RIFT-AND-GRABEN SYSTEMS OF THE EURASIAN ARCTIC CONTINENTAL MARGIN

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ABSTRACT

Based on interpretation of marine geologic and geophysical data, there is a widespread, systematic development of rift-and-graben systems in the structure of the Eurasian Arctic continental margin. The characteristics of the largest structures are presented, including the Varanger, Bear-Ol'ga, Eastern Barents, Kara-West Siberian, Laptev-Kolyma, and Chukchi-Bering Sea.

INTRODUCTION

Offshore geological and geophysical data acquired in recent years over the Arctic continental shelf has allowed us to locate rift-and-graben systems that transect the Eurasian Arctic margin both lengthwise and crosswise (Fig.1A,B). These systems are similar to the well-known structures of the North Sea (Central and Viking rifts) and the Canadian Arctic Archipelago.

According to our data (Senin et al., 1989; Shipilov, 1989; Shipilov and Mossur, 1990, 1991) and that from other sources (Gramberg and Pogrebitsky, 1984; Gramberg and Pushcharovsky, 1989; Gabrielsen et al., 1990), the most significant rift-and-graben systems of the Eurasian Arctic continental margin are the Varanger, Bear-Ol'ga, Eastern Barents, Kara-West Siberian, Kara-Khatanga, Laptev-Kolyma, Chukchi-Bering Sea.

GENERAL CHARACTERISTICS OF RIFT-AND-GRABEN SYSTEMS

The Varanger rift-and-graben system includes the Hammerfest and Nordkapp basins. The system has a northeasterly trend in the southern Barents Sea. The southeast extension of this zone is a structure in the sedimentary cover known as the West Kola saddle. This is interpreted to be a continuation of the rift-and-graben system. The separation of the system into two branches, the Nordkapp and the West Kola (Varanger or Murmansk graben and the saddle proper), is related to its curvature around the Central Barents ancient basement block.

In the basins of the Varanger rift-and-graben system, salt domes have been identified with their roots (saliferous horizons), according to Norwegian scientists, in the Lower to Middle Carboniferous and Permian.

We have not yet found clear signs of magmatic activity related to the main phases of rifting in the system. However, available geophysical data about its anomalous crustal structure (e.g., its marked thinning, the absence of a granitic layer, elevated heat flow values --up to 80 mW/m^2) confirm the deep, extensional nature of this system.

The Bear-Ol'ga rift-and-graben system is composed of a zone consisting of three main segments that are offset with respect to one another. The Bear segment coincides with the Bear trench, which is expressed in the relief of the seafloor. The Eastern segment is located on the extension of Ol'ga Strait, and the Ol'ga segment is located south of King Karl Land. This system is the least studied, especially in its central (Eastern) and northeastern (Ol'ga) segments.

According to gravity and magnetic data, the depth to basement exceeds 8-12 km in all segments.

A number of seismic-stratigraphic units are seen on the reflection sections. These units are correlated with the geological section of Svalbard and correspond to Cambrian to Silurian carbonate and terrigenous sediments, Devonian to Lower Carboniferous terrigenous sediments, Lower Carboniferous to Lower Permian sulfate-carbonate, Upper Permian siliceous carbonates, and Mesozoic terrigenous sediments.

In the upper terrigenous part of the section, we presume that Triassic and Cretaceous intrusive sheets and dikes are present. There are also signs of salt-dome tectonics in the system, related to Lower to Upper Carboniferous and Early Permian sedimentation.

The Eastern Barents rift-and-graben system has no analogues elsewhere in northern Eurasia. It is unique in its large dimensions, thick sedimentary cover (over 14-18 km), depth to basement, and the existence of geophysical anomalies in the crust and upper mantle. In the west, the system is bounded by the north-south-striking Main Barents fault, at 42° E. This complex fault has a basement offset of over 5 km.

The system includes several major depressions (South, North, and East Barents). The depressions are located either at junctions between the system branches (North and East Barents depressions), at junctions of the Main system with transverse grabens (South Barents), or with transverse older grabens (i.e., Western Kola and Pechora-Kolva). The depressions are separated by deep-seated regional ridges, which are expressed to a varying degree in the basement and sedimentary cover.

A number of factors suggest crustal destruction processes in both the South Barents depression and, probably, the entire Eastern Barents rift-and-graben system. These include the decrease in crustal thickness in the South Barents depression from 30 km to 25 km with the relief of the Moho surface breaking into separate domes under the central part of the depression, the layering of the upper mantle, anomalous seismic velocities in both the mantle and crust, indistinct and gradual transition from the basement to the sedimentary

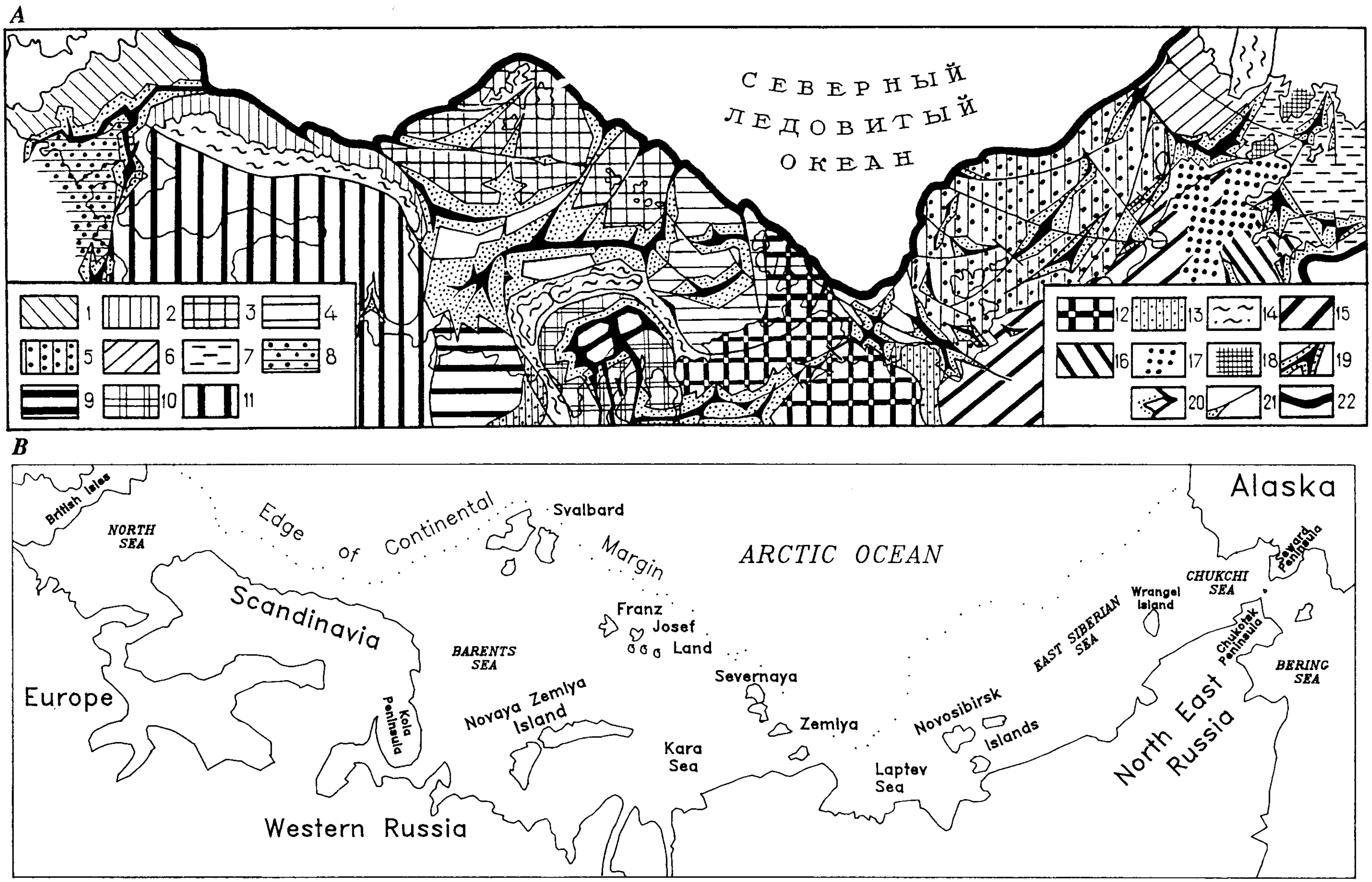

Fig.1. A. Tectonic position of rift-and-graben systems of different ages in the structure of the Eurasian Arctic continental margin. Marginal continental plates (or geoblocks) (1-7): 1 - British; 2 - Lofoten; 3 - Barents; 4 - North Kara; 5 - East Siberian - Chukchi; 6 - Chukchi - Beaufort; 7 - Dezhnev. Continental plates (8-10): 8 - Central Europe; 9 - Pechora; 10 - South Kara (West Siberian). Precambrian platforms: 11 - East European; 12 - Siberia; 13 - marginal troughs (of various ages); 14 - foldbelts (of various ages) on land and under the sedimentary cover. Foldbelts: 15 - Verkhoyansk - Chukchi; 16 - Koryak; 17 - Okhotsk-Chukotsk volcanic belt; 18 - Chukchi - Seward massif; 19 - rift-and-graben systems and their axes; 20 - horsts; 21 - faults; 22 - outer boundary (flexural) or marginal continental plates (or geoblocks). B. Parallel geographic map.

cover, a wide distribution of faults, and intense block shattering (Shipilov and Mossur, 1991).

Late Paleozoic and Mesozoic sequences comprise most of the fill in the basins of the system. The Cretaceous-Cenozoic unit is locally present in connected depressions (South, North, and East Barents). The greatest thickness of Cenozoic sediments is found in the Franz-Victoria and St. Anna grabens. Limited Cenozoic and present-day tectonic activity in these regions is indicated by earthquake epicenters that are restricted to the northern and mouth areas of the grabens, and by virtually identical contour shapes of the top of basement and the seafloor relief.

The sedimentary section in the South Barents depression is up to 4.5 km thick in bore holes on isolated basement highs. Seismic data indicate that the basin fill reaches 12-14 km and locally is up to 16-17 km thick.

Shipilov and Mossur (1990, 1991) observed "anomalous seismic horizons" in the sediments of the depressions and troughs of the system and associated them with magmatic activity during the structural development of the rift-and-graben system. This conclusion is supported by deep drilling data. The areas of these "anomalous horizons" also have high magnetic anomalies and, according to gravity data, have positive density contrasts.

On the whole, the band of "anomalous horizons" is limited to the rift-and-graben system but continues in a north-south direction, becoming shallower in its stratigraphic and topographic position until it is exposed in the form of trap complexes on Franz Josef Land.

The Kara-West Siberian system is generally considered to be a typical rift or graben within continental crust. The early phases of its development began at the beginning of the Paleozoic, but most activity probably took place in the Early to Middle Mesozoic. The formation of the volcanic and sedimentary Thurinian series (Early to Middle Triassic) is presumed to have occurred in this time. This series fills all the troughs of the system.

The Kara-Khatanga system probably had multiple phases of activity. In the western part of the system, grabens are filled with Late Permian to Early Triassic traps, while there are Precambrian rift structures in the eastern part. The system also has deep fault zones (tens of km wide and hundreds of km long) filled with ultramafic and mafic magmatic rocks.

At the junction of the Kara-West Siberian and Kara-Khatanga systems is the South Kara depression, one of the largest depressions on the Arctic shelf. Geophysical data indicate that crustal thickness under the depression is reduced to 26 km and that the top of basement is 12-14 km or more deep.

The sedimentary cover of the South Kara depression consists of three sequences. The "lower" sequence is represented by thin Late Proterozoic to Early Permian carbonates, overlapped by thick (3-4 km) Late Permian to Middle Triassic volcanogenic sediments. The "upper" sequence is composed of up to 7 km of sandy, argillaceous, and silty Upper Permian to Cenozoic sediments and unconformably overlies the "lower" sequence. A Neogene to Quaternary sequence overlies the "upper" sequence with an angular unconformity.

The Laptev-Kolyma rift-and-graben system is tectonically complex. In the south it is divided into two major zones, the South Anyui and Moma, which bound the southwestern and northeastern sides of a large central block composed of projections of crystalline and folded basement (Prikolyma, Omolon, and other massifs).

The Laptev Sea is a region where intersecting rift systems of different strikes are breaking apart old Precambrian basement. The crustal thickness in the Laptev Sea area reaches 25-30 km. A detailed examination of basement structure of the Laptev Sea shows that it consists of three cross-cutting rift-and-graben systems. In the west and southwest, there are uplifted elements along the strike of the Kara-Khatanga system. There are also structures that correlate morphologically with submeridional depressions of the Anabar-Olenek interfluve along the northern edge of the Siberian platform. The South Laptev depression is situated at the junction of these zones. In its central part there are several uplifts, some of which correlate with deformation zones of the Verkhoyansk belt. Other uplifts (West and Central Laptev highs) may be considered parts of the old Precambrian basement. To the west and north, this Precambrian core is bounded by the Ust' Lena and Omoloi grabens, which extend into Buor-Khaya Bay. They extend northward to the central and western parts of the continental slope, crossing a number of saddles. Finally, in the eastern part of the basin, there is a series of northwest-striking grabens (Ust' Yana, Chondon, Shirokostan, Bel'kov-Svyatoi Nos, Lyakhov, etc.). These grabens connect with the Moma rift system and the South Anyui fault zone to the south and southeast and with the eastern part of the Laptev continental slope in the north.

The maximum depth to basement of 10-12 km is found in the western and southwestern parts of the basin and in the southern parts of the Omoloi graben. In the eastern part of the basin, the depth to basement is only 2-4 km and is found in the narrow grabens.

The sedimentary sequence includes the complete Phanerozoic section, from Riphean and Vendian to the Pleistocene.

In the southwestern Laptev Sea, there are indications of salt-dome tectonics within Devonian strata in the lower part of the sedimentary section. In the upper terrigenous section, "anomalous" seismic reflectors coincide with the presence of magnetic bodies. These horizons correlate with the Permian to Triassic tuff and lava section of the Yenisei-Khatanga trough.

As noted above, the available geological and geophysical data, including CDP reflection surveys, do not support the theory that the Gakkel rift extends directly into the Moma continental rift through a graben on the Laptev shelf. Instead, they are connected by a series of discontinuous fault zones.

The Chukchi-Bering Sea rift-and-graben system was examined in detail in the Chukchi Sea area by the authors (Shipilov, 1989, 1990). There, it has three main segments, the submeridional Chukchi, and two segments superposed on Chukchi Peninsula, Kolyuchin-Mechigmen and the Hope submeridional trough. Rifts and grabens of the Chukchi Sea are connected to zones of Cenozoic volcanism in the central (Norton basin) and eastern parts of the Bering Sea shelf and the Yukon coast of Alaska by way of the Kolyuchin-Mechigmen graben and other, smaller grabens in the Bering Strait inferred from the morphology of the top of basement.

The Chukchi rift-and-graben zone is comprised of narrow troughs in the basement, 3-3.5 km deep, reaching 4.5 km at the junction of the Chukchi and Hope troughs (the South Chukchi depression). The actual depth to basement may be greater but is obscured by volcanics within the sedimentary section.

According to seismic data, sediments within the troughs of the Chukchi Sea rift-and-graben system presumably include the Upper Triassic to Neogene and Quaternary. These consist of two sequences. The lower sequence consists of Upper Triassic, Lower Cretaceous, Lower to Upper Cretaceous, and Upper Cretaceous strata. The upper sequence is composed of Paleogene and Neogene to Quaternary sediments. The upper sequence includes some Upper Cretaceous strata.

Aeromagnetic anomalies characteristic of volcanic rocks are found in some parts of the Chukchi Sea, suggesting that there may be volcanic formations in the Chukchi Sea. Thus, there may be a temporal and geodynamic relationship between the volcanism of the Chukchi Sea and the Chukchi branch of the marginal Asian volcanic belt (Okhotsk-Chukotsk volcanic belt). The Okhotsk-Chukotsk volcanic belt began in the Aptian to Albian and reached its maximum activity in the Late Cretaceous.

CONCLUSIONS

The above descriptions of the rift-and-graben systems of the Eurasian Arctic continental margin lead to these general observations about their structure:

- They display a complex internal structure of the basement and lowest sedimentary sequences as represented by horsts and grabens bounded by high-amplitude faults and characterized by elevated faulting and fissuring tectonics.
- They exhibit branching of rift systems associated with circumvention of major rigid crustal blocks, which are composed of projections of Archean or Baikalian (Late Proterozoic) basement.
- They usually show a structural link with intracontinental paleorift structures. However, it should be noted that the rift-and-graben systems of the continental shelf are not continuations of the continental paleorifts and are separated from them by basement uplifts beneath the sedimentary cover. Sometimes these are expressed in basement relief by ridges with the systems connected by offsetting fault systems. There may be a link between the rift-and-graben systems of the continental shelf and oceanic rift systems, such as observed at the junction of the Chukchi-Bering Sea system with rift systems of the Central Arctic block.
- Where rift-and-graben systems intersect, there are major depressions with deeply buried basement and thick sedimentary cover. These are primarily within the inner part of the shelf (South Barents, South Kara, South Laptev, South Chukchi, North Barents, etc., depressions)
- Almost all of the rift-and-graben systems are reflected in the thickness of Cenozoic sediments, the relief of the sea bottom, and the orogenic relief of the adjacent land. On land, they are expressed in the form of vast and extended rift valleys or graben troughs that have been affected by glaciers and other kinds of erosion, which shows the long activity of the rift-and-graben systems that lasted throughout the neotectonic period.

Thus, destructive processes have played a significant role along the Arctic continental margin in the form of rifting. These processes have complicated the structure of the sedimentary cover. The principal sedimentary cycles are Late Proterozoic to pre-Late Mesozoic and Late Mesozoic to Cenozoic, or preoceanic and synoceanic.

Along the Arctic continental margin, the structures define a gradual transformation of continental crust into oceanic crust. This proceeds through a succession of transitions: from a continent to a shelf cut by a network of grabens and rifts of multiphase development; to continental margin plateaus, separated by the preexisting or superposed troughs (grabens); to a narrow, linear, fissure-like basin (e.g., Eurasian); to a system of aseismic highs (Lomonosov and Mendeleev-Alpha ridges) and a wide isometric basin (Amerasian basin).

Analogous structures are observed in other oceans and continent-to-ocean transition zones and indicate that similar destructive processes occur within other continental margins, finally leading to the formation of basins with oceanic crust and to the detachment of segments of continental crust segments (e.g., Lomonosov Ridge).

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