circles) and Kap Broer Ruys (closed circles) complexes.

TABLE VII Mean compositions of 'basalts' (basic rocks with 4-8% MgO) of the UPLS, NE-SW dyke swarm and Myggbukta.
Major element analyses recalculated, anhydrous, to 100%.
Numbers of analyses involved indicated in brackets.

	1 UPLS (17)	2 Dykes (12)	3 Myggbukta (29)
SiO_2	51.26	50.96	51.67
TiO_2	2.18	2.48	2.48
Al_2O_3	15.02	14.42	14.86
FeO*	10.69	11.66	11.34
MnO	0.17	0.20	0.19
MgO	6.38	5.86	5.53
CaO	10.90	10.83	10.18
Na_2O	2.29	2.44	2.51
K_2O	0.87	0.87	0.96
P_2O_5	0.24	0.28	0.28
	100.00	100.00	100.00
$\frac{FeO^* + MgO}{MgO}$	2.68	2.99	3.05
Sr	342	343	326
Ba	293	295	298
Rb	27	18	33
Th	4	2	3
Pb	8	8	9
La	22	23	22
Ce	47	52	48
Nd	25	28	25
Y	29	32	33
Zr	181	190	204
Nb	20	22	25
Sc	33	34	34
V	280	324	347
Zn	88	97	98
Cu	59	62	78
Cr	146	98	103
Ni	60	53	53

(FeO*: total Fe as FeO)

Scoresby Sund are such as to suggest overall contemporaneity of the early flood tholeiite events. In the main province this event is believed to have occurred just prior to anomaly 24 and 55-53 Ma ago (Brooks and Nielsen, 1982). Attempts to date the early lavas and sills in the northern province have so far been unsuccessful although the strongly silica undersaturated lavas of the nunataks some 200 m west of Myggbukta have been tentatively dated at 56 ± 1 Ma (Brooks *et al.*, 1979).

K/Ar ages of 55.1 ± 1.8 and 47.2 ± 1 Ma have been obtained from one sample of UPLS basalt from Hold with Hope (Table VIII). This age of 51.5 (± 5.4) Ma is consistent with a broad contemporaneity between the lower plateau basalts of the northern province and their counterparts south of Scoresby Sund. Apparently reliable ages of 47.8 ± 1.1 and 48.8 ± 1.1 were obtained from a dyke sample and the whole swarm may have been emplaced at approximately 48 Ma ago, whereas the Kap Broer Ruys intrusion(s) may have been emplaced at 46.9 ± 2 Ma. (Table VIII). The Myggbukta Complex itself, however, may have continued activity into the Oligocene at *c.* 28 Ma. Two samples, from what are believed on field-evidence to be the youngest intrusions in Myggbukta yielded the following ages: (*a*) a sample of olivine dolerite (228127), 24.4 ± 1.3 Ma and (*b*) a picrite sample (228139), between 29.0 and 27.4 Ma. Such very young ages may be compared to figures of 35 ± 2 Ma for the Kialineq Complex of the main province (Brown *et al.*, 1977) and *c.* 30 Ma for the Werner Bjerge Complex of the northern coast-marginal province (Rex *et al.*, 1979; Gleadow and Brooks, 1979).

The geology and petrochemistry of the Hold with Hope extrusive and intrusive members strongly indicate quasi-continuous evolution from the UPLS formation through the major NE-SW dyke swarm to the growth of the Myggbukta Complex, yet the K/Ar age data suggest that this evolution may have extended over an interval of twenty million years or more. Closer examination of these data suggests

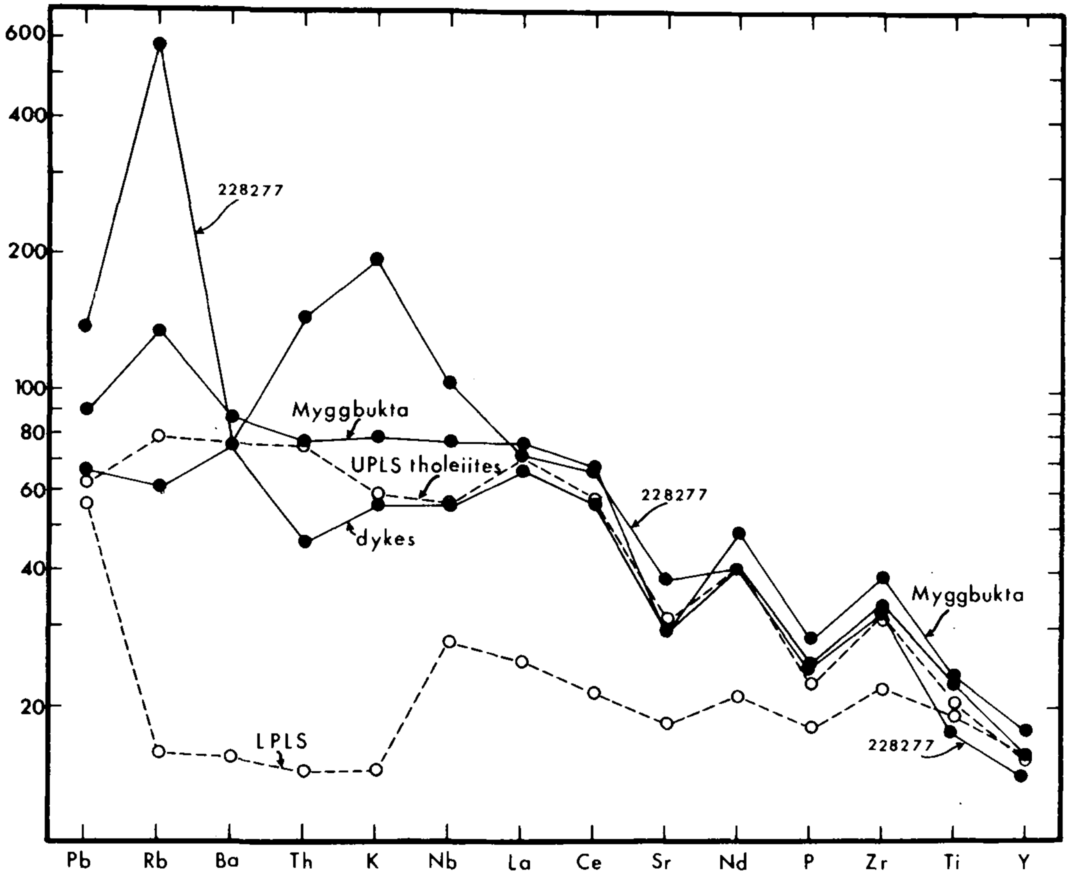

FIG. 11. Chondrite-normalized plots for 'incompatible elements' in Myggbukta trachybasalt 228277 and averages of (*a*) Myggbukta and (*b*) dyke-swarm basaltic compositions (i.e. those between 4 and 8% MgO). Dashed lines show corresponding trends for average LPLS and tholeiitic ('normal') UPLS basalts.

a gap within the Myggbukta Complex; thus, the often intensely altered Central Series lavas, NW–SE dolerite dykes, inclined sheets and syenitic, trachytic and acid sheets etc. are considered on geological grounds to follow closely on the UPLS formation and the NE–SW dyke-swarm, while the very fresh olivine dolerite bodies on which the young ages have been obtained represent a late invasion of the Complex by relatively primitive basaltic magmas.

In view of the uncertainty with respect to precise ages it is necessary to assume an age in order to calculate the initial $^{87}Sr/^{86}Sr$ ratios. For the majority of the samples analysed in the study described in this paper (and all the samples analysed for the accompanying paper on the sills and plateau lavas; Upton *et al.*, 1984) the Rb/Sr ratios are so low that the corrections for radiogenic growth in $^{87}Sr/^{86}Sr$ since the rocks crystallized are in the fifth place of decimals and the assumption of a particular age is not critical. The felsite sheet (sample no. 228072) from Kap Broer Ruys has such a high Rb/Sr ratio that model ages may be calculated assuming various values for initial ratios as follows:

Present day $^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Assumed initial $^{87}Sr/^{86}Sr$	Age
42.224	0.73623	0.703	55 Ma
		0.710	44 Ma

In view of the large number of samples analysed by Upton *et al* (1984) and in this paper from Tertiary volcanic rocks with initial $^{87}/Sr^{86}Sr$ ratios between 0.703 and 0.704 it is very unlikely that an assumed initial ratio value less than 0.703 would be appropriate. Thus the model age of 55 Ma (assuming, of course, no metasomatic changes since crystallization) may be regarded as a reliable upper limit. The assumed age of 50 Ma thus appears reasonable,

TABLE VIII. *K-Ar ages from the Hold with Hope region*

	Size (mm)	K (wt. %)	$^{40}Ar^*$ ($\times 10^{-7}$scc/g)	$\frac{^{40}Ar^*}{^{40}Ar_T}$(%)	T (Ma)
Myggbukta					
228139 (picrite)	−3.5+1.4	0.967	10.76	72.5	28.4±0.6
	−1.4+20¶	0.980	10.75	76.2	28.0±0.6
228127 (ol. dolerite)	−1.4+20¶	0.676	8.715	58.7	32.9±0.8
	−1.4+20¶	0.676	8.749	61.4	34.4±1.3
	−1.4+20¶	0.676	9.121	33.4	34.4±1.3
Kap Broer Ruys					
228100 (felsite)	−3.5+1.4	4.54	85.54	82.8	47.9±1.0
	−1.4+20¶	4.50	81.32	86.9	45.9±1.0
Dyke					
228191.1 (ol-plag-phyric basalt)	−3.5+1.4	0.450	8.466	68.4	47.8±1.1
	−1.4+20¶	0.442	8.490	68.0	48.8±1.1
UPLS					
228204 (aphyric)	−3.5+1.4	0.597	13.00	41.8	55.1±1.8
	−1.4+20¶	0.617	11.47	71.0	47.2±1.1

$^{40}Ar^*$ = radiogenic ^{40}Ar; $^{40}Ar_T$ = total ^{40}Ar.
$\lambda_\beta = 4.962\times10^{-10}yr^{-1}$; $\lambda_e = 0.581\times10^{-10}yr^{-1}$; $^{40}K = 1.167\times10^{-2}$ atom %; errors computed from $[E_K^2+(1+A/R)^2E_{40}^2+E_{38}^2+(A/R)^2E_{36}^2]^{1/2}$ where $R = (100-A) = {}^{40}Ar^*/{}^{40}Ar_T$ with error in K, $E_K = 1.5\%$ and errors in peak heights, $E_{40} = E_{38} = 0.5\%$; $E_{36} = 1\%$.

pending better data, and this age assumption is only really significant for the five samples marked † in Table VI.

Discussion

Myers (1980) concluded that the gabbro-syenite-granite complexes of the Blosseville Coast were deeply eroded remnants of central volcanoes like those seen in Iceland. Myggbukta helps to confirm this relationship and is an example of a volcano on the continental margin eroded to a level similar to, and showing much structurally and compositionally in common with, the more deeply dissected of the Icelandic volcanoes. In its continental setting, well separated from the contemporary active spreading-centre magmatism (Upton *et al.*, 1980), it invites comparison with the British Tertiary Volcanic Province and, in particular, with the Mull centre.

Relationship of the Myggbukta and dyke-swarm basalts to the previous magmatic history. The parental magmas of the Myggbukta volcano and its dyke swarm were potassic hy-normative basalts. That they are themselves relatively fractionated liquids is inferred from their comparatively low Mg, Cr, and Ni contents (Table VII). The average compositions for basic rocks with MgO contents between 4–8 wt. % for these two groups are closely comparable and show little difference from the corresponding average for the preceding tholeiitic (normal) UPLS. There is, however, progression in time from average 'normal' UPLS to average dyke to average Myggbukta 'basalt' with generalized increases in Na, K, Ti, P, Ba, Zr, Nb, V, Zn, Cu, and FeO+Mgo/MgO and concomitant decrease in Mg, Cr, and Ni (Table VII).

The petrogenesis of the UPLS basalts has been discussed in Upton *et al.* (1984). In brief, it was proposed that whereas the change from 'depleted' LPLS-type tholeiite to 'enriched' UPLS basalt may have involved some crustal interaction, the principal UPLS geochemical characteristics must have been acquired at sub-crustal levels. Wall-rock reaction between ascending basalt magma and relatively old (pre-300 Ma) heterogeneous sub-continental lithospheric mantle was invoked to explain the elevation in incompatible and radiogenic element contents.

Saemundsson (1978) wrote, apropos of Icelandic magmatism, that magma collects at shallow levels in the root-zone of central volcanoes from whence it may be intermittently injected into the associated fissure-swarm, the controlling factor being that the magma pressure must attain a critical level 'to trigger a jerk of rifting'. If the ascent of magma into the collection chamber continues beyond the widening capacity of the fissure-swarm, an eruption will ensue. In the Hold with Hope context, prolonged development of an early (UPLS) Myggbukta basaltic shield was interrupted by a phase of distension and lateral injection producing the dyke-swarm. This episode allows a simple sub-division of the evolution of the volcano into three stages: (1) basalt shield growth, with or without caldera formation; (2) dyke emplacement and (3) late-stage collapse and development of the differentiated suite of Myggbukta.

Petrogenesis of the Myggbukta differentiated suite. The Myggbukta rocks display an essentially continuous composition range from 46–76 wt. % SiO_2, a slightly greater range than the otherwise closely comparable suite from the Beinn Chaisgidle Centre, Mull (Walsh and Clarke, 1982). This sequence, with Fe, Ti, V, P, and Cu attaining maxima in the intermediate stages between basaltic and rhyolitic extremes, cannot be attributed to magma mixing or primary melt batches and has all the hall-marks of extreme fractionation. Major and trace element chemistry indicated this to have resulted from ol+cpx fractionation with Cr-spinel participation in the higher-temperature stages; subsequent fractionation involving plagioclase led to moderate iron-enrichment. Separation of Fe-Ti oxides at a relatively late stage was succeeded by fractionation of apatite and Cu-rich sulphide (liquid?) and, in more extreme compositions, of relatively Ba-rich alkali feldspar. The Myggbukta rhyolites, reaching such high levels of trace element enrichment as sample no. 228254 (Zr, 1034; Nb, 185; Rb, 224; Pb, 20; Th, 28; La, 212; Ce, 606; Nd, 275; Y, 154, and Zn, 358 ppm), with Ba and Sr reduced to 26 and 14 ppm respectively, may be compared to the more extreme peralkaline granophyres of the British Tertiary Province (Meighan, 1979; Thompson, 1982). Zr shows the progressive enrichment from values of *c.* 100 ppm in the basic members to over 1000 ppm (sample no. 228254) in the acid rocks, comparable with the behaviour reported for Skaergaard liquids (Brooks, 1969). The concentration of Zr in the residual liquids suggests an affinity with peralkaline rhyolites (Carmichael, 1962) and the Myggbukta acid rocks may be compared to the peralkaline granophyres of the British Tertiary Province (Meighan, 1979; Thompson, 1982). In the British Province an origin for the acid rocks involving strong fractionation from basaltic parents with variable degrees of crustal contamination, has now become a consensus view (Bell, 1976; Thorpe *et al.*, 1977; Meighan, 1979; Walsh et al., 1979; Walsh and Clarke, 1982). Similarly, crystal fractionation has been regarded as the key petrogenetic process for generation of salic rocks in the Tertiary complexes of the Blosseville Coast by Wager and Brown, 1968, Brown *et al.*, 1977, and Myers, 1980, as also in Iceland (Carmichael, 1964). The problems of acid magma genesis in the British Tertiary Province have been admirably reviewed by Thompson (1982) where many of the puzzles can be resolved by the concept that these magmas represent low melting-point 'froths' that collected above the basic magmas and which could be repeatedly recycled by refusion from below.

The $^{87}Sr/^{86}Sr_i$ ratios for Myggbukta are substantially lower than those (0.70608–0.70868) reported from the otherwise comparable suite in the Beinn Chaisgidle Centre (Walsh and Clarke, 1982). However, like the latter there is some tendency for more siliceous rocks to have higher ratios. Thus the range in samples with less than 52 wt. % SiO_2 is 0.70353–0.70499 compared with 0.70410–0.70593 for the more siliceous samples (Table VI). In their low Sr ratios and lack of clear distinction from ratios of the associated basic rocks the Myggbuka suite more closely resembles the Tertiary basic to acid suites from Kialineq (Blosseville Coast) with an initial ratio of 0.70385 ± 0.00015 (Brown *et al.*, 1977) and Sarqâta qâqâ (West Greenland), initial ratio 0.7045 ± 0.0003 (Beckinsale *et al.*, 1974). Consequently, from the available data it would appear that crustal contribution, either through fusion and magma mixing or through selective isotopic contamination (Patchett, 1980; Dickin, 1981) has been small in relation to what has occurred in the British Tertiary volcanic province.

Kap Broer Ruys acid intrusions. While a strong case can be established for the Myggbukta acid rocks being the residual products from basalt fractionation, the Kap Broer Ruys intrusions have no visible intermediate or basic associates. The Kap Broer Ruys rocks differ compositionally from their Myggbukta counterparts in being generally more siliceous and richer in Rb, Th, and Pb. They have less Fe, Mg, Ti, P, Sr, distinctly less Zr, *REE*, and Y (fig. 12) and have lower K/Rb values. The initial $^{87}Sr/^{86}Sr$ ratios are notably high in comparison with Myggbukta but, with an observed maximum at 0.71034, are still distinctly low in comparison with, for example, the Skye granophyres (Bell, 1976). Possibly they represent still more extreme compositions than were produced at Myggbukta, with a marked negative Eu anomaly due to extensive plagioclase fractionation and Ba, *REE*, Y, Sr, P, Fe, and Ti generally reduced by fractionation of alkali feldspar, apatite, and ferromagnesian minerals. Possibly, if Zr had exceeded its solubility in the residual liquids, zircon fractionation may have reduced the content of this

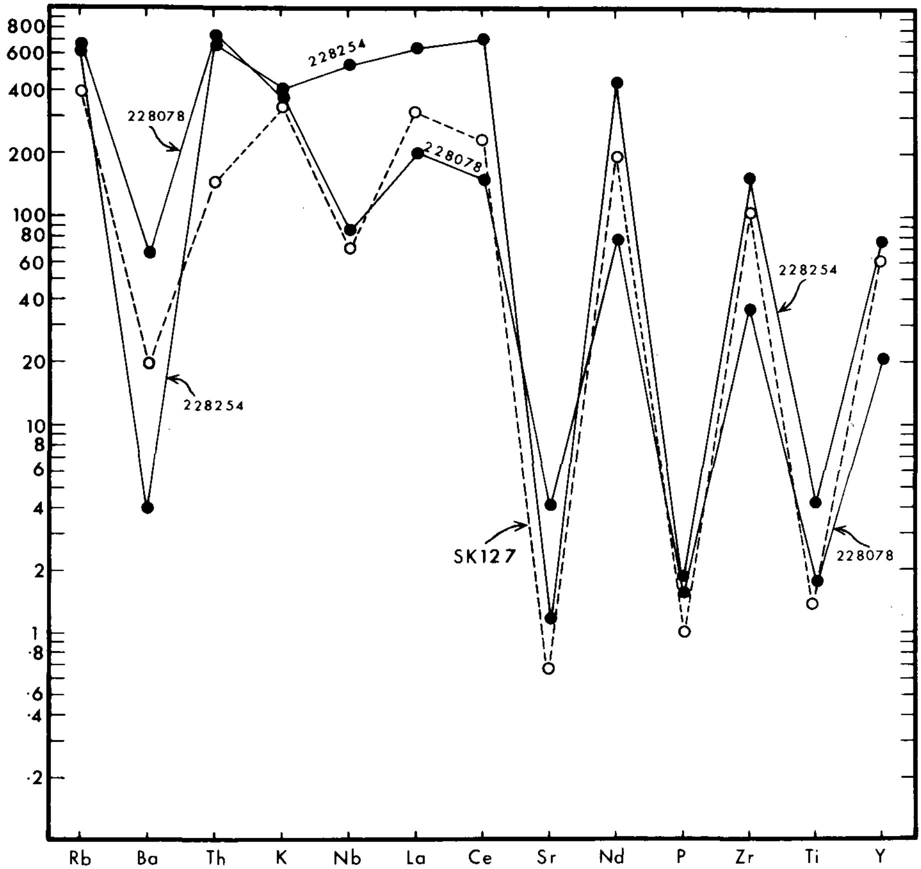

FIG. 12. Chrondrite-normalized plots for incompatible elements in representative salic rocks from Myggbukta (228254) and Kap Broer Ruys (228078). Dashed line shows comparative plot for Skye granophyre SK127 (re-drawn from Thompson, 1982).

element to the low values (relative to Myggbuykta!) observed.

On the basis of the very limited data to hand we tentatively ascribe the Kap Broer Ruys rhyolite magmas to extreme fractionation of an hypothetical basic pluton beneath the hornfelsed region, coupled with more extensive crustal contamination than occurred at Myggbukta.

Conclusions

The Myggbukta Complex represents the old-age stages of a large, predominantly basaltic shield volcano. The Upper Plateau Lava Series of Hold with Hope and Gauss Halvø were produced during the early growth of the volcano. A rifting event followed in which the Hold with Hope–Gauss Halvø dyke-swarm was emplaced. The change of strike in the dyke-swarm may relate to deep structures in the crystalline basement and the ensuing caldera collapse was controlled by the inflexion. Continued supply of basaltic magma and development of caldera lake(s) led to numerous phreatic eruptions while vigorous hydrothermal circulation through the lavas and pyroclastic rocks was efficacious in 'trapping' magma with production of a complex infrastructure of hypabyssal sheets (Upton *et al.*, 1980).

Whereas limited fractionation (ol + sp and ol + (? Al) cpx) in the underlying magma chamber produced dykes ranging from (accumulitic) oceanites to tholeiitic andesites, more extreme fractionation following collapse involved plagioclase, Fe–Ti oxides, apatite, Cu-bearing sulphide liquid (?) and alkali feldspar. This gave rise to a differentiated suite of magmas culminating in (probably peralkaline) rhyolites, with only very limited contamination by ancient continental crustal rocks. The culminating events, possibly several million years later, saw emplacement of the most magnesian basalt sheets.

The dykes and Myggbukta basic magmas were, in common with the earlier normal UPLS, enriched in K and other incompatible elements. However, the somewhat flatter *REE* patterns for the dyke swarm and Myggbykta samples (fig. 8) suggest that the primary magmas from which they derive represent higher degrees of partial melting in the mantle source than those responsible for the UPLS basalts.

The Kap Broer Ruys felsites and granophyres are geochemically distinct from any at Myggbukta. Nevertheless, they too probably originated from basaltic parentage by fractionation but with more crustal contamination than occurred at Myggbukta.

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