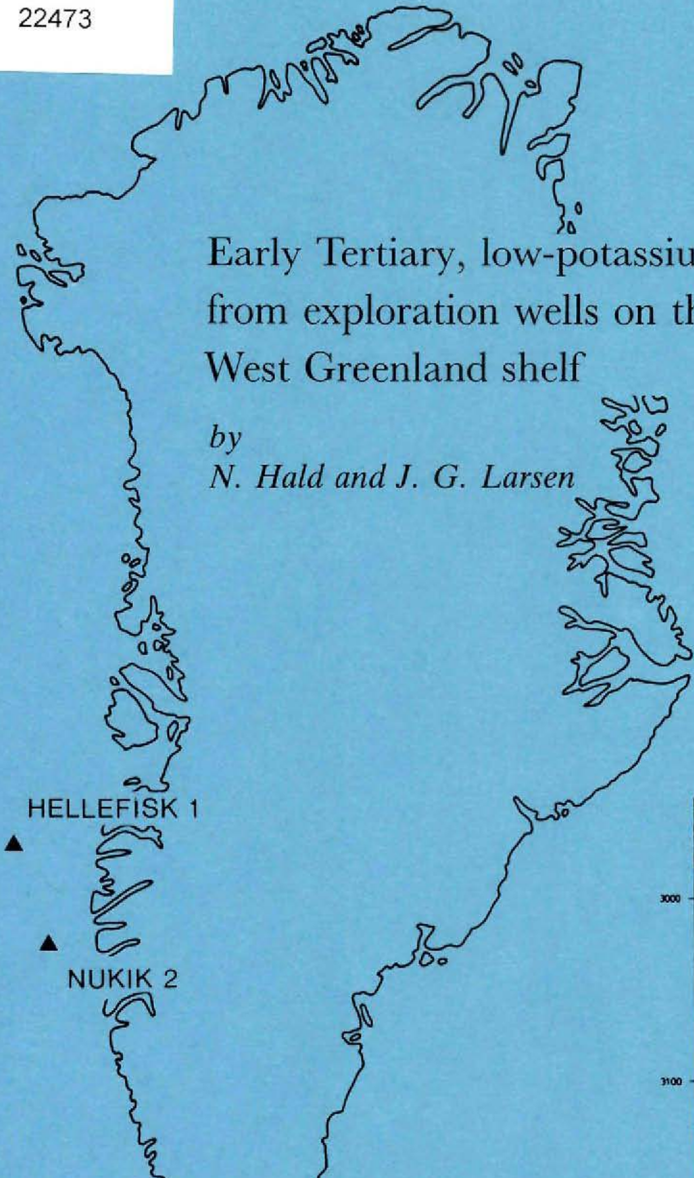
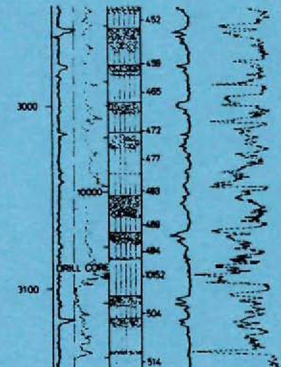
# Early Tertiary, low-potassium tholeiites from exploration wells on the West Greenland shelf

*by*
*N. Hald and J. G. Larsen*

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# Early Tertiary, low-potassium tholeiites from exploration wells on the West Greenland shelf

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## Abstract

Data on the Tertiary basalts in the Davis Strait region are reported from two exploration wells drilled by Arco and Mobil on the West Greenland shelf. Hellefisk 1 (67°53′N, 56°44′W), situated only 60 km east of the mid-line in Davis Strait, penetrated the upper 690 m of a subaerial lava sequence continuous with the onshore volcanics of Disko and situated beneath 2.3 km of Paleocene to Quaternary sediments. The lavas are feldspar microporphyritic tholeiites and mostly unmetamorphosed despite the presence of laumontite and prehnite in the vesicular top zones. Nukik 2 (65°38′N, 54°46′W) penetrated 150 m of hyaloclastites and tholeiitic olivine dolerite sheets, presumably sills, some 200 km further to the south. These volcanics are also deeply buried and are of unknown extension. The drilled rocks, except for the much altered hyaloclastites in the Nukik 2 well, have low contents of $TiO_2$ (0.99 – 2.03%), $K_2O$ (0.09 – 0.18%) and $P_2O_5$ (0.08 – 0.21%), La/Sm ratios less than one and $^{87}Sr/^{86}Sr$ ratios of 0.7032 to 0.7044. Chemically they are related to the MORB-like picrites of Baffin Island rather than the less depleted tholeiites of West Greenland. In both areas the MORB affinity may be related to eruptions through a strongly attenuated lithosphere associated with the opening of Baffin Bay and Davis Strait.



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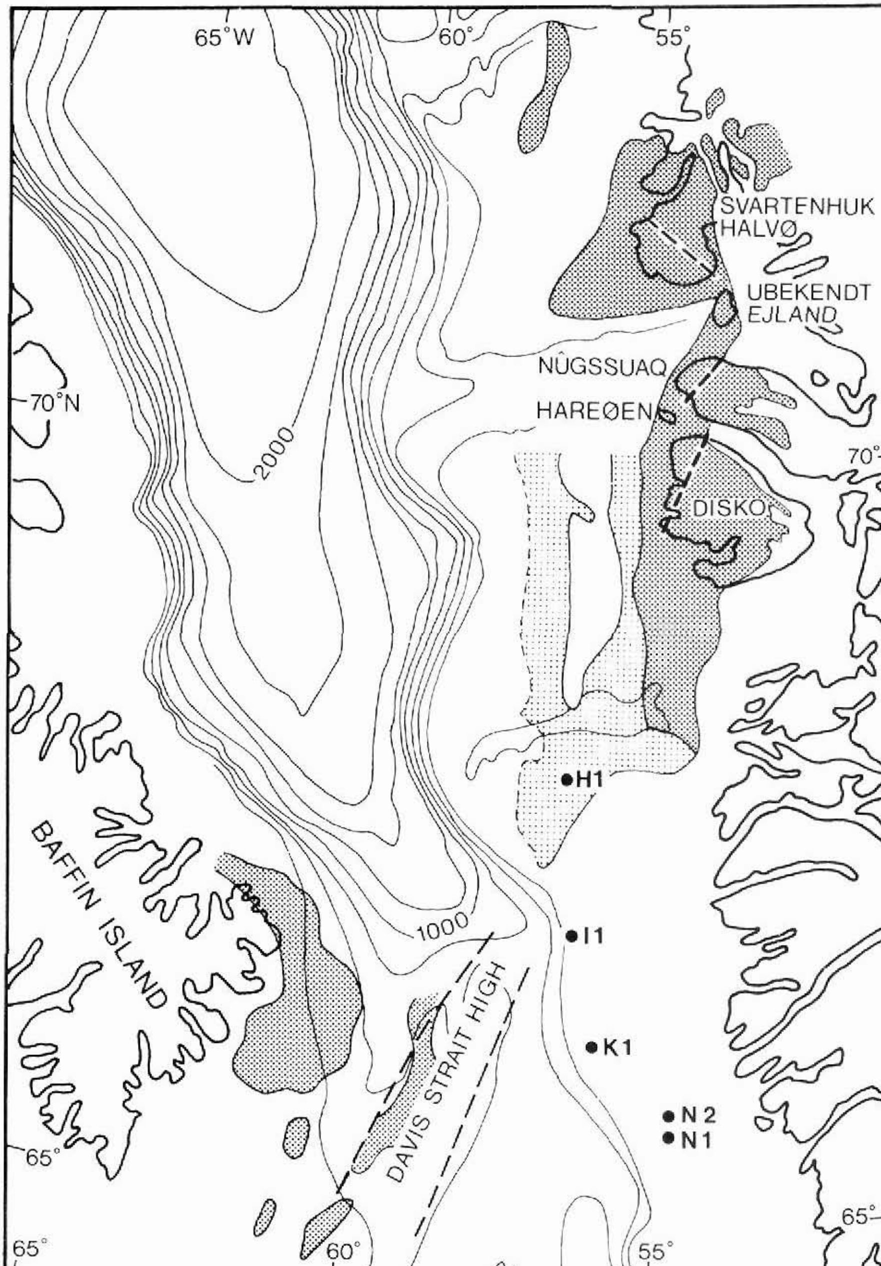



Fig. 1. Distribution of basalts in the Davis Strait region, compiled from Park *et al.* (1971), Ross & Henderson (1973), Denham (1974), Henderson *et al.* (1981) and Srivastava *et al.* (1982). Grey: onshore basalts and offshore basalts at sea floor. Light grey: offshore basalts covered by sediments. Dashed lines: boundaries of the structural high in Davis Strait. Short dashed line in onshore West Greenland: eastern boundary of Henderson's (1973) graben zone. Filled circles: exploration wells: H1 Hellefisk 1; I1 Ikermiut 1; K1 Kangâmiut 1; N1 Nukik 1; and N2 Nukik 2.

# Introduction

Early Tertiary volcanism in the Davis Strait region formed large volumes of plateau basalts covering parts of central West Greenland, southeastern Baffin Island and adjacent shelf areas in Davis Strait (fig. 1). The onshore basalts have been described in a number of publications (e.g. Clarke, 1970; Clarke & Upton, 1971; Clarke & Pedersen, 1976; Pedersen, 1985) while our knowledge of those offshore is poor and restricted to three dredge stations on the West Greenland shelf (Keen & Clarke, 1974; Clarke, 1975) and some short drill cores on the shelf outside Baffin Island (MacLean *et al.*, 1978). Deeply buried Tertiary basalts were recovered from two wells drilled by Arco and Mobil in 1977 in connection with the industrial exploration for oil and gas on the West Greenland shelf: Hellefisk 1, located only 60 km east of the mid-line in northern Davis Strait (fig. 2), penetrated 690 m of subaerial lavas continuous with the onshore basalts of Disko, and Nukik 2, located some 200 km further to the south, penetrated 150 m of hyaloclastites and olivine dolerites in an area where volcanic rocks were not expected from seismic and magnetic surveys (Henderson *et al.*, 1981). The nature of the Davis Strait has been discussed in several papers (e.g. Menzies, 1982; Srivastava *et al.*, 1982), and in this context the distribution and composition of the onshore and offshore volcanic rocks is important as one of the means of clarifying the tectonic evolution of the area. The present paper reports on the petrography and chemistry (including REE and Sr isotopes) of the volcanic rocks and briefly discusses their relationship to the onshore basalts of West Greenland and Baffin Island.

# Geological setting

Volcanic activity in onshore West Greenland began in the Paleocene. The volcanic rocks accumulated in the Nûgssuaq embayment (Henderson *et al.*, 1976), first as subaqueous pillow breccias overlying Cretaceous and Tertiary sediments, and later as subaerial lava flows. The volcanics eventually overflowed the marginal Precambrian basement to the east. The composition of the volcanic products changed with time from tholeiitic picrites and olivine porhyritic basalts (Vaigat Formation) to tholeiitic, plagioclase porphyritic basalts (Maligât Formation) (e.g. Hald & Pedersen, 1975; Clarke & Pedersen, 1976). On Hareøen and Ubekendt Ejland the tholeiites were followed by basaltic lavas of transitional to mildly alkaline affinities (Hald, 1976; Larsen, 1977).

The surface extension of the Tertiary lavas on adjacent parts of the West Greenland shelf (fig. 2) has been mapped by Park *et al.* (1971), Ross & Henderson (1973), Denham (1974) and Brett & Zarudski (1979). The investigations by the industrial companies in the region south and west of Disko (Henderson *et al.*, 1981) have shown that the offshore lavas dip westwards beneath Tertiary and Quaternary sediments with maximum thicknesses of more than 4000 m. The lavas are interrupted by a N – S trending ridge interpreted as Precambrian basement and located *c.* 50 km west of Disko. To the south nearly 700 metres of basaltic lavas were drilled by the Hellefisk 1 well situated above a depressed part of this ridge and close to the southern

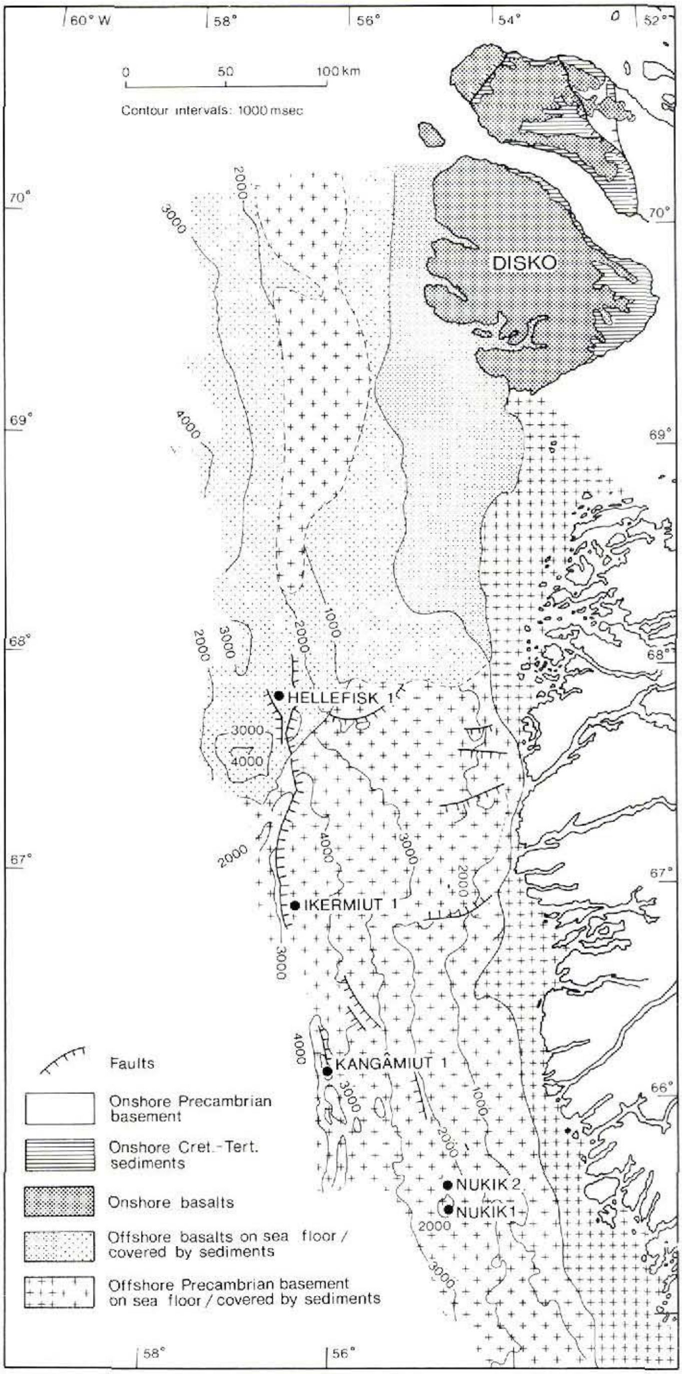



Fig. 2. Configuration of the Precambrian basement and the Tertiary basalts on the West Greenland shelf between 65°N and 71°N. Contours are in milliseconds of two-way travel time to acoustic basement. Simplified after Henderson *et al.* (1981).

boundary of the lava field (Henderson *et al.,* 1981). East of the Hellefisk 1 well the boundary is determined by a basement high, while to the southwest the top of the lavas rises above the basement (Henderson *et al.,* 1981, figs 8 and 9). No evidence of faulting along the boundary has been observed.

South of the Tertiary lava cover, in the region between 64°N and 68°N, the Precambrian basement dips westwards from exposures near the coast beneath Cretaceous to Quaternary sediments which in places are around 6000 m thick (Henderson *et al.,* 1981; Rolle, 1985). The sloping Precambrian surface is interrupted by a basement ridge on the outer shelf, at least partially fault-bounded and possibly corresponding to the ridge west of Disko. Among the four wells in the southern area three have either penetrated into basement highs (Kangâmiut 1 and Nukik 1) or bottomed in Late Cretaceous deposits (Ikermiut 1) without recovery of any volcanic material. The fourth well (Nukik 2) terminated in a sequence of flat-lying (as shown by the seismic survey) hyaloclastite breccias and dolerites. Apparently the volcanic rocks directly overlie the Precambrian basement with an estimated thickness of 500 m, and they wedge out towards the small high drilled by Nukik 1. The hyaloclastites are not easily identified by surface geophysical methods and may have a wider distribution in the deeper parts of the Cretaceous-Tertiary basin; however, it appears that the volcanic activity in this southern region was much less voluminous than in the northern Hellefisk area.

## State of material

The igneous material available from the wells is mainly cuttings, a few junk basket samples and side wall cores in addition to two conventional cores. The present work is mainly based on the 1 – 4 mm fraction of the rock cuttings. Further information has been obtained from the geophysical well data, especially the sonic, density and gamma ray logs.

## Hellefisk 1

Hellefisk 1 (67°53′N, 56°44′W, at a water depth of 163 m) penetrated Quaternary and Tertiary sediments overlying basaltic lavas at 2507 m below rotary table. The well bottomed within the lava pile at a depth of 3201 m. The basalt cuttings display cyclic variation with depth, being either grey, massive and well crystallised from flow interiors (characterised by high sonic velocity and high bulk density) or reddish and vesicular with quench crystals from flow tops (characterised by low sonic velocities and low bulk density) (fig. 3). Lava thicknesses of 5 – 50 m are indicated with an average of 20 m including the vesicular top zones, presumably of aa type. The cyclic variation of the cutting samples shows that mixing between individual lava flows was slight.

### *Petrography*

Judged from the cuttings the lavas are aphyric or plagioclase ± olivine ± clinopyroxene microporphyritic basalts. However, scattered phenocrysts could easily have been lost during the sample recovery and preparation as suggested by the presence of less than 0.5% plagioclase glomerocrysts ($An_{83}$) up to 3 mm in size in the cored basalt.

The groundmass consists of plagioclase ($An_{70-50}$), augite, pigeonite, Fe-Ti oxides and

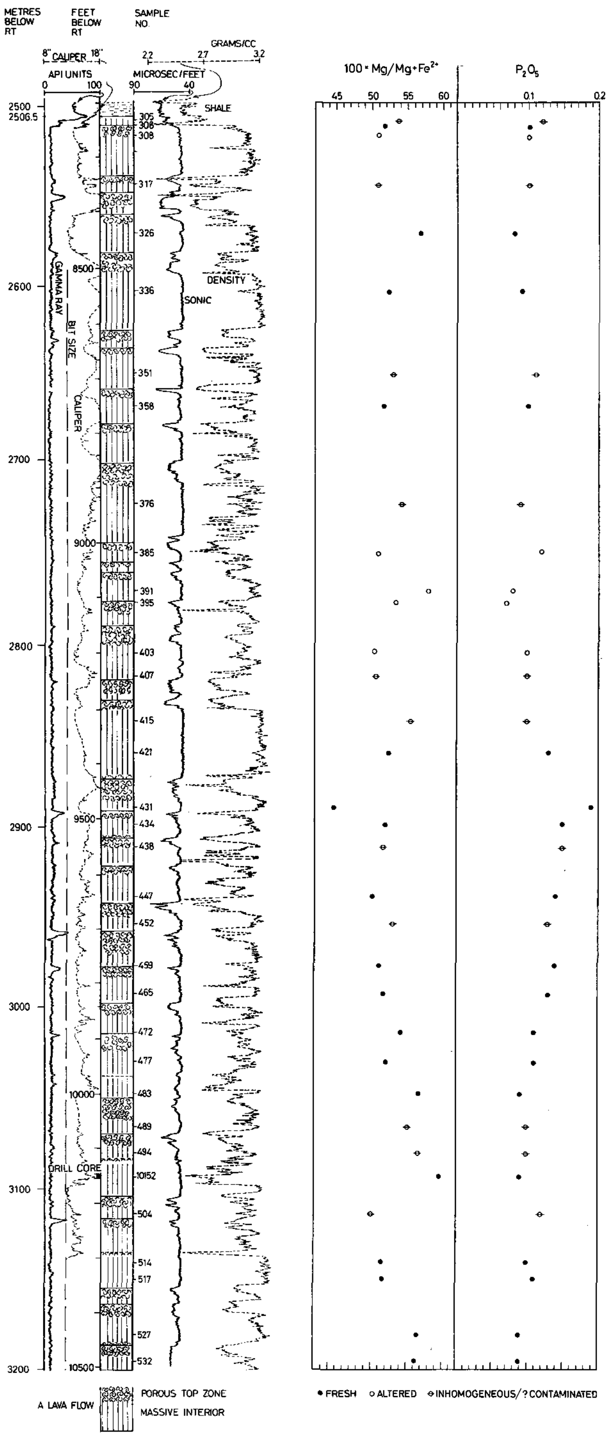



Fig. 3. The basaltic lavas in the Hellefisk 1 well. The discrim ination between flow interiors and flow tops is based on cuttings and geophysical log data. The figure shows from left to right: the depth below the rotary table (RT; 12 m above sea level) in metres, the gamma ray log in API units (100 units correspond to *c.* 7% $K_2O$), the bit size and the caliper log (actual diameter of the well) in inches, the depth below RT in feet, the drilled sequence, sample numbers, the sonic log in microseconds/feet, the density log in grams/cubic centimetres, and the variations in *mg'* and $P_2O_5$.

interstitial sheet silicates. Most of the lavas contain small amounts of altered groundmass olivine. Microprobe analyses are shown in fig 4. In general the more calcic plagioclase and magnesian pyroxene occur in the more magnesian lavas. The grain size (plagioclase) varies between 0.1 and 0.3 mm and the texture is intergranular to subophitic (in the more coarse-grained types). A preliminary study of the secondary minerals in the vesicular flow tops shows the presence of prehnite together with laumontite and other zeolites, indicative of zeolite facies metamorphism (Coombs *et al.,* 1959; Turner, 1981). In spite of this, most of the massive flow interiors are relatively fresh similar to the onshore plagioclase porphyritic basalts in West Greenland. Certain flows (mainly from 2750 to 2800 m below rotary table) are more pervasively metamorphosed with strongly altered plagioclase.

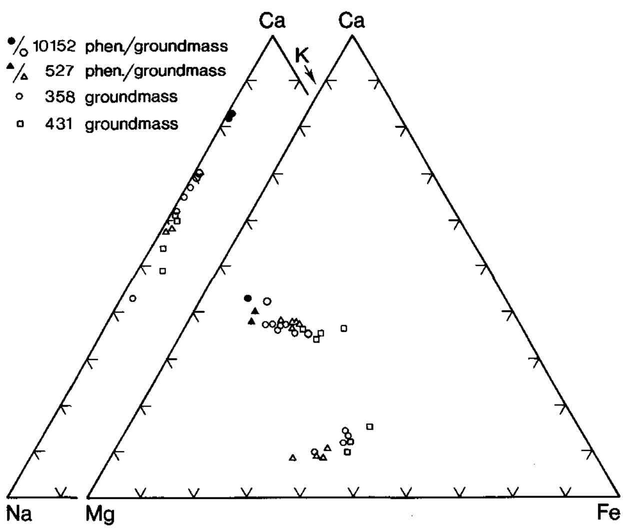



Fig. 4. Plot of plagioclase and pyroxene microprobe analyses, Hellefisk 1. Atomic proportions. Bulk rock analyses in Table 1.

## *Age*

The fresh, cored lava flow obtained from 600 m below the top of the lava pile has given K-Ar ages of 63.3 ± 12.6, 53.1 ± 5.3 and 54 ± 5.4 Ma, while both younger and older ages have been produced on rather altered material from cuttings and junk basket samples (Wolfenden, 1977).

Dating based on microfossils (Toxwenius, 1986b; personal communication, 1987) shows that the sediments immediately overlying the lava sequence in the Hellefisk 1 well were deposited in the Late Paleocene (NP zone 6). Following the correlation scheme of Berggren *et al.* (1985) this corresponds to an age of *c.* 61 Ma, which accordingly should be the minimum age of the lavas.

Microfossil dating on the youngest pre-volcanic sediments in onshore West Greenland yields an Upper Danian or Middle Paleocene age (Jørgensen & Mikkelsen, 1974; Hansen, 1980; B. B. Toxwenius, personal communication, 1987). Athavale & Sharma (1975) have demonstrated a reverse-normal-reverse magnetic stratigraphy in the lower 1500 m of the lava sequence on northwestern Disko. Using the time scale of Heirtzler *et al.* (1968) they suggested that the lavas were erupted between anomalies 25r and 24r. However, the new correlation scheme of Berggren *et al.* (1985) indicates that the eruptions rather took place between 27r and 26r (cf. Soper *et al.*, 1982) corresponding to the NP zones 4 to 6. It thus appears that the Hellefisk lavas are roughly contemporaneous with the main part of the onshore volcanics, while considerably younger ages have been obtained on late alkalic dykes on Ubekendt Ejland (30 – 40 Ma, $^{40}Ar/^{39}Ar$, Parrott & Reynolds, 1975) and on rhyolite glass from a conglomerate in the upper part of the lava sequence on Disko (*c.* 45 Ma, fission track dating of zircon, Hansen & Pedersen, 1985).

## Nukik 2

Nukik 2 (65°38′N, 54°46′W, at a water depth of 117 m) penetrated Quaternary and Tertiary sediments overlying a volcanic sequence at 2553 m below rotary table (fig. 5). The well bottomed within this sequence at a depth of 2694 m. Two 6 – 7 m thick hyaloclastite beds have been identified in the Tertiary sediments by side wall coring at 2375 m and 2465 m below rotary table, while the presence of a third hyaloclastite bed, 5 m thick at 2490 m, is indicated by the log data. From the upper 10 m of the volcanic sequence below 2553 m only glass and sediment cuttings were recovered, but at greater depth the cuttings are composed of a mixture of 40 – 60% sediments, 10 – 25% glass, 10 – 20% basalt and 10 – 20% dolerite down to the base of the well, where a massive dolerite was cored.

Combined evidence from cuttings and the sonic, density and gamma ray logs (fig. 5) suggests that the sequence below 2553 m is dominated by dolerite sheets, with subordinate deposits of hyaloclastite and shale. The lowermost dolerite sheet is at least 100 m thick. A mixing of cuttings has certainly taken place as there is no significant correlation between relative amounts of different rock cuttings and lithology as inferred from the log data. The absence of oxidized, vesicular material, common among the cuttings from the Hellefisk 1 well, indicates that no subaerial lavas are present. The hyaloclastites may either predate the dolerites or they may have formed during the intrusion of the basaltic magma into poorly consolidated sediments as described from Disko by Pedersen & Larsen (1987).

### *Petrography*

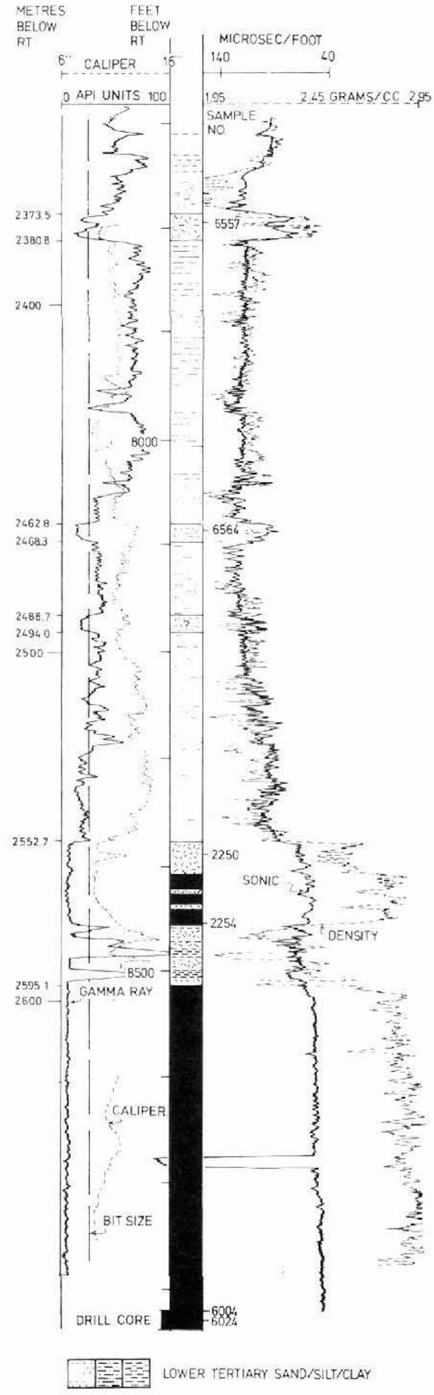
The two upper hyaloclastite layers from which side wall cores are available consist of porous, devitrified glass fragments in a fine-grained matrix. The glass is yellow and brown to opaque and shows irregular flow structures and drawn out vesicles. It carries euhedral and fragmentary plagioclase phenocrysts ($An_{63-56}$ in sample no. 6557), while a few micropheno-crysts of altered ?olivine may also be present.

The glassy cuttings from the volcanic sequence below 2553 m are composed of yellow-brown, devitrified, aphyric glass. They are almost homogeneous, with very few vesicles containing carbonate and greenish brown sheet silicates, while some are more vesicular and show irregular flow structures. A few cuttings contain plagioclase microlites up to 0.1 mm in size.

The basaltic cuttings are aphyric with a grain size of 0.1 – 0.5 mm and consist of plagioclase laths, subhedral altered olivine, intergranular to subophitic clinopyroxene and Fe-Ti oxides. Brownish sheet silicates are found as interstitial material and as fillings in the sparse vesicles. The more coarse grained basalt fragments grade into the dolerite described below.

The cored dolerite is composed of plagioclase laths ($An_{84-54}$), 1 – 2 mm in size, subhedral olivine ($Fo_{66-57}$) (*c.* 10%), ophitic augite, pigeonite surrounding olivine in some places, Fe-Ti

Fig. 5. Volcanic beds and dolerite sheets in the Nukik 2 well. The interpretation is based on cuttings, core samples (including side wall cores) and geophysical log data. The figure shows from left to right: the depth below the rotary table (24 m above sea level) in metres, the bit size, the caliper log (stippled graph), the gamma ray log (solid graph), the depth below RT in feet, the drilled sequence, the sample numbers, the density log (stippled graph) and the sonic log (solid graph). See fig. 3 for further explanation.



oxides and small amounts of fine grained interstitial material. The dolerite cuttings compare well with the core sample. The olivine is altered in the cuttings from the uppermost part of the volcanic sequence below 2553 m, but is mostly fresh at lower levels.

### *Age*

Two K-Ar age determinations on the dolerite from the drill core have given 68 ± 7 Ma and 62 ± 6 Ma (D. C. Rex, written communication, 1977) and suggest an Upper Cretaceous to Paleocene age (correlation scheme of Berggren *et al.*, 1985). Microfossil dating of the sediments in the uppermost part of the sequence below 2553 m indicates that the extrusive rocks are broadly contemporaneous with the basalts in the Hellefisk 1 well (Toxwenius, 1986a, b). The uppermost hyaloclastite layer at 2375 m is interbedded with Late Paleocene sediments (NP zone 9) (Toxwenius, 1986b), and is therefore younger than the Hellefisk 1 basalts.

## Chemistry

### *Hellefisk 1*

Thirty-three cutting samples from Hellefisk 1 together with the drill core were chosen for chemical analysis. The samples have all been selected from flow interiors and with few exceptions all the lava flows have been analysed. Mixing between individual lava flows was slight. A total amount of 2 – 2.5 g of each sample was carefully hand-picked under a low magnifying binocular microscope and *c.* 0.3 g was used for thin section. In 11 cases the hand-picked samples proved to be inhomogeneous in grain size or texture; these analyses are excluded from the tables and figures except for fig. 3, even though the inhomogeneities may reflect variations within the same lava flow. Comparisons between cutting samples and the drill core sample suggest that the former, despite lower Mg/Fe ratios, have not suffered from significant changes in chemical composition during the drilling operations or subsequent preparation.

Major and trace element concentrations are given in Table 1 together with analytical details and CIPW norms based on $Fe_2O_3/FeO$ ratios adjusted to 0.15 in order to diminish the effect of post-eruptional oxidation (Brooks, 1976). The data are arranged in order of decreasing depth. The samples with fresh plagioclase are characterised by volatile contents between 1.03 and 1.91%. These values are higher than expected for unaltered tholeiitic basalts. However, the small scatter displayed by Na, K, and Sr in the variation diagrams (fig. 6) indicates only a slight mobilisation of these elements, which are sensitive to alteration processes. Therefore, the analyses of samples with fresh plagioclase are believed to represent the origal composition of the basalts fairly closely in spite of the zeolite facies minerals in the vesicular top zones. The remaining samples with altered plagioclase have volatile contents between 2.2 and 4.5%, higher contents of $Na_2O$, $K_2O$ and Sr and lower CaO. Except for the calcium leaching similar chemical changes are reported by Wood *et al.* (1976) from Icelandic flood basalts affected by zeolite facies metamorphism.

The unaltered samples are tholeiites with 8.4% normative olivine to 1.7% normative quartz and with low concentrations of $TiO_2$, $K_2O$, $P_2O_5$, Sr, Ba and Zr (Table 1). The adjusted 100 × $Mg/(Mg + Fe^{2+})$ ratios (= *mg'* values) range between 60 and 50 excluding sample no. 431 with a value of 45. The ratio tends to decrease with height from 3100 to 2900 m, but

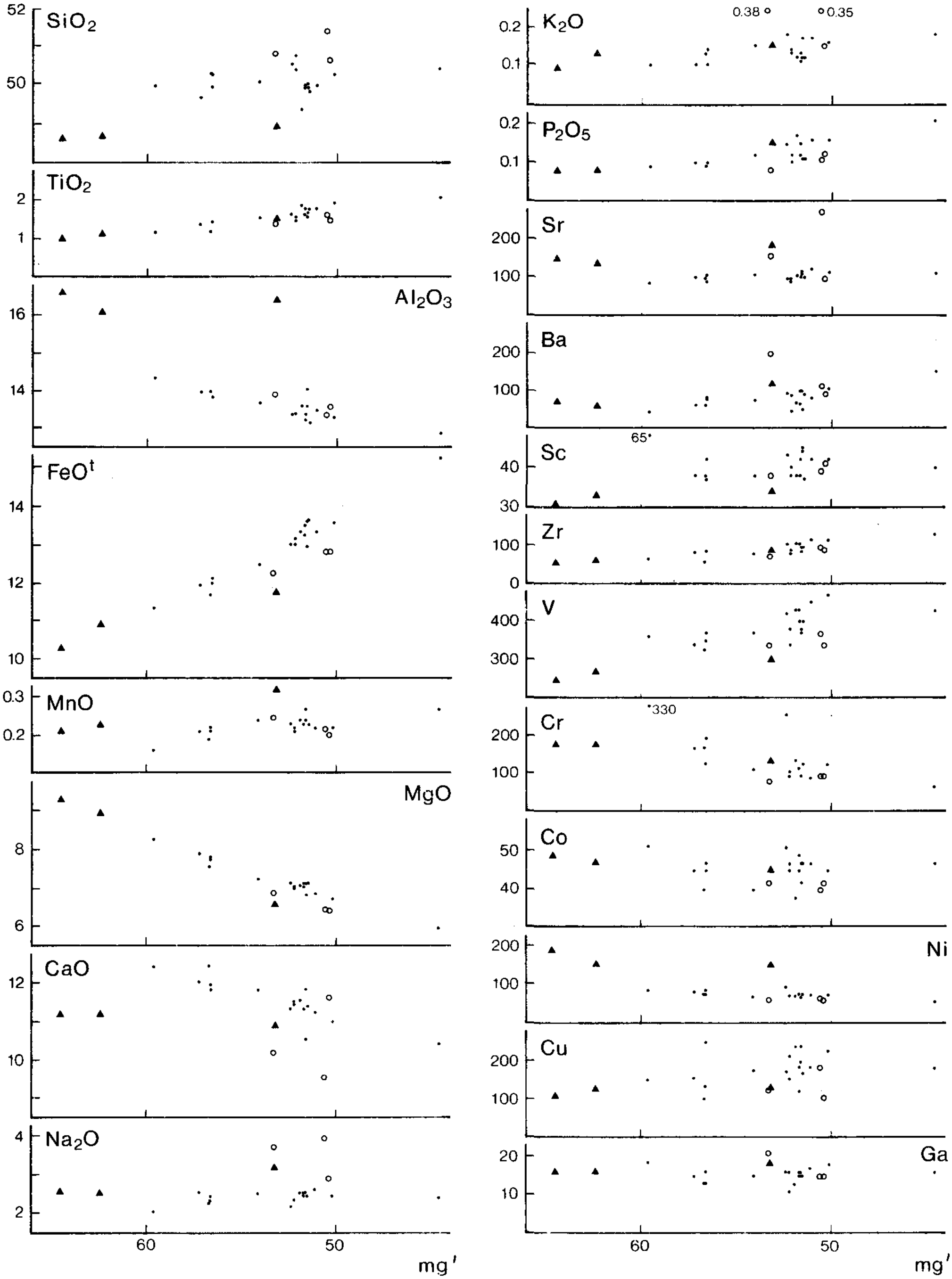



Fig. 6. Major and trace element variation related to the adjusted 100 × $Mg/(Mg+Fe^{2+})$ ratio (= *mg'*) for the Hellefisk basalts (dots: unaltered; open circles: altered) (from Table 1) and the Nukik 2 dolerites (triangles) (from Table 3, nos 1 – 3). Oxides in weight percent (analyses without l.o.i. and recalculated to 100%) and trace elements in ppm.

*Table 1. Chemical analyses of basaltic lavas from the Hellefisk 1 well*

| Sample | 532[1] | 527 | 517 | 514 | 10152[2] | 483 | 477 | 472 | 465 | 459 | 447 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 49.15 | 49.28 | 49.69 | 49.23 | 49.17 | 49.57 | 49.59 | 49.35 | 49.44 | 49.51 | 49.75 |
| $TiO_2$ | 1.37 | 1.39 | 1.65 | 1.74 | 1.11 | 1.39 | 1.52 | 1.50 | 1.75 | 1.78 | 1.92 |
| $Al_2O_3$ | 13.84 | 13.62 | 13.13 | 12.97 | 14.12 | 13.64 | 13.18 | 13.45 | 13.24 | 13.30 | 13.16 |
| $Fe_2O_3$ | 4.84 | 4.18 | 5.14 | 5.03 | 3.58 | 4.42 | 5.63 | 4.85 | 4.73 | 6.13 | 6.27 |
| FeO | 7.46 | 8.21 | 8.78 | 8.97 | 7.96 | 7.86 | 7.89 | 7.94 | 9.02 | 7.70 | 7.81 |
| MnO | 0.21 | 0.21 | 0.23 | 0.23 | 0.16 | 0.22 | 0.21 | 0.24 | 0.23 | 0.22 | 0.22 |
| MgO | 7.82 | 7.71 | 7.10 | 7.08 | 8.16 | 7.64 | 6.98 | 7.16 | 7.02 | 6.82 | 6.69 |
| CaO | 11.91 | 11.67 | 11.29 | 11.28 | 12.25 | 11.80 | 11.31 | 11.67 | 11.23 | 11.15 | 10.91 |
| $Na_2O$ | 2.51 | 2.42 | 2.54 | 2.42 | 2.03 | 2.28 | 2.32 | 2.46 | 2.47 | 2.60 | 2.45 |
| $K_2O$ | 0.10 | 0.14 | 0.13 | 0.12 | 0.10 | 0.10 | 0.14 | 0.15 | 0.11 | 0.17 | 0.16 |
| $P_2O_5$ | 0.10 | 0.10 | 0.12 | 0.11 | 0.09 | 0.10 | 0.12 | 0.12 | 0.15 | 0.16 | 0.16 |
| volat. | 1.37 | 1.60 | 1.18 | 1.25 | 1.32 | 1.24 | 1.54 | 1.29 | 1.20 | 1.03 | 1.15 |
| | 100.68 | 100.53 | 100.98 | 100.43 | 100.05 | 100.26 | 100.43 | 100.18 | 100.59 | 100.57 | 100.65 |
| *mg'* | 57.2 | 56.6 | 51.7 | 51.5 | 59.6 | 56.6 | 52.2 | 54.1 | 51.7 | 51.1 | 50.2 |
| *C.I.P.W. norms ($Fe_2O_3/FeO = 0.15$)* | | | | | | | | | | | |
| Q | | | | | | | | | | | 0.19 |
| or | 0.60 | 0.84 | 0.77 | 0.72 | 0.60 | 0.60 | 0.84 | 0.90 | 0.66 | 1.01 | 0.95 |
| ab | 21.46 | 20.75 | 21.61 | 20.72 | 17.44 | 19.54 | 19.93 | 21.12 | 21.09 | 22.20 | 20.93 |
| an | 26.47 | 26.24 | 24.17 | 24.45 | 29.56 | 27.03 | 25.52 | 25.58 | 24.94 | 24.34 | 24.67 |
| di | 26.77 | 26.14 | 25.96 | 26.02 | 25.85 | 25.99 | 25.36 | 26.71 | 25.07 | 25.20 | 23.97 |
| hy | 11.15 | 14.84 | 17.40 | 18.57 | 18.01 | 18.84 | 22.16 | 15.86 | 19.23 | 17.27 | 22.63 |
| ol | 8.41 | 5.96 | 4.08 | 3.31 | 4.02 | 2.80 | 0.45 | 4.27 | 2.74 | 3.64 | |
| mt | 2.29 | 2.32 | 2.58 | 2.62 | 2.17 | 2.30 | 2.52 | 2.39 | 2.57 | 2.56 | 2.60 |
| il | 2.63 | 2.68 | 3.15 | 3.34 | 2.14 | 2.67 | 2.93 | 2.89 | 3.35 | 3.41 | 3.68 |
| ap | 0.23 | 0.23 | 0.28 | 0.26 | 0.21 | 0.23 | 0.28 | 0.28 | 0.35 | 0.37 | 0.37 |
| *Trace elements, in ppm* | | | | | | | | | | | |
| Sr | 100 | 105 | 100 | 100 | 83 | 88 | 88 | 105 | 100 | 120 | 115 |
| Ba | 61 | 80 | 65 | 89 | 41 | 76 | 88 | 72 | 100 | 80 | 108 |
| Sc | 38 | 37 | 38 | 37 | 65 | 42 | 40 | 38 | 42 | 42 | 42 |
| Zr | 82 | 87 | 105 | 96 | 65 | 87 | 87 | 78 | 105 | 114 | 118 |
| V | 340 | 350 | 400 | 400 | 360 | 370 | 380 | 370 | 430 | 450 | 470 |
| Cr | 170 | 195 | 115 | 125 | 330 | 125 | 92 | 110 | 115 | 88 | 125 |
| Co | 45 | 47 | 49 | 47 | 51 | 45 | 45 | 40 | 45 | 47 | 45 |
| Ni | 83 | 88 | 75 | 75 | 86 | 78 | 72 | 69 | 72 | 72 | 75 |
| Cu | 155 | 250 | 185 | 170 | 150 | 135 | 215 | 180 | 122 | 185 | 230 |
| Ga | 15 | 13 | 15 | 15 | 18 | 16 | 16 | 15 | 16 | 17 | 18 |

*mg'* = $100 \times Mg/Mg+Fe^{2+}$ ($Fe_2O_3/FeO = 0.15$)

1 The three-digit sample numbers are abbreviations. The full numbers are 02-A-00-532, etc.

2 Analysis made on drill core.

3 Samples with strongly altered plagioclase.

| 434 | 431 | 421 | 403[1] | 395[1] | 358 | 336 | 326 | 317[1] | 306 |
|---|---|---|---|---|---|---|---|---|---|
| 48.59 | 49.78 | 50.08 | 48.13 | 49.57 | 49.42 | 50.24 | 49.77 | 49.85 | 48.91 |
| 1.82 | 2.03 | 1.60 | 1.38 | 1.34 | 1.64 | 1.44 | 1.16 | 1.55 | 1.52 |
| 13.38 | 12.67 | 13.22 | 12.87 | 13.53 | 13.41 | 13.23 | 13.82 | 12.93 | 13.75 |
| 5.49 | 6.25 | 4.38 | 4.68 | 5.76 | 5.71 | 5.07 | 5.11 | 5.15 | 6.51 |
| 8.16 | 9.24 | 9.09 | 7.97 | 6.79 | 7.65 | 8.30 | 6.97 | 7.81 | 7.47 |
| 0.24 | 0.27 | 0.23 | 0.19 | 0.24 | 0.27 | 0.22 | 0.19 | 0.21 | 0.24 |
| 6.99 | 5.91 | 7.08 | 6.11 | 6.75 | 6.74 | 6.94 | 7.50 | 6.29 | 7.02 |
| 11.39 | 10.30 | 11.25 | 11.09 | 9.96 | 11.72 | 11.41 | 12.33 | 9.28 | 10.33 |
| 2.47 | 2.39 | 2.17 | 2.76 | 3.62 | 2.46 | 2.33 | 2.27 | 3.87 | 2.48 |
| 0.12 | 0.18 | 0.18 | 0.14 | 0.37 | 0.12 | 0.13 | 0.13 | 0.34 | 0.17 |
| 0.17 | 0.21 | 0.15 | 0.11 | 0.08 | 0.11 | 0.10 | 0.09 | 0.11 | 0.11 |
| 1.45 | 1.09 | 1.05 | 4.52 | 2.19 | 1.40 | 1.16 | 1.32 | 2.98 | 1.91 |
| 100.27 | 100.32 | 100.48 | 99.95 | 100.20 | 100.65 | 100.57 | 100.66 | 100.37 | 100.42 |
| 51.9 | 44.6 | 52.4 | 50.4 | 53.3 | 51.6 | 52.2 | 56.7 | 50.6 | 51.6 |
| | | | | | | | | | |
| | 1.71 | 0.86 | | | | 0.37 | | | |
| 0.72 | 1.08 | 1.07 | 0.87 | 2.24 | 0.72 | 0.78 | 0.78 | 2.07 | 1.02 |
| 21.23 | 20.47 | 18.52 | 24.55 | 31.39 | 21.06 | 19.90 | 19.41 | 33.75 | 21.41 |
| 25.46 | 23.60 | 26.02 | 23.46 | 20.06 | 25.49 | 25.49 | 27.42 | 17.42 | 26.40 |
| 25.48 | 22.34 | 24.22 | 27.90 | 24.83 | 27.00 | 25.64 | 27.81 | 24.28 | 20.82 |
| 15.34 | 23.53 | 23.38 | 12.99 | 1.56 | 16.96 | 22.34 | 16.32 | 4.16 | 20.67 |
| 5.30 | | | 4.76 | 14.78 | 2.89 | | 3.60 | 12.57 | 3.86 |
| 2.55 | 2.88 | 2.52 | 2.45 | 2.35 | 2.48 | 2.49 | 2.24 | 2.46 | 2.60 |
| 3.51 | 3.90 | 3.06 | 2.76 | 2.61 | 3.15 | 2.76 | 2.23 | 3.03 | 2.94 |
| 0.40 | 0.49 | 0.35 | 0.27 | 0.19 | 0.26 | 0.23 | 0.21 | 0.26 | 0.26 |
| | | | | | | | | | |
| 105 | 110 | 96 | 96 | 155 | 110 | 96 | 96 | 270 | 115 |
| 68 | 152 | 94 | 89 | 200 | 100 | 46 | 61 | 115 | 49 |
| 38 | 40 | 43 | 41 | 38 | 45 | 38 | 38 | 39 | 44 |
| 105 | 130 | 105 | 87 | 74 | 96 | 78 | 59 | 96 | 87 |
| 430 | 430 | 420 | 340 | 340 | 380 | 340 | 325 | 370 | 370 |
| 135 | 65 | 255 | 92 | 79 | 92 | 102 | 170 | 92 | 95 |
| 38 | 47 | 51 | 42 | 42 | 47 | 47 | 40 | 40 | 42 |
| 72 | 57 | 92 | 60 | 60 | 69 | 72 | 78 | 66 | 66 |
| 240 | 185 | 175 | 107 | 125 | 240 | 155 | 103 | 185 | 200 |
| 13 | 16 | 16 | 15 | 21 | 15 | 11 | 13 | 15 | 16 |

Major elements by X-ray fluorescence ($Na_2O$ by atomic absorption), modified after Sørensen (1975); analyst: GGU chemical laboratories.

Trace elements by emission spectrography; analyst: H. Bollingberg, Institute of Petrology, University of Copenhagen.

See fig. 3 for correlation between sample nos. and depth below rotary table.

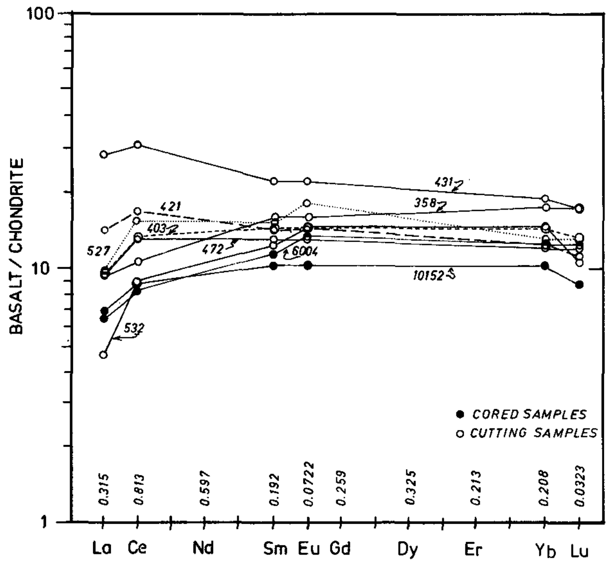



Fig. 7. Chondrite normalised REE distribution patterns in Hellefisk basalts and a Nukik dolerite. The chondrite values are those accepted by Taylor & Gorton (1977) and are given above the analysed elements.

*Table 2. REE and $^{87}Sr/^{86}Sr$ analyses*

| | Hellefisk 1 | | | | | | | | Nukik 2 |
|---|---|---|---|---|---|---|---|---|---|
| | 532 | 527 | 10152 | 472 | 431 | 421 | 403 | 358 | 6004 |
| La | 1.46 | 3.01 | 2.11 | 3.10 | 9.00 | 4.73 | 3.02 | 3.16 | 1.99 |
| Ce | 7.45 | 12.4 | 7.40 | 10.6 | 24.6 | 14.2 | 10.7 | 8.98 | 6.42 |
| Sm | 2.46 | 2.99 | 2.06 | 2.53 | 4.34 | 2.79 | 2.75 | 3.07 | 2.25 |
| Eu | 1.02 | 1.26 | 0.75 | 0.96 | 1.60 | 1.05 | 1.02 | 1.19 | 0.93 |
| Yb | 3.09 | 2.75 | 2.18 | 2.57 | 3.82 | 2.66 | 3.02 | 3.62 | 2.51 |
| Lu | 0.35 | 0.42 | 0.28 | 0.39 | 0.57 | 0.38 | 0.45 | 0.55 | 0.40 |
| $^{87}Sr/^{86}Sr$ | | 0.70324 ± 0.00014 | | | 0.70356 ± 0.00014 | | | 0.70444 ± 0.00005 | 0.70324 ± 0.00004 |

REE by instrumental neutron activation, analyst R. Gwozdz, Isotope Laboratory, Risø National Laboratory. Sr isotopes analysed by O. Larsen, Institute of Petrology, University of Copenhagen.

shows no systematic trend above this level (fig. 3). The chemical variation as a function of the *mg'* value is shown in fig. 6: decreasing *mg'* values correlate with decreasing contents of MgO, CaO, $Al_2O_3$, Cr and Ni and increasing contents of $TiO_2$, $FeO^t$, MnO, $K_2O$, $P_2O_5$, Ba, Zr and V, while $SiO_2$, $Na_2O$, Sr, Sc, Co, Cu and Ga are relatively constant. The REE data (Table 2) for most of the samples show a depletion in La and Ce (fig. 7) with normalized La/Sm ratios between 0.37 and 0.76. Higher concentrations of the light REE correlates with lower *mg'* values. Sample no. 421 has a flat REE pattern and no. 431 is enriched in the light REE with La/Sm = 1.3. The latter sample has the highest REE content.

The $^{87}Sr/^{86}Sr$ ratios show a considerable variation from 0.7032 to 0.7044, possibly due to the incipient alteration (cf. Wood *et al.,* 1976). We regard the lower value as representing an original low ratio similar to other data from West Greenland and Baffin Island (O'Nions & Clarke, 1972; Carter *et al.,* 1979).

*Table 3. Chemical analyses of volcanic rocks from the Nukik 2 well*

| Sample No. | 6024 | 6004 | 2254 | 2250 | 6564 | 6557 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 47.29 | 47.06 | 46.24 | 40.00 | 45.49 | 47.90 |
| $TiO_2$ | 1.08 | 0.99 | 1.41 | 1.68 | 1.56 | 1.53 |
| $Al_2O_3$ | 15.65 | 16.05 | 15.46 | 13.34 | 15.79 | 15.27 |
| $Fe_2O_3$ | 2.71 | 2.14 | 4.21 | 7.02 | 2.97 | 7.07 |
| FeO | 8.12 | 7.98 | 7.30 | 8.42 | 5.50 | 3.83 |
| MnO | 0.22 | 0.20 | 0.30 | 0.39 | 0.23 | 0.13 |
| MgO | 8.67 | 8.94 | 6.23 | 7.41 | 3.97 | 5.57 |
| CaO | 10.84 | 10.86 | 10.31 | 3.25 | 4.79 | 6.82 |
| $Na_2O$ | 2.46 | 2.46 | 3.00 | 3.29 | 6.73 | 3.64 |
| $K_2O$ | 0.13 | 0.09 | 0.14 | 0.54 | 0.34 | 0.51 |
| $P_2O_5$ | 0.08 | 0.08 | 0.15 | 0.17 | 0.27 | 0.38 |
| l.o.i. | 1.76 | 1.79 | 3.88 | 12.83 | 10.62 | 5.72 |
| | 99.01 | 98.64 | 98.63 | 98.34 | 98.26 | 98.37 |
| *mg'* | 62.4 | 64.6 | 53.2 | 50.4 | 49.5 | 52.5 |
| *C.I.P.W. norms* ($Fe_2O_3/FeO$ *= 0.15)* | | | | | | |
| or | 0.79 | 0.55 | 0.88 | 3.75 | 2.30 | 3.27 |
| ab | 21.43 | 21.51 | 26.87 | 32.75 | 43.95 | 33.45 |
| an | 32.20 | 33.57 | 29.96 | 17.66 | 13.58 | 25.87 |
| ne | | | | | 11.69 | |
| di | 18.43 | 17.51 | 19.13 | | 9.59 | 6.76 |
| hy | 7.99 | 7.05 | 3.58 | 9.85 | | 20.17 |
| ol | 14.75 | 15.70 | 14.14 | 26.28 | 13.41 | 4.24 |
| mt | 2.08 | 1.96 | 2.25 | 3.32 | 1.79 | 2.12 |
| il | 2.11 | 1.94 | 2.83 | 3.75 | 3.39 | 3.16 |
| ap | 0.21 | 0.22 | 0.37 | 0.46 | 0.72 | 0.96 |
| C | | | | 2.17 | | |
| *Trace elements, in ppm* | | | | | | |
| Sr | 135 | 150 | 185 | 120 | 130 | 425 |
| Ba | 58 | 69 | 120 | 21 | 220 | 790 |
| Sc | 33 | 30 | 34 | 34 | 28 | 19 |
| Zr | 59 | 55 | 87 | 122 | 110 | 200 |
| V | 265 | 245 | 300 | 265 | 265 | 160 |
| Cr | 180 | 180 | 133 | 125 | 115 | 26 |
| Co | 47 | 49 | 45 | 51 | 49 | 23 |
| Ni | 150 | 188 | 150 | 130 | 120 | 45 |
| Cu | 128 | 110 | 130 | 140 | 128 | 31 |
| Ga | 16 | 16 | 18 | 20 | 33 | 15 |

6024 & 6004 (05-D-00-6024 & 05-D-00-6004): Cored dolerite. 2694 m and 2689 m below rotary table.
2254 (05-B-00-2254): Dolerite cuttings. 2576 m below rotary table.
2250 (05-B-00-2250): Devitrified glass cuttings. 2557 m below rotary table.
6564 (05-E-00-6564): Devitrified hyaloclastite from side wall core. 2465 m below rotary table.
6557 (05-E-00-6557): Devitrified hyaloclastite from side wall core. 2375 m below rotary table.

See fig. 5 for correlation between sample nos. and depth below rotary table.

### *Nukik 2*

Chemical analyses of the hyaloclastite fragments are available from the side wall cores of the layers at 2375 m and 2465 m and from cuttings from the volcanic sequence below 2553 m (Table 3). The hyaloclastites are strongly hydrated and probably enriched in alkalies and leached in CaO, but an original basaltic composition is indicated by the concentration of the immobile elements Ti, P, Zr and Cr and by the presence of labradorite phenocrysts in the upper two layers. The dolerite core and the dolerite cuttings (from 2576 m below rotary table) are olivine tholeiites characterised by *mg'* values of 65 to 53, low concentrations of incompatible elements and a depleted REE pattern. In fig. 6 the Nukik dolerites line up with the trends of the Hellefisk basalts for most elements suggesting similar parental magmas. The Sr isotope ratio of 0.7032 obtained from the fresh, cored dolerite also agrees with the lowest value recorded in the Hellefisk basalts.

## Relationship to the onshore basalts in the Davis Strait region

The early opening of the Labrador Sea and the Baffin Bay, and the position of the Early Tertiary volcanic activity in relation to the rifting and spreading is not well understood. According to Srivastava (1978) and Srivastava & Falconer (1982) oceanic sea floor formed in the Labrador Sea along an east-northeast spreading direction from the Late Cretaceous to prior magnetic anomaly 24, and a north-northeast direction between anomalies 24 to 13. The second stage also includes spreading in Baffin Bay, which appears to be underlain by oceanic crust, at least in the central part of the basin (see discussion by Srivastava *et al.* (1981) and Keen & Peirce (1982)).

In the Davis Strait region the Kangâmiut 1 well has demonstrated that continental basement is at least locally present only 65 km east of the mid-line, 3500 m below the sea-bed (Henderson *et al.*, 1981). The seismic data indicate that the central part of the strait is underlain by attenuated continental crust possibly modified by numerous dyke intrusions, or by thickened oceanic crust similar to the crust below Iceland or the Iceland – Faeroe Ridge (see Menzies, 1982; Srivastava *et al.*, 1982). A prominent, fault-bounded structural high (fig. 1) crosses the strait from south-southwest to north-northeast parallel to the post-anomaly 25 spreading direction. The high is possibly associated with a major transform fault (the Ungawa fracture zone of Hood & Bower (1975) and Menzies (1982)), which may have linked the spreading in Labrador Sea and Baffin Bay.

The volcanic activity in the Davis Strait region is apparently related to the propagation of spreading northwards into Baffin Bay (cf. Soper *et al.*, 1982). In a structural analysis of the West Greenland volcanic province, Henderson (1973) placed a productive graben zone along the west coast, characterised by dyke injections and westwards tilted basalts. We suggest that the basement ridge located on the shelf *c.* 50 km west of Disko may form the western boundary of the graben. The basement ridge presumably continues beneath the Hellefisk basalts to the area west of Ikermiut 1 where the uplift is around 4000 m (fig. 2). The uplift predates a Middle Eocene marker horizon (Toxwenius, 1986b); it may, according to Risum (1979), be related to the Paleocene volcanism and associated tectonic activity in onshore West Greenland, although N – S trending faults in the Hellefisk area show that some of the uplift postdates the basaltic lavas. The depression of the basement ridge in the Hellefisk area is possibly related to the tectonism in the Davis Strait as the southern boundary of the West Greenland lava field lies on trend with the fault-controlled northern boundary of the Davis Strait High and with the inferred Ungawa fracture zone.

With an average thicknesss of 20 m the Hellefisk lavas may represent voluminous extrusions from distant eruption sites, comparable to the lava flows which flooded the Precambrian basement east of the West Greenland graben zone (see e.g. Larsen, 1981). Three possible source areas may be considered: the West Greenland graben; zones of attenuation further to the west; and a leaky Ungawa fault zone as suggested by Menzies (1982).

The chemical data give some constraints regarding the source area for the shelf volcanics as Clarke (1970) and O'Nions & Clarke (1972) have demonstrated distinctive differences between the lavas of Baffin Island and West Greenland (Svartenhuk Halvø) in terms of LIL element contents (Table 4; figs 8 and 9). The Hellefisk basalts (except no. 431) and the Nukik dolerites are similar to abyssal tholeiites (N-type MORB of Wood, 1979) in terms of most

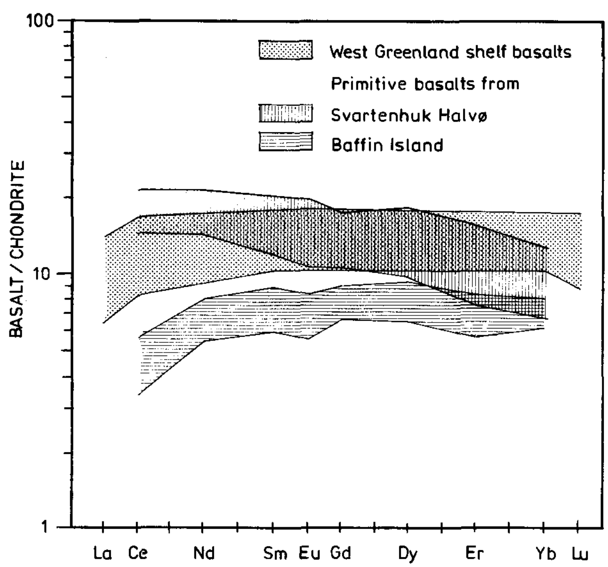
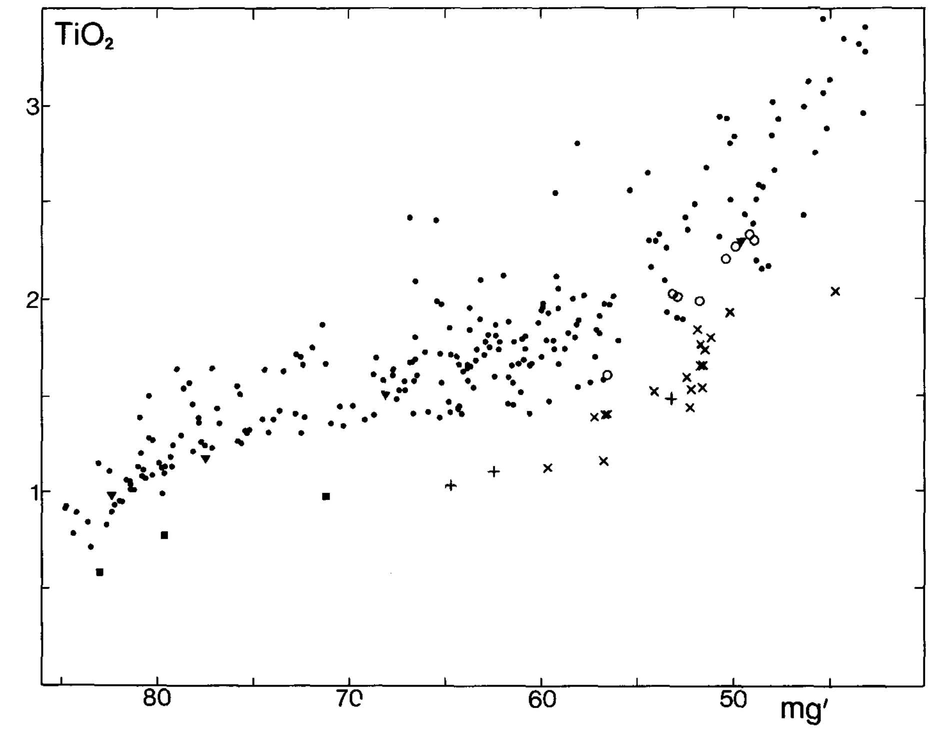
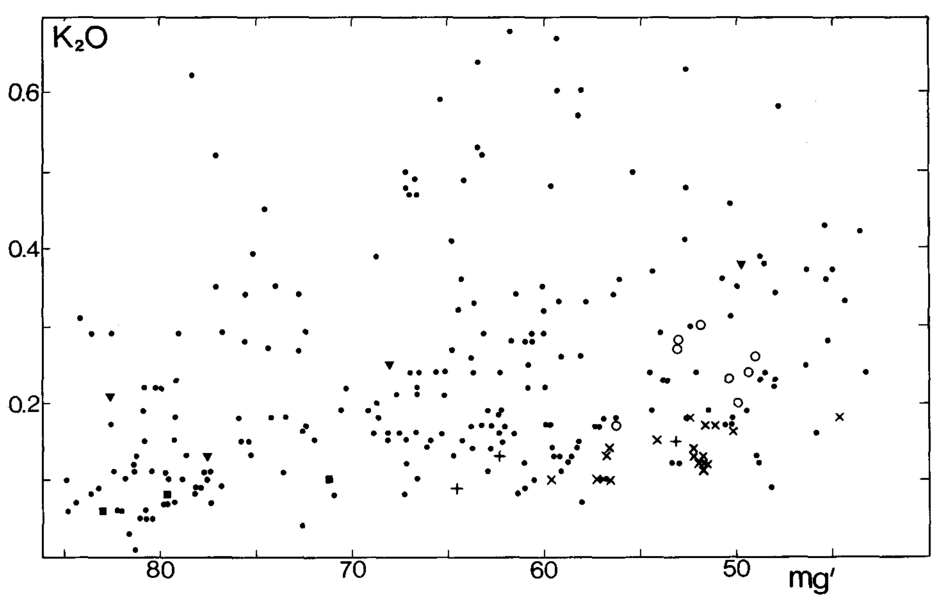



Fig. 8. Comparison between the REE in the West Greenland shelf basalts (not including no. 431) and the onshore basalts of Baffin Island and Svartenhuk Halvø after O'Nions & Clarke (1972). In order to show the different patterns of these data the most REE enriched basalt (with a flat pattern) of Baffin Island and the REE poorest basalt of Svartenhuk Halvø (enriched in the light REE) have been removed.

major and trace elements. They are low in $TiO_2$ (0.99 – 1.92%), $K_2O$ (0.09 – 0.18%), $P_2O_5$ (0.09 – 0.17%), Sr (83 – 185 ppm), Zr (55 – 118 ppm) and light REE with normalised La/Sm ratios below 1. The Ba contents (41 – 120 ppm) and the $^{87}Sr/^{86}Sr$ ratios are relatively high and suggest a less depleted mantle source relative to the N-type MORB. All these features tie the shelf basalts chemically to the picrites and olivine basalts of Baffin Island, although a direct comparison is made difficult by the small overlap in *mg'* values represented only by intraflow differentiates of the Baffin Island lavas. In contrast, the onshore plagioclase porphyritic basalts from the Maligât Formation in West Greenland have higher contents of $TiO_2$ (2.30%), $K_2O$ (0.38%) and $P_2O_5$ (0.26%) according to the average values from Svartenhuk Halvø


TiO2
3
2
1
80
70
60
50
mg'


K2O
0.6
0.4
0.2
80
70
60
50
mg'

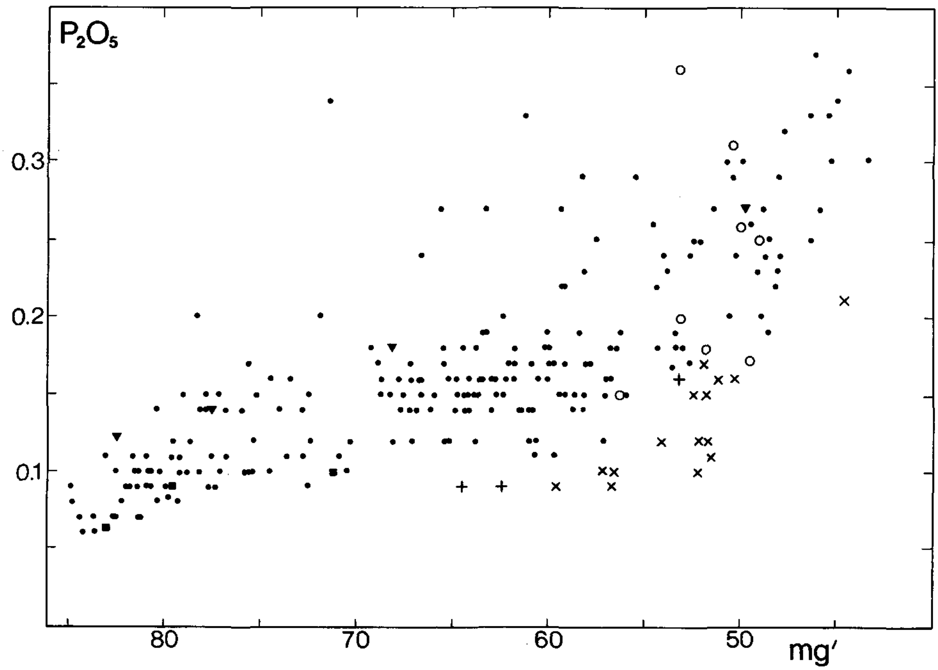



Fig. 9. Plots of $TiO_2$, $K_2O$ and $P_2O_5$ versus *mg′*. × : unaltered Hellefisk basalts; + : Nukik dolerites; dots: onshore basalts from Svartenhuk Halvø and Ubekendt Ejland (J. G. Larsen, unpublished analyses). All analyses by the chemical laboratory of the Geological Survey of Greenland. Open circles: shelf basalts dredged south of Disko (Clarke, 1975). Squares and triangles: average analyses of Baffin Island basalts and Svartenhuk Halvø basalts respectively (Clarke, 1970).

(Clarke, 1970; see also fig. 9 and Table 4, nos 3 and 4). Low potassium tholeiites are found in the lava sequences of Svartenhuk Halvø and Ubekendt Ejland (Larsen, 1977; see Table 4, nos 5 and 6), Nûgssuaq (Hald, 1976) and Disko (F. Ulff-Møller, personal communication, 1986), but still they are slightly enriched in $TiO_2$, $K_2O$ and $P_2O_5$ relative to the Hellefisk basalts and Nukik dolerites with similar *mg′* values. The same applies to the samples dredged from the sea-floor south of Disko (Clarke, 1975; see fig. 9 and Table 4, no. 7).

Clarke (1970) and Clarke & Pedersen (1976) introduced a generalised petrogenetic scheme, whereby the plagioclase porphyritic basalts of West Greenland were formed by olivine and olivine gabbro fractionation from picritic liquids with compositions similar to the olivine rich lavas of the lower Vaigat Formation. Plagioclase porphyritic basalts have not been found on Baffin Island, but primitive lavas of the Baffin Island type could be parental to the Hellefisk basalts and the Nukik dolerites. According to Clarke (1970) the Baffin Island picrites were generated by partial melting at 25 kb pressure in the mantle (see also Francis, 1985). The Hellefisk basalts probably represent liquids which were equilibrated at pressures less than 5 kb because they show a trend towards slightly oversaturated compositions with lower *mg′* values (Table 1) (cf. Green & Ringwood, 1967). Silicic differentiates were, however, apparently not formed, in contrast to the situation in onshore West Greenland.

*Table 4. Comparison between Hellefisk basalts, other basalts from the Davis Strait region and ocean ridge basalts*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| No. of analyses | 17 | 1 | 10 | 14 | 4 | 7 | 8 | 7 |
| $SiO_2$ | 49.47 ± 0.40 | 49.5 | 46.8 | 48.4 | 48.31 | 46.31 | 49.44 | 49.3 |
| $TiO_2$ | 1.55 ± 0.22 | 1.32 | 1.51 | 2.30 | 1.90 | 1.89 | 2.09 | 1.53 |
| $Al_2O_3$ | 13.44 ± 0.31 | 14.4 | 12.9 | 14.2 | 14.01 | 14.75 | 14.59 | 13.9 |
| $Fe_2O_3$ | 5.12 ± 0.78 | 2.7 | 2.9 | 4.3 | 5.19 | 4.80 | 4.41 | 2.44 |
| FeO | 8.07 ± 0.60 | 6.3 | 8.0 | 8.0 | 6.60 | 7.05 | 8.40 | 9.93 |
| MnO | 0.22 ± 0.02 | 0.17 | 0.17 | 0.20 | 0.19 | 0.18 | 0.20 | 0.21 |
| MgO | 7.20 ± 0.41 | 8.0 | 11.2 | 5.8 | 7.54 | 7.47 | 6.52 | 7.35 |
| CaO | 11.46 ± 0.48 | 14.5 | 11.6 | 11.8 | 12.20 | 11.55 | 10.78 | 11.37 |
| $Na_2O$ | 2.39 ± 0.14 | 1.91 | 2.00 | 2.55 | 2.36 | 2.20 | 2.75 | 2.05 |
| $K_2O$ | 0.13 ± 0.03 | 0.09 | 0.25 | 0.38 | 0.10 | 0.12 | 0.24 | 0.16 |
| $P_2O_5$ | 0.12 ± 0.03 | 0.13 | 0.18 | 0.26 | 0.15 | 0.22 | 0.23 | 0.14 |
| Volat. | 1.32 ± 0.22 | 0.52 | 2.25 | 1.03 | 1.47 | 3.86 | 0.53 | 0.94 |
| | 100.49 | 99.54 | 99.76 | 99.22 | 100.02 | 100.40 | 100.18 | 99.32 |
| *Trace elements, in ppm* | | | | | | | | |
| Sr | 101 ± 10 | 177 | 286 | 277 | | 223 | 231 | 125 |
| Ba | 75 ± 20 | 46 | 95 | 141 | | 75 | 83 | 43 |
| Sc | 42 ± 7 | | | | | | | |
| Zr | 91 ± 16 | 76 | 98 | 161 | | 100 | 142 | 92 |
| V | 387 ± 41 | | | | | | | |
| Cr | 143 ± 65 | 340 | 753 | 205 | | 308 | 193 | |
| Co | 45 ± 4 | | | | | 40 | | |
| Ni | 76 ± 7 | 160 | 390 | 80 | | 160 | 71 | 89 |
| Cu | 182 ± 43 | 108 | 149 | 207 | | 208 | 166 | |
| Ga | 15 ± 2 | 22 | 20 | 23 | | | | |

1. Average composition of Hellefisk basalts with l.o.i. < 2% (1σ) (no. 431 is excluded).
2. Segregation vein in Baffin Island picrite (Clarke, 1968, anal. R – 16).
3. Average composition of olivine poor basalts from Svartenhuk Halvø (Clarke, 1970).
4. Average composition of plagioclase porphyritic basalts from Svartenhuk Halvø (Clarke, 1970).
5. Average composition of low potassium plagioclase porphyritic basalts ($K_2O$ < 0.2%) from Svartenhuk Halvø (Larsen, unpublished).
6. Average composition of low potassium plagioclase porphyritic basalts ($K_2O$ < 0.2%) from Ubekendt Ejland (Larsen, 1977).
7. Average composition of dredged plagioclase porphyritic basalts south of Disko (Clarke, 1975).
8. Average composition of olivine tholeiites from Reykjanes Ridge, 63°17.6′N; 24°13.5′W (Brooks *et al.*, 1974).

In conclusion, we suggest that the depleted character of the Hellefisk basalts and the Nukik dolerites, both located on the outer part of the shelf, reflects a transition towards an oceanic lithosphere or a strongly attenuated continental lithosphere, and their position may thus be comparable with that of the Early Tertiary MORB-like basalts drilled from the Rockall Plateau margin (e.g. Joron *et al.,* 1984). In most pre-drift reconstructions (e.g. Srivastava *et al.,* 1981), the Hellefisk lavas are located within 100 to 150 km from the onshore volcanics of Baffin Island and much closer to the offshore extension of these. We have shown above that the volcanics from the two localities on both sides of Davis Strait are closely related in terms of LIL element contents and La/Sm ratios. In addition, Clarke & Upton (1971) have demonstrated that the Baffin Island lavas and breccias have flown in from the east. Following in part the ideas of these authors we therefore propose that both the Hellefisk lavas and the Baffin Island volcanics (but not the onshore West Greenland volcanics) were extruded through a central rift zone during the initial opening of Davis Strait and Baffin Bay.

The Hellefisk basalts may alternatively have erupted within the present West Greenland shelf: the intersection of the West Greenland graben with an Ungawa fault zone could have caused periods of strong rifting and generation of MORB-like basalts, either in the fault zone or in the southern end of the graben.

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## References

Athavale, R. N. & Sharma, P. V. 1975: Paleomagnetic results on Early Tertiary lava flows from West Greenland and their bearing on the evolution history of the Baffin Bay – Labrador Sea region. *Can. J. Earth Sci.* **12,** 1 – 18.

Berggren, W. A., Kent, D. V. & Flynn, J. J. 1985: Paleogene geochronology and chronostratigraphy. *In* Snelling, N. J. (edit.) *Geochronology and the geological record,* 141 – 195. *Mem. geol. Soc. Lond.* **10,** 141 – 195.

Brett, C. P. & Zarudzki, E. F. K. 1979: Project Westmar. A shallow marine geophysical survey on the West Greenland continental shelf. *Rapp. Grønlands geol. Unders.* **87,** 29 pp.

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

Brooks, C. K., Jakobsson, S. P. & Campsie, J. 1974: Dredged basaltic rocks from the seaward extensions of the Reykjanes and Snaefellsnes volcanic zones, Iceland. *Earth planet. Sci. Lett.* **22,** 320 – 327.

Carter, S. R., Evensen, N. M., Hamilton, P. J. & O'Nions, R. K. 1979: Basalt magma sources during the opening of the North Atlantic. *Nature* **281,** 28 – 30.

Clarke, D. B. 1968: Tertiary basalts of the Baffin Bay area. Unpublished Ph. D. thesis, Univ. Edinburgh.

Clarke, D. B. 1970: Tertiary basalts of Baffin Bay: possible primary magma from the mantle. *Contr. Miner. Petrol.* **25,** 203 – 224.

Clarke, D. B. 1975: Tertiary basalts dredged from Baffin Bay. *Can. J. Earth Sci.* **12,** 1396 – 1405.

Clarke, D. B. & Pedersen, A. K. 1976: Tertiary volcanic province of West Greenland. *In* Escher, A. & Watt, W. S. (edit.) *Geology of Greenland,* 364 – 385. Copenhagen: Geological Survey of Greenland.

Clarke, D. B. & Upton, B. G. J. 1971: Tertiary basalts of Baffin Island: field relations and tectonic setting. *Can. J. Earth Sci.* **8,** 248 – 258.

Coombs, D. S., Ellis, E. J., Fyfe, W. S. & Taylor, A. M. 1959: The zeolite facies, with comments on the interpretation of hydrothermal synthesis. *Geochim. cosmochim. Acta* **17,** 53 – 107.

Denham, L. R. 1974: Offshore geology of northern West Greenland (69° to 75°N). *Rapp. Grønlands geol. Unders.* **63,** 24 pp.

Francis, D. 1985: The Baffin Bay lavas and the value of picrites as analogues of primary magmas. *Contr. Miner. Petrol.* **89,** 144 – 154.

Green, D. H. & Ringwood, A. E. 1967: The genesis of basaltic magmas. *Contr. Miner. Petrol.* **15,** 103 – 190.

Hald, N. 1976: Early Tertiary flood basalts from Hareøen and western Nûgssuaq, West Greenland. *Bull. Grønlands geol. Unders.* **120,** 36 pp.

Hald, N. & Pedersen, A. K. 1975: Lithostratigraphy of the Early Tertiary volcanic rocks of central West Greenland. *Rapp. Grønlands geol. Unders.* **69,** 17 – 24.

Hansen, J. M. 1980: Stratigraphy and structure of the Paleocene in central West Greenland and Denmark. Unpublished lic. scient. thesis, Univ. Copenhagen, 154 pp.

Hansen, K. & Pedersen, A. K. 1985: Fission track dating of lower Tertiary rhyolitic glass rocks from Disko. *Rapp. Grønlands geol. Unders.* **125,** 28 – 30.

Heirtzler, J. R., Dickson, G. O., Herron, E. M., Pitman III, W. C. & Le Pichon, X. 1968: Marine magnetic anomalies, geomagnetic field reversals, and the motion of the ocean floor and continents. *J. geophys. Res.* **73,** 2119 – 2136.

Henderson, G. 1973: The geological setting of the West Greenland basin in the Baffin Bay region. *Pap. geol. Surv. Can.* **71-23,** 521 – 544.

Henderson, G., Rosenkrantz, A. & Schiener, E. J. 1976: Cretaceous – Tertiary sedimentary rocks of West Greenland. *In* Escher, A. & Watt, W. S. (edit.) *Geology of Greenland,* 340 – 362. Copenhagen: Geological Survey of Greenland.

Henderson, G., Schiener, E. J., Risum, J. B., Croxton, C. A. & Andersen, B. B. 1981: The West Greenland Basin. *In* Kerr, J. W. & Fergusson, A. J. (edit.) *Geology of the North Atlantic borderlands. Mem. Can. Soc. Petrol. Geol.* **7,** 399 – 428.

Hood, P. & Bower, M. 1975: Aeromagnetic reconnaissance of Davis Strait and adjacent areas. *In* Yorath, C. J., Parker, E. R. & Glass, D. J. (edit.) Canada's continental margins and offshore petroleum exploration. *Mem. Can. Soc. Petrol. Geol.* **4,** 433 – 451.

Joron, J. L., Bougault, H., Mauray, R. C., Bohn, M. & Desprairies, A. 1984: Strongly depleted tholeiites from the Rockall Plateau margin, North Atlantic: geochemistry and mineralogy. In Roberts, D. G. & Schnitker, D. *et al.* (edit.) *Initial Reports Deep Sea Drilling Project* **81,** 783 – 794. Washington: U.S. Govt. Printing Office.

Jørgensen, T. & Mikkelsen, N. 1974: Coccoliths from volcanic sediments (Danian) in Nûgssuaq, West Greenland. *Bull. geol. Soc. Denmark* **23,** 225 – 230.

Keen, M. J. & Clarke, D. B. 1974: Tertiary basalts of Baffin Bay: geochemical evidence for a fossil hot-spot. *In* Kristjansson, L. (edit.) *Geodynamics of Iceland and the North Atlantic area,* 127 – 137. Dordrecht: D. Reidel Publishing Company.

Keen, C. E. & Peirce, J. W. 1982: The geophysical implications of minimal Tertiary motion along Nares Strait. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland Geosci.* **8,** 327 – 337.

Larsen, J. G. 1977: Transition from potassium olivine tholeiites to alkali basalts on Ubekendt Ejland, the Tertiary volcanic province of West Greenland. *Meddr Grønland* **200**(1), 42 pp.

Larsen, J. G. 1981: A preliminary study of flow directions of Tertiary hyaloclastites and pahoehoe lava flows on Svartenhuk Halvø, West Greenland. *Rapp. Grønlands geol. Unders.* **105,** 28 – 32.

MacLean, B., Falconer, R. K. H. & Clarke, D. B. 1978: Tertiary basalts of western Davis Strait: bedrock core samples and geophysical data. *Can. J. Earth Sci.* **15,** 773 – 780.

Menzies, A. W. 1982: Crustal history and basin development of Baffin Bay. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland Geosci.* **8**, 295 – 312.

O'Nions, R. K. & Clarke, D. B. 1972: Comparative trace element geochemistry of Tertiary basalts from Baffin Bay. *Earth. planet. Sci. Lett.* **15**, 436 – 446.

Park, I., Clarke, D. B., Johnson, J. & Keen, M. J. 1971: Seaward extension of the West Greenland Tertiary volcanic province. *Earth planet. Sci. Lett.* **10**, 235 – 238.

Parrott, R. J. E. & Reynolds, P. H. 1975: Argon-40/argon-39 geochronology: age determinations of basalts from the Labrador Sea area. *Abstr. geol. Soc. Am.* **7**, 835 only.

Pedersen, A. K. 1985: Reaction between picrite magma and continental crust: early Tertiary silicic basalts and magnesian andesites from Disko, West Greenland. *Bull. Grønlands geol. Unders.* **152**, 126 pp.

Pedersen, A. K. & Larsen, L. M. 1987: Early Tertiary volcanic rocks from eastern Disko and south-eastern Nûgssuaq. *Rapp. Grønlands geol. Unders.* **135**, 11 – 17.

Risum, J. B. 1979: Seismic mapping of lower Tertiary sediments offshore West Greenland between 66° and 68°N. *Rapp. Grønlands geol. Unders.* **95**, 51 – 53.

Rolle, F. 1985: Late Cretaceous – Tertiary sediments offshore central West Greenland: lithostratigraphy, sedimentary evolution, and petroleum potential. *Can. J. Earth Sci.* **22**, 1001 – 1019.

Ross, D. I. & Henderson, G. 1973: New geophysical data on the continental shelf of central and northern West Greenland. *Can. J. Earth Sci.* **10**, 485 – 497.

Soper, N. J., Dawes, P. R. & Higgins, A. K. 1982: Cretaceous – Tertiary magmatic and tectonic events in North Greenland and the history of adjacent ocean basins. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland Geosci.* **8**, 205 – 220.

Srivastava, S. P. 1978: Evolution of the Labrador Sea and its bearing on the early evolution of the North Atlantic. *Geophys. J. roy. Astr. Soc.* **52**, 313 – 357.

Srivastava, S. P. & Falconer, R. K. H. 1982: Nares Strait: a conflict between plate tectonic predictions and geological interpretation. *In* Dawes, P. R. & Kerr, J. W. (edit.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland Geosci.* **8**, 339-352.

Srivastava, S. P., Falconer, R. K. H. & MacLean, B. 1981: Labrador Sea, Davis Strait, Baffin Bay: geology and geophysics – a review. *In* Kerr, J. W. & Fergusson, A. J. (edit.) *Geology of the North Atlantic borderlands. Mem. Can. Soc. Petrol. Geol.* **7**, 333 – 398.

Srivastava, S. P., MacLean, B., Macnab, R. F. & Jackson, H. R. 1982: Davis Strait: structure and evolution as obtained from a systematic geophysical survey. *In* Embry, A. F. & Balkwill, H. R. (edit.) Arctic geology and geophysics. *Mem. Can. Soc. Petrol. Geol.* **8**, 267 – 278.

Sørensen, I. 1975: X-ray fluorescence spectrometry at GGU. *Rapp. Grønlands geol. Unders.* **75**, 16 – 18.

Taylor, S. R. & Gorton, M. P. 1977: Geochemical application of spark source mass spectrography – III. Element sensivity precision and accuracy. *Geochim. cosmochim. Acta* **41**, 1375 – 1380.

Toxwenius, B. B. 1986a: Biostratigraphical zonation and correlation of five Late Cretaceous – Tertiary wells, offshore central West Greenland: summation of main results. *Rapp. Grønlands geol. Unders.* **130**, 36 – 43.

Toxwenius, B. B. 1986b: Compilation of Late Cretaceous – Tertiary biostratigraphic data and correlation of five wells, offshore central West Greenland. 69 pp. Grønlands geol. Unders. Open file report.

Turner, F. J. 1981: *Metamorphic petrology. Mineralogical, field and tectonic aspects.* 2 ed. 524 pp. New York: Mc Graw-Hill.

Wolfenden, E. B. 1977: Potassium-argon age dating of four samples from the Arco Greenland Inc. Hellefisk-1 well drilled off West Greenland. 10 pp. Robertson Research International Limited, report no. 4117P.

Wood, D. A. 1979: A variably veined suboceanic upper mantle genetic significance for mid ocean ridge basalts from geochemical evidence. *Geology* **7**, 499 – 503.

Wood, D. A., Gibson, I. L. & Thompson, R. N. 1976: Elemental mobility during zeolite facies metamorphism of Tertiary basalts of eastern Iceland. *Contr. Miner. Petrol.* **55**, 241 – 254.

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