ISSN 1028-334X, Doklady Earth Sciences, 2009, Vol. 427, No. 5, pp. 740–745. © Pleiades Publishing, Ltd., 2009.
Original Russian Text © A.V. Zayonchek, A.O. Mazarovich, V.Yu. Lavrushin, S.Yu. Sokolov, M.D. Khutorskoy, A.S. Abramova, R.Kh. Aliulov, V.R. Akhmedzyanov, Yu.A. Zaraiskaya, A.V. Ermakov, V.N. Efimov, E.A. Moroz, A.A. Peive, D.A. Prokhorov, E.P. Radionova, Yu.N. Raznitsyn, A.A. Razumovskii, A.A. Chernykh, K.P. Yampol'skii, 2009, published in Doklady Akademii Nauk, 2009, Vol. 427, No. 1, pp. 67–72.

GEOLOGY

Geological–Geophysical Studies in the Northern Barents Sea and on the Continental Shelf of the Arctic Ocean during Cruise 25 of the R/V *Akademik Nikolai Strakhov*

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Presented by Academician Yu.G. Leonov July 30, 2008

Received September 16, 2008

DOI: 10.1134/S1028334X09050080

Cruise 25 of the R/V *Akademik Nikolai Strakhov* was organized by the Geological Institute of the Russian Academy of Sciences in the framework of the "International Polar Year." It was conducted by a team of scientists with A.V. Zayonchek being the chief of an expedition in the northern Barents Sea and on the continental slope of the Arctic Ocean in the areas with coordinates 78°–82° N, 30°–35° E during the period of August 29–September 18, 2007 (Fig. 1). The studies were carried out in line with programs of the Presidium of the Russian Academy of Sciences "Environmental and Climatic Changes: Natural Catastrophes" and "Basic Problems of Oceanography: Physics, Geology, Biology, Ecology" (project "Comparative Study of the Evolution and Recent Structure of Eastern Atlantic and Arctic Continental Margins"), and the program of the Earth Sciences Branch of the Russian Academy of Sciences "The Formation History of the Arctic Ocean and Regime of Recent Natural Processes in the Arctic Region." The hydroacoustic system RESON (SeaBat software system) was applied during the cruise. In addition, the bathymetric survey was carried out using the acoustic profilograph EdgeTech 3300 and equipment for conducting continuous seismic profiling designed by GIN RAS. Geological works at stations included heat flow and sound velocity measurements, sediment sampling by piston cores, and dredging. The geothermal survey was performed by the new sonde "GEOS-M." Thermal conductivity was measured in sediment cores sampled by piston cores.

The geological–geophysical studies were carried in both the Russian and Norwegian segments of the Barents Sea. In the first of these areas, several regional profiles were shot south and west of the Franz Josef Archipelago and Hooker Island was examined by the land geological team. In the Norwegian segment, the Orel Trough [1] was mapped and several additional reconnaissance profiles were shot. The ice situation in the Arctic Ocean permitted a set of profiles, which crossed the entire continental slope up to abyssal depths, to be shot in the region extending up to 82° N.

With respect to geology, the region in question is poorly studied. Its study is limited by occasional route works (e.g., [5]) and examination of accessible sections in the Spitsbergen and Franz Josef archipelagoes [1, 3, 4, 8, 9]. The Quaternary sedimentation in the northern Barents Sea is also insufficiently known. It is assumed [6] that this area is characterized by development of sedimentary complexes comparable with their counterparts in the central part of the basin, where the oldest sequences are composed of moraine overlain by asuccession of three units represented by marine postglacial sediments.

The heat flow in the region was never measured, and modeling is usually based on its average background values [2].

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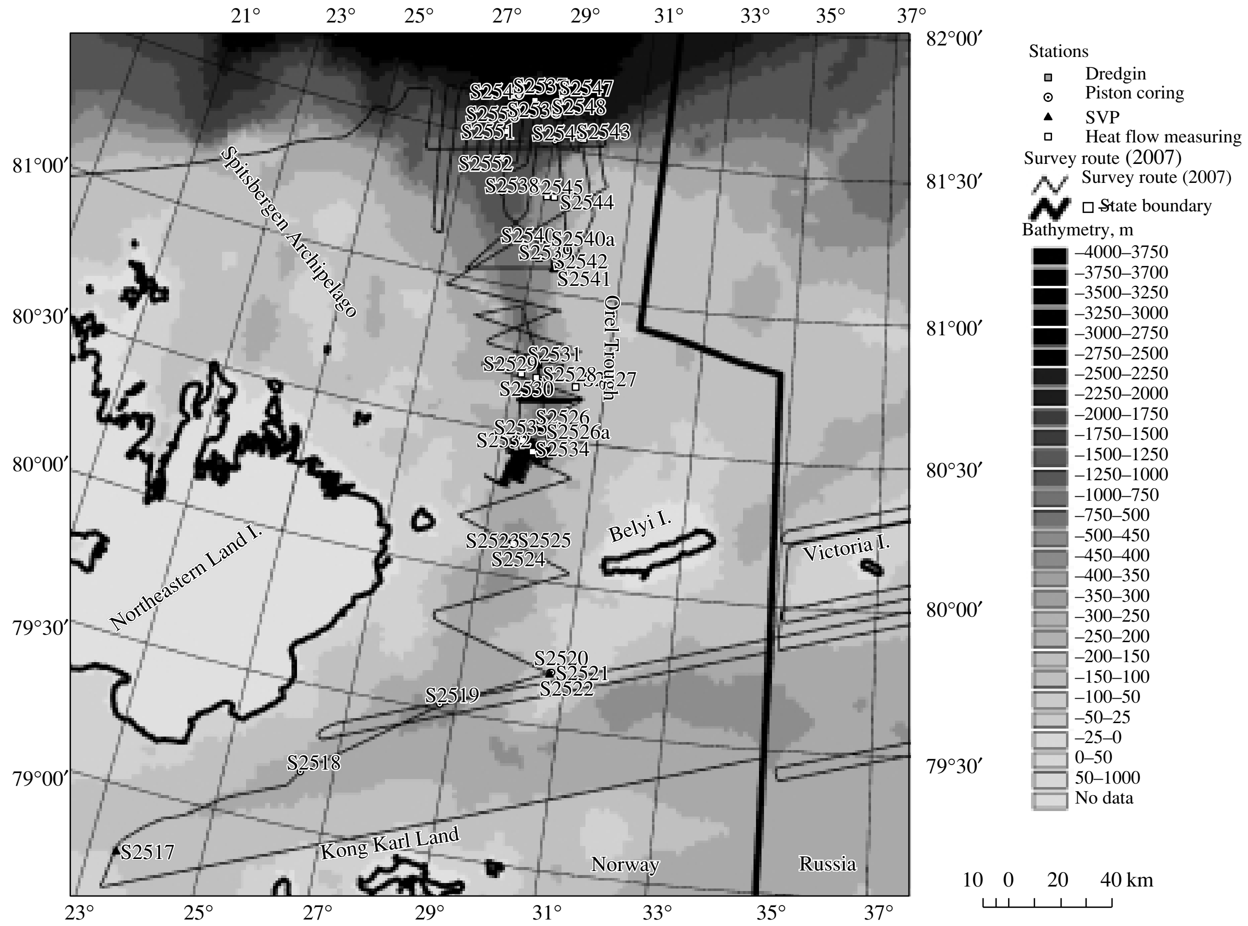

Fig. 1. Schematic map illustrating geological–geophysical activities during Cruise 25 of the R/V *Akademik Nikolai Strakhov* in the northern part of the Barents Sea and on the continental slope of the Arctic Ocean. The topographic basis is the International Bathymetric Chart of the Arctic Ocean (IBCAO) [www.ngdc.noaa.gov/mgg/bathymetry/arctic/].

General regularities in the morphological structure of the northern Barents Sea bottom are well known [www.ngdc.noaa.gov/mgg/bathymetry/arctic/]. This region hosts several gentle rises (Persey, Kong Karl, and others) separated by near-latitudinal (Erik-Eriksen, Kong Karl, and others) and near-meridional (Orel, Franz–Victoria, St. Anna) trenches. In the last structures, depths (up to 450 m) exceed average values.

According to the IBCAO [ww.ndgc.noaa.gov/mgg/bathymetry/arctic/], the Orel Trough rounds Northeastern Land Island of the Spitsbergen Archipelago to join in the south the Erik-Eriksen Trench and open in the north toward the continental slope. The trench is characterized by flattened bottom areas with depths of approximately 300 m. They are separated by thresholds with water depths of approximately 200 m. The southern part of the trench is shallower as compared with the northern one. At 80° N, the valley of the trench becomes narrower and deeper.

Our studies revealed that the trench is characterized by a complex morphological structure (Fig. 2). In its southernmost part, this structure is asymmetrical with a steeper western wall located at depths of 60–80 m. It extends along the deepest part of the trench with depths of 420–440 m to 460–480 m in some depressions. The valley width varies from 2 to 4–5 km. Thus, the bathymetric survey revealed a deeper bottom as compared with that shown in IBCAO.

According to continuous seismic profiling and profilograph data, the acoustic basement is marked by half-grabens bordered in the west by normal faults with an amplitude of approximately 200–250 m, which are reflected also in the present-day bottom topography (Fig. 3). The heat flow measured approximately on the Belyi Island beam 26 km south of the study area appeared to be anomalously high (approximately 340 mW/m^2). Heat flow values measured during the cruise at seven stations west and southwest of the Franz Josef Land range from 30 to 97 mW/m^2.

At 80°25′ N, the trench becomes narrower (up to 400–500 m) and is dammed by a threshold. Its western wall is accompanied by a channel 6 km long. This area is also characterized by relatively higher differentiation of the acoustic basement, which turns into a system of

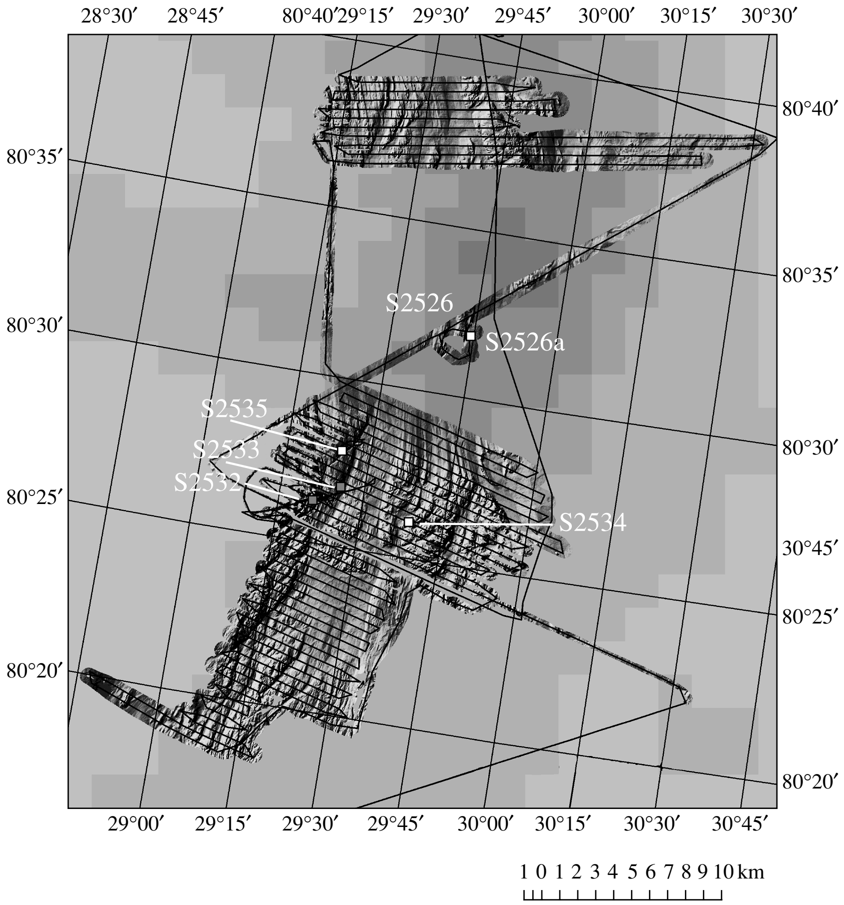

Fig. 2. The shadowed relief of the Orel Trough and route of the R/V *Akademik Nikolai Strakhov* during Cruise 25. The topographic basis is the International Bathymetric Chart of the Arctic Ocean (IBCAO) [www.ngdc.noaa.gov/mgg/bathymetry/arctic/]. Numerals designate geological stations.

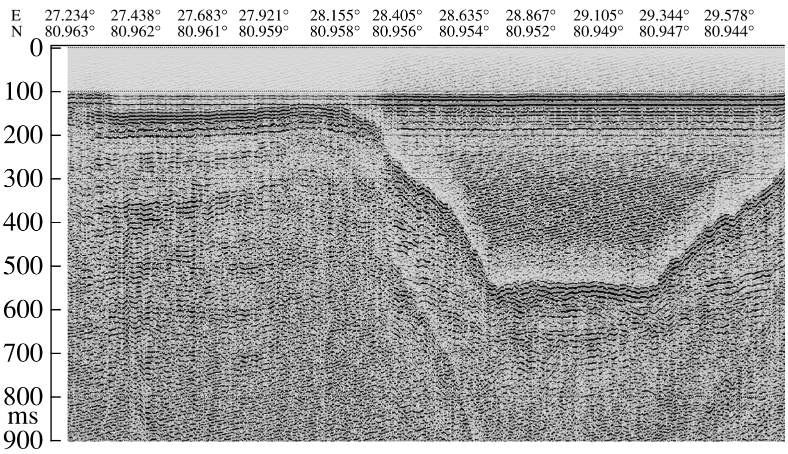

Fig. 3. The continuous seismic profiling record across the Orel Trough along 80.963° N.

horsts and grabens, which are traceable up to the northern boundary of the study area.

In the northern part of the area, the Orel Trough widens up to 10 km. Dissimilar to areas located to the south, the maximal depths of the trough bottom (460–480 m) are recorded near its eastern wall. In its configuration, the trough is similar to a river valley with many tributaries. The latter are separated by isolated mounds or their systems, which extend along the trough strike. The summits of these mounds are located at depths of

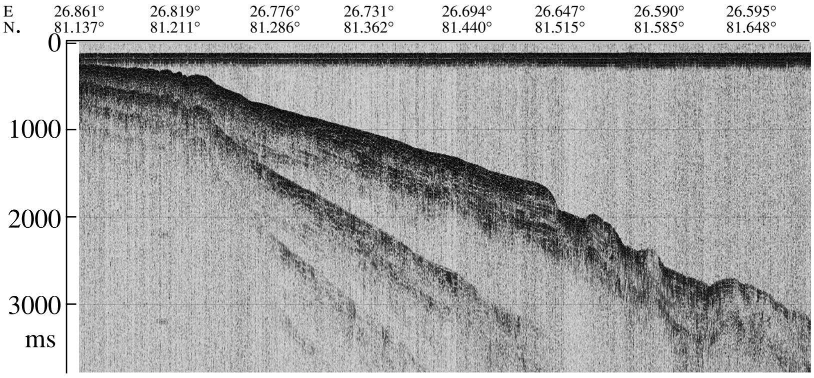

Fig. 4. The continuous seismic profiling and profilograph records across the continental slope along 26.9° E between 81.14° and 81.67° N.

180 to 200 m, while their heights relative to the bottom amount to 250 m. The mounds are characterized by droplike shapes in plane and steeper southern slopes, which are usually wider as compared with their northern counterparts. All the morphological features of the bottom in the study area point to development of strong N-directed currents, which are responsible for the erosional relief. The heat flow measured in the area is characterized by elevated values ranging from 280 to 520 mW/m^2 and averaging approximately 330 mW/m^2.

In the area located 12–13 km to the north at 80°38′ N, the trench was mapped by a system of 10 profiles. In this area, the maximal bottom depths (460–490 m) are registered along its eastern wall, the edge of which is located at depths of 180–200 m. By the general morphological features of its bottom and acoustic basement, this area is similar to southerly parts of the trough. At 80°37′ N, the profilograph survey revealed several grabens developed on trough slopes with displacement amplitudes along bordering faults ranging from 30 to 100 m.

The northern part of the trough up to its mouth on the shelf was crossed by a system of rare profiles, which show that between 81° and 81°15′ N this structure becomes U-shaped in the transverse section with maximal bottom depths of 500–600 m. Its acoustic basement demonstrates a distinct graben in this area. Northward on the shelf and continental slope, the trough gradually disappears. The bathymetric survey in the Orel Trough area revealed an inconsistency between the IBCAO data and the real echo-sounding measurements north of 80°30′ N with the eastward displacement of the morphostructure by at least 10–15 km.

The transition area between the shelf and Nansen Basin north of 81°30′ M was crossed by several near-parallel profiles shot across the shelf edge. It is established that in this area depths increase rapidly at a distance of approximately 35 km from 200 to 2500 m and deeper. The continental slope is characterized by the development of large slumping bodies up to depths of 2400–2500 m particularly in the western part of the mapped area (Fig. 4). Eastward, large rectilinear furrows are a dominant feature of the bottom morphostructure. The heat flow measured on the shelf and at the base of the continental slope is approximately 100 and 53 mW/m≅2, respectively.

Several regional near-latitudinal profiles were shot south of Franz Josef Land. In this area, the Barents Sea shelf is characterized by a system of gentle rises and depressions with depths of 300–400 m and crossed by numerous iceberg plucking furrows 6–8 m deep, which are traceable up to depths of ~300 m.

The lithological studies of unconsolidated sediments included visual core description and measurements of sediment moisture and carbonate content. Special attention was paid to the analysis of *Eh* and *pH* variations and study of the chemical composition of interstitial waters and gases.

It was established that, similar to other areas of the Barents Sea, the Quaternary sedimentary section in the northern peripheral part of the basin is characterized by a three-member structure [6, 7]. The upper (Holocene) complex consists of silt with abundant Polychaeta tubes and hydrotroilite films. The middle member corresponding to the late deglaciation stage is composed of laminated to uniform semiliquid pelitic mud. The lower unit (fluvioglacial or moraine diamicton) is represented by dark gray viscous–plastic heavy loams with high contents of sandy and gravel–boulder material. In the western part of the Franz Josef Land–Spitsbergen profile, coloration of sediments constituting the second and third members becomes lighter with the simultaneous growth of $CaCO_3$ contents in sediments of the early and late deglaciation stages up to 35 and 3.5%, respectively, which is explained by the increased influx of carbonate material from Spitsbergen.

The strongest variations in the thickness and lithology of sediments are characteristic of the second member. It is mapped only in axial parts of troughs at depths exceeding 300 m. The bedding patterns of these sediments are best developed in the Franz Josef Archipelago straits at water depths of >300–350 m. Westward, the thickness of this member decreases with mud becoming uniform. In the Orel Trough, its thickness is strongly reduced ranging from 10–15 to 100 cm. Dissimilar to the Franz Josef Land area, in the trough this member is represented by uniform pelitic mud differing from the overlying Holocene sediments in its peculiar semiliquid consistency and low carbonate content.

It is assumed [6] that the laminated fabrics of the member reflecting the late deglaciation stage is related to the high influx of fine suspended particulate matter during ice shield thawing 9.0–13.5 ka ago. Our data imply that glaciers of Franz Josef Land were the main source of this fine suspended matter. In the vicinity of the latter, the beds of these sediments are thicker and their bedding patterns are more distinct. The influx of particulate matter from the northwestern coast of Spitsbergen was likely substantially lower. In this connection, the near-latitudinal zonality in mud lithology may reflect the natural lateral variability in the mud composition away from the source area (Franz Josef Land glaciers).

At the same time, different interpretation of these data is possible. Such variability in the thickness and composition of the second member could result from intense plucking of unconsolidated sediments by icebergs. It is clear that this process was most intense at the stage of ice shield degradation, not during the Holocene. It was accompanied by intense mixing of sediments constituting the second member occurring at shallow depths. In deeper areas of trough valleys, their sequences retain the primary texture with distinct bedding patterns.

The analysis of Cl contents in interstitial waters shows that in sediments of the second and third members they are by 1.0–1.5 g/l lower as compared with that in Holocene mud. This observation points to slight water desalination in the northern peripheral part of the Barents Sea during ice shield degradation.

The *Eh* measurements demonstrate that interstitial waters of sediments are characterized by dominant slightly to strongly reducing conditions (*Eh* ranging from –100 to +100 mW), which are favorable for biogenic sulfate reduction. Despite the general lowered background *Eh* values registered for all the sedimentary complexes, sediments of the second and third members are characterized by slightly higher *Eh* values (by 20–30 mW) as compared with Holocene mud, which indicates the lower concentration of organic remains and less intense diagenetic processes in them. It is also established that mixed sediments (due to slope processes or glacier plucking) are characterized by lower *Eh* values as compared with undisturbed mud.

The preliminary paleontological analysis (macro- and microfauna, microflora) performed for some levels in 10 of 18 sampled cores revealed that planktonic and benthic foraminifers are the most abundant among microfossils: they occur in the upper layer of most cores corresponding to the Holocene. The sediments of the third sedimentary member (diamicton corresponding to the early deglaciation stage) contain diverse benthic foraminiferal assemblage accompanied by single tests of planktonic form *Neogloboquadruna pachyderma*, which point to accumulations of this member (at least, its upper part) in the open sea basin with normal salinity. Dissimilar to the upper and lower members, sediments of the second lithological unit enclose only rare benthic foraminifers and diatom frustules.

The preliminary micropaleontological data imply that sediments of the second member were deposited in the basin with suppressed bioproductivity, which could result from an unstable hydrological and chemical regime in the surface waters in response to intense glacier thawing. It should be noted that planktonic forms are found only in sediments of the third lithological unit in a single core from the Orel Trough, which was likely first subjected to the influence of intruding Atlantic waters after the Visla Glaciation (approximately corresponding to the Valdai one). The sampled sediments yielded also bivalves, rhizopods, ostracods, radiolarians, and diatoms.

CONCLUSIONS

(1) The Orel Trough represents a recent rift with complex bottom and acoustic basement topography and anomalously high heat flow (up to 500 mW/m^2).

(2) The Orel Trough area is influenced by two currents, one of which (surface) transports waters from the Arctic Ocean southward and the other (bottom), sedimentary material in the opposite direction.

(3) The continental slope of the Arctic Ocean is characterized by development of large slumping bodies.

(4) Interstitial waters in Quaternary sediments accumulated during the degradation period of the last glaciation in the northern peripheral areas of the Barents Sea indicate desalination of the basin.

(5) The marine microfauna found in sediments (diamicton) corresponding to the early deglaciation stage points to ingression of normal-salinity waters into the northern Barents Sea.

ACKNOWLEDGMENTS

This work was supported by the Presidium of the Russian Academy of Sciences (Programs 14, 16 and, 17), grant NSH-9664.2006.5, and the Norwegian Petroleum Directorate.

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