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GEOPHYSICS

New Data on Heat Flow in the North Atlantic Region

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Forty-one new measurements of heat flow on the Arctic Sea bottom were obtained in the course of marine expeditions (2008 and 2010). The high geodynamic activity of the lithosphere in the North Atlantic Region west of the Svalbard Archipelago near Knipovich Ridge was confirmed in the course of numerical modeling of deep temperatures. In this region, the mantle material solidus isotherm (~ 1200°C) is at the depth of 15 km. This testifies to the fact that Knipovich Ridge has developed as a young oceanic rift having existed since the Miocene.

Numerical modeling of heat transfer in the lithosphere of the North Atlantic Region based on new measurements made it possible to estimate deep temperatures in that part of the ocean and to make a conclusion on recent geodynamic activity near Knipovich Ridge.

Geothermal investigations of the Arctic shelf margin, continental slope, and adjacent water zones of the North Atlantic Region west of the Svalbard Archipelago were carried out under the scientific program of the Russian Academy of Sciences "Geological History and Lithosphere of the Polar Regions." The main objective of our investigations was to obtain new data on heat flow, to calculate deep temperatures in the oceanic lithosphere, and to study tectonothermal evolution at the newest stage of the region's development.

Geothermal investigations were started under the mentioned program in 2007, when the recent destruction zones at the edge of the Svalbard Plate were discovered in the course of cruise 25 of the R/V *Akademik Nikolai Strakhov* [1]. Anomalously high heat flow in the Orel Trough (Sturö) and elevated heat flow in the Franz–Victoria Trough, as well as other geological factors (recent hydrothermal activity in the Svalbard Archipelago, high concentration of earthquake epicenters) prove the high recent geodynamic activity of the whole region, including the archipelago and surrounding water zones.

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The investigations continued in cruises 26 (2008) and 27 (2010) were carried out by the system of profiles extending from the archipelago to Knipovich and Mona ridges in the North Atlantic Region.

The Knipovich Ridge zone has served for many years as a test site for complex and special international investigations by research vessels. The particular interest of scientists from all over the world in this region is not accidental: the Svalbard Archipelago and adjacent Norwegian–Greenland ocean basin are key structures for understanding tectonics and evolution of the western sector of the Atlantic Region and development of structural relations between the North Atlantic Region and the Arctic Ocean in the Late Cenozoic. Most researchers admit the spreading nature of Knipovich Ridge in the Norwegian–Greenland ocean basin. A well-defined elevated rift plain, recent seismicity near the ridge, and alternating-sign magnetic field allow us to refer it to an ordinary segment of the world system of mid-ocean ridges. However, many anomalous features in the structure of this morphostructure do not fit ordinary conceptions and should be explained.

In the course of investigations, we obtained 41 new measurements of heat flow (table) and also seismic profiling and multibeam echo-sounding data, which were used for construction of geothermal models, in particular, for simulation of the bottom morphology and upper part of the sedimentary cover. Measurements were carried out with a GEOS-M telemetric multichannel probe applied previously [1].

As a whole, the heat flow in the region is characterized by high values. It is necessary to comment on some measurements that either fall out spatially from the whole measurement scheme or display great influence of exogenetic factors destructing the deep conductive heat flow.

Measurements of heat flow in cruises 26 and 27

Station No.	Date	Coordinates		Sea depth, m	Temperature gradient, mK/m	Thermal conductivity, W/(m K)	Average heat flow, mW/m^2
		N	E				
2603	Jan. 9, 2009	75.000°	15.533°	703	–174	1.00	–174
2604	Jan. 9, 2009	75.150	15.050	614	–302	1.00	–302
2604_2	Jan. 9, 2009	75.167	15.000	645	–212	1.00	–212
2605	Jan. 10, 2009	75.217	13.433	1535	66	0.80	53
2606	Jan. 12, 2009	75.983	17.027	324	–401	1.00	–401
2607	Jan. 13, 2009	75.667	14.067	550	–179	1.04	–186
2608	Jan. 13, 2009	75.552	12.985	1480	69	0.80	55
2609	Jan. 13, 2009	75.433	12.067	1993	64	1.00	64
2610	Jan. 13, 2009	75.300	11.000	2360	86	1.04	89
2611	Jan. 13, 2009	75.133	9.850	2511	120	0.98	118
2612	Jan. 14, 2009	74.900	8.400	3450	288	0.80	230
2614	Jan. 16, 2009	74.733	9.867	2548	113	1.05	119
2615	Jan. 16, 2009	74.883	11.317	2431	92	0.90	83
2616	Jan. 17, 2009	75.017	12.500	2147	66	1.00	66
2617	Jan. 20, 2009	75.800	12.850	1505	61	0.80	49
2618	Jan. 20, 2009	75.778	13.232	1247	53	1.00	53
2619	Jan. 21, 2009	75.769	13.374	1207	57	0.88	50
2620	Jan. 21, 2009	75.753	13.575	997	45	1.15	52
2621	Jan. 21, 2009	75.737	13.725	873	28	1.14	32
2622	Jan. 21, 2009	75.729	13.854	774	16	1.02	16
2701	Aug. 24, 2010	80.470	29.853	390	170	1.00	170
2702	Aug. 24, 2010	80.470	29.875	438	216	0.94	203
2703	Aug. 24, 2010	80.466	29.878	440	205	0.95	195
2704	Aug. 24, 2010	80.443	29.536	357	327	1.15	376
2705	Aug. 26, 2010	77.185	11.517	573	162	1.25	202
2706	Aug. 26, 2010	77.284	10.955	1093	103	1.03	106
2707	Aug. 26, 2010	77.400	10.391	1422	124	0.88	109
2708	Aug. 26, 2010	77.515	9.609	1750	163	0.81	132
2709	Aug. 26, 2010	77.616	8.843	2066	203	0.93	189
2710	Aug. 26, 2010	77.719	8.312	2190	183	1.04	190
2711	Aug. 26, 2010	77.766	8.059	2620	204	1.00	204
2712	Aug. 27, 2010	78.254	2.597	2615	65	1.08	70
2713	Aug. 27, 2010	78.241	2.986	2690	77	0.98	75
2714	Aug. 28, 2010	78.218	3.242	2772	66	1.04	69
2715	Aug. 28, 2010	77.799	7.796	3320	401	0.75	301
2716	Sept. 2, 2010	78.789	5.155	2640	152	0.96	146
2717	Sept. 4, 2010	78.189	3.881	1270	111	1.4	156
2718	Sept. 4, 2010	78.164	4.315	1975	93	1.12	104
2719	Sept. 4, 2010	78.128	4.628	1550	49	1.21	59
2720	Sept. 4, 2010	78.077	5.144	2670	102	0.94	96
2721	Sept. 4, 2010	78.047	5.593	2584	128	1.03	132

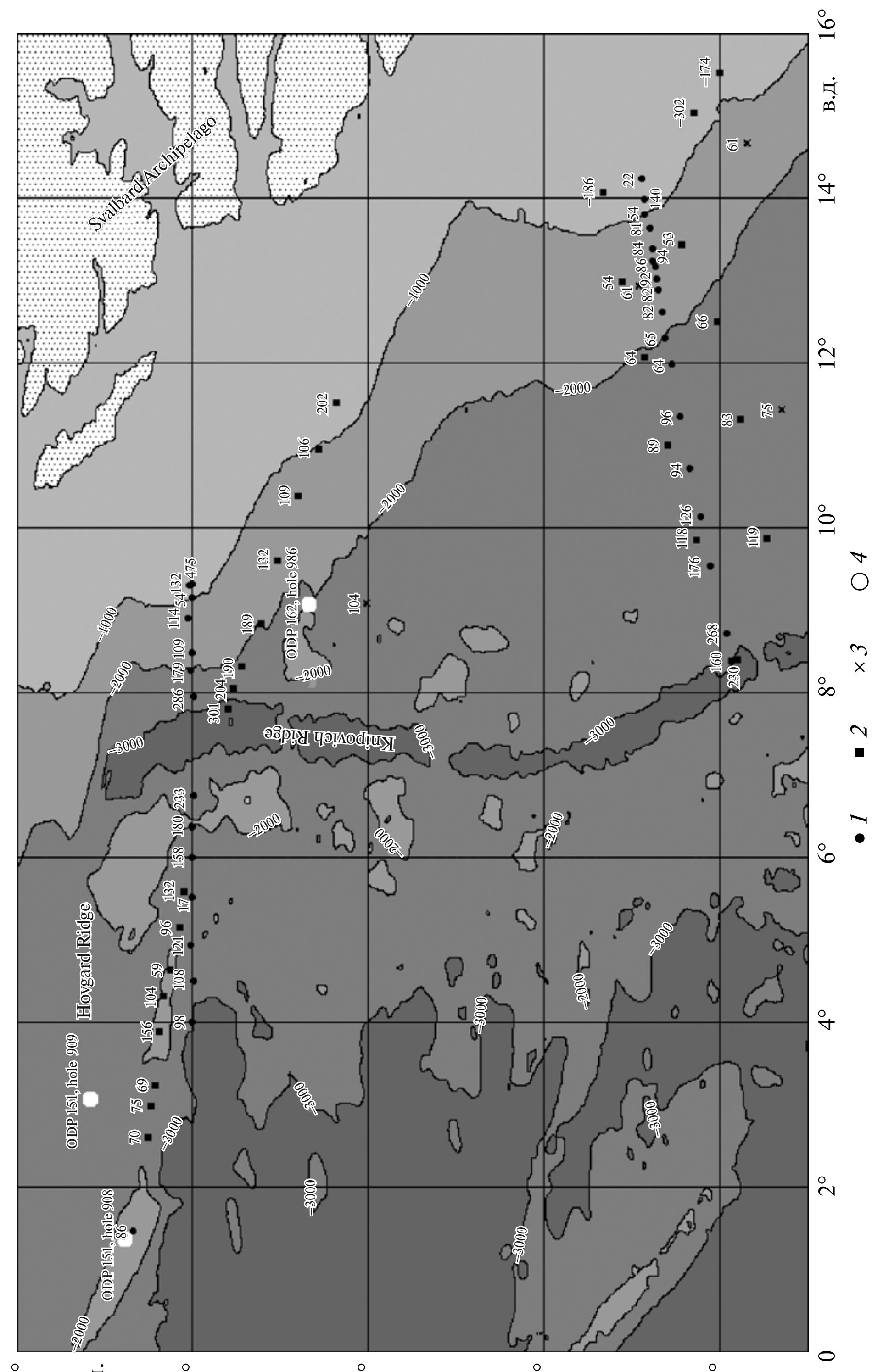

Fig. 1. Distribution of heat flow measurements (mW/m^2) west of the Svalbard Archipelago. Measurements: (*1*) cruises 26 and 27; (*2*) [2]; (*3*) [3]; (*4*) ODP drill holes.

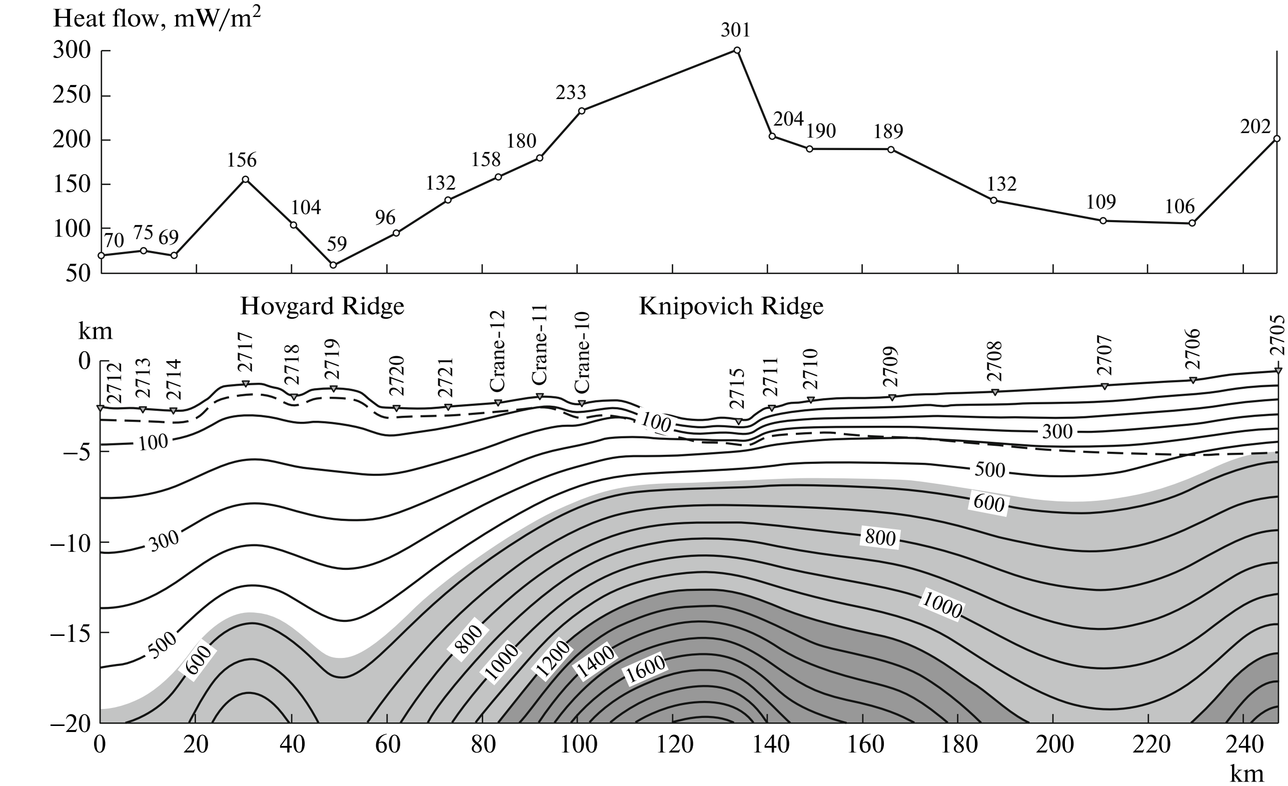

Fig. 2. Measurements of heat flow and geothermal model (°C), cruise 27. The Curie temperature region (above 570°C) is colored in light gray, the basalt melting temperature region (above 1200°C) is colored in dark gray, and the boundary of the acoustic basement is indicated with a dashed line.

Four control measurements in the Orel Trough (Sturö) located east of the Northeast Svalbard Land were carried out in cruise 27 to confirm the existence of an anomaly identified in cruise 25 (stations 2701–2704). The maximum measurement value (376 mW/m^2) was obtained for the ring structure on the bottom surface at a depth of about 360 m. Hence, we observe complete consistency of geothermal data spaced three years apart.

Four measurements in the continental slope southwest of the Svalbard Archipelago demonstrated negative values of the geothermal gradient (table). The stations were located on the Gulf Stream route (at a sea depth of up to 400 m), which explained the increase in the seafloor temperature and formation of a negative temperature gradient. Since those negative gradients were related to exogenetic distortion of the heat field, they were not taken into account in the course of further deep temperature modeling. Moreover, we established that the heat flow temperature interval extended for up to 500 m and more.

Maximum values of the heat flow (230 and 301 mW/m^2) were registered in the Knipovich Ridge axial zone.

Thermal conductivity of bottom soils yielded almost identical values at all heat flow measurement stations 1.02 ± 0.06 W/(m K).

The values of heat flow obtained by the probe method and in the ODP[1] holes (908, 909, and 986) correlate well with each other. For instance, the calculated heat flow attained 154 mW/m^2 in drill hole 986 (ODP 162), while the heat flow measured at the nearest station 2708 attained 132 mW/m^2. The distance between the hole and the station is about 22.5 km. In drill holes 908 (ODP 151) and 909 (ODP 151), the values of heat flows attained 70 and 87 mW/m^2, respectively. The measured heat flow at the nearest station 2712 attained 70 mW/m^2. The distance between these drill holes and the station is 31 and 38 km. This correlation of heat flows at different depths may testify to correct estimation of the heat flow in the investigation area, at least, to depths of 100 m in the bottom sediments.

Modeling along the geothermal profiles was based on data obtained in the course of cruises and the heat flow values from foreign papers. For the most part, these are measurements of K. Crane [2] and O. Eldholm [3] (Fig. 1). When the data were synthesized, a few profiles were formed and calculations were performed along them.

[1] Ocean Drilling Program is the International Ocean Drilling Program carried out in 1983–2003.

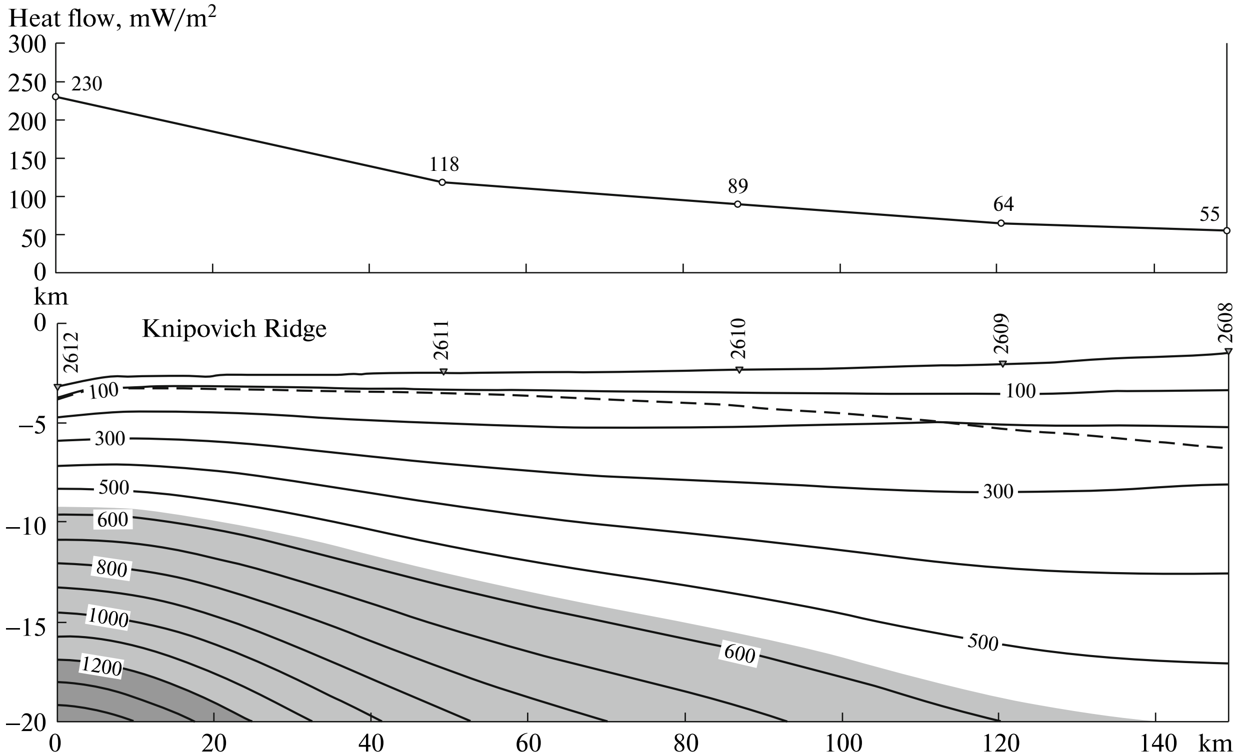

Fig. 3. Measurements of heat flow and geothermal model (°C), cruise 26.

The results of numerical modeling of deep temperatures confirmed the suggestion about high geodynamic activity of the North Atlantic lithosphere west of the Svalbard Archipelago near Knipovich Ridge (Figs. 2, 3). The mantle substance solidus isotherm[2] (~1200°C) is at the depth of 15 km. The average thickness of the ocean lithosphere for the ocean plates far from the mid-ocean ridges is 70–80 km [4]; near the mid-ocean ridges and active submarine volcanoes, it decreases to 10–15 km [5]. This very phenomenon is observed under Knipovich Ridge. This ridge can be undeniable referred to as a segment of active continuation of the Mid-Atlantic Ridge [6, 7]. But its structure has not yet formed into a typical spreading ridge with central rift valleys.

With distance from the Knipovich Ridge axis in the eastern direction towards the Svalbard Archipelago, the thermal lithosphere thickness increases dramatically and attains already 45–50 km near the continental slope foot, which, nevertheless, testifies to activity of the whole ocean crust block.

[2] This isotherm is known [8, 9] to be associated with a "thermal lithosphere" foot. As follows from the results of investigations devoted to calculations of lithosphere thickness in continents and the ocean by seismologic, magnetotelluric, and geothermal data, there are no statistically important differences in these values. Nevertheless, in order to emphasize the lithosphere foot depth method, we mean the thickness of the "thermal lithosphere"; i.e., the 1200°C isotherm depth will be calculated.

Knipovich Ocean Ridge was localized in the eastern part of the Norwegian–Greenland basin near the West Svalbard margin in the Miocene. This conclusion is based on analysis of seismic sections having stratigraphic ties by faunistically characterized sections of deep ocean drill holes.

All the above information points to specific features of Knipovich Ridge not typical of ordinary mid-ocean ridges. Knipovich Ridge more likely represents a young oceanic rift having existed since the Miocene, the activity of which was constantly supported during the last 20 million years by the proximity and activity of the asthenosphere.

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