ISSN 1028-334X, Doklady Earth Sciences, 2010, Vol. 430, Part 2, pp. 265–270. © Pleiades Publishing, Ltd., 2010.
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OCEANOLOGY

Structure of the Transition Zone from the Barents Sea Shelf to the Knipovich Ridge Northward from Medvezhii Island (Preliminary Results of the 26th Cruis of R/V *Akademik Nikolaj Strakhov*)

A. V. Zayonchek, H. Brekke, S. Yu. Sokolov, A. V. Ermakov, V. N. Efimov, Yu. A. Zaraiskaya, V. R. Akhmedzyanov, N. D. Kalinin, A. V. Kokhan, E. A. Moroz, D. M. Ol'shanetskii, A. A. Razumovskii, and K. P. Yampol'skii

Presented by Academician Yu.G. Leonov May 21, 2009

Received May 25, 2009

DOI: 10.1134/S1028334X10020261

The works of the 26th cruis of R/V *Academik Nikolaj Strakhov* scientific research vessel showed that the Barents Sea shelf located north of Medvezhii island experiences lift and erosion delivering terrigenous material for fan systems from the shelf edge to the Knipovich Ridge. Bottom relief indicates the presence of tectonic fracturing in the region of intensive isostatitical process in a continent–ocean transition zone and traces of movements of icebergs formed at different times. The survey in the zone of the Knipovich Ridge from 74°40′ to 75°20′ N indicates intensification of neotectonic processes on the eastern side of the rift valley and increase of their amplitude to 1.5 km. The nature of deformations of the sedimentary cover testifies to the continuation of Riedel fractures under sediments on the eastern side and confirms the right strike-slip model of the ridge zone. The survey in the region of the south slope of the Mohn Ridge indicates neotectonic activity on the flank. Medvezhii trough is a source of drift of sediments, which are accumulated southward from the ridge. Geothermic data confirming the assumption about the dependence of heat flow on the crust age in the northern part of the Atlantic Ocean were gathered. Data about water temperatures in the region of the continental slope on the western edge of the Barents Sea were collected.

In the context of the International Polar Year program, from December 30, 2008, to January 29, 2009, in the northwestern Barents Sea (continental slope and the Knipovich Ridge), the 26th cruis of R/V *Academik Nikolaj Strakhov* scientific research vessel (R/V) was carried out (chief of station is A.V. Zayonchek) (Fig. 1). The purpose of the cruis was study of the geological structure and evolution of the Norwegian–Greenland Basin and the northwestern part of the Barents Sea according to the programs of the Presidium of the Russian Academy of Sciences no. 16 "Changes in Environment and Climate: Environment Disasters" and no. 17 "Fundamental Problems of Ecology: Physics, Geology, Biology, Ecology" (projects "Comparative Study of Evolution and Modern Structure of Continental Margins of the East Atlantic and the Arctic Zone," Division of Earth Sciences no. 14), "The History of Formation of the Arctic Ocean Basin and the Regime of Modern Nature Processes in the Arctic," and also the programs of the Geological Institute (GIN), Russian Academy of Sciences and the Norwegian Petroleum Directorate "Late Mesozoic–Cenozoic Tectono-Magmatic History of the Barents Sea Shelf and Slope as a Clue to Paleodynamic Reconstructions in the Arctic Seas" (leaders A.V. Zayonchek and Kh. Brekke).

During the expedition, data collection about the relief and uppermost layers of the sedimentary cover was made with hydroacoustic system REASON, which includes the multibeam echo sounders SeaBat-8111 (shallow) and SeaBat-7150 (deep-water) and also the high-frequency subbottom profiler (SBP) EdgeTech-3300. The survey was conducted by continuous seismic profiling (CSP), by equipment developed at GIN RAS. At the stations, the heat flow and sound velocity profiles were measured with acoustic probes GEOS M and SVP 24, respectively.

The values of heat flow were received at 20 stations, and at four stations, the sound velocity profiles in

Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia
e-mail: sysokolov@yandex.ru
Norwegian Petroleum Directorate, P.O. Box 600, 4003 Stavanger, Norway

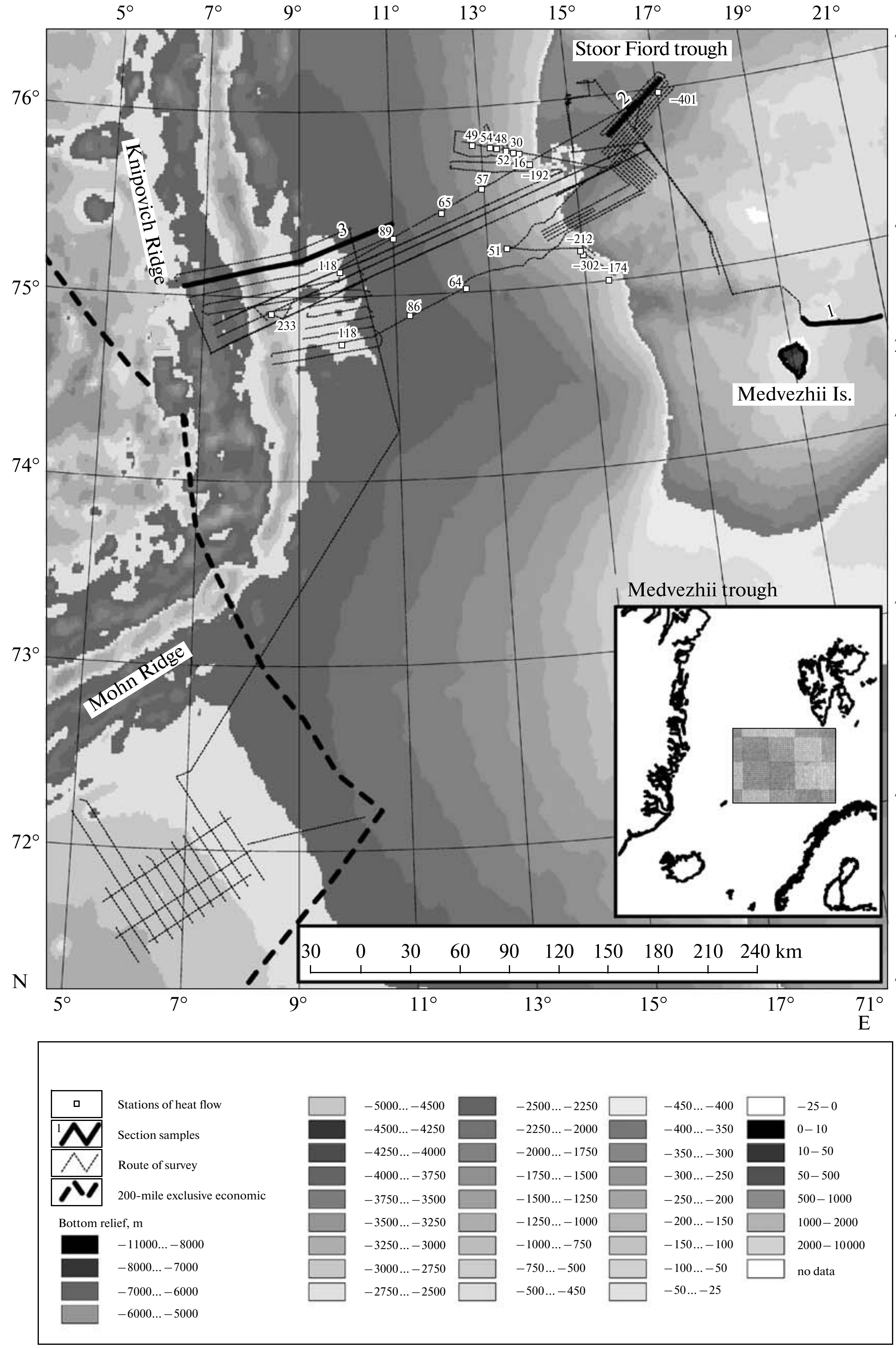

Fig. 1. The scheme of works of 26th cruis of R/V *Akademik Nikolaj Strakhov.*

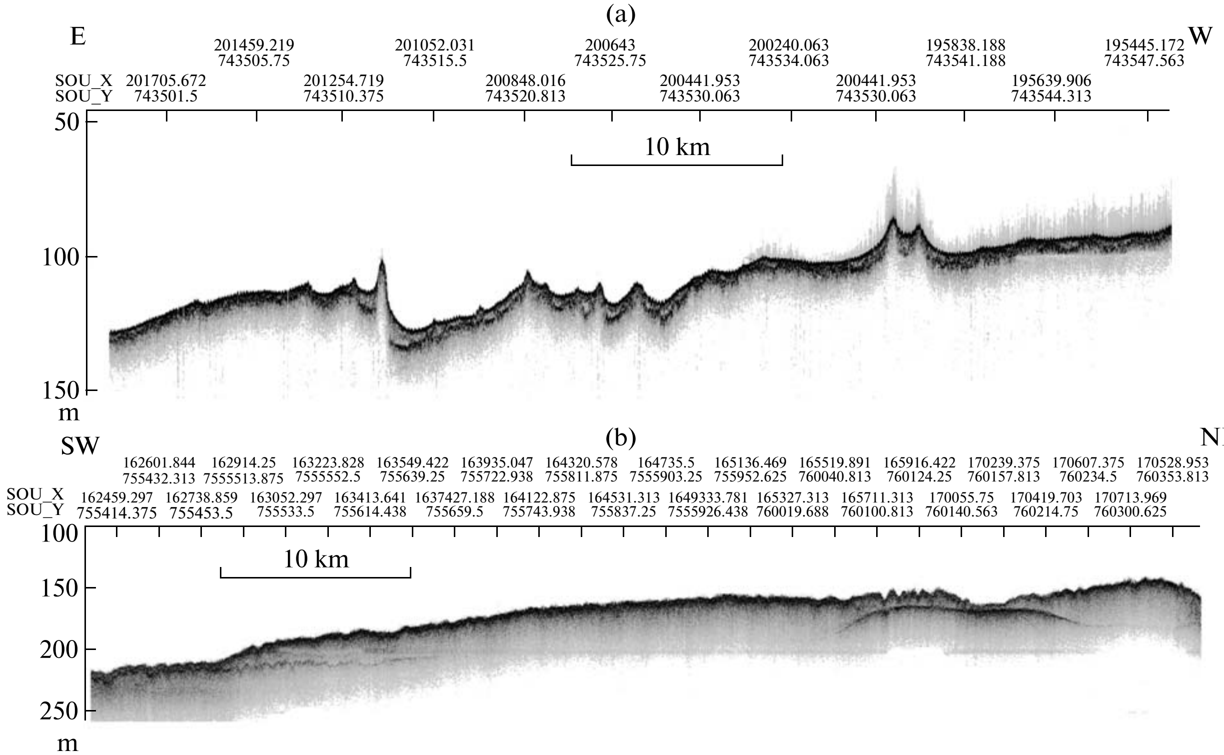

Fig. 2. The fragments of sections of SBP EdgeTech-3300.

water was measured. The total length of the survey with echo-sounding and SBP came to 6200 km. In combination with seismic profiling, it came to 3000 km.

The information about the structure of the upper part of the sedimentary cover is very poor. The data about the structure of the upper part of the sedimentary cover of the Knipovich Ridge are quoted in [1]; similar data exist about the cover structure in the Stoor Fiord trough south of the Spitsbergen archipelago [3]. The important thing is a mention about the presence of gas hydrates and structures of their discharge east of Medvezhii Island [9].

Initially, the research was planned in the Stoor Fiord trough, but due to the ice condition, only its south slope was accessible for swath survey. Further investigations were conducted on the continental slope, the Knipovich Ridge, and the northwest flank of the Mohn Ridge (Fig. 1) throughout the surveys of the 24th and 25th cruises. The basic results of the study are presented in this work.

Shelf and Continental Slope

According to a high precision multibeam bathymetric survey within the limits of the shelf part of the mouth of the Stoor Fiord trough, it was established that the data of IBCAO essentially did not match the received information about the relief, which came to 220 m. It was revealed that the trough bed is indented by numerous furrows put into two groups: linear furrows (presumably of tectonic genesis) and exaration ones. Northward and to the northeast, linear furrows have a length up to 10 km; the distance between sides of the largest furrows is 400 m and its relative depth is 15 m. In structural plan they look like a strip 7 km in width. The major part of exaration furrows has no defined direction. Some exaration furrows are grouped in subparallel systems and differ (in structural plan) from tectonic ones by the twisting contour of themselves. According to the relationship of these forms of relief, it can be supposed that they were formed in different stages. The furrows are not registered at a depth of 500–600 m. Under these benchmarks the relief of the continental slope is smoothed.

By the SBP data, the character of acoustic stratification of the bedrock changes from an opaque character connected with the outcrop of consolidated rocks to the layering of acoustically well-stratified units of 2–3 m in thickness. On the north margin of the Medvezhinskoe uplift, extensive outcrops of basement rocks have been discovered. The reflection intensity and record nature make it possible to interpret these outcrops as dikes (Fig. 2a). Similar outcrops above, where positive magnetic anomalies are registered, were discovered northward and to the northwest of the study region [2]. Outcrops of intrusions on the bed surface testify to the uplift of the bed, leading to erosion of the enclosing rocks.

At a depth of 20–25 m, a near-bottom reflector is discovered; generally, it replicates the bed contours, but does not concur with them in the places where exaration furrows are located (Fig. 2b). It is more

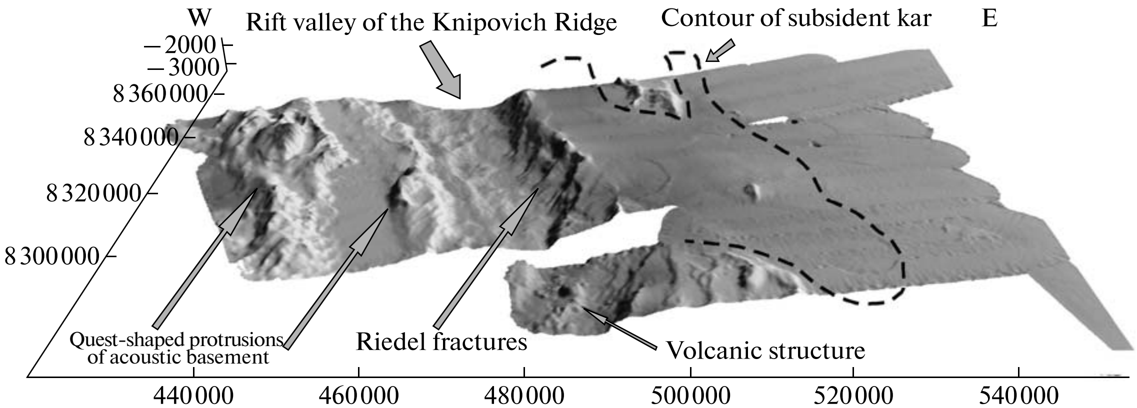

Fig. 3. Three-dimensional shadow relief of the survey fragment on the Knipovich Ridge.

likely that the near-bottom reflector has a physical but not stratigraphic nature and is a thermal boundary or zone boundary of gas hydrate stability. In the northern part of the Stoor Fiord trough, the reflectors have a stable three-layered character conforming to the bed relief. Such conditions are characteristic for sedimentary rocks formed due to rhythmic income of terrigenous sediments.

In the northwestern part of the study region, a reflector with a sharp increase in the dynamics of reflections has been discovered (Fig. 2b). It is close to the bed surface in the middle of a ring-shaped morphostructure. Two explanations of this can be advanced. First, the initial discharge stage of gas hydrates changed into the mobile fluid condition occurred. Second, the top of a magmatic body, which an isolated magnetic anomaly is conformed to [10], is registered. In this region we revealed acoustic disturbances similar to gas torches. This region needs special investigation.

According to CSP the zone of the shelf and Stoor Fiord trough is exposed to erosion and contains reflectors of the BSR (bottom simulated reflector) type. Most of the sedimentary cover "visible" by the CSP method is dated to the Middle–Late Pliocene [3]. This part of the cover contains glacial progradation deltas with a specific wave pattern. The transition from the edge of the shelf to the slope is accompanied by an increase in thickness of shelf seismic complexes.

Knipovich Ridge

Rift valley and rift mountains that are the quest-shaped protrusions of the acoustic basement are shown in the relief of the studied segment of the Knipovich Ridge. On the eastern side, single uplifts of the acoustic basement in the frame of the sedimentary cover are located (Fig. 3). In the region of the polygon on the western side of the ridge, two parallel systems of uplifts divided by a depression filled with sediments are distinguished. The eastern side in the studied region is characterized by the smoothed relief with a well-distinguished contour of sunken sediments and a level difference about 60–120 m (Figs. 1, 3). The rift valley has a U-shaped profile; the bed width comes to 10 km; and the width from edge to edge comes to about 20 km. The valley bed is complicated with benches of the northeastrtn and the southwestern orientation, which are the Riedel fractures oriented angularly about 35° to the axis of rift, which is an extension structure [6]. The relative height of benches comes to 200 m above the valley bed. A volcanic structure of the central type was discovered in the valley.

According to the SBP in the region of the continental rise, near a depression on the eastern side of Knipovich Ridge, the transition to pelagic sediment accumulation and the presence of different deformations affecting the upper 100 m of the sedimentary cover are observed. These deformations are normal faults; thrust-fault and plicative deformations, which are not observed on the western side of the ridge. This is evidence of the modern mobility of the structure on the east. The stratification character of sediments on the western side is different from that on the east and it indicates that sediments of turbidity flows do not extend through the ridge. Sediments of the fan both in condensed sections and in enlarged lenses interstratify so, like in the whole, the section along the line abyss–shelf has a transgressive look.

By the data of CSP, the transition from the continental slope to the rise registers itself by the facial change in the pattern of the wave field from acoustically transparent complexes with a chaotic nonstratified inner structure to the more contrasting and correlating reflectors (Fig. 4) of the distant parts of the fan.

Near the ridge lag-faults deformations are discovered, especially in the region of a "subsident kar" between 74°40′ and 75°20′ N. Here and there narrow zones with thrust-fault deformations occur. The subsidence amplitude of the acoustic basement in the region of the "kar" may be equal to 300–400 m. The lag-fault amplitude of the rift valley along the edge (in

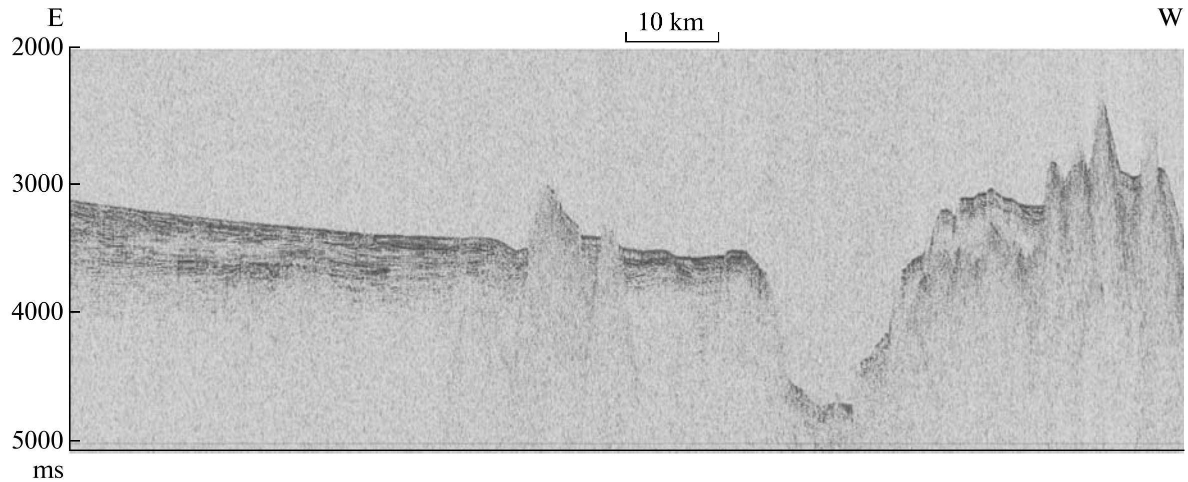

Fig. 4. Fragment of CSP section S26-P3-13 (location 3 in Fig. 1) through the rift valley of Knipovich Ridge.

the segment of the ridge) comes to 1.5 km. Near 75°5′ N on the submeridional profile at a depth of 150 m, the reflector experiences a sharp submersion by the lag-fault. This probably indicates that Riedel fractures continue by the tangent tension on the eastern side of the ridge at distances from its axis of no less than 65 km.

Mohn Ridge

The survey area is situated on the southern side of the slow-spreading Mohn Ridge. The polygon relief is smoothed with single uplifts, which are the outcrops of the acoustic basement. The fan of the Medvezhii trough serves as a source of terrigenous material. By the data of profiling and echo-sounding in the southwestern part of the polygon, a con-sedimentation depression is discovered. Under the depression a lag-fault with an amplitude of about 20 m is observed. This testifies to local extension.

Basement outcrops represent two hills, the highest of which is closer to the Mohn Ridge. The top of the hill is situated at a depth 1900 m; the relative height is about 1000 m. The second hill represents a southwestward elongated uplift with a relative height about 500 m.

By the SBP data on the south slope of the Mohn Ridge, the drift direction of sediments is from the east to the west. Within the limits of the polygon, a transition from interstratifying of lenses in the middle zone of the fan to its distant part with a condensed section is observed. Extension of drift source of terrigenous sediments from the south to the north is practically excluded. As was mentioned above, a depression of the northwest orientation filled with con-sedimentation deposits of variable thickness is observed in the limits of the polygon. On the profiles perpendicularly oriented to the material drift of the fan of the Medvezhii trough, the thickness of the sedimentary cover reaches up to 900 m. The dynamics of seismic facieses of the sedimentary cover is proper to the middle and distant parts of the fan with possible traces of volcanoclastic material. The transition to pelagic sediment accumulation occurs at distances of about 350 km from the mouth of the Medvezhii trough, which is two times further than the same transition on the fan of the Stoor Fiord trough.

Heat flow

Measurement of the water layer temperature, thermal conductivity, and heat flow (HF) was conducted at 20 stations (Fig. 1). Conditioned values of deep HF were received at 15 stations; at the other stations, HF distorted by exogenous factors (bottom flows, periodic seasonal fluctuations of bed temperature, and, possibly, the presence of permafrost lenses in bed sediments) was registered. The values of HF conform well to the ideas of its dependence on the age of the second layer of the oceanic crust. The HF increases together with the age decrease of the second layer of the oceanic crust and the approach to the spreading axis on the Knipovich Ridge. Moreover, the obtained data conform well to earlier data for this region [7, 11].

The values of heat conductivity measured in situ are within the limits 0.77–1.15 W/(m · K). There were no patterns in the distribution of the values of heat conductivity. The mean value of heat conductivity at all stations comes to 0.96 W/(m · K).

The temperatures of the water surface are positive everywhere. The zero isotherm is situated at depths from 500 to 950 m. On all the profiles, the water thick looks well stratified by temperature. The maximal temperature was registered at station no. 2603 situated on the continental slope along the North-Atlantic Current. It comes to 5.8°C at a depth of 0–240 m. The minimal temperatures (–0.75°C) were registered at stations no. 2605, 2617, and 2618 at depths from 1220–1450 to 1251–1533 m. The received data are important for understanding the role of the north branch of the Gulf Stream in forming bottom thermal conditions.

Analysis of the available data of borehole and probe measurements in the Barents Sea suggests the tendency of HF increase in the southeast and southwest. So, in the joint zone of the Kola plate and the Baltic plate, the mean value of HF comes to 54 mW/m^2; in the regions of the North Barents depression and the Central Barents uplift, it is 70 mW/m^2. Earlier, we associated that tendency of the HF trend with the approach to the North Atlantic spreading center and, hence, rejuvenation of the continental crust [4, 5]. Newly received data about HF in the northwestern part of the sea confirm this point of view.

CONCLUSIONS

An uplift of shelf zone has been discovered in the region north of Medvezhii Island. This is a reason for intensive erosion processes, which are the sources of terrigenous material for fan systems occupying the space from the shelf edge to the Knipovich Ridge. Relief peculiarities in the mouth of the Stoor Fiord trough indicate tectonic fracturing in the region of the intensive isostatitical process in the continent–ocean transition zone where the crust is subsident. The nature of movement traces of icebergs show that they were formed at different times.

The survey in the zone of the Knipovich Ridge from 74°40′ to 75°20′ N indicates intensification of neotectonic processes on the east side of the rift valley and increase of their amplitude to the maximum over the length of the ridge. The nature of deformations of the sedimentary cover testifies to continuation of the Riedel fractures under sediments on the east side and confirms the right strike-slip model of the ridge zone.

The survey in the region of the south slope of the Mohn Ridge indicates neotectonic activity on the flank as a depression of northwest orientation with lag-fault deformation. Medvezhii trough is a source of drift of sediments, which are accumulated southward from the ridge.

We received geothermic data confirming the assumption about the dependence of heat flow on crust age in the northern part of the Atlantic Ocean. Data about water temperatures in the region of the continental slope on the western edge of the Barents Sea have been obtained.

ACKNOWLEDGMENTS

We are grateful to the crew of R/V *Academik Nikolaj Strakhov* providing for ship navigation in winter. This work was supported by the programs of the Presidium of the Russian Academy of Sciences, nos. 16 and 17; the program of the Branch of Earth Sciences no. 14, and the Norwegian Petroleum Directorate.

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