DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2007/67

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G E U S

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Abstract

During the summer of 2006, seabed sampling was carried out in the Labrador Sea, in the Davis Strait, and the waters around Hareøen, Nuussuaq and Disko. Igneous rocks were recovered in almost all dredges. In the Labrador Sea the dredged features were two physiographic highs around 62°28′ N, 56°18′–57°55′ W (Seamounts A and B). The eastern side of the Davis Strait High was dredged at six stations around 66°08′–66°36′ N, 57°16′–57°41′ W. The southern Aasiaat Basin was dredged at two stations around 68°08′–68°13′ N, 58°05′–58°28′ W. Several dredge stations around Disko and Nuussuaq yielded igneous rocks that were recognised as derived from the surrounding land areas. One station in the northeastern Disko Bugt at 69°19′ N, 51°37′ W yielded large amounts of uniform gabbroic rocks that are considered to be of local derivation. The submarine features sampled in 2006 are partly new and partly the same as were sampled by dredging in 2003 and 2004 and reported on by Larsen & Dalhoff (2006), to which the present report is a sequel.

A total of 41 samples of igneous rocks were chemically analysed. The results show that the same compositional groups as identified by Larsen & Dalhoff (2006) are present. Seven samples have been sent for radiometric dating by the $^{40}Ar/^{39}Ar$ method, to be carried out in 2008.

Seamount A was dredged for the first time in 2006. All the structures dredged south of 64°N have remarkably similar populations of igneous rock compositions irrespective of their different tectonic settings, with the 'main' compositional type constituting 59–73% of the analysed clast population in all of Seamounts A, B, C, E, H, and Canyon A. This supports a transported origin for the major part of the rocks, most probably from the Hecla High volcanic complex as suggested by Larsen & Dalhoff (2006).

The analytical data set from the Davis Strait High is greatly extended. Still, all the recovered rocks are geochemically depleted basalts of which the majority are different from the depleted basalts onshore West Greenland and Canada. They are considered to be derived from a relatively local source. The extended data set shows a larger spread in indications of melting depth on the Davis Strait High than on Baffin Island and the West Greenland shelf, suggesting a lithosphere of variable thickness, and partly very thin.

Five analysed samples from the southern Aasiaat Basin all show great similarities to the lavas of the Maligât Formation onshore West Greenland. If they are derived from the Maligât Formation, three of the samples are evolved high-Ti samples which can only be derived from a few specific lava flows at the top of the Rinks Dal Member. If the dredged samples are derived from an other volcanic area, this must contain lavas compositionally similar to those of the Maligât Formation, and the dredged basalts could represent the preserved top part of a lava succession.

The gabbro sample dredged in northeastern Disko Bugt represents one of several sill complexes in the sediments beneath the waters of Disko Bugt. The dredged sill is dissimilar to other sills in the region but similar to a widespread suite of late dykes of unknown age on Disko. Our knowledge and understanding of the Paleocene-Eocene succession of igneous events, even in the onshore areas, is far from complete.

Introduction

In order to obtain information on the geology of the regions offshore West Greenland, a number of physiographic features were dredged by GEUS in 2003 and 2004. These features comprised seamounts, submarine canyons, and the Davis Strait High which is a structural high of disputed origin. Igneous rocks were recovered from nearly all of these features, and the results of investigations of these rocks are reported by Larsen & Dalhoff (2006). In 2006, new dredging was carried out over both old and new targets, and again igneous rocks turned up in almost every dredge haul. This report on the igneous rocks recovered in 2006 should be considered as a supplementary sequel to Larsen & Dalhoff (2006). It is particularly concerned with a small seamount (Seamount A) in the northern Labrador Sea, the Davis Strait High, the southern Aasiaat Basin, and the northeastern Disko Bugt.

Dredge localities

Dredging in 2006 was carried out from the Danish research vessel R/V Dana. Detailed technical information is found in the cruise report (Dalhoff et al. 2006).

In total 33 stations were dredged, and igneous rocks were recovered at all of these. Particular care was given to obtain a good selection of rocks from several stations on the Davis Strait High. On the other hand, the igneous rocks from 20 stations close to Hareøen, Nuussuaq and Disko are considered to be derived from the surrounding land areas, and in several cases onshore lithologies could be recognised in the dredged samples, for example picritic hyaloclastites from the Vaigat Formation. Consequently, with one exception (Station 148, see below) no samples from the Hareøen–Nuussuaq–Disko region were analysed. Site information for the 13 stations from which igneous rocks were analysed is given in Table 1, and the locations are shown in Fig. 1.

Table 1. Coordinates for dredge stations 2006 with analysed igneous rocks

Station	Location	Latitude N	Longitude W	UTM Northing	UTM Easting	Depth, m
DANA06-01D	Seamount A	62°29.161′	57°54.851′	6928658	452883	2400
		62°28.247′	57°54.541′	6926957	453126	
DANA06-02D	Seamount A	62°28.454′	57°51.208′	6927303	455995	2550
		62°27.779′	57°51.646′	6926054	455602	
DANA06-04D	Seamount B	62°27.448′	56°24.796′	6925282	530269	2100
		62°28.098′	56°24.921′	6926487	530151	
DANA06-05D	Seamount B	62°27.741′	56°18.081′	6925883	536037	2100
		62°26.963′	56°18.015′	6924439	536110	
DANA06-29D	Davis Strait High	66°08.287′	57°40.767′	7335471	469329	550
		66°08.339′	57°39.551′	7335558	470245	
DANA06-30D	Davis Strait High	66°08.283′	57°38.363′	7335445	471138	560
		66°08.332′	57°37.097′	7335526	472091	
DANA06-31D	Davis Strait High	66°08.296′	57°37.668′	7335464	471661	550
		66°08.401′	57°36.430′	7335650	472594	
DANA06-32D	Davis Strait High	66°30.328′	57°17.589′	7376283	486959	650
		66°30.166′	57°18.808′	7375987	486054	
DANA06-33D	Davis Strait High	66°28.003′	57°36.269′	7372063	473067	550
		66°27.827′	57°37.479′	7371745	472165	
DANA06-34D	Davis Strait High	66°36.441′	57°16.423′	7387636	487873	620
		66°36.329′	57°17.668′	7387432	486953	
DANA06-50D	South Aasiaat Basin	68°12.805′	58°05.394′	7567057	454859	400
		68°13.000′	58°04.579′	7567410	455428	
DANA06-51D	South Aasiaat Basin	68°08.031′	58°28.044′	7558512	439015	400
		68°08.209′	58°27.950′	7558841	439088	
DANA06-148D	NE Disko Bugt	69°18.673′	51°36.566′	7698417	712305	235-170
		69°18.835′	51°36.686′	7698710	712200	

Each dredge is located by its starting point and its ending point.

Latitude and longitude in degrees and decimal minutes. UTM coordinates for zone 21.

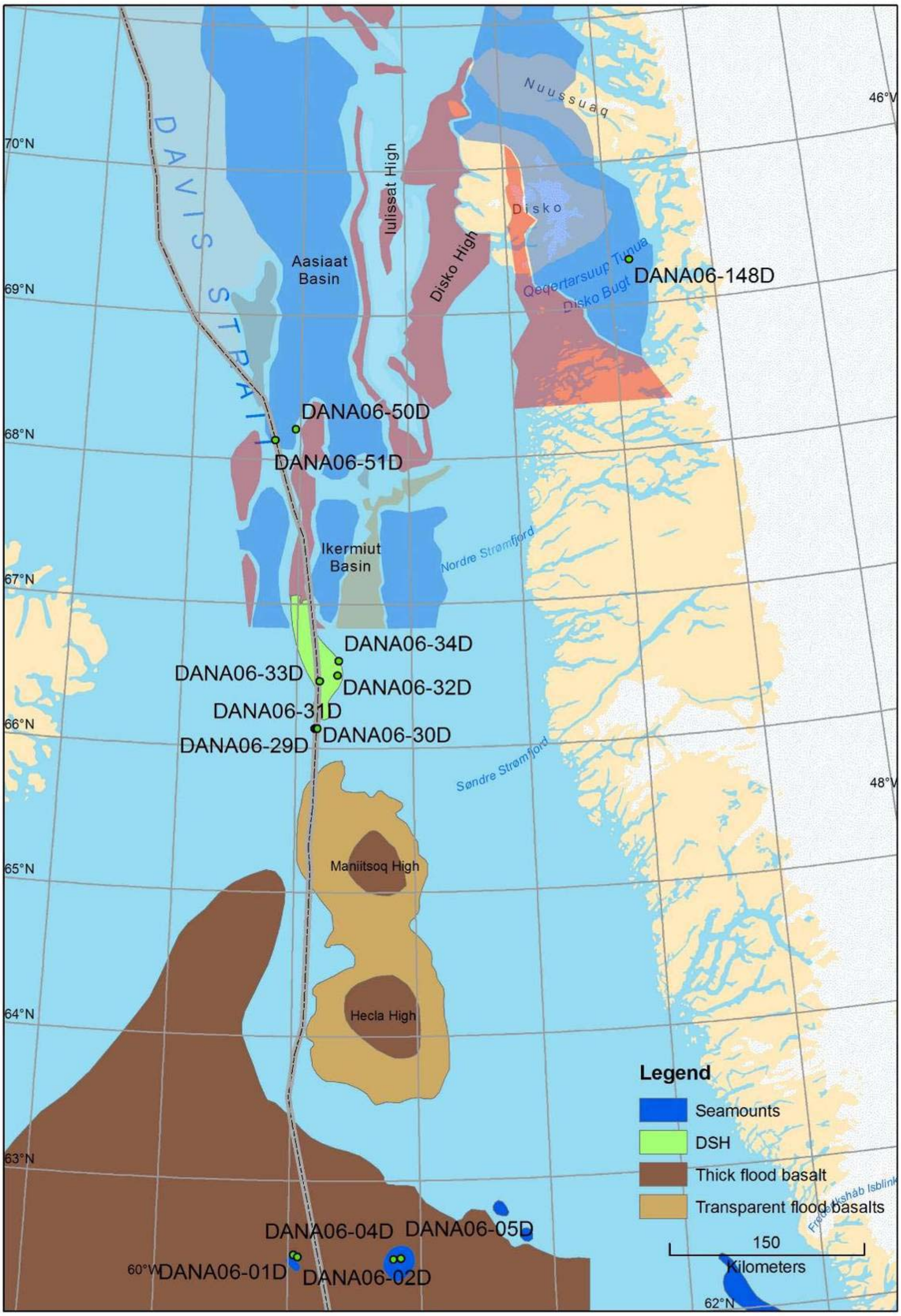

Fig. 1. The location of the dredged features in the Labrador Sea and the Davis Strait. Igneous rocks were recovered from seamounts A and B, the Davis Strait High, the southern Aasiaat Basin, and several sites around Hareøen, Nuussuaq and Disko. Only the dredges with analysed igneous rocks are indicated.

Seamount A

Seamount A is a structure located at the western rim of the Lady Franklin Basin in Canadian waters on top of the Hudson Fracture Zone. The seamount rises *c* 750 m above the seabed from 2600 m depth through Cenozoic sediments. It has the same seismic properties as Seamount B and is, like this, considered to be of volcanic origin. A seismic line crossing Seamount A is shown in Fig. 2.

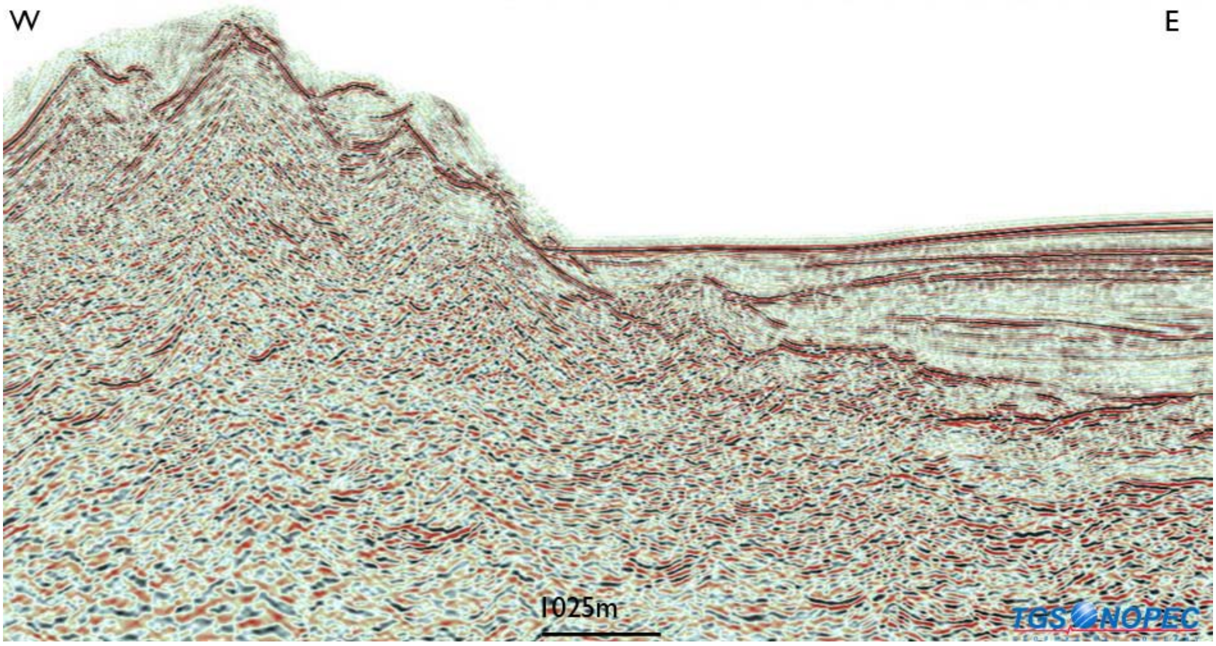

Fig. 2. Seismic line GRC02-5, across Seamount A. The seamount rise from below Cenozoic sediments and is considered to be of volcanic origin.

Two dredges on Seamount A yielded a total of 277 clasts of which 70 were igneous rocks.

Seamount B

Seamount B is a relatively large structure in the Lady Franklin Basin, situated c. 80 km west of Seamount C and 75 km east of Seamount A. It is considered to be of volcanic origin (Sørensen 2006) and has a guyot-like morphology with a flat surface from which several small cone-shaped seamounts rise up to 1000 m above the surface. Many igneous rocks were recovered from this seamount in 2003–2004, among these a few strongly alkaline rocks (basanites) of local aspect (Larsen & Dalhoff 2006). The dredges in 2006 attempted to recover more of these local rocks.

Two dredges on Seamount B yielded a total of 396 clasts of which 128 were igneous rocks.

Davis Strait High

The Davis Strait High is a structural high in the central part of the Davis Strait. It is fault-bounded and is associated with the large NNE–SSW-trending Ungava fault zone. It possesses a positive gravity anomaly, and its acoustic basement comes very close to the sea bed. It has been suggested to consist of oceanic crust (Keen & Barrett 1972), a mixture of continental crust and plume-related volcanic rocks similar to those at Cape Dyer on Baffin Island and in West Greenland (Keen et al. 1974), and a sliver of continental crust surrounded by oceanic crust (Srivastava et al. 1982). However, there is no oceanic crust east of the Davis Strait High (Chalmers & Pulvertaft 2001). Basalts have been recovered by shallow core drilling on the exposed hard surface of the High (Srivastava et al. 1982). Some of these drill sites are situated within 6–26 km from the dredge sites.

Palaeozoic limestone appears to be present on the High, because clasts of Palaeozoic limestone are frequent and large in all dredge hauls from all years and are considered to be of local derivation from an exposed sedimentary packet (Stouge et al. 2006).

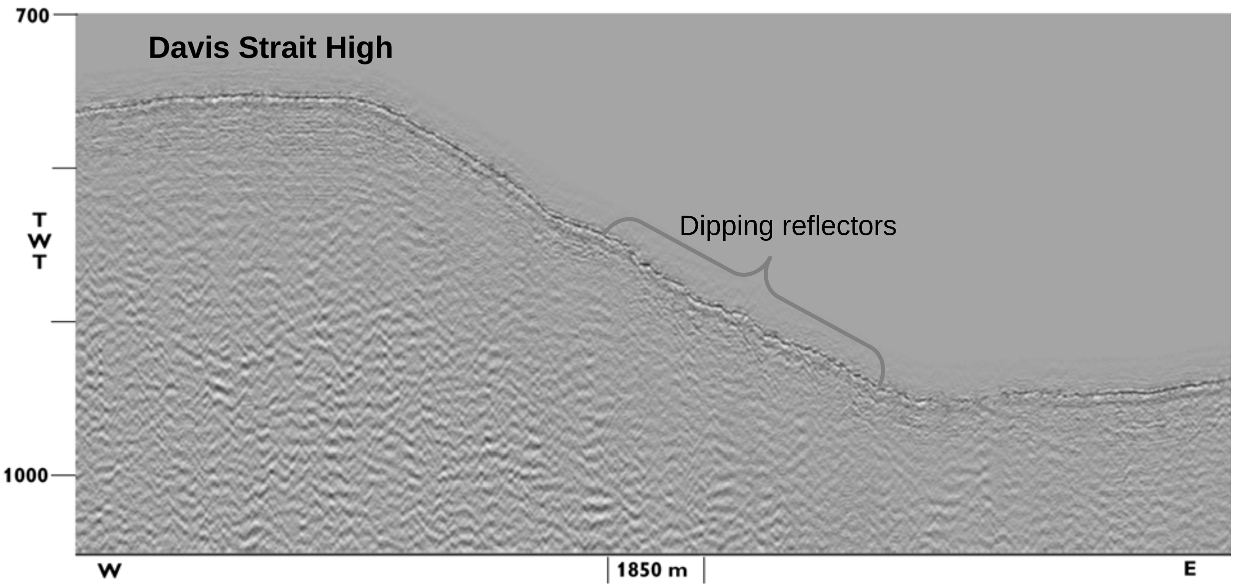

Fig. 3. Single channel seismic line acquired during the seabed campaign in 2003 across the eastern part of the Davis Strait High showing eastward dipping reflectors.

On the eastern side of the Davis Strait High, seismic profiles show a number of weakly eastward-dipping stratiform units outcropping or very close to the sea floor (Fig. 3). Six dredges which all recovered igneous rocks were made here over a stretch of 52 km in 2006. They yielded a total of 1567 clasts of which 207 were igneous rocks.

Southern Aasiaat Basin

Dredge stations 50D and 51D are situated 18 km apart from each other in the southernmost part of the Aasiaat Basin, west of the northern end of the Davis Strait High. Station 50D is located very close to the west side of the Davis Strait High and is sampled from east towards west along seismic line DW05-115, shot point 2000, across a pronounced escarpment originating from a seabed-penetrating fault. The target of Dana06-51D was likewise to test possible outcropping sediments across another seabed-penetrating fault resulting in a pronounced escarpment, located on seismic line DW05-201 near shot point 15200, as shown in Fig. 4. No local igneous rocks are known from the area.

The two dredges yielded a total of 400 clasts which were mainly Precambrian gneisses considered to be ice-rafted debris. There were 24 igneous rocks and 15 sedimentary rocks.

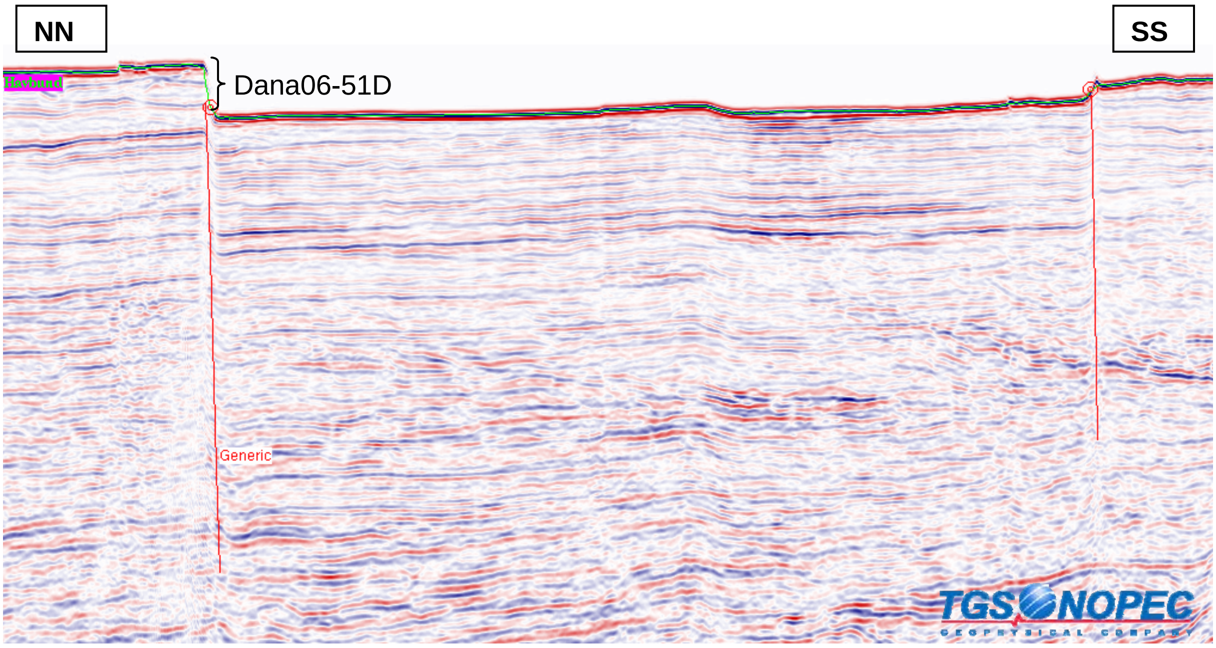

Fig. 4. Seismic line DW05-201 showing sample location of the Dana06-51D dredge from c. 400 m of water depth. Figure modified from Nunaoil A/S.

Hareøen-Nuussuaq-Disko region

With one exception (Station 148D), 20 dredge stations close to Hareøen, Nuussuaq and Disko all yielded igneous rocks that are considered to be derived from the surrounding land areas. Very frequently, igneous lithologies known from the onshore areas could be recognised in the dredged rocks, for example picritic hyaloclastites from the Vaigat Formation. Consequently, except for Station 148 (see below), no samples from the Hareøen–Nuussuaq–Disko region were investigated further.

Northeastern Disko Bugt

Dredge station 148D is situated on seismic line GGUi95-05 in an area where the pattern on the aeromagnetic map indicates a large sill close to the sea bed (Rasmussen 2002). The dredge haul returned a full dredge in which an estimated 98% of the recovered material consisted of irregular, non-abraded blocks of uniform, massive, very coarse-grained gabbro. This gabbro is considered to be derived from a local sill outcrop on the sea floor.

Igneous rocks

As for the 2003–2004 work, the material recovered in 2006 was shipped to Copenhagen, visually inspected, and the clasts classified into three groups: Precambrian rocks (gneisses, amphibolites, and metasediments), sediments, and igneous rocks. The igneous clasts were lumped into lithological groups (massive, vesicular, fragmentary, aphyric, plagioclase-phyric, olivine-phyric, gabbroic, rhyolitic, other), and slightly less than half the clasts were selected for thin sectioning, making sure the various lithological types were all represented. For Seamount B, which was also investigated earlier, fewer samples were selected.

Inspection of the thin sections revealed that five samples from Seamount A, four from Seamount B, and 13 from the Davis Strait High have petrographic features (saussuritised and tinted plagioclases, uralitised mafic minerals) indicating a Precambrian age. Most of these are gabbros, and four are fine-grained metasediments. These samples were not analysed. The remaining samples are mainly fine- to medium-grained aphyric, plagioclase-phyric and olivine-phyric rocks. There were a few singular samples such as a rhyolite from Seamount B and an amphibole-phyric rock from Seamount A. Also, a native-iron-bearing basalt was found on the Davis Strait High; this sample (Dana-06-30D-13) is petrographically so unique that it can with certainty be identified as derived from a very big lava flow in the Niaqussat Member of the Maligât Formation in western Disko (Pedersen 1977), and it was therefore not analysed. A representative set of samples was selected for analysis, as given in Table 2. From Seamount B only three samples, including the rhyolite, were selected because 11 samples from 2003–2004 have already been analysed. Sample statistics are shown in Table 2.

Table 2. Dana 2006: Igneous rocks recovered and further investigated

Feature	Recovered	Thin sectioned	Analysed	Earlier analysed*	Total analysed
Seamount A	70	30	12	0	12
Seamount B	128	30	3	11	14
Davis Strait High	207	91	20	12	32
S. Aasiaat Basin	24	9	5	0	5
NE Disko Bugt	Numerous	1	1	0	1

*Dredges 2003 and 2004.

In total, 41 samples from 2006 were analysed by the Rock Geochemical Laboratory at GEUS. Major elements were measured by X-ray fluorescence (XRF) analysis of fused glass discs as described by Kystol & Larsen (1999). Trace elements were measured by ICP-MS analysis using a modified version of the method described by Turner et al. (1999). Reproducibility, based on replicate digestion of samples, varied from 1.5% to 4% for most analyses. All the analyses obtained are included in Appendix 1.

Analytical results

The analyses are treated in the same way as the analyses of the 2003–2004 samples. Before plotting in diagrams the analyses were recalculated to 100% on a volatile-free basis. In the following presentation of the results, all data from 2003, 2004 and 2006 are plotted in the diagrams for Seamount B and the Davis Strait High.

In the presentation of the results for the 2003–2004 dredges, Larsen & Dalhoff (2006) identified 12 compositional groups. The same groups are found in the 2006 samples. The groups are shown in Table 3 in a slightly simplified form because the three groups 'Main basalts', Extended main basalts' and 'probably associated basalts', which are closely related, have been lumped into one group.

Table 3. Analysed dredged igneous rocks 2003, 2004 and 2006

Number of samples in each chemical group	Seamount A 2006	Seamount B 2003-2004	Seamount B 2006	Davis Strait High 2003-04	Davis Strait High 2006	Southern Aasiaat Basin 2006
1-3. Main group+extended+associated	7	6	1	0	0	0
4. Flat-patterned basalts	1	1	1	0	0	0
5. Contam. enriched or normal basalts	0	0	0	0	0	0
6. Rhyolites	0	0	1	0	0	0
7. Highly depleted basalts	1	0	0	4	6	0
8. Depleted basalts	0	0	0	4	13	5
9. Contaminated depleted basalts	0	0	0	4	1	0
10. Enriched basalts	2	1	0	0	0	0
11. Basanites	0	2	0	0	0	0
12. Precambrian basalts	1?	3	0	0	0	0
Sum	12	13	3	12	20	5
In per cent of young rocks	**%**	**%**		**%**	**%**	**%**
1-3. Main group+extended+associated	64	60	-	0	0	0
4. Flat-patterned basalts	9	10	-	0	0	0
5. Contam. enriched or normal basalts	0	0	-	0	0	0
6. Rhyolites	0	0	-	0	0	0
7. Highly depleted basalts	9	0	-	33	30	0
8. Depleted basalts	0	0	-	33	65	100
9. Contaminated depleted basalts	0	0	-	33	5	0
10. Enriched basalts	18	10	-	0	0	0
11. Basanites	0	20	-	0	0	0

Seamounts A and B

The three additional samples from Seamount B that were analysed are one main-group basalt, one flat-patterned basalt and one rhyolite (Fig. 5). No further samples of the local basanite were found. The rhyolite is new for Seamount B (which is why it was analysed), but rhyolites are also known from Canyon A (one) and Seamount H (one), so the type is known from the dredge locations in the northern Labrador Sea south of 64°N (Larsen & Dalhoff 2006). The rhyolite from Canyon A has an age of 58.98 ± 0.37 Ma. The new sample from Seamount B is unsuitable for dating because of alteration.

In Seamount A, the 'extended main group' (groups 1–3) of basalts constitutes the majority of the samples (Table 3 and Fig. 5). As demonstrated by Table 3, the distribution of compositional types from Seamount A is very similar to that of Seamount B. It is also similar to the other dredge locations south of 64°N as given in Larsen & Dalhoff (2006, Table 2). One highly depleted sample has two other counterparts south of 64°N, on Seamounts C and E. One sample with amphibole phenocrysts is as strongly alkaline as the basanites of Seamount B but its major element composition is radically different; it is a trachyandesite marginal to alkali trachyte. It is also compositionally different from the amphibole-bearing Tertiary camptonite dykes onshore West Greenland (Larsen 2006), and it is tentatively considered to be from the Proterozoic Gardar Province in South Greenland. A Gardar gabbro sample has also been recognised from Seamount B (Larsen & Dalhoff 2006).

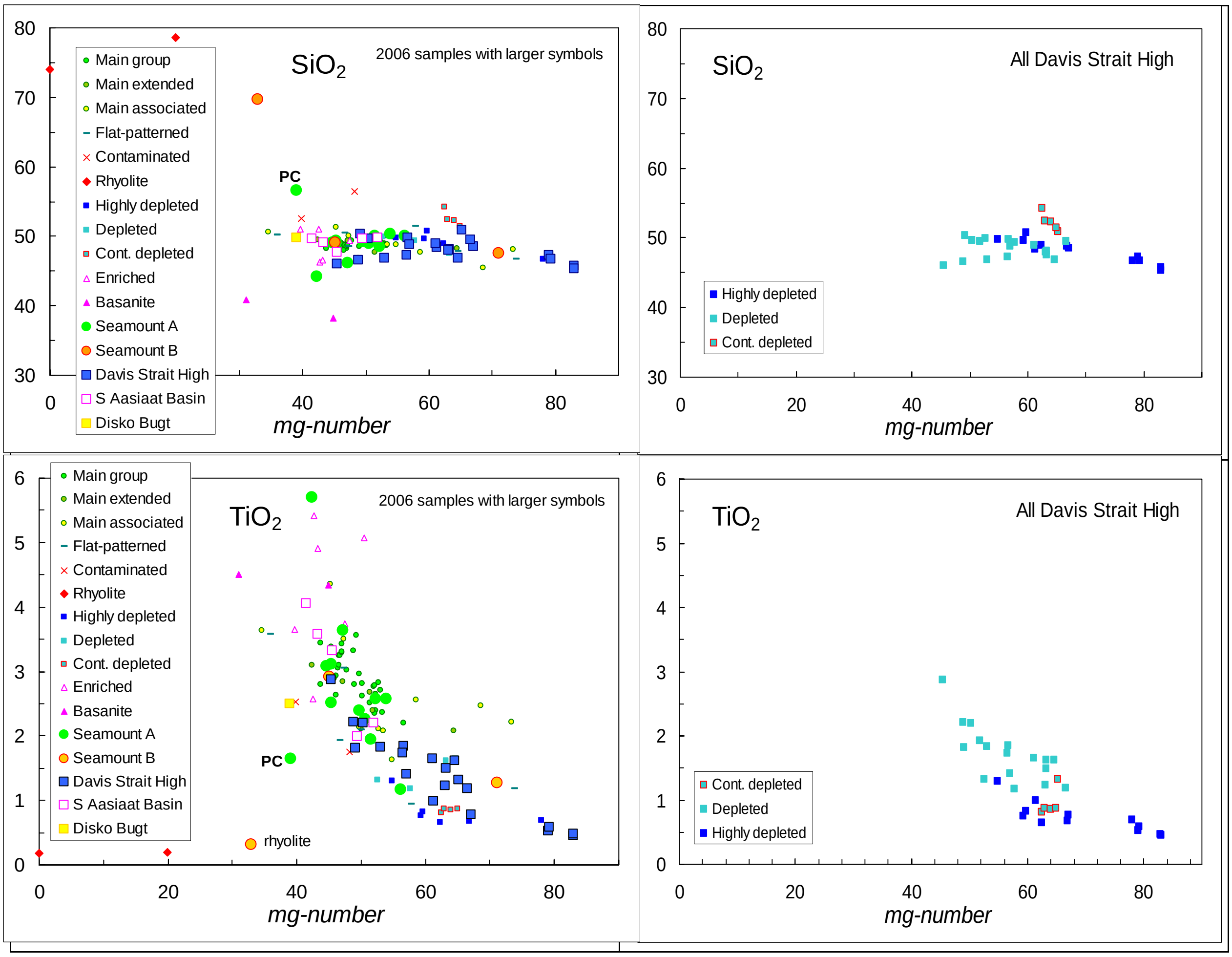

Fig. 5. Major element variation diagrams. **Left**: All samples from 2003, 2004 and 2006. The 2006 samples are coloured according to the dredge target, not the chemical type. PC: Alkaline trachyandesite, considered to be Precambrian (Gardar). **Right**: All samples from the Davis Strait High, coloured according to the chemical type.

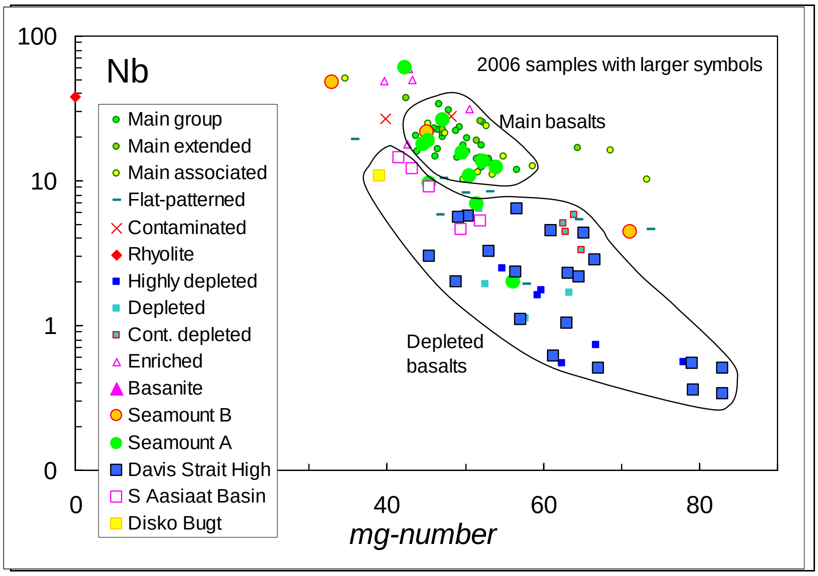

Fig. 6. Nb variation diagram. All samples from 2003, 2004 and 2006 are shown. The 2006 samples are coloured according to the dredge target, not the chemical type. The basanites and the alkaline trachyandesite have more than 100 ppm Nb and are off-scale. Note logarithmic scale on the Nb axis. All samples from the Davis Strait High, the southern Aasiaat Basin and the Disko Bugt are relatively poor in Nb (depleted type).

Davis Strait High

The 2006 results from the Davis Strait High confirm the 2003–2004 results: There are no 'main basalts' on the Davis Strait High. The basalts there are depleted to highly depleted in character, and a few are crustally contaminated (Figs 5, 6, 7). They are in general more magnesian than the basalts in the dredge locations south of 64°N, and picrites with mg-numbers >70 are frequent. However, the diversity of the depleted basalt group is increased; *mg*-numbers go down to 45.4 and TiO_2 contents are up to 2.87 wt%, giving little indication of 'depletion' in Fig. 5. However, the rocks are still depleted with respect to the most incompatible trace elements such as Nb, as shown in Fig. 6. As an expression of the same depletion the multi-element diagrams show low levels of Rb-Ba-Th-U-Nb-La-Ce, and the REE patterns have La-Sm limbs that slope towards La (La_N/Sm_N<1, N stands for chondrite normalised ratios), see Fig. 7.

In the 2006 dredges some of the depleted basalts with La_N/Sm_N <1 have Gd_N/Lu_N ratios that are fairly high (>1.5), giving the REE and multi-element patterns a 'hump-backed' shape (Fig. 7, third row). The same character is seen in the basalts and picrites on Nuussuaq and Disko. It is therefore a problem to distinguish between basalts of local derivation and basalts ice-rafted from onshore West Greenland. The presence of a fragment of the iron-bearing lava flow from western Disko proves that ice-rafting has indeed happened. This is further considered in the discussion.

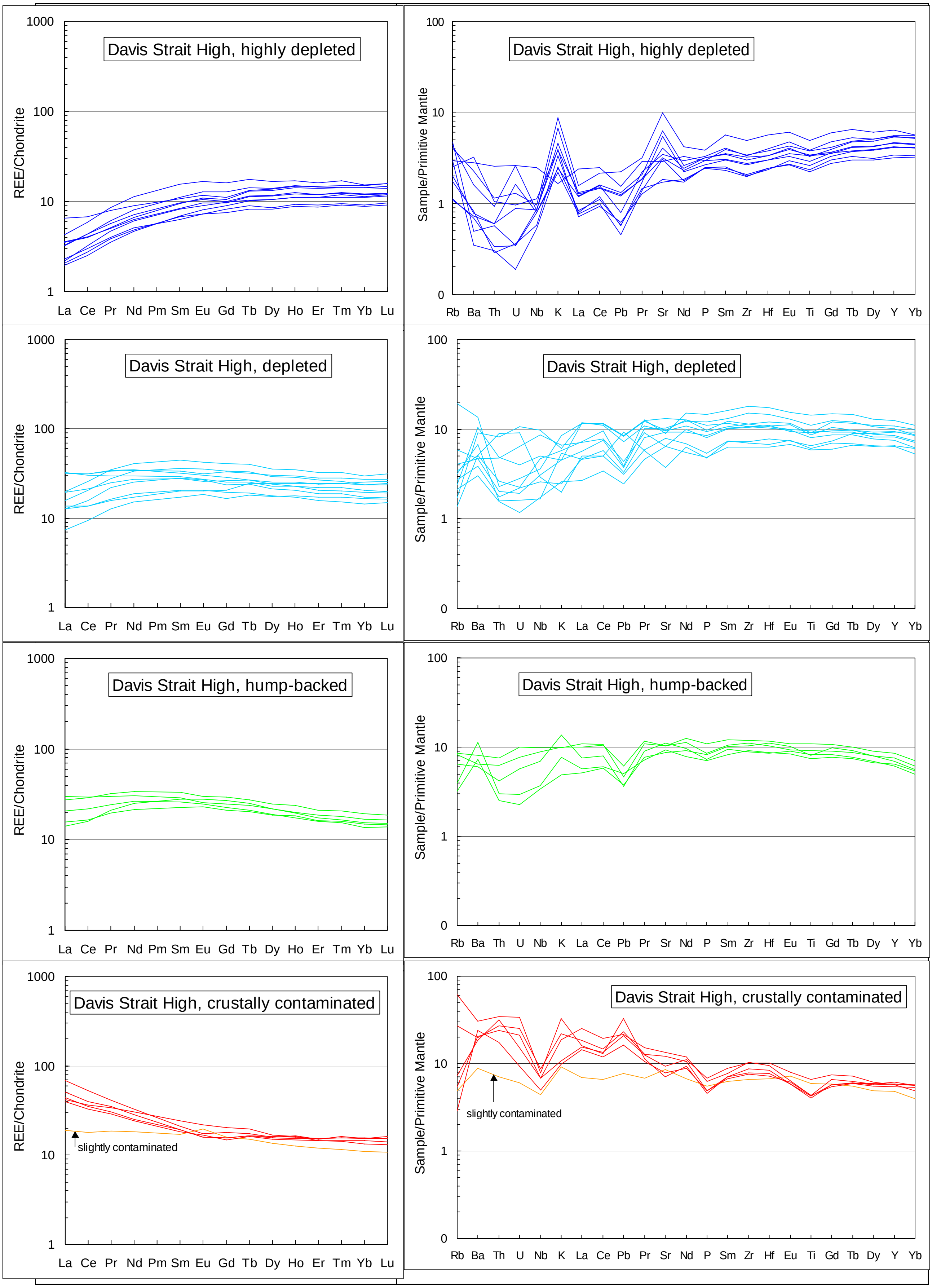

Fig. 7. REE and multi-element patterns for Davis Strait High. Normalisation factors from McDonough & Sun (1995).

Southern Aasiaat Basin

The two dredge stations, situated 18 km apart, yielded petrographically uniform plagioclase-clinopyroxene-olivine phyric or microphyric basalts. The five samples analysed are all evolved basalts with *mg*-numbers of 41–52 (MgO=5.2–6.5 wt%). TiO_2 contents vary from 1.0 to 4.1 wt%. In major-element cross plots they cannot be distinguished from 'main basalts' or 'enriched basalts', but trace element plots show depletion in incompatible elements. Their REE and multi-element patterns are parallel indicating a close genetic relation between the five samples (Fig. 8). The patterns are characteristically 'humpbacked' similar to the basalts of the Maligât Formation onshore West Greenland. The major elements are also similar to the basalts of the Maligât Formation.

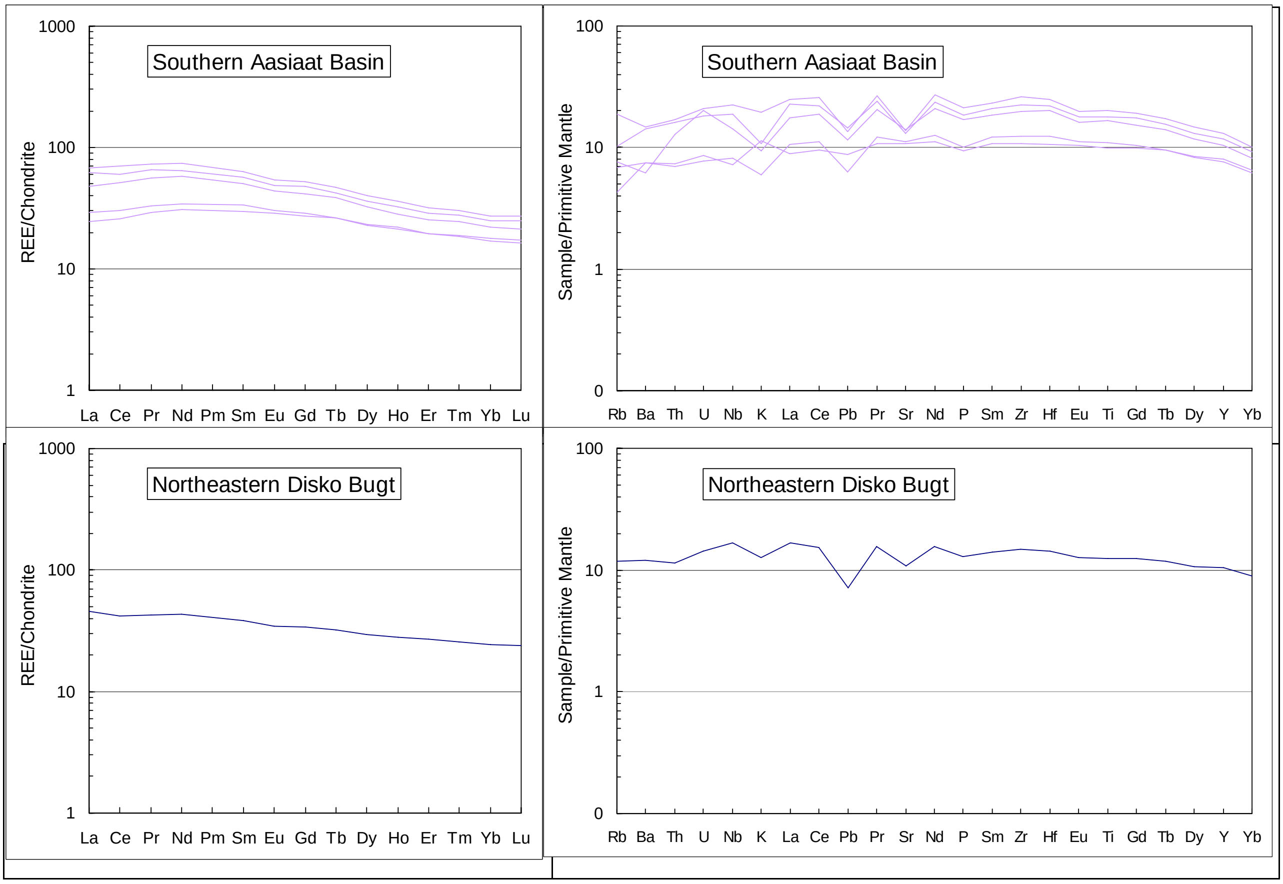

Fig. 8. REE and multi-element paterns for southeastern Aasiaat Basin and northeastern Disko Bugt. Normalisation factors from McDonough & Sun (1995).

Northeastern Disko Bugt

The recovered large, local gabbro sample is an evolved basalt with low *mg*-number (39.0) and low MgO (4.1 wt%) but not particularly high TiO_2 (2.5 wt%, Fig. 5). It has relatively high Al_2O_3 (16.3 wt%) and may be somewhat plagioclase cumulative. Considering its degree of evolution it is rather trace-element-poor and 'depleted' (Fig. 6). Its REE and multielement patterns are flat (Fig. 8) and it has been grouped as a flat-patterned basalt.

$^{40}Ar/^{39}Ar$ dating

A total of seven igneous samples were selected for radiometric dating by the $^{40}Ar/^{39}Ar$ step-heating method. Samples suitable for dating should be fresh and have not-too-low K contents. The samples represent the different dredged targets as far as possible; however the strongly depleted basalts from the Davis Strait High are poorly suited for Ar-Ar dating and only one sample passed the scrutiny.

The samples will be dated at Oregon State University, the Noble Gas Mass Spectrometry Laboratory led by Professor Robert Duncan. The laboratory and method is described at http://www.coas.oregonstate.edu/research/mg/chronology.html. The results are not yet available.

Discussion

Provenance of the dredged igneous rocks

Seamounts A and B

The new dredge location of Seamount A is situated about 75 km west of Seamount B and is the westernmost of the structures dredged south of 64°N (northern Labrador Sea, Fig. 1). None the less, all the structures dredged south of 64°N have remarkably similar populations of igneous rock compositions, with the main type constituting 59–73% of the analysed clast population in all of Seamounts A, B, C, E, H, and Canyon A (Table 3 and Larsen & Dalhoff 2006 Table 2).

Larsen & Dalhoff (2006) discussed the possibilities of far-range transport of the clasts from the volcanic areas onshore West and East Greenland. They concluded that transport from the onshore areas in West Greenland is improbable. Transport of some, but not all, of the rocks from East Greenland is possible, but at least half of the dredged rocks *cannot* come from East Greenland. They concluded that the volcanic complex of the Hecla High on the shelf around 64°N (Fig. 1) is the most likely source for the main part of the igneous rocks dredged south of 64°N. The new data from Seamounts A and B do not change this conclusion.

Davis Strait High and southern Aasiaat Basin

The geochemically depleted basalts and picrites dredged on the Davis Strait High and the southern Aasiaat Basin are akin to the basalts and picrites onshore West Greenland and Baffin Island. Larsen & Dalhoff (2006) used four cross plots of incompatible trace elements to show that the dredged rocks are different from the rocks on both of the onshore areas and most similar to basalts drilled on the Davis Strait High itself. We here repeat these plots in Figs 9 and 10 with all the new data for the northern areas included and data from the areas south of 64°N not shown. For comparison, data from the onshore Vaigat and Maligât Formations in West Grenland are plotted in the same diagrams in Fig. 9, and data from onshore Baffin Island are plotted in Fig. 10.

Fig. 9 shows that most of the rocks from the Davis Strait High are clearly distinguishable from the West Greenland rocks in these diagrams, and that the majority of the Davis Strait High rocks are more depleted than the West Greenland rocks, with lower La_N/Sm_N, Gd_N/Lu_N, Nb_N/Yb_N and Nb/Y. (The large spread in Nb_N/La_N and Nb_N/Th_N of the strongly depleted rocks is due to higher analytical uncertainty on the determination of the very low Nb and La contents in this group.) However, a group of five samples (those with the ‘humpbacked’ patterns in Fig. 7) are so similar to the West Greenland rocks in all four diagrams that it is impossible to distinguish them. An origin for these five samples, of which four come from one dredge station (Dana-06-29D), in West Greenland is therefore possible. Of these five samples, two with 6–7 wt% MgO are quite similar to the Maligât Formation lavas, also in major elements, whereas such Mg-poor compositions are very rare in the Vaigat Formation. Three samples with 8–11 wt% MgO are outside the range of 97% of the uncontaminated Maligât Formation and could better fit with the more magnesian Vaigat Formation; however the major elements show deviations from the Vaigat Formation and in particular the

CaO/Al_2O_3 ratios are lower than in the Vaigat Formation and in line with the other rocks dredged on the Davis Strait High. In conclusion, by far the majority of the rocks dredged on the Davis Strait High cannot be ice-rafted from onshore West Greenland; a few may be so, and one clast, a native-iron-bearing basalt (not analysed), is with certainty from western Disko.

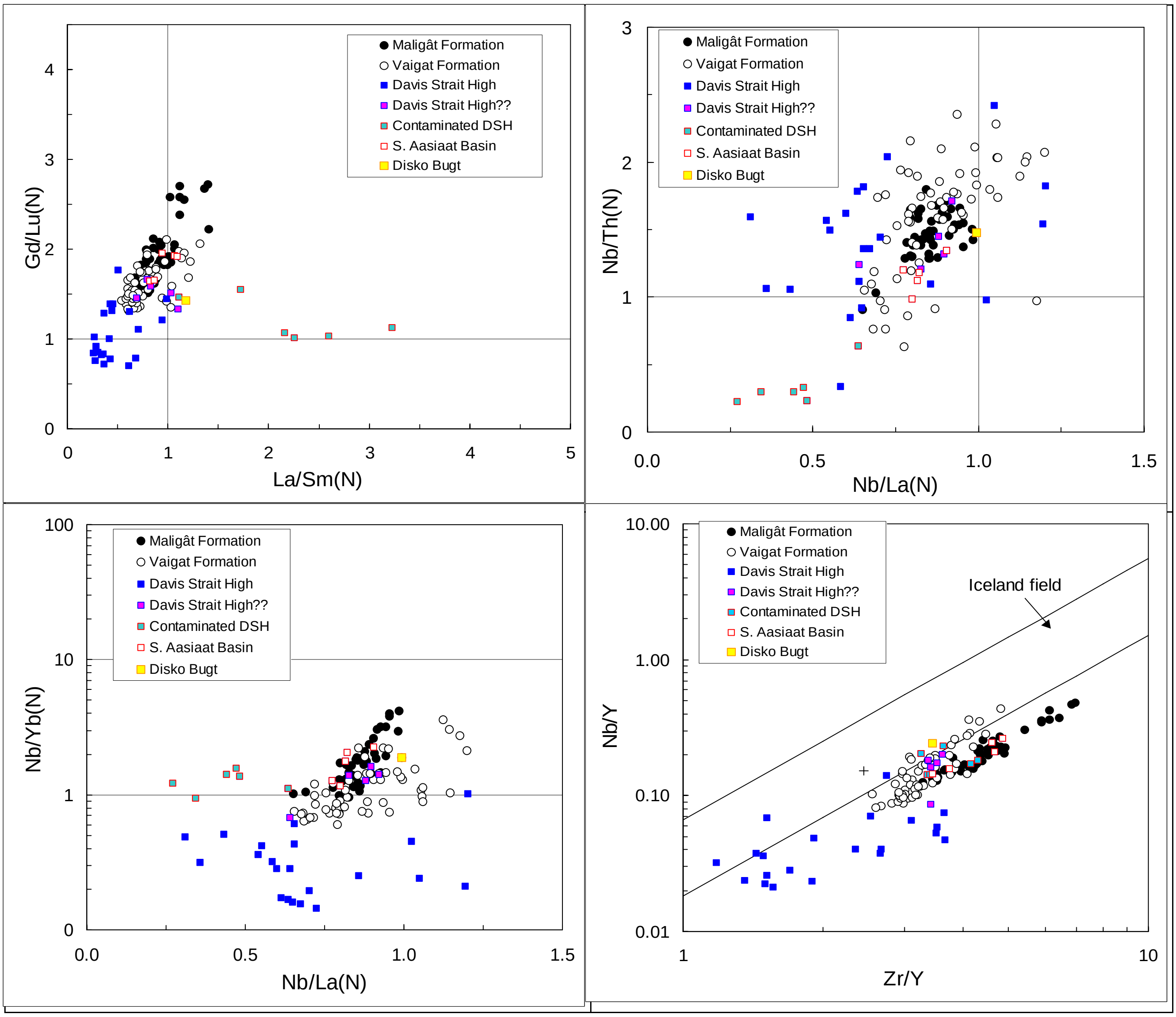

Fig. 9. All analysed samples from the Davis Strait High, Southern Aasiaat Basin and Disko Bugt compared with the uncontaminated parts of the Vaigat and Maligât Formations of onshore West Greenland (unpublished GEUS data). There is mainly good discrimination, but the question marked samples are indistinguishable from the West Greenland lavas in the Gd_N/Lu_N vs La_N/Sm_N plot. One of these samples has however lower Nb_N/Yb_N and Nb/Y than the West Greenland lavas. The samples from the Southern Aasiaat Basin are indistinguishable from the Maligât Formation in these diagrams (but see Fig. 11). Normalisation factors from McDonough & Sun (1995).

Lavas on Baffin Island comprise two geochemical groups: depleted (N-type) and non-depleted (E-type) lavas (Francis 1985; Robillard et al. 1992; Kent et al. 2004; Lass-Evans 2004). Fig. 10 shows that the dredged rocks from the Davis Strait High are very dissimilar to the E-type basalts on Baffin Island. They are more akin to the N-type basalts, but there are clear differences particularly in the Gd_N/Lu_N vs La_N/Sm_N diagram. It is clear that the greatest similarity is to a suite of dykes from

Baffin Island, which are an improbable source of the dredged rocks, and to rocks drilled on the High itself, where lava flows are exposed on the sea floor (Srivastava et al. 1982; M.-C. Williamson, unpublished data).

On the balance of all the evidence, by far the majority of the rocks dredged on the Davis Strait High are of relatively local origin.

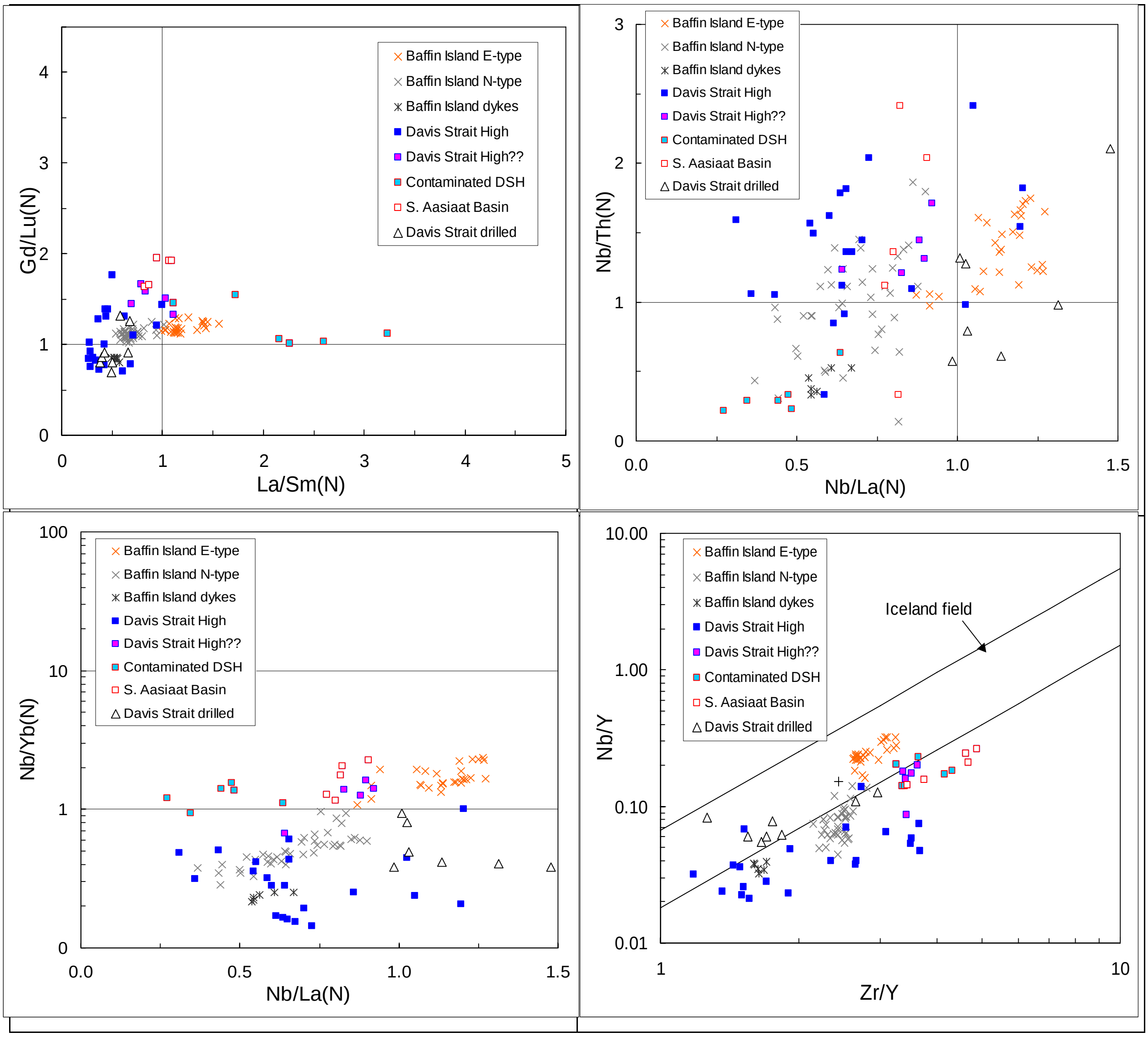

Fig. 10. All analysed samples from the Davis Strait High and Southern Aasiaat Basin compared with the lavas of onshore Baffin Island (data from Lass-Evans 2004) and with lavas drilled on the High itself (M-C. Williamson, unpublished). The dredged lavas are akin to the N-type Baffin Island lavas but not identical to them. The difference is most clearly seen in the Gd_N/Lu_N vs La_N/Sm_N diagram. The similarity is closest to a suite of dykes on Baffin Island and to the drilled basalts. The samples from the Southern Aasiaat Basin have no counterparts on Baffin Island.

The five basalts from the Southern Aasiaat Basin have no counterparts on Baffin Island (Fig. 10). On the other hand they are indistinguishable from the uncontaminated Maligât Formation in the cross plots in Fig. 9. Two of the dredged samples have TiO_2 contents of 2.0–2.2 wt% which is similar to numerous lavas in the Maligât Formation. Three of the five dredged samples have very high contents of TiO_2 (3.3–4.1 wt%) which allows further discrimination to be made because such compositions only occur in two units of the Maligât Formation. The uncontaminated lower part of the Maligât Formation, the Rinks Dal Member (Larsen & Pedersen 1990) is up to 1500 m thick, and its middle part is constituted by up to 400 m of high-Ti lava flows with 3.2–4.8 wt% TiO_2 (the Akuarut unit, Larsen & Pedersen unpublished). The only other occurrence of such high-Ti lava flows in the Maligât Formation is at the very top of the Rinks Dal member where a few (1–4) high-Ti flows are widespread. These two levels of Ti-rich flows can be distinguished because the flows of the Akuarut unit have steeper REE patterns (higher Gd_N/Lu_N ratios, seen in Fig. 9) and higher Zr/Y ratios than all other flows in the Rinks Dal Member, also the flows with similar high TiO_2 contents in the uppermost Rinks Dal Member. Fig. 11 shows these relations for Zr/Y, and it also shows that the dredged basalts from the Southern Aasiaat Basin cannot be derived from the Akuarut unit. On the other hand they are very similar to the high-Ti flows in the uppermost Rinks Dal Member. Inspection of other elements revealed no differences.

The question is whether it is probable that three out of five samples from two dredge sites are derived from a few very specific flows 250 km away. Another possibility is that the dredged samples represent a volcanic succession in the offshore area with flows that are compositionally similar to those in the Rinks Dal Member because both the melting processes and mantle materials were similar. A dredged sample has been sent for dating; only if the age is different from that of the Maligât Formation can we decide between the two possibilities.

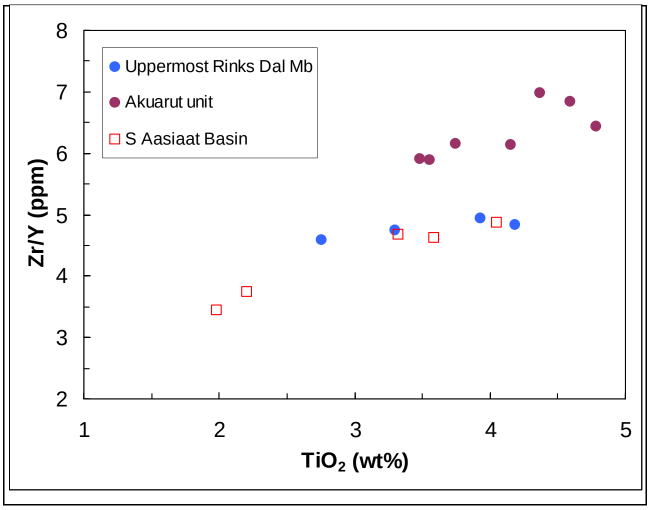

Fig. 11. Zr/Y vs TiO_2 for the dredged basalts of the southern Aasiaat Basin compared with high-Ti lavas from the Rinks Dal Member of the Maligât Formation in West Greenland.

Northeastern Disko Bugt

There is no doubt that the sample dredged from site 148D is local. Its chemical character is, however, different from the lavas of the Maligât Formation. It has relatively flat REE and multi-element patterns (Fig. 8) with $La_N/Sm_N > 1$ (Fig. 9). This type of pattern is uncommon in the surrounding onshore areas and is only known in some late, low-Ti dykes on Disko that cut the whole lava pile (Larsen 2006). A sample has been sent for dating.

Comparison with other igneous rocks on the shelf

Fig. 12 shows data for basalts from wells drilled in the Labrador Sea and the Davis Strait. The lavas of the Hellefisk, Hekja, and Gjoa wells are all more or less depleted, with the Hekja lavas the most depleted and most similar to the lavas from the Davis Strait High. The Nukik-2 well presents a large range of compositions; however, in this well the volcanics occur at very different levels (Hald & Larsen 1987) and are of very different ages.

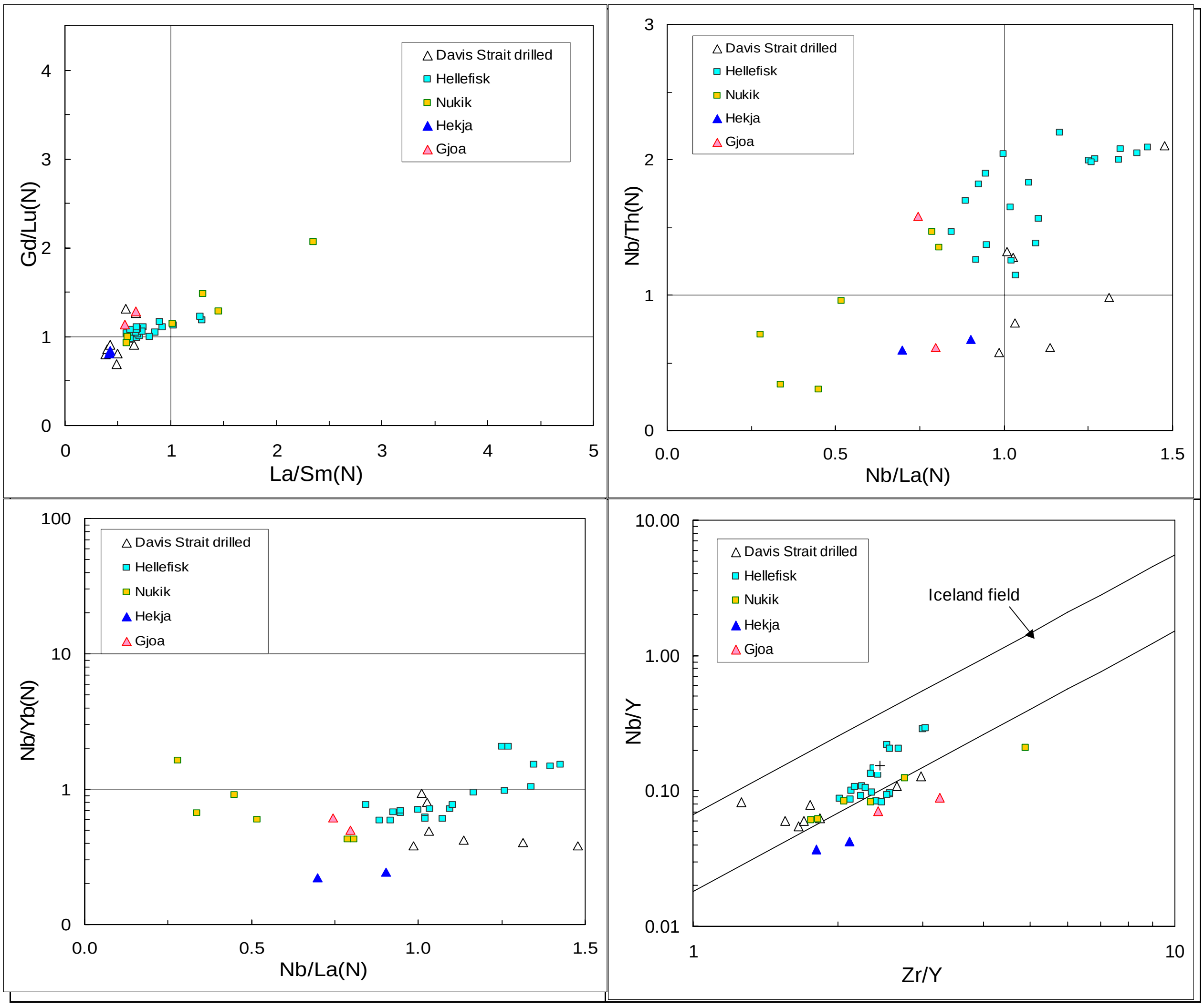

Fig. 12. Analyses of basalts drilled in the northern Labrador Sea and the Davis Strait. Unpublished data from M.-C. Williamson and GEUS. Compare with Figs 9 and 10.

Geodynamic implications

Areas south of 64°N

Larsen & Dalhoff (2006) concluded that the igneous clast population on the seamounts in the region, with a few notable exceptions from Seamount B, are most likely transported or originated from the Hecla High volcanic complex. This complex is situated on the continental shelf close to the margin. Seamount B is situated on the very edge of the continent, and Seamount A should be situated on oceanic crust according to Chalmers & Pulvertaft (2001) and Funck et al. (2007). A transported origin for most of the igneous rocks recovered in the southern areas is supported by the fact that all the structures dredged south of 64°N have remarkably similar populations of igneous rock compositions, irrespective of their different tectonic settings.

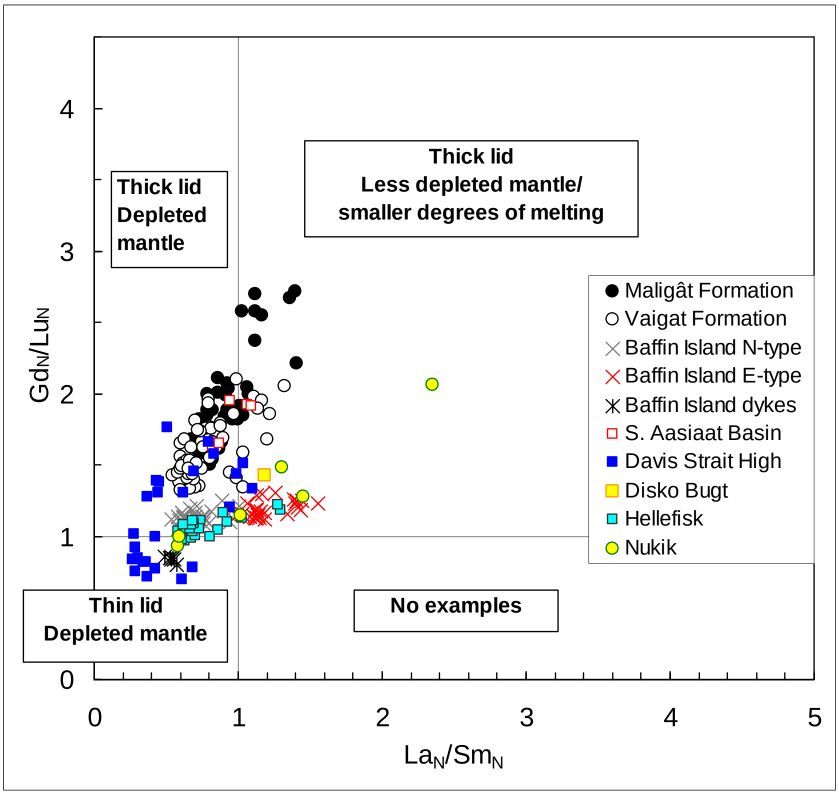

Fig. 13. Cross plot of REE ratios (as in Figs 9, 10, and 12) indicating the effects of melting beneath lithospheric lids of varying thickness and varying degrees of melting and mantle depletion. Only data for the Davis Strait region.

Davis Strait

Larsen & Dalhoff (2006) concluded that the depleted basalts and picrites dredged on the Davis Strait High were most likely of local derivation. The strong degree of depletion and the heavy REE ratios $Gd_N/Lu_N<1$ suggest extensive melting under a thin lithospheric lid without garnet in the residual mantle, i.e. a lithospheric thickness of around 80 km or less. This conclusion must be modified somewhat in the light of the new data: there are now several samples with $Gd_N/Lu_N>1$, suggesting melting beneath thicker lithosphere with residual garnet (Fig. 13). It is still clear from Fig. 13 that the thinnest lithosphere (lowest Gd_N/Lu_N ratios) is found on the Davis Strait High and that the lithosphere is thicker both on the West Greenland shelf (Hellefisk), on Baffin Island and in particular in West Greenland. However, the Davis Strait High is complicated and there seems to be two compositional groups with Gd_N/Lu_N respectively below and above one. The significantly larger spread in Gd_N/Lu_N ratios on the Davis Strait High than on Baffin Island and the West Greenland shelf suggest a very irregular lithospheric base, as may be expected for a structural high with a complicated tectonic history and cut by large and deep faults with large throws.

If the samples dredged in the southern Aasiaat Basin are from an offshore volcanic area, this must possess lavas similar to those of the Rinks Dal Member on Disko and Nuussuaq, and it must be situated on a lithosphere considerably thicker than beneath the more southerly parts of the Davis Strait High (Fig. 13). The evolved, Ti-rich nature of three of the five dredged samples suggest waning melt supply similar to the closing stages of the formation of the Rinks Dal Member. The dredged basalts in the southern Aasiaat Basin could originate from the Rinks Dal Member itself, or from the preserved top part of a lava succession in the offshore area.

Disko Bugt

The gabbro sample dredged in northeastern Disko Bugt represents one of several sill complexes in the sediments beneath the waters of Disko Bugt. The dredged sill is dissimilar to other sills in the region. The large sill exposed at Grønne Ejland in the south-eastern part of the bay is magnesian and depleted with a hump-backed REE pattern, and has been dated at 60 Ma (Larsen 2006). The sills and large dykes intruded along the eastern boundary fault of the Nuussuaq Basin in eastern Nuussuaq are distinctly enriched, with high contents of incompatible elements and both La/Sm>1 and Gd/Lu>1; they have been dated at around 55 Ma (Larsen 2006). The unexpected close similarity between the dredged sill and a widespread suite of late dykes of unknown age on Disko indicates that our knowledge and understanding of the Paleocene-Eocene succession of igneous events is far from complete.

Summary and conclusions

During the summer of 2006, seabed sampling was carried out by dredging in the Labrador Sea, the Davis Strait, and the waters around Hareøen, Nuussuaq and Disko. Igneous rocks were recovered in all dredges. In the Labrador Sea, the dredged features were two seamounts (A and B) at 62°27′–62°29′ N, 56°18′–57°55′ W. In the Davis Strait, the eastern side of the Davis Strait High was dredged at six sites at 66°08′–66°36′ N, and the southern Aasiaat Basin was dredged at two sites around 68°10′ N. Several dredge sites in the waters around Hareøen, Nuussuaq and Disko yielded igneous rocks with lithologies well known from the onshore volcanic areas; these rocks are therefore considered transported from these areas and not investigated further. The only exception is a site in the northeastern Disko Bugt at 69°18′ N, 51°36′ W.

The submarine features sampled in 2006 are partly new and partly the same as were sampled by dredging in 2003 and 2004 and reported on by Larsen & Dalhoff (2006), to which the present report is a sequel.

Laboratory work

After inspection and classification of the dredged samples, thin sections were made of 161 igneous rocks. After inspection of the thin sections and exclusion of Precambrian lithologies, 41 representative samples were chemically analysed by XRF and ICP-MS. The results showed that the same compositional groups as identified by Larsen & Dalhoff (2006) are present.

Six samples have been sent for Ar-Ar age determination; the results will appear medio 2008.

Labrador Sea (south of 64°N)

Seamount A, situated about 75 km west of Seamount B, was dredged for the first time in 2006. Of the 12 analysed samples, seven (64%) belong to the common ‘main’ compositional group. The remaining samples are two enriched basalts, one‘flat-patterned’ basalt, and one highly depleted basalt.

Seamount B was dredged in an attempt to obtain more of the local basanite recovered in 2003, but none were found. Only three new samples from Seamount B were analysed because there is good analytical coverage of this seamount from the 2003–2004 work. A rhyolite sample is new for Seamount A and increases the number of rhyolites recovered south of 64°N to three.

All the structures dredged south of 64°N have remarkably similar populations of igneous rock compositions irrespective of their different tectonic settings, with the main compositional type constituting 59–73% of the analysed clast population in all of Seamounts A, B, C, E, H, and Canyon A. This supports a transported origin for the major part of the rocks, most probably from the Hecla High volcanic complex as suggested by Larsen & Dalhoff (2006).

Davis Strait High

The new analytical data extend the number of analysed rocks from the Davis Strait High from 12 to 32. However, the conclusion of Larsen & Dalhoff (2006), that there are no ‘main’ type basalts on the Davis Strait High, remains unchanged. The rocks are geochemically depleted basalts of which the major part are different from the depleted basalts onshore West Greenland and Canada but similar to basalts drilled on the High itself. The dredged rocks must be mainly locally derived. The extended data set shows a larger variability than the earlier data, particularly with regard to indications of lithosphere thicknesses. While some of the samples indicate melting in spinel facies beneath a thin lithosphere (80 km or less), other rocks show indications of melting in garnet facies beneath a thicker lithosphere. There is a significantly larger spread in indications of melting depth on the Davis Strait High than on Baffin Island and the West Greenland shelf, suggesting a very irregular lithospheric base, as may be expected for a structural high with a complicated tectonic history and cut by large and deep faults with large throws.

Southern Aasiaat Basin

Five analysed samples from two sites all show great similarities to the lavas of the Maligât Formation onshore West Greenland. Three evolved high-Ti samples can, however, only be derived from a few specific lava flows at the top of the Rinks Dal Member of the Maligât Formation. If the dredged samples are from a volcanic succession in the offshore area, this must comprise lavas compositionally similar to those of the Maligât Formation. The three evolved samples suggest waning melt supply during the closing stages of a melting event. The dredged basalts are either from the Rinks Dal Member itself, or they could perhaps originate from the preserved top part of an offshore lava succession.

Northeastern Disko Bugt

The gabbro sample dredged in northeastern Disko Bugt represents one of several sill complexes in the sediments beneath the waters of Disko Bugt. The dredged sill is dissimilar to other sills in the region but similar to a widespread suite of late dykes of unknown age on Disko. Our knowledge and understanding of the Paleocene-Eocene succession of igneous events, even in the onshore areas, is far from complete.

Acknowledgements

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Appendix 1

Analyses of dredged samples 2006

Appendix 1. Analyses of igneous rocks dredged 2006 Major elements in wt% oxides. Analyses by XRF (X-ray fluorescence spectrometry) on fused glass discs at GEUS Rock Geochemical Laboratory.

Sample_ID	Feature	Phenocrysts	SiO2	TiO2	Al2O3	Fe2O3	FeO	MnO	MgO	CaO	Na2O	K2O	P2O5	Volat	Sum	FeO*	Mg#
Dana-06-04D-01	Seamount B	plag+cpx, fine-grained	48,17	2,87	13,89	5,26	8,79	0,20	5,49	10,34	2,81	0,458	0,329	1,00	99,61	13,52	45,10
Dana-06-04D-09	Seamount B	Picrite, fresh, fine-grained	46,02	1,23	13,38	5,45	5,44	0,16	12,57	9,99	2,43	0,397	0,123	2,23	99,41	10,35	71,07
Dana-06-05D-01	Seamount B	devitrified rhyolite, welded?	67,80	0,31	13,81	3,96	0,52	0,07	0,99	0,49	3,89	5,626	0,060	1,84	99,36	4,08	32,88
Dana-06-01D-03	Seamount A	plag+cpx+ol mic	48,56	2,48	13,33	4,42	9,81	0,22	5,65	10,68	2,95	0,297	0,266	0,94	99,60	13,79	45,31
Dana-06-01D-06	Seamount A	sparse plag, fine-grained	48,23	3,06	12,74	6,05	8,80	0,22	5,84	10,34	2,89	0,323	0,365	0,57	99,42	14,25	45,31
Dana-06-01D-08	Seamount A	sparse plag+ol, fine-grained	49,15	1,15	13,38	5,49	7,07	0,19	7,60	11,67	2,74	0,166	0,105	1,18	99,88	12,01	56,14
Dana-06-01D-09	Seamount A	big plag+ol, seriate	42,92	5,53	12,84	9,71	6,76	0,24	5,62	10,15	2,80	0,475	0,733	1,77	99,55	15,50	42,31
Dana-06-01D-10	Seamount A	big plag+ol, seriate	48,20	2,34	13,87	5,95	7,23	0,20	6,14	11,22	2,84	0,210	0,239	1,06	99,49	12,58	49,67
Dana-06-01D-13	Seamount A	ol+plag+cpx, fine-grained	49,32	2,53	13,90	6,70	5,59	0,16	6,72	9,97	2,84	0,461	0,245	1,02	99,45	11,62	53,92
Dana-06-01D-17	Seamount A	Coarse-grained, fresh	45,36	3,57	13,24	4,49	10,45	0,21	6,39	10,60	3,02	0,749	0,546	0,83	99,45	14,49	47,13
Dana-06-01D-23	Seamount A	brown amph+ol, alkaline	54,79	1,59	17,80	2,90	2,96	0,15	1,76	4,06	6,30	4,296	0,471	2,58	99,66	5,57	39,06
Dana-06-02D-01	Seamount A	Coarse-grained, fresh	47,40	2,52	14,23	6,75	6,25	0,21	6,67	10,58	2,97	0,395	0,237	1,34	99,54	12,32	52,27
Dana-06-02D-02	Seamount A	plag+ol+cpx, fine-grained	48,06	2,21	14,23	5,96	7,17	0,18	6,34	11,15	2,90	0,156	0,233	1,04	99,63	12,54	50,56
Dana-06-02D-03	Seamount A	plag+oxide mic, segr. patches	48,22	3,03	12,73	5,28	9,50	0,23	5,68	10,58	2,81	0,257	0,302	1,00	99,62	14,25	44,64
Dana-06-02D-06	Seamount A	Coarse-grained	49,28	1,92	13,67	3,14	9,77	0,20	6,61	11,02	2,67	0,229	0,178	1,22	99,91	12,60	51,47
Dana-06-29D-01	Davis Strait High	ol+plag mic, fine-grained	47,99	1,62	14,73	4,08	6,88	0,17	8,18	11,61	2,56	0,391	0,148	1,45	99,80	10,55	61,05
Dana-06-29D-03	Davis Strait High	plag glom + ol, heterog.	46,08	1,43	15,62	6,85	4,66	0,15	9,19	9,23	2,87	0,212	0,139	3,12	99,55	10,82	63,20
Dana-06-29D-07	Davis Strait High	plag glom+big cpx, fine-grained	48,85	2,17	14,17	5,53	7,33	0,20	6,16	10,95	2,99	0,286	0,220	0,50	99,35	12,30	50,31
Dana-06-29D-10	Davis Strait High	coarse, gabbroic, fresh	49,24	1,82	15,16	3,74	7,27	0,17	6,87	11,53	2,87	0,279	0,175	0,93	100,05	10,64	56,63
Dana-06-29D-18	Davis Strait High	med-coarse-grained, ophitic	45,70	1,18	15,81	3,74	7,55	0,15	9,19	9,27	2,68	0,148	0,105	3,69	99,20	10,91	63,00
Dana-06-30D-03	Davis Strait High	ol-phyric, ophitic	45,62	1,58	15,01	3,57	8,85	0,17	10,85	8,75	2,91	0,137	0,165	1,81	99,41	12,06	64,53
Dana-06-30D-04	Davis Strait High	plag+ol sparse, fine-grained	48,24	1,15	16,14	4,09	5,55	0,15	9,07	10,68	2,22	0,259	0,111	1,71	99,37	9,23	66,53
Dana-06-30D-08	Davis Strait High	plag+ol+cpx mic, fine-grained	44,50	2,78	15,80	6,98	8,66	0,19	6,14	8,21	3,63	0,162	0,292	2,52	99,87	14,94	45,39
Dana-06-31D-05	Davis Strait High	plag-rich, brown cpx, ol, fresh	45,72	2,17	16,03	4,82	9,98	0,19	6,75	8,31	4,13	0,128	0,244	1,41	99,88	14,32	48,82
Dana-06-31D-09	Davis Strait High	ol+crm, picrite, fine-grained	45,58	0,51	12,24	2,44	7,22	0,16	17,52	9,55	1,28	0,108	0,049	2,80	99,47	9,42	79,00
Dana-06-32D-01	Davis Strait High	aphyric, fine-grained	49,63	1,29	14,47	3,13	7,02	0,17	9,09	10,32	2,27	0,301	0,137	1,52	99,34	9,83	65,16
Dana-06-32D-02	Davis Strait High	plag+ol, fine-grained	46,77	0,96	15,43	5,95	5,27	0,18	8,32	11,25	2,75	0,243	0,076	2,52	99,72	10,63	61,29
Dana-06-32D-04	Davis Strait High	ol+crm, picrite, ophitic	43,94	0,43	9,83	3,61	6,51	0,16	23,51	7,20	1,06	0,070	0,048	3,08	99,44	9,76	82,97
Dana-06-32D-08	Davis Strait High	plag+ol, fine-grained	48,05	1,39	14,78	3,96	7,87	0,18	7,50	12,13	2,63	0,080	0,120	0,79	99,48	11,44	57,01
Dana-06-33D-09	Davis Strait High	ol+crm, picrite, ophitic	44,40	0,56	12,27	2,96	6,61	0,15	17,52	8,82	1,92	0,092	0,052	4,05	99,40	9,27	79,25
Dana-06-33D-10	Davis Strait High	ol+crm, picrite, ophitic	43,50	0,45	9,99	3,36	6,65	0,15	23,21	7,40	1,38	0,061	0,049	3,12	99,34	9,68	82,91
Dana-06-33D-12	Davis Strait High	med-coarse-gr., olivine, fresh	49,51	1,79	13,43	3,44	10,03	0,22	6,25	10,87	2,66	0,190	0,164	0,78	99,32	13,13	49,07
Dana-06-34D-02	Davis Strait High	med-grained ophitic	47,02	0,75	15,70	5,13	5,26	0,16	9,94	11,12	2,16	0,068	0,065	2,75	100,12	9,87	67,07
Dana-06-34D-07	Davis Strait High	plag laths+ol+cpx, fine-grained	46,09	1,80	15,54	4,84	9,14	0,22	7,51	10,21	2,89	0,129	0,197	0,80	99,36	13,49	52,96
Dana-06-34D-12	Davis Strait High	plag+ol mic, fine-grained	46,40	1,70	16,49	5,23	7,30	0,20	7,70	9,99	2,93	0,242	0,223	0,97	99,37	12,01	56,46
Dana-06-50D-01	S. Aasiaat Basin	plag mic+cpx mic, fine-grained	48,93	3,99	12,33	5,04	10,08	0,23	5,11	9,32	2,85	0,552	0,429	0,89	99,76	14,62	41,42
Dana-06-50D-02	S. Aasiaat Basin	plag laths + cpx, fine-grained	48,39	3,53	12,57	4,86	10,32	0,21	5,54	9,91	2,76	0,306	0,378	0,82	99,59	14,69	43,26
Dana-06-50D-04	S. Aasiaat Basin	plag+cpx+ol, fine-grained	48,84	1,95	14,50	6,60	6,42	0,17	5,97	10,81	2,99	0,324	0,190	0,69	99,44	12,35	49,44
Dana-06-51D-02	S. Aasiaat Basin	plag mic + cpx mic, fine-grained	46,75	3,26	13,23	7,14	8,22	0,31	6,04	10,19	2,72	0,265	0,344	0,83	99,28	14,65	45,46
Dana-06-51D-04	S. Aasiaat Basin	plag glom+ol+cpx, fine-grained	48,99	2,17	14,18	3,95	8,38	0,19	6,37	11,40	2,60	0,170	0,205	0,84	99,45	11,93	51,92
Dana-06-148D-01	NE Disko Bugt	gabbro, very coarse	49,14	2,46	16,09	4,24	8,98	0,20	4,04	10,28	3,01	0,360	0,265	0,78	99,84	12,79	38,98

Trace elements in ppm. Analyses by ICP-MS (inductively coupled plasma mass spectrometry) at GEUS Rock Geochemical Laboratory.

Sample_ID	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Cs	Ba
06-04D-01	33,88	358,76	70,90	55,98	59,86	225,54	119,13	22,31	3,59	305,32	35,65	182,67	21,78	0,039	182,46
06-04D-09	32,91	272,57	749,81	62,00	406,97	131,58	68,40	15,44	2,33	329,71	19,88	65,12	4,42	0,032	65,85
06-05D-01	6,65	6,43	3,50	39,09	5,23	7,44	82,58	18,24	126,10	57,80	51,02	486,14	47,91	1,271	829,91
06-01D-03	39,98	394,48	43,21	50,53	51,44	234,55	112,35	20,91	7,50	226,48	39,84	164,31	18,95	0,102	96,28
06-01D-06	36,99	455,27	64,82	57,78	51,51	230,67	127,39	23,92	4,81	251,95	42,23	183,54	9,60	0,085	60,94
06-01D-08	49,00	348,01	162,10	53,02	87,88	201,26	87,20	16,57	2,40	92,47	29,87	61,23	2,02	0,115	21,38
06-01D-09	32,51	399,33	153,66	49,27	99,03	428,79	174,55	30,11	4,37	286,06	60,53	459,74	60,42	0,021	124,34
06-01D-10	42,47	376,39	108,28	51,50	77,08	135,45	107,32	20,32	1,56	218,89	37,71	148,20	15,67	0,052	66,45
06-01D-13	32,42	339,80	271,77	51,14	112,56	190,89	100,34	22,47	9,70	251,29	31,52	177,77	12,44	0,182	106,62
06-01D-17	28,90	423,63	95,92	54,70	83,98	196,99	120,80	22,89	12,88	499,92	29,70	178,70	26,08	0,240	289,61
06-01D-23	5,20	76,68	1,06	31,10	2,87	8,59	76,28	24,10	116,58	1081,62	29,66	603,09	132,34	0,912	1864,07
06-02D-01	37,29	375,02	208,70	49,06	95,39	234,37	104,30	22,10	11,62	240,24	32,03	151,41	13,69	0,790	74,33
06-02D-02	40,47	403,81	116,60	53,53	70,62	224,56	102,04	21,73	0,78	255,80	35,16	140,58	10,71	0,035	61,87
06-02D-03	37,29	433,24	62,85	54,39	73,54	287,47	177,50	23,42	11,53	255,07	40,03	196,02	17,98	0,080	79,69
06-02D-06	44,22	359,16	218,09	51,31	84,84	193,49	98,48	19,70	4,58	159,44	36,74	116,22	6,86	0,241	53,34
06-29D-01	39,16	350,70	369,16	50,10	142,46	165,12	76,97	19,86	3,83	216,68	25,95	91,35	4,51	0,015	39,03
06-29D-03	35,50	281,35	552,54	56,87	218,48	78,62	72,84	17,46	2,29	177,67	26,85	91,86	2,32	0,038	72,12
06-29D-07	39,94	401,61	113,16	51,24	62,10	219,27	98,29	21,90	4,88	204,60	35,95	122,80	5,76	0,059	42,09
06-29D-10	39,75	386,87	264,78	46,13	118,89	213,45	82,94	20,85	5,04	203,35	32,03	116,03	6,41	0,115	53,33
06-29D-18	36,08	286,58	650,64	64,46	361,09	53,91	70,23	18,22	1,81	151,04	26,09	69,57	1,04	0,046	42,86
06-30D-03	35,76	243,24	580,20	63,51	275,58	96,88	84,95	17,83	1,88	169,88	29,11	106,38	2,18	0,057	47,23
06-30D-04	38,98	302,03	851,57	44,96	25,44	43,68	69,93	19,23	2,84	164,42	19,95	67,07	2,82	0,023	57,28
06-30D-08	37,28	376,43	82,91	53,73	88,43	64,97	114,17	22,20	1,97	172,35	51,87	182,72	3,01	0,069	32,85
06-31D-05	26,75	198,94	94,28	56,22	111,70	99,82	90,40	16,85	2,40	200,54	42,55	155,98	2,00	0,079	30,18
06-31D-09	40,04	217,31	1261,43	68,88	663,78	92,99	58,55	11,52	2,72	35,52	17,12	20,21	0,54	0,056	3,13
06-32D-01	39,71	303,20	756,96	46,48	22,61	24,41	79,88	19,24	3,16	180,08	24,16	104,22	4,39	0,014	131,70
06-32D-02	49,21	307,02	280,17	52,85	91,12	158,71	74,20	16,28	2,36	191,37	26,40	50,10	0,61	0,099	14,36
06-32D-04	33,27	178,64	1825,26	81,95	1043,84	74,42	57,35	9,78	1,69	32,98	13,15	19,95	0,34	0,091	2,19
06-32D-08	49,48	362,16	277,72	52,87	103,94	183,54	78,27	18,49	0,73	138,95	29,65	78,68	1,11	0,035	6,60
06-33D-09	38,95	212,77	1190,45	70,01	632,36	81,02	55,81	11,84	0,99	102,49	17,10	26,75	0,36	0,064	5,14
06-33D-10	32,16	179,60	1753,44	81,49	1031,66	77,00	56,20	9,96	0,65	58,09	14,08	21,03	0,50	0,028	4,33
06-33D-12	49,06	445,36	100,63	51,55	70,54	252,26	104,94	19,86	3,45	125,06	39,82	109,16	5,56	0,045	30,29
06-34D-02	46,32	291,45	301,85	51,05	148,70	197,83	59,86	15,15	0,63	66,84	22,69	34,17	0,51	0,025	4,64
06-34D-07	46,00	394,58	102,56	59,29	111,94	137,38	105,72	22,12	1,41	190,10	46,15	117,14	3,26	0,059	67,58
06-34D-12	36,36	326,79	104,59	56,18	130,84	112,26	93,01	20,93	11,31	256,25	35,67	110,59	2,32	0,909	88,43
06-50D-01	37,80	530,82	45,51	58,09	43,43	367,94	145,72	25,82	11,10	271,83	55,59	270,62	14,58	0,191	95,87
06-50D-02	38,17	482,26	80,24	54,29	58,99	249,54	141,34	25,03	6,03	255,93	49,98	230,93	12,14	0,123	92,67
06-50D-04	36,05	369,71	79,09	50,99	61,34	78,34	99,49	22,13	4,06	211,13	32,17	110,69	4,64	0,034	48,41
06-51D-02	37,21	468,25	91,78	54,54	65,70	317,41	133,46	26,92	4,51	270,64	43,77	204,73	9,17	0,268	39,73
06-51D-04	38,77	387,38	150,16	46,72	79,10	221,22	96,30	21,60	2,55	219,75	34,02	127,53	5,31	0,053	48,72
06-148D-01	32,40	436,60	19,86	40,92	34,52	454,39	111,14	24,08	7,07	211,88	44,52	153,64	10,80	0,157	78,10

Sample_ID	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
06-04D-01	19,07	43,62	6,44	29,00	6,98	2,21	7,25	1,167	6,904	1,373	3,587	0,512	3,099	0,464	4,619	1,485	1,875	1,447	0,407
06-04D-09	4,80	12,13	1,92	9,45	2,88	1,05	3,42	0,573	3,608	0,751	2,009	0,290	1,803	0,262	1,746	0,846	0,623	0,372	0,073
06-05D-01	59,81	115,57	13,20	46,69	8,34	1,14	7,96	1,361	8,444	1,747	5,314	0,851	5,404	0,835	12,118	3,690	14,002	9,374	1,928
06-01D-03	15,22	34,17	5,01	22,65	6,07	2,03	6,77	1,136	6,967	1,465	4,010	0,596	3,700	0,546	4,204	1,175	1,290	1,483	0,398
06-01D-06	10,33	28,11	4,60	23,17	6,97	2,35	7,74	1,281	7,679	1,548	3,976	0,590	3,465	0,520	4,799	1,039	1,328	0,789	0,254
06-01D-08	2,26	6,10	1,08	6,21	2,57	0,96	3,59	0,704	4,844	1,112	3,058	0,470	2,986	0,458	1,715	0,375	0,506	0,206	0,137
06-01D-09	42,24	100,34	14,30	62,66	14,14	4,15	13,83	2,104	11,505	2,199	5,696	0,791	4,713	0,694	10,402	3,583	2,852	3,625	1,042
06-01D-10	12,77	30,19	4,43	20,66	5,61	1,84	6,12	1,062	6,445	1,364	3,669	0,553	3,474	0,519	3,809	1,027	0,962	1,067	0,301
06-01D-13	12,64	31,33	4,77	22,68	6,12	1,96	6,37	1,021	6,003	1,157	2,967	0,417	2,521	0,376	4,479	1,692	1,645	1,233	0,313
06-01D-17	23,75	55,94	8,18	36,60	8,27	2,71	7,79	1,140	6,101	1,101	2,796	0,374	2,138	0,311	4,318	1,790	1,990	1,480	0,435
06-01D-23	87,23	163,87	18,99	65,84	10,57	3,15	8,11	1,175	5,996	1,034	2,784	0,390	2,378	0,350	11,704	7,883	8,908	14,313	4,196
06-02D-01	11,52	28,48	4,37	20,41	5,51	1,83	5,97	0,975	5,721	1,142	3,056	0,448	2,685	0,394	3,794	0,972	1,156	1,019	0,227
06-02D-02	11,09	26,29	3,97	18,76	5,24	1,80	5,86	0,987	5,888	1,230	3,216	0,488	2,865	0,419	3,481	1,129	1,159	0,896	0,287
06-02D-03	14,69	36,71	5,67	26,67	7,04	2,30	7,71	1,262	7,381	1,510	3,869	0,536	3,339	0,500	5,039	1,416	1,323	1,290	0,367
06-02D-06	6,44	16,81	2,69	13,73	4,30	1,48	5,24	0,952	5,935	1,274	3,415	0,517	3,252	0,505	3,046	0,851	0,648	0,568	0,174
06-29D-01	4,82	13,13	2,23	11,82	3,80	1,36	4,44	0,751	4,612	0,935	2,490	0,375	2,162	0,331	2,388	0,530	0,534	0,323	0,113
06-29D-03	3,56	9,72	1,73	9,40	3,21	1,25	4,05	0,709	4,363	0,965	2,465	0,377	2,304	0,345	2,354	0,260	0,734	0,230	0,058
06-29D-07	6,43	17,52	2,93	15,32	4,83	1,65	5,76	0,981	5,991	1,282	3,345	0,506	3,061	0,450	3,239	0,884	0,902	0,488	0,154
06-29D-10	7,03	17,85	2,76	13,90	4,24	1,43	4,86	0,845	5,277	1,077	2,946	0,438	2,671	0,398	2,903	0,570	0,694	0,597	0,201
06-29D-18	2,86	7,97	1,43	8,18	2,87	1,10	3,66	0,652	4,205	0,898	2,416	0,356	2,221	0,347	1,819	0,109	0,444	0,121	0,031
06-30D-03	3,27	9,50	1,91	11,22	4,05	1,53	5,21	0,883	5,218	1,037	2,726	0,398	2,401	0,364	3,039	0,596	0,547	0,197	0,045
06-30D-04	4,36	10,72	1,68	8,14	2,46	1,08	3,07	0,530	3,225	0,678	1,874	0,279	1,712	0,260	1,850	0,358	1,117	0,547	0,120
06-30D-08	4,53	15,44	3,11	18,18	6,35	2,31	7,87	1,393	8,380	1,832	5,001	0,774	4,675	0,742	4,776	0,248	0,567	0,204	0,044
06-31D-05	3,63	12,35	2,52	15,12	5,27	1,96	6,62	1,181	7,000	1,525	4,166	0,626	3,767	0,590	4,049	0,291	0,546	0,157	0,038
06-31D-09	0,45	1,49	0,31	2,08	0,99	0,44	1,73	0,353	2,495	0,590	1,719	0,283	1,761	0,283	0,637	0,197	0,090	0,043	0,007
06-32D-01	9,76	21,85	3,10	13,65	3,54	1,20	3,94	0,690	4,040	0,857	2,281	0,348	2,103	0,316	2,801	0,513	3,036	1,847	0,422
06-32D-02	0,98	3,46	0,77	5,03	2,23	0,91	3,13	0,618	3,973	0,894	2,517	0,408	2,395	0,379	1,555	0,188	0,323	0,089	0,025
06-32D-04	0,52	1,77	0,35	2,23	0,90	0,39	1,44	0,286	1,949	0,465	1,329	0,217	1,360	0,216	0,664	0,097	0,083	0,023	0,004
06-32D-08	1,81	6,49	1,36	8,04	3,08	1,21	4,15	0,760	4,770	1,039	2,843	0,437	2,636	0,400	2,169	0,248	0,252	0,084	0,020
06-33D-09	0,49	1,88	0,41	2,67	1,16	0,48	1,85	0,355	2,482	0,579	1,691	0,264	1,692	0,271	0,806	0,094	0,081	0,022	-0,003
06-33D-10	0,47	1,60	0,34	2,14	0,96	0,40	1,58	0,310	2,004	0,492	1,410	0,227	1,416	0,229	0,663	0,199	0,065	0,026	0,007
06-33D-12	4,55	12,86	2,26	12,14	4,02	1,42	5,16	0,954	6,100	1,364	3,756	0,598	3,716	0,577	3,063	0,617	0,650	0,375	0,127
06-34D-02	0,74	2,57	0,55	3,57	1,60	0,70	2,49	0,501	3,333	0,801	2,241	0,342	2,215	0,334	1,083	0,179	0,115	0,046	0,032
06-34D-07	7,41	18,84	3,07	15,48	4,89	1,75	6,45	1,139	7,256	1,589	4,419	0,685	4,297	0,660	3,340	0,342	1,222	0,379	0,080
06-34D-12	7,35	18,96	3,11	15,53	4,62	1,68	5,60	0,953	5,798	1,217	3,437	0,533	3,220	0,480	3,027	0,183	1,253	0,179	0,056
06-50D-01	15,84	42,31	6,71	33,24	9,29	3,02	10,25	1,669	9,760	1,943	5,061	0,740	4,340	0,658	6,894	1,108	1,983	1,331	0,419
06-50D-02	14,56	36,40	5,99	29,21	8,33	2,70	9,32	1,509	8,733	1,758	4,551	0,679	3,975	0,601	6,127	1,844	2,143	1,262	0,363
06-50D-04	5,71	15,61	2,68	13,80	4,34	1,58	5,28	0,931	5,497	1,141	3,071	0,452	2,686	0,399	2,955	0,782	1,286	0,578	0,172
06-51D-02	11,06	30,85	5,12	25,75	7,30	2,43	8,16	1,358	7,778	1,519	4,006	0,596	3,500	0,516	5,544	1,009	1,691	1,005	0,400
06-51D-04	6,76	18,33	3,04	15,44	4,85	1,69	5,57	0,937	5,645	1,186	3,086	0,458	2,811	0,417	3,471	0,621	0,935	0,544	0,156
06-148D-01	10,70	25,54	3,91	19,44	5,64	1,93	6,72	1,149	7,154	1,516	4,253	0,625	3,876	0,583	3,977	0,851	1,059	0,899	0,286