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SHORT COMMUNICATIONS

Composition and Morphology of Seafloor Highs in the Southwestern Greenland Continental Margin

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GEOLOGICAL SETTING

The Greenland continental margin is a modern example of a passive margin formed as a result of the opening of the northern Atlantic in the Late Mesozoic–Early Cenozoic. The time of the beginning of spreading in the Labrador Sea is not precisely known. There were attempts to reconstruct seafloor spreading history, by the identification and calculation of magnetic anomalies in the Labrador Sea [1]. It is supposed that the opening of the oceanic basin started 68 Ma ago. A change in spreading axis orientation occurred simultaneously with the beginning of the spreading between the European and Greenland plates (55.9–53.3 Ma), followed by the opening of the northern part of the Atlantic Ocean. Seafloor spreading in the Labrador Sea terminated in the early Eocene, when post-rifting sedimentation started (Pg_3). The type of the crust underlying this basin is an important geological problem for this region. Based on geophysical data, a tectonic map of the northern part of the Labrador Sea was constructed (Fig. 1) [2]. It can be seen from this map that the oceanic lithosphere is located in deep parts of the sea, and its distribution shows V-shaped patterns controlled by numerous faults. The continental crust occupies a much smaller area in the Labrador Sea and borders the oceanic crust in the north, west, and east [2].

The Davis Strait High is located north of the Labrador Sea. The structure of the crust in this region was studied by the refraction method, which provided evidence for the presence of continental blocks in the central part of the strait with the Moho discontinuity at 22 km. The available data show that the Davis Strait is underlain by the continental crust. The composition of volcanic rocks and their affiliation to particular magmatic series may help to solve the problem of the nature of crust in this area. For this purpose we carried out a mineralogical and petrographic investigation of volcanic rocks collected in the northern part of the Labrador Sea.

METHODS OF INVESTIGATION

Our investigation involved a number of methods including combined field work on board the R/V *Professor Logachev* during Leg 13 of the UNESCO-IOC Program “Floating University” to the northern Atlantic and laboratory analysis of collected samples. A combined study of geological objects by geophysical methods and direct observations was carried out as part of the Training Through Research Program. The geophysical methods included seismic profiling, bottom survey by OKEAN and MAK-1M sidescan sonars with a bottom profiler, and an underwater television survey. The seismic operations were usually performed by Pulse pneumatic sources of sonic oscillations, a seismic streamer, and a PC-based recording system. The seismic source is a 3-liter airgun with a pressure of 120 bar (12 MPa). The bottom survey by sidescan sonars of two types (OKEAN and MAK-1M) was also carried out during the cruise. The OKEAN sidescan sonar is used for acoustic study of the sea bottom, its relief, and acoustic properties of deposits. The MAK-1M sidescan sonar gives higher resolution images compared with the OKEAN, which provides an opportunity for a more detailed and accurate study of the acoustic properties of bottom structures. The obtained geophysical data allowed us to construct a 3D model for the bottom topography of the area studied (Fig. 2), which is a high (plateau) with several conelike seamounts.

The geophysical investigations were followed by sampling using two dredges (direct method). Standard techniques described in the Floating University Report were used [3]. The laboratory studies of rocks included a microscopic description of thin sections, a microprobe examination, and chemical analysis. Microprobe analyses were obtained at the laboratory of local analytical methods, Department of Petrology, Faculty of Geology, Moscow State University (electron microprobe Camscan-4DV with a Link AN 10 000 analyzer, analyst E.V. Guseva). The silicate analysis of rocks was performed by the “wet” chemical method at the spectral chemical laboratory of the Faculty of Geology, Moscow State University.

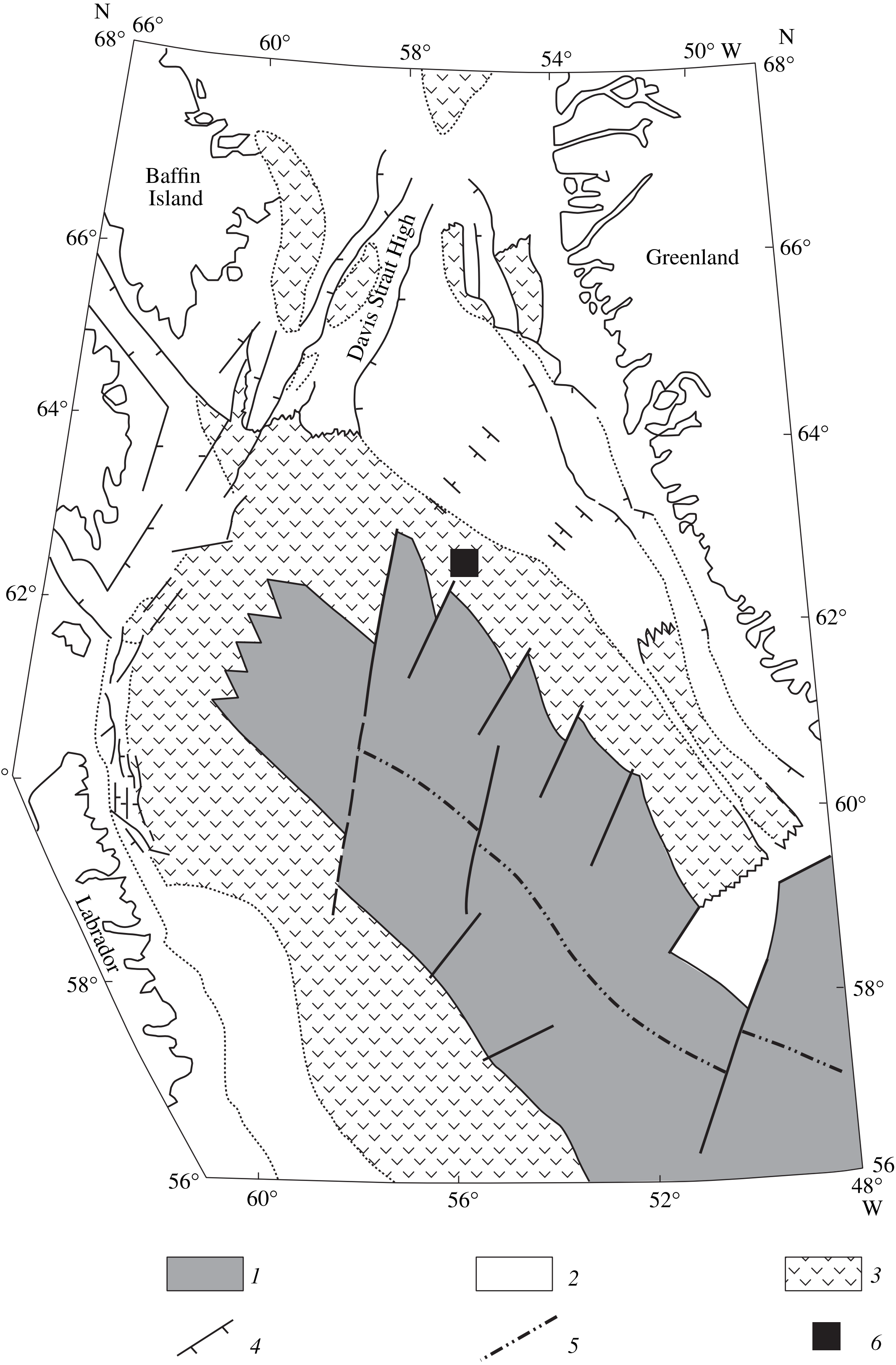

Fig. 1. Tectonic sketch map for the northern part of the Labrador Sea [2]. (*1*) Oceanic crust, (*2*) continental crust, (*3*) and volcanic rocks within the area of continental crust, (*4*) fault, (*5*) extinct spreading axis, and (*6*) area of rock sampling.

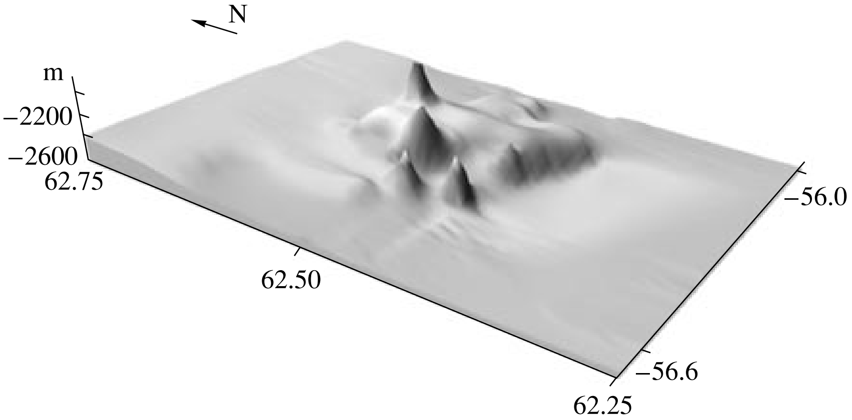

Fig. 2. 3D model of the high in the Western Greenland continental margin.

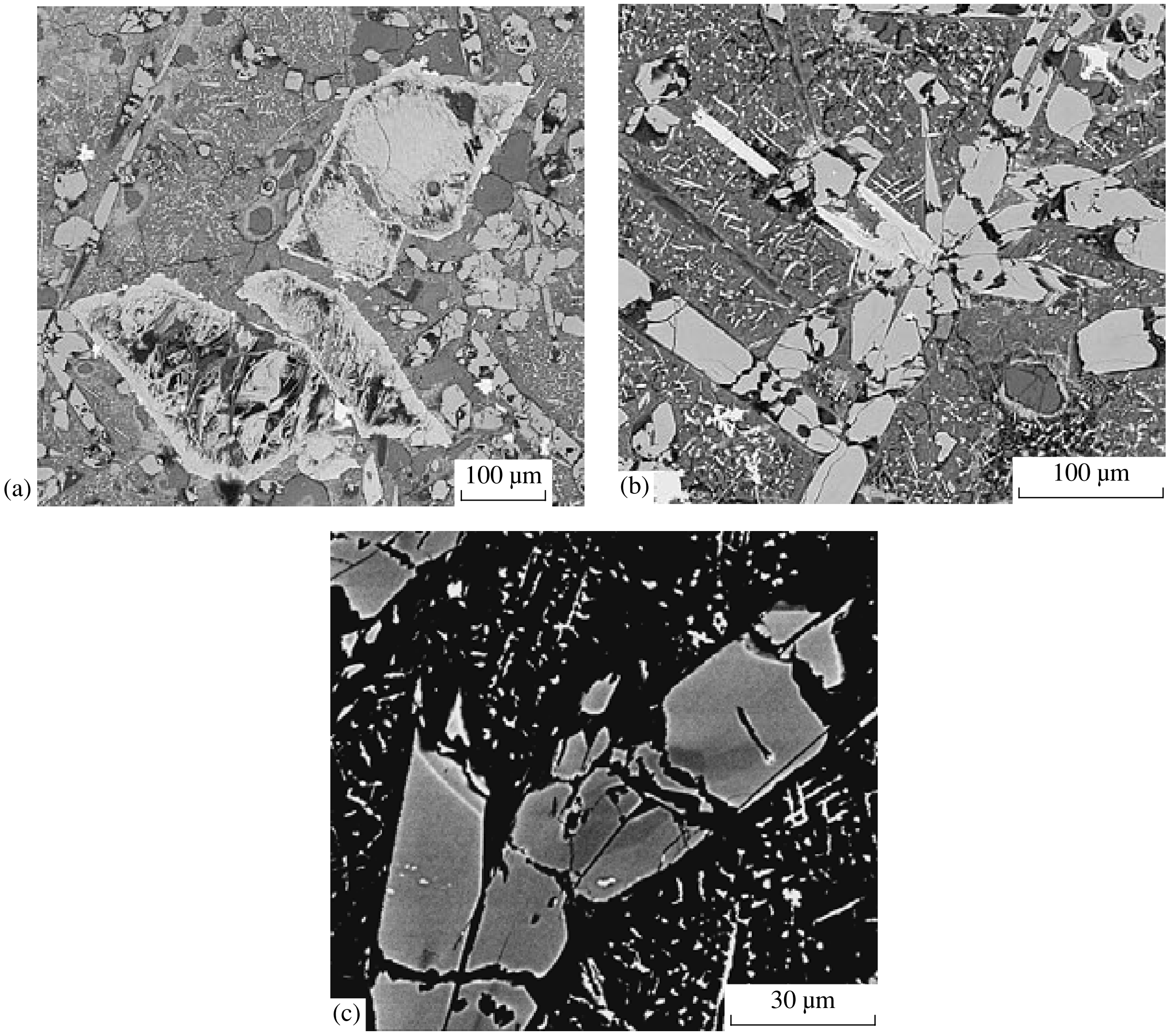

Fig. 3. Alkaline picrites from the seafloor highs of the southwestern continental margin of the Labrador Sea. Sample 4/20, backscattered electron images. (a) Phenocrysts of ferruginated olivine in the groundmass, (b) elongated prismatic titanaugite crystals in devitrified glass with oriented ilmenite inclusions, and (c) zoned titanaugite crystal.

Table 1. Composition of phases of alkali picrites from seafloor highs in the southwestern Greenland continental margin (Sample 4/20)

Component	1	2	3	4	5	6
SiO_2	39.62	40.99	38.78	–	40.59	51.69
TiO_2	7.17	5.21	6.73	17.83	3.31	1.00
Al_2O_3	11.63	9.83	12.99	5.77	28.65	22.15
FeO	8.83	10.19	8.74	70.73	14.35	4.92
MnO	–	–	–	0.56	–	–
MgO	9.24	12.89	9.20	5.11	2.59	1.07
CaO	22.73	20.48	23.06	–	5.24	4.28
Na_2O	0.78	0.41	0.50	–	0.53	5.46
K_2O	–	–	–	–	1.63	6.86
P_2O_5	–	–	–	–	3.11	2.57

Note: Analyses were obtained on a Camscan microprobe at Moscow State University, analyst E.V. Guseva. The compositions were recalculated to totals of 100 wt %. (1) Titanaugite of groundmass; (2) and (3) zoned titanaugite phenocryst (2, center and 3, rim); (4) titanomagnetite phenocryst; (5) and (6) composition of groundmass (averaged over area).

Table 2. Chemical analyses of alkaline picrite

Component	Sample 4/3	Sample 4/5	Sample 4/20	Sample 4/22
SiO_2	33.74	29.38	32.98	32.14
TiO_2	3.95	2.67	3.67	4.03
Al_2O_3	13.68	9.43	13.89	13.24
Fe_2O_3	13.14	9.20	11.94	16.63
FeO	1.10	0.87	2.39	0.30
MnO	0.46	0.60	0.25	1.18
MgO	3.65	2.77	3.91	3.11
CaO	5.96	16.85	8.76	3.15
Na_2O	1.28	1.55	1.31	1.55
K_2O	1.87	1.75	1.14	2.02
P_2O_5	2.06	2.39	1.36	1.77
L.O.I.	8.40	14.81	7.93	9.97
Total	96.93	97.12	95.69	96.88
H_2O^-	7.64	4.85	6.16	7.79

Note: Analyses were obtained at the spectral chemical laboratory, Faculty of Geology, Moscow State University.

RESULTS AND DISCUSSION

Mineralogy and Petrography of Rocks

About 60 rock samples were collected during the dredging of submarine volcanic structures. All samples were visually inspected and divided into several groups: sedimentary, magmatic (plutonic and volcanic), and metamorphic rocks. Particular attention was given to volcanic rocks, which are described below.

The rocks have porphyritic textures (Fig. 3a) and amygdaloidal structures. Their phenocrysts are represented by completely altered olivine forming euhedral isometric grains, up to 1 mm in size. More scarce are elongated prismatic brown titanaugite and titanomagnetite (0.1–0.3 mm) phenocrysts. The phenocrysts account for 10–15% of the rocks. Amygdules (about 15% of the rocks) have elongated irregular shapes and zonal structures: their central parts are filled with zoisite and chlorite and surrounded by a chalcedony rim.

The fine-granular groundmass consists of elongated prismatic titanaugite crystals and altered interstitial glass (Fig. 3b). The composition of pyroxene is presented in Table 1. One pyroxene grain (Fig. 3c) showed weak zoning with a decrease in silicon and magnesium and an increase in aluminum concentration from the core to the rim (analyses 2 and 3 in Table 1, respectively). The titanomagnetite phenocrysts (analysis 4, Table 1) are relatively enriched in aluminum and magnesium. Unaltered glass was never found. Judging from the areal microprobe analyses of groundmass (analyses 5 and 6, Table 1), the newly formed mineral aggregate consists of plagioclase, alkali feldspar, and ilmenite, which forms acicular oriented crystals in the groundmass (Figs. 3b, 3c). Tiny apatite crystals also occur in the groundmass. The composition of the groundmass is strongly variable, especially in iron and alkali contents.

The chemical and mineral compositions of this rock correspond to alkali picrite.

Petrochemistry

The chemical analyses of volcanic rocks are presented in Table 2. Noteworthy are high L.O.I. values and H_2O concentrations in the rocks, providing evidence for extensive alteration of the rocks.

The picrites show very low silica contents (30.3–34.8 wt % SiO_2), which is related in the high alkalinity and a high degree of alteration of the rocks. The latter is supported by the high concentration of ferric iron (9.2–16.6 wt % Fe_2O_3). The low magnesium concentration in the rocks also results from metasomatic alteration: magnesium-rich olivine is usually replaced by iron hydroxides. The high alkalinity of the rocks is confirmed by the high concentration of titanium, which is incorporated in titanomagnetite, titanaugite, and possibly glass, and phosphorus, which is concentrated in groundmass apatite. The silicate analyses show high concentrations of alkalis (Table 2).

The picrites of the seafloor highs are affiliated to the subalkaline K–Na series [4]. This series is widespread, regardless of the structure and type of the crust, and most common in submarine basements and subaerial volcanoes of ocean islands, seamounts, and oceanic

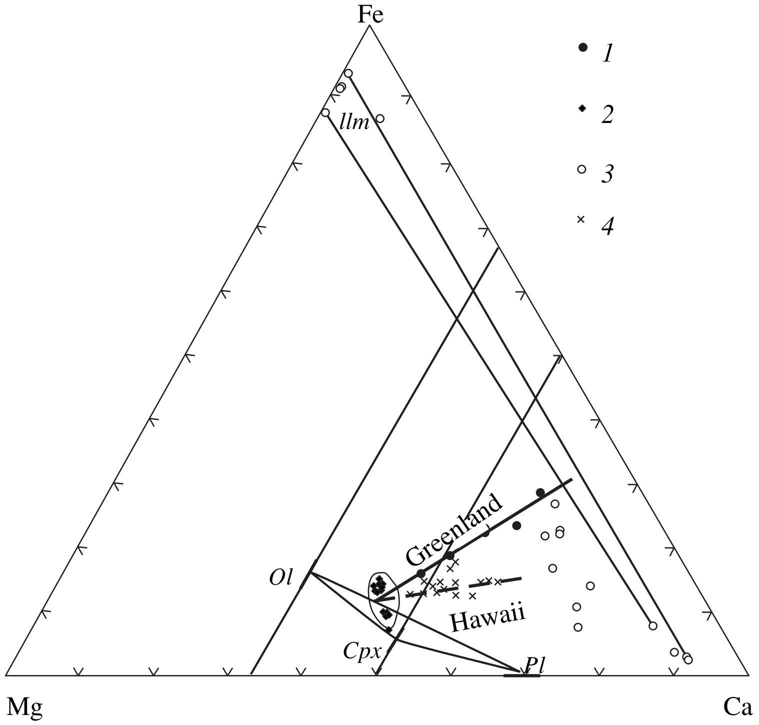

Fig. 4. Trends of magma differentiation for the seafloor highs of the southwestern Greenland margin compared with the evolution of subalkaline melts from the Hawaiian Islands [6]. (*1*) Chemical composition of Greenland subalkaline picrites, (*2*) titanaugite from these rocks, (*3*) ilmenite and feldspars from the crystallized groundmass of these rocks, and (*4*) tholeiitic and subalkaline basalts of Hawaii [4].

plateaus. Thus, the suggestion on the formation of the highs studied on the continental crust [1] cannot be confirmed by the petrographic data. These structures are most likely embryonic oceanic islands formed on the oceanic crust. The confirmation of this suggestion requires additional data on the rocks of volcanic highs belonging to the series under investigation.

The rocks of this series were most extensively studied in the Hawaiian Islands, where shallow differentiation with olivine fractionation is the main factor of the evolution of the initial tholeiitic magma [5]. Figure 4 shows melt differentiation paths for the seafloor highs of the southwestern Greenland margin in comparison with the data on the Hawaii. The steeper slope of the differentiation trend in our case results from simultaneous crystallization of olivine and titanaugite during the early stages of melt evolution

CONCLUSIONS

(1) The Labrador Sea is a basin with oceanic crust in its deep part.

(2) The bottom morphology of the Labrador Sea is rather complicated. The data of seismic profiling in this region indicate the presence of numerous submarine mountains and hills, which are dominated by volcanic rocks.

(3) Some chemical and mineral characteristics of the rocks, in particular, high concentrations of alkalis and phosphorus, and the presence of high-titanium augite, ilmenite, and devitrified glass enriched in K and Na, allow us to attribute them to K–Na subalkaline picrites typical of ocean islands, seamounts, and oceanic plateaus.

(4) The rocks of the K–Na subalkaline series usually form submarine basements and subaerial volcanoes of ocean islands, seamounts, and oceanic plateaus. Thus, the suggestion on the formation of the highs on the continental crust is not confirmed by the petrographic data, which requires a refinement of the tectonic model of the northern part of the Labrador Sea.

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