THE ARCTIC GEODYNAMIC SYSTEM: ITS BOUNDARIES, DEEP GEOLOGY, AND STRUCTURAL EVOLUTION

I. S. Gramberg and Y. E. Pogrebitsky, VNIIOkeangeologia, 1 Maklin Prospect, St. Petersburg, 190121, Russia

ABSTRACT

The spatial limits of the Arctic geodynamic system can be defined as the source area for clastic-material influx into the deep-water basins of the Arctic Ocean that correspond to the outlines of the drainage area. The topographic feature that corresponds to this region is the Arctic geodepression, which forms a geodynamic system composed of various tectonic styles located within three distinct, nearly concentric zones with abyssal basins in their centers. The primary deep structures of the deep abyssal core, continental slope, and shelf areas are discussed based on seismic surveys and surface geology. The structural evolution of the Arctic geodynamic system during the "preoceanic" (Permian to Cretaceous) and "oceanic" (Paleogene to Recent) stages is outlined based on paleogeographic and facies reconstructions. We conclude that the lateral displacements of lithospheric plates are a small-scale phenomena within the Arctic.

INTRODUCTION

According to contemporary geodynamic opinion, the opening of an ocean and its subsequent evolution are due to lateral convective movements of mantle matter beneath the lithosphere on either side of a divergent zone with a seismically active midocean ridge developing and resulting in seafloor spreading, rifting, and volcanic activity. Based on this viewpoint, the Arctic Ocean is a continuation of the Atlantic Ocean, as evidenced not only by their contiguous water area but also by the Arctic and Atlantic midocean ridges that join in Iceland. However, the Arctic Ocean is morphologically isolated from the Atlantic by the Iceland-Faeroe Ridge, a wide transverse uplift that separates the seafloor of these oceans and is underlain by crust not typical of oceans or continents (Zverev et al., 1977; Vogt et al., 1980).

The Arctic system is a long-lived, evolving structure, which thus must have some geodynamic autonomy and forms a branch (daughter) system within the Atlantic segment of the earth. The zone of divergence responsible for the development of the entire Atlantic wedges out in the Arctic geodynamic system. Linear magnetic anomalies (numbers 1-24) and the axial Arctic Midocean (Gakkel) Ridge terminate against the Eurasian continent, and thus the Arctic Ocean is an intercontinental extension of the Atlantic Ocean.

It is this peculiar feature of the Arctic geodynamic system that allows us to more fully discuss the synchronous development of the oceanic and continental geologic structures in their relation to one another and to shed light on the origin of the Arctic Ocean as a whole.

ARCTIC GEODYNAMIC SYSTEM

Generally speaking, a geodynamic system of any rank is a region of interrelated geological processes that relax the energetic perturbations occurring within the Earth. As a result, these processes represent different kinds of mass transport. The mass transport is mainly endogenic and takes place in the form of convective mantle movements that are responsible for the transformation and relief of the lithosphere. In such a process, the deep zone of divergence beneath the ocean, and the associated seismically and magmatically active midocean ridge on the surface, form the axial, central zone of the geodynamic system. The outer boundaries of such a convective system, except where they are represented by oceanic convergent sutures (subduction zones and island arcs), are obscured by continental plates. This is the case for most of the Atlantic geodynamic system, and especially for the Arctic Ocean, which has classic passive margins of the Atlantic-type. Currently available geophysical methods cannot unambiguously show the location of the outer edge of the convective cell. However, mass transport on the earth's surface is well known and easily mappable. The primary type of mass transport is sediment load, which at a first approximation may be considered to be in balance with relief-forming endogenous mass transport. Thus, the Arctic geodynamic system includes the abyssal basins of the Arctic Ocean, shelves of the marginal seas, and extensive areas of the surrounding continents including watershed ridges. Within these limits, the Arctic geodynamic system is clearly expressed topographically in the form of a huge geodepression marked by a closed shape and with a regular slope of the lithosphere surface from boundary watersheds towards the seafloor. The name "Arctic" applies both to the geodynamic system and the geodepression (Pogrebitsky, 1978).

Based on topography, neotectonic movements, and exogenic processes within the Arctic geodepression, three subconcentric geodynamic zones are recognized in its present stage of development (Fig. 1). The outer zone is characterized by uplift and denudation processes. It consists of a continuous chain of ridges, rises, and sills and may be called a boundary orogenic belt. An intermediate zone is represented mainly by depositional and denudational-depositional plains and marginal sea shelves whose area is dominated by submergence. Based on the dip from the boundary orogenic belt to the center of the depression, this zone may be classed as a continental centrocline, which includes six major sedimentary basins and the Central Siberian Arch. The sedimentary basins are large, autonomous centers of deposition surrounded by minor, linear and arcuate, orogenic belts. The inner zone, or abyssal core, consists of abyssal basins separated by ridges and sills and is the locus of conjugate descending and horizontal (spreading) crustal movements. New lithosphere forms here and is covered with an accumulation of pelagic sediments. Midocean ridges form the boundary between the Eurasian and North American lithospheric plates within the abyssal zone (Fig. 1).

As mentioned above, the divergent zone responsible for the opening of the entire Atlantic, including the Arctic Ocean, wedges out within the Arctic geodynamic system. The topographically expressed boundary separating the lithospheric plates ends with the Arctic Midocean (Gakkel) Ridge. Based on magnetic anomalies and earthquake foci, the boundary can be projected into the continental rise that separates the abyssal basin and the Laptev Sea shelf. Landward from this point, linear magnetic anomalies have not been recorded, and earthquake epicenters are scattered in an extensive, diffusive zone about 600 km across (Avetisov, 1979). However, a series of

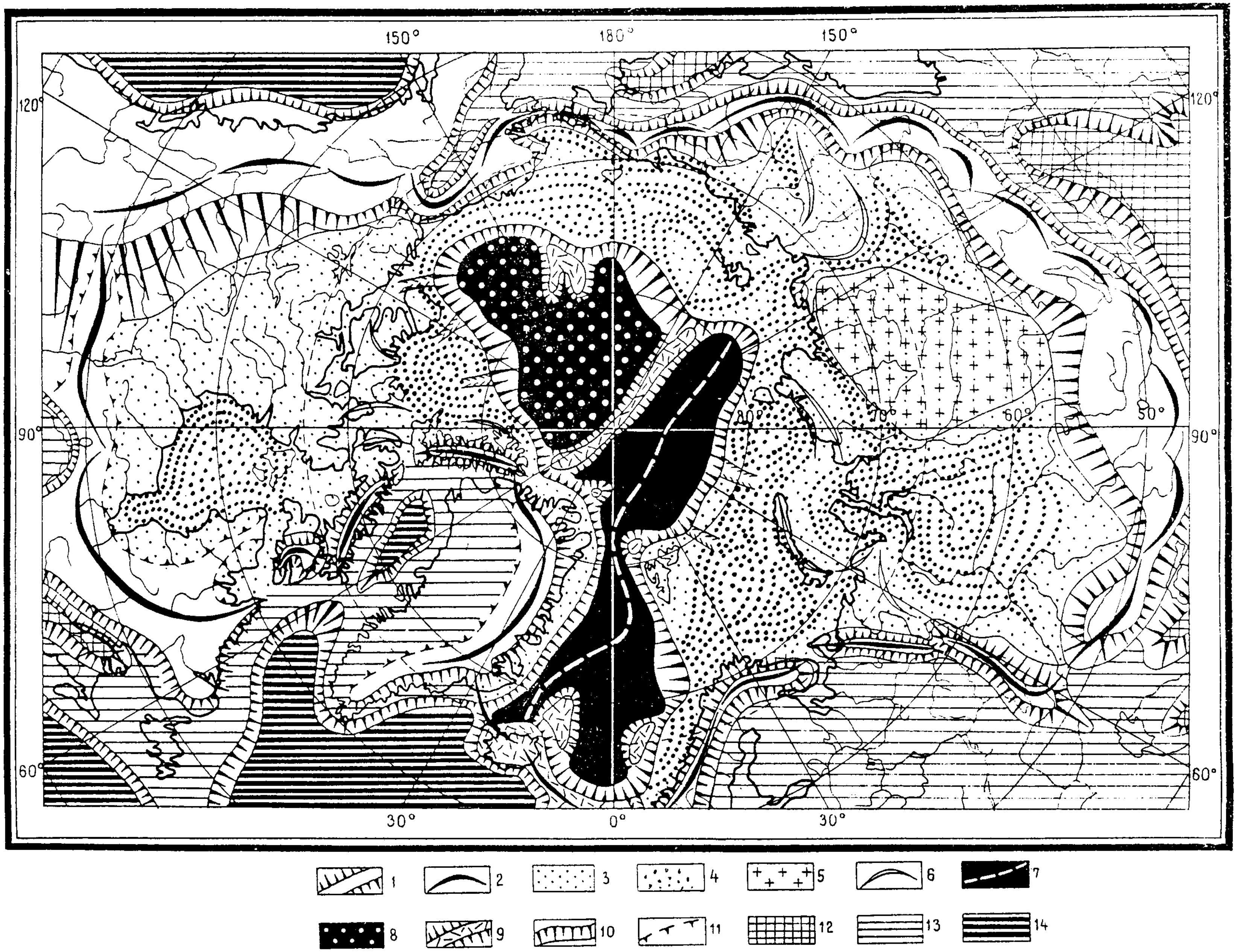

Fig.1. The Arctic geodepression.
1 - boundary orogenic belt, 2 - mountain chain, ridge, and sill watersheds forming the boundary orogenic belt, 3-6 - continental centroclines: 3 - stable plains and highlands, 4 - actively subsiding sedimentary basins, 5 - Central Siberian arch, 6 - interbasin (secondary) orogenies, 7-9 - abyssal core: 7 - rift-spreading basins, dashed line - axial rift, 8 - epicontinental oceanized basins, 9 - sills, plateau and terraces, 10 - slopes, 11 - conventional boundaries of highs, 12-14 - areas beyond the Arctic geodepression: 12 - mountain massifs undergoing uplift, 13 - stable and subsiding plains and shelves, 14 - oceanic basins.

buried grabens can be traced under the floor of the Laptev Sea from the continental slope to the mouth of the Lena River (Vinogradov, 1984). The geometrical (Euler) pole of the opening of the North Atlantic and Arctic Ocean calculated from the position of the rifts and spreading anomalies on the earth's sphere lies near the mouth of the Lena River (Karasik, 1980). If the tensional (oceanic opening) sector lies north of the pole of rotation, a compression sector should occupy the symmetrical position south of the pole. In the area of 120° E. long. lies the Verkhoyansk fold-and-thrust system. Along its eastern edge is the Chersky seismic belt, which contains earthquakes with foci marked by lateral compression across the strike (Fujita et al., 1990). Thus, within the Arctic geodynamic system, the boundary between the Eurasian and North American lithospheric plates crosses the pole of rotation and changes from a divergent to a convergent (obduction) boundary. The boundary follows the western thrust front of the Verkhoyansk fold-and-thrust belt up to the transverse trending boundary orogenic belt. Figure 2 shows the relationship between the northern Atlantic geodynamic system, its Arctic subsystem, and the lithospheric plate boundaries in their present stage of development.

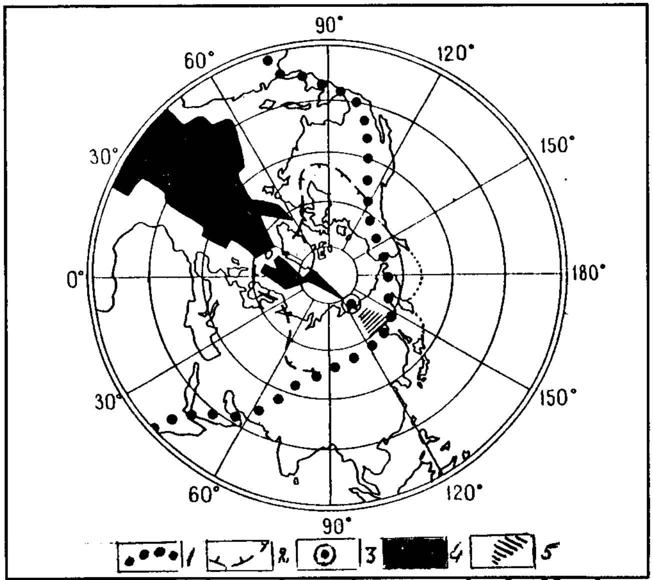

Fig.2. The Atlantic geodynamic system in the Northern Hemisphere. 1 - boundary orogenic belt of the Atlantic geodynamic system (continental seismic belt); 2 - inner boundary of the Arctic geodynamic subsystem; 3 - Arctic-Atlantic pole of opening; 4 - Arctic-Atlantic rift (extensional region of seafloor spreading with axial oceanic seismic belt); 5 - compressional sector (Verkhoyansk thrust zone).

DEEP STRUCTURE

The abyssal zone of the Arctic Ocean is divided into three morphostructurally separated abyssal basins, the Norwegian-Greenland, Eurasian, and Amerasian basins.

Norwegian-Greenland Basin

The Norwegian-Greenland Basin is a typical oceanic structure with a centrally located midocean ridge broken into three segments (Kolbeinsey, Mohns, and Knipovich Ridges). The entire area between the Greenland and Norwegian continental slopes has a seafloor-spreading-type anomalous magnetic field, with 24 pairs of linear anomalies (Paleocene-Recent). Anomaly numbers 1-6 (Miocene-Recent) lie within the midocean ridges. The crustal thickness of the abyssal plates is about 7 km. Oceanic layer 1, composed of sediments whose pelagic nature increases up-section (Talwani and Udintsev, 1982), has a thickness increasing from zero on the ridge crests to 2000 m in troughs near the continent trough, and P-wave velocities of 1.7 to 4.6 km/s. Oceanic layer 2 (middle) is about 3 km thick with velocities of 4.9 to 5.4 km/s and is inferred from seismic data to be the acoustic basement. Based on outcrops on the ridge crests and deep-sea drilling data (Sites 337, 344, 348), it is identified as a sequence of basalt sheets. Oceanic layer 3 (lower) is a crystalline substrate with a velocity of 6.5-8.0 km/s. It is apparently composed of a basalt sequence pierced by gabbro intrusions (Talwani and Eldholm, 1977). On the Iceland Plateau (Site 348), basalts are overlain by Late Oligocene silt and sand deposits interbedded with gravel (Talwani and Udintsev, 1976). On Aegir Ridge, in the Norwegian Basin (Site 337), Eocene to Middle Oligocene marine terrigenous rocks overlie the basalts and are, in turn, disconformably overlain by Pliocene to Pleistocene glacial deposits. On the eastern slope of the Iceland Plateau, this break is complicated by an angular unconformity (Sites 346, 347, 349).

Eurasia Basin

The Eurasian Basin is located between the Kara and Barents Sea shelves on one side and the Lomonosov Ridge on the other. Its boundary with the Norwegian-Greenland Basin is formed by the Spitzbergen Fracture Zone, and it is closed on the side of the Laptev Sea. The Arctic Midocean (Gakkel) Ridge divides the Eurasian Basin into two roughly symmetric parts. Based on morphological and geophysical characteristics, it can be classed as a typical midocean ridge. Starting at the Spitzbergen Fracture Zone, the Arctic Midocean (Gakkel) Ridge crosses a flat part of the basin to the Laptev Sea, retaining a distinct morphostructural character for a distance of 2000 km. The ridge crest reaches a depth of about 3000 m and disappears at 80° N. lat., about 250 km from the edge of the transversely trending continental slope. However, a seismically active zone related to the axial rift valley extends farther into the continental slope (Avetisov, 1979).

A peculiar block and ridge relief is caused by a distinct axial rift valley and numerous small transform faults crossing the valley. The relief corresponds with the anomalous magnetic field. About 6 of the 24 seafloor-spreading magnetic anomalies (Paleocene-Recent) that have been identified occur within the ridge on either side of the axial valley (Miocene-Recent). An anomaly-free zone exists along the continental slopes and along the Lomonosov Ridge. Within the ridge, the basaltic basement is overlain by a basal layer of discontinuous Upper Cenozoic (by anomaly number) glaciofluvial deposits up to 200-250 m thick. At the top of oceanic layer 2, basalts (dredged at 81° 57' N. lat. and 118° 47' E. long. in the zone of anomaly numbers 1-5) consist of a porous clinopyroxine-olivine porphyry.

Two elongate basins, the Nansen Basin (up to 3500 m deep) located on the Eurasian side and the Amundsen Basin (>4000 m) adjoining the Lomonosov Ridge, correspond to the oceanic plates contiguous to the Gakkel Ridge. Data from seismic surveys imply that the thickness of oceanic layer 1 increases from the base of the midocean ridge towards the margins of the basins, where it exceeds 4500 m in the marginal magnetic anomaly-free zone. Here, the succession is characterized by four seismic horizons with velocities of 1.7, 2.2, 2.7 to 3.0, and 4.5 to 5.0 km/s. The latter two horizons occur only within the marginal zone, and the rocks are probably folded into small structures. The age of the basalt sequence is apparently Upper Cretaceous-Paleocene. The total crustal thickness within the oceanic part of the plates is estimated at 6-8 km (Kiselev, 1984).

Amerasia Basin

The Amerasia Basin includes the abyssal basins and submarine ridges lying between the Lomonosov Ridge (including the ridge proper) and continental margins off North America and northeastern Asia. The abyssal basins have a flat seafloor at a depth of 3000 to 4000 m. The crust is about 10 km thick, and no granite layer has been inferred from geophysical data. Based on seismic data, sedimentary deposits vary in thickness from 4 km in the Wrangel Abyssal Plain (Toll' Trough) to 6 km in the Canada Basin. Five seismic horizons were recorded in their sections with the following velocities (in descending order): 1.7 to 1.8, 2.0 to 2.2, 2.5, 3.0 to 3.2, and 4.5 to 5 km/s. These velocities, by analogy with sedimentary basins of the adjacent shelves, suggest the presence of Cenozoic, Mesozoic, and probably older deposits in the Amerasia Basin (Kiselev, 1984).

The Lomonosov and Alpha-Mendeleev (Alpha Cordillera) ridges exhibit a complex block structure. Low-velocity sedimentary layers in the basins become thinner on the ridges and bedrock protrusions in the crestal zones exhibit velocities of 5.0 to 5.5 km/s. The crustal thickness is estimated to be 17 to 20 km and 15 km for the Lomonosov and Alpha-Mendeleev ridges, respectively. A distinct horizon, with a seismic velocity of 6.3-6.5 km/s, recorded on Lomonosov Ridge is considered to be a granitic layer. Marine seismic studies indicate the presence of intense folding and small fault-related folds in the semiconsolidated upper beds in the crestal zone of the ridges.

The magnetic anomaly pattern and small topographic features reported from the Alpha-Mendeleev Ridge suggest the presence of volcanic sheets just under the Cenozoic cover. This was confirmed by dredging on the axial zone of the Alpha-Mendeleev Ridge (Weber and Sweeney, 1990). On the whole, the anomalous magnetic field above basins and ridges of the Amerasia Basin exhibits a complex irregular regional pattern and high (1000γ) intensity. It is similar to magnetic fields of continental shields and differs from those of the other regions of the world's ocean. The existence of pre-Cenozoic (?) spreading anomalies, inferred by some authors, is inconsistent with either an asymmetrical spreading axis along the Alpha-Mendeleev Ridge or within the abyssal basins (Lawver and Scotese, 1990).

Continental Slope Belt

The continental slope belt includes a fault and flexure zone along the slope commonly associated with the outer wall of the foredeep of an oceanic plate, and the zone of shelf margin uplifts along the edge of the continental shelf (Pogrebitsky, 1984a).

The fault and flexure zone generally consists of several sedimentary steps, simultaneously undergoing deposition, parallel to the margin bounded by normal faults.

The step subsidence of the basement blocks is responsible for the continental slope structure. This is emphasized by the presence of large, separate, semisubmerged "avant-shelf" steps or plateaus. These are the Voring Plateau in the Norwegian-Greenland Sea, Yermak and Morris Jesup Plateaus in the Eurasia Basin, and the Chukchi Borderland in the Amerasia Basin. At present, the Voring Plateau is best known of these structures. Its sea floor is at a depth of about 1300 m. Seismic surveys reveal that the plateau is characterized by a thin (15-20 km) continental crust and a multilayered sedimentary cover that reaches 8 km in thickness. Drilling data show the presence of Cenozoic semiconsolidated deposits (about 2 km as inferred from seismic data) underlain by about 4 km of Mesozoic and about 2 km of Paleozoic rocks. Holes drilled by the Glomar Challenger at the base of the Voring Plateau penetrated 153 m of acoustic basement composed of altered basalts and overlain by terrigenous Eocene rocks, 430 m thick. Basaltic breccia, cemented by sandy-limestone, at the contact suggests that the Voring Plateau was originally at very shallow depths and subsided after the extrusion of the basalt (Eldholm et al., 1984; Talwani and Udintsev, 1982).

Regional geological and geophysical studies carried out in the Amerasia Basin include the Chukchi Borderland, whose surface lies at a depth of 273 to 1000 m. Based on seismic data, it has a continental crust 15-20 km thick and a structure similar to that of an ancient platform. In the Chukchi Borderland, crystalline basement is overlain by a thin veneer of dense (high-velocity) rocks and discontinuous, thin, semiconsolidated sediments. Bottom samples from the Chukchi Borderland include fragments of gneiss, limestone, dolomite, and sandstone of Riphean-Paleozoic age, which is in agreement with the conclusions from geophysical data.

The entire continental slope belt has a zone of shelf-margin uplifts. These are formed primarily of buried horsts, which form a chain along the edge of the continental slope. The horsts are composed of folded basement rocks and strata of the lower sedimentary section of adjacent shelf basins (Pogrebitsky, 1984a). Along the boundary between the Eurasia Basin and the Barents-Kara shelf, the shelf-margin uplifts consist of block-arches and are represented by Spitzbergen, Franz Josef Land, and Severnaya Zemlya (Gramberg and Pogrebitsky, 1984).

The major faults and folds of the continental slope belt are further complicated by a large number of transverse grabens, which are expressed in bottom topography as troughs dipping towards the abyssal basins. These structures are Late Cenozoic in age, and they mark a new stage in the destruction of the continental margin along the Arctic Ocean.

Continental Shelf

The continental shelf of the Arctic Ocean has a thin continental crust (about 30-35 km), which can be divided into three structural-stratigraphic stages. The upper stage is a series of simultaneously developing troughs filled with Mesozoic to Cenozoic sediments initially formed in the Late Permian. The upper stage is everywhere subdivided into a predominantly Cenozoic synoceanic, and a Late Permian to Mesozoic preoceanic, substage. The middle (intermediate) stage is represented by relict strata of the platformal cover that was deposited before the emplacement of Mesozoic to Cenozoic troughs. The formation of these troughs, in the zones of Early Mesozoic folding, results in the wedging out of the intermediate stage. The lower stage consists of folded rocks of various ages and forms the basement of the continental margin. The upper part of the basement is composed of folded sedimentary formations and metamorphic rocks, together forming the granite-gneiss crustal layer.

Around the periphery of the Norwegian-Greenland and Eurasia Basins, basement is represented by fold systems of Early Paleozoic and Proterozoic age that were reactivated in structural suture zones during Devonian and Permo-Triassic tectonism. In regions not involved in this deformation, the intermediate stage contains remnants of Riphean to Paleozoic platformal strata. The upper stage is characterized by terrigenous and nearshore marine strata occupying linear troughs. These troughs are mainly parallel to the edges of the continent and are contiguous with troughs of the adjacent near-shore lowlands. Sedimentation peaked during the Late Permian and Triassic. In contrast, deposits of the synoceanic substage are much thinner and represented only by thin beds in the axes of trough zones. At the boundary between the Pechora and Barents seas, seismic surveys reveal a unique depression where the total thickness of the platformal assemblage reaches 20 km and there is no evidence of a granitic layer in the basement (Verba, 1984).

In the shelves of the Amerasia Basin, there are two types of relationships between the structural stages. Seismic-reflection profiles show that relics of Paleozoic strata and Proterozoic foldbelts of the platformal basement are buried under the subsiding basins of the Sverdrup and North Chukchi basins. The foreland basins along the boundary with mountain ranges of Alaska and Northeast Russia are controlled by the Mesozoic foldbelt structures of the Pacific orogenic belt. In the Amerasia Basin, Cretaceous marine clastic deposits and Cenozoic synoceanic sedimentary assemblages dominate the section (Livshits and Zarkhidze, 1984; Grantz, et al., 1990).

The Laptev Sea shelf has a peculiar tectonic position among structures of the shelf. It is composed primarily of a shallow Cenozoic sedimentary basin with a flat bottom that forms the landward extension of the abyssal Eurasia Basin. The Laptev Shelf basin is underlain by a large platform block consisting of Archean to Proterozoic basement and a Riphean to Cretaceous sedimentary cover similar to that of the northern Siberian Platform. Tectonically, the active zones of the abyssal Eurasia Basin (a median rift zone and a symmetrically located pair of continental troughs) continue onto the Laptev Sea shelf as a chain of centrally located grabens and two flanking troughs (Taimyr-Anabar and New Siberian). The central graben area exhibits a decrease in mantle density and a low seismic velocity (v_p = 7.4 km/s). Seismic and gravity data from the shelf, collected up to Buor Khaya Bay, show crustal thicknesses of 30 km in the central grabens as compared to 35 km for the limbs. These grabens and troughs are seismically active and are filled with primarily Cenozoic sands and clays 3.5-4 km thick. Upper Cretaceous deposits may occur at the base of the section as they do in the onshore Kengdei and other shallow grabens (Vinogradov, 1984).

STRUCTURAL EVOLUTION

Based on paleogeographic reconstructions, the Arctic geodepression was isolated by Early to Late Permian time (Pogrebitsky, 1978). The large-scale rhythmic pattern of sedimentation in continental basins and the dating of volcanic activity cycles in the boundary orogenic belt allow us to distinguish six major phases in the structural evolution of the Arctic geodepression since 260 Ma: (1) Permian-Early Triassic, (2) Middle-Late Triassic, (3) Jurassic-Neocomian, (4) Aptian- Maastrichtian, (5) Danian-Paleogene, and (6) Miocene-Recent (Pogrebitsky, 1984b). These six phases can be grouped into two stages, the Permian-Cretaceous preoceanic stage and the Cenozoic (including Danian) synoceanic stage.

In the course of the tectonic evolution, three types of regional structures developed within the Arctic geodepression during the pre-oceanic stage: (1) linear-arcuate orogenies; (2) arches or geotumors; and (3) epicontinental sedimentary basins, i.e. troughs and oval regions of subsidence covering areas underlain by continental crust that has been dissected by rifting. The development of linear-arcuate orogenies followed a pattern of localized recurrent multiphase growth with some displacement towards the center of the geodepression. The other structures also exhibit multiple stages of growth, but their centers and axes are not laterally displaced. An arch in the present site of the Norwegian-Greenland and Eurasia basins was a major element of the pre-Cenozoic structural ensemble of the Arctic geodepression. In reconstructions, this arch serves as a major sediment source area for surrounding shelf basins. In Franz Josef Land, along the edge of the Barents Sea basin, there is a zone of Jurassic and Cretaceous strata containing littoral facies. Erosional products of volcanic and metamorphic rocks, including blueschists, were supplied from the area presently occupied by oceanic basins (Ronkina et al., 1982). However, seismic sections from the Amerasia Basin suggest that it already existed in pre-Cenozoic time and adjoined the eastern (Lomonosov Ridge) limb of the paleoarch.

Based on paleogeographic reconstructions, the arch occupied the area now underlain by spreading crust. The edges of the arch were characterized by deep troughs formed in response to mantle compensation. Drilling data from Franz Josef Land and seismic sections across the Voring Plateau and Greenland shelf reveal that these troughs are filled with thick Triassic deposits. It is noteworthy that after the formation of the arch above a mantle diapir, the region entered the classical plate-tectonic model suggested for most regions of the Atlantic with the initiation of seafloor spreading.

During the synoceanic stage, the continental structural ensemble remained essentially the same. Its structure became more complex, with the formation of linear folds and thrusts, only along the outer margin of the sedimentary basins of the North American plate (Verkhoyansk-Chukchi, Colville, and Sverdrup basins). The greatest tectonic activity occurred in the Verkhoyansk-Chukchi basin, where new mountains and folds were formed. However, folded structures and mountains in this region degenerate rapidly toward the center of the geodepression, and late Paleozoic and Mesozoic deposits of the Verkhoyansk-Chukchi basin exhibit a platformal or paraplatformal mode of occurrence in the littoral zone of the modern shelf.

In the Cenozoic, major changes took place in the center of the Arctic geodepression where abyssal oceanic basins were formed.

As mentioned above, oceanic opening is generally preceded by crustal swelling above a mantle diapir; however, its mechanism still remains uncertain. Data on the crustal structure of the continental slope of the Arctic Ocean and logs in oceanic layer 1 suggest that three phases of submergence took place against the background of horizontal movements of the lithosphere (Pogrebitsky, 1984a):

Phase I (pre-Oligocene) was characterized by the break-up and active rifting of the axial part of the central uplift (arch) while the entire central part of the Arctic geodepression underwent generally gentle subsidence.

Phase II (Oligocene-Miocene) was characterized by active submergence of the margin of subsiding basins; numerous listric faults formed in the upper layers of the crust.

Phase III (Pliocene-Quaternary) is distinguished by continuous, submergent, subsidence of the topographically expressed abyssal zone and the continental margins and the concurrent emergence of a midoceanic ridge.

Relict continental blocks such as the Voring, Yermak, and Iceland plateaus; Chukchi Borderland; and Lomonosov Ridge form a submarine terrace dipping from the continent towards the center of the deep basin at 750 to 1500 m depth. The depth of 750 m may correspond to the general amplitude of Cenozoic subsidence of the Arctic geodepression center excluding the superimposed Oligocene to Miocene collapse. In the case of the latter, the amplitude of subsidence for the abyssal basins is 2.5-3 km, and the subsidence rate is about 10 cm per 1000 years.

Thus, in the course of the structural evolution of the Arctic geodynamic system, a long period (Permian-Cretaceous) of epicontinental changes that took place around a mantle diapir growing in the center of the system. In the Cenozoic, the arches above the diapir underwent inversion caused by rifting inversion and oceanic basins with seafloor spreading (Norwegian-Greenland and Eurasian basins) formed in their place. The Amerasia Basin is an oceanized epicontinental basin that formed as one of a series of basins during the Mesozoic (others being the Sverdrup, Colville and Verkhoyansk-Chukchi basins). Its transformation into an abyssal basin took place during the Oligocene to Miocene because the core of the Arctic geodepression was subsiding rapidly and was sediment-starved.

CONCLUSIONS

The mass-transport processes within the Arctic geodynamic system resulted in the formation of newly formed ferric lithosphere in its abyssal core and newly formed sialic lithosphere in the boundary orogenic belt. These are separated by a wide transitional zone of relict lithosphere. Within the tectonosphere, these processes include orogeny, rifting, subsidence, mantle diapirism, and spreading. All the forms of mass transport are complementary to each other, i.e., interrelated and complementing each other to form a single whole: the Arctic geodepression. If the Earth is considered as a first-order geodynamic system and the Atlantic segment a second-order system, then the above-discussed Arctic system can be considered as a third-order natural grouping. We have no evidence for the existence of such a hierarchical division or about the interrelated development of the systems composing in the Paleozoic and Precambrian. This suggests, therefore, the earth has had a new level of internal organization during the last 250 m.y.

Earlier, global paleogeographic analyses have shown that the appearance of deep oceans and high mountain chains on the Earth since the Mesozoic reflects a total increase of amplitude with time due to evolutionary changes that took place in the thermal and density stratification of the Earth (Yanshin, 1988).

The existence and the interrelated development of large ocean-forming geodynamic systems, as well as from the thermal and gravitational segmentation of the solid shell of the earth (Pogrebitsky, 1978) caused by irregular expansion with time.

evolution of the Arctic geodepression since 260 Ma:

ACKNOWLEDGEMENTS

This manuscript was extensively edited for clarity by K. Fujita, who hopes that no changes in meaning were introduced in this process.

REFERENCES

Avetisov, G.P., 1979. K voprosu o tektonicheskoi prirode Arkticheskogo seismichesogo poyasa. In: Y.E. Pogrebitsky (Editor), Tektonika Arktiki, Razlomy Materikovoi Otmeli i Okeana. NIIGA, Leningrad, 1979, pp. 69-80 (in Russian).

Eldholm, O., Myhre, A.M. and Sundvor, E., 1984. Structure and evolution of the margins around the Norwegian-Greenland Sea. In: I.S. Gramberg (Editor), Arctic Geology, Colloquium 04. 27th Int. Geol. Cong., Moscow, Reports, 4: 43-58.

Fujita, K., Cook, D.B., Hasegawa, H., Forsyth, D. and Wetmiller, R., 1990. Seismicity and focal mechanisms of the Arctic region and the North American plate in Asia. In: A. Grantz, L. Johnson, and J.F. Sweeney (Editors), The Geology of North America, v. L., The Arctic Ocean Region: Geological Society of America, Boulder, pp. 79-100.

Grantz, A., May, S.D., Taylor, P.T. and Lawver, L.A., 1990. Canada basin. In: A. Grantz, L. Johnson, and J.F. Sweeney (Editors), 1990. The Geology of North America, v. L., The Arctic Ocean Region: Geological Society of America, Boulder, pp. 379-402.

Karasik, A.M., 1980. Osnovnye osobennosyi istorii razvitiya i struktury dna Arkticheskogo basseina po aeromagnitnym dannym. In: Morskaya Geologia, Sedimentologiya, Osadochnaya Petrografiya i Geologiya Okeana. Nedra, Leningrad, pp. 178-193 (in Russian).

Kiselev, Y.G., 1984. Zemnaya kora Severnogo Ledovitogo okeana, osobennosti stroeniya i stadii razvitiya. In: Struktura Zemnoi Kory Mirovogo Okeana. Sevmorgeologiya, Leningrad, pp. 19-37 (in Russian).

Lawver, L.A. and Scotese, C.R., 1990. A review of tectonic models for the evolution of the Canada basin. In: A. Grantz, L. Johnson, and J.F. Sweeney (Editors), The Geology of North America, v. L., The Arctic Ocean Region: Geological Society of America, Boulder, pp. 593-618.

Livshits, Y.Y. and Zarkhidze, V.S., 1984. Sinokeanicheskaya Kainozoiskaya stadiya. In: I.S. Gramberg and Y.E. Pogrebitsky (Editors), Geologicheskoe Stroenie SSSR i Zakonomernosti Razmeshcheniya Poleznykh Iskopaemykh, v. 9, Morya Sovetskoi Arktiki. Nedra, Leningrad, pp. 175-191.

Pogrebitsky, Y.E., 1978. Geodynamic system of the Northern Arctic Ocean and its structural evolution. Int. Geol. Rev., 20: 1251-1266.

Pogrebitsky, Y.E., 1984a. Perekhodnye zony materik - okean v geodinamicheskoi sisteme Severnogo Ledovitogo okeana. In: Colloquium 07. 27th Int. Geol. Cong., papers, 7: 29-37 (in Russian).

Pogrebitsky, Y.E., 1984b. Arkticheskii segment zemli i ego tektonicheskaya evolyutsiiya. In: I.S. Gramberg, and Y.E. Pogrebitsky (Editors), Geologicheskoe Stroenie SSSR i Zakonomernosti Razmeshcheniya Poleznykh Iskopaemykh, v. 9, Morya Sovetskoi Arktiki. Nedra, Leningrad, pp. 246-253.

Ronkina, Z.Z. and Vishnevskaya T.N., 1982. Glaukofan v osadochnykh tolshchakh zapadnoi chasti Sovetskoi Arktiki. Sovetskaya Geologiya, (7): 90-93 (in Russian).

Talwani, M. and Eldholm O., 1977. Evolution of the Norwegian-Greenland Sea. Bull. Geol. Soc. Amer., 88: 969-999.

Talwani, M. and Udintsev, G.B. (Editors), 1976. Initial Reports of the Deep Sea Drilling Project, v. 38. U.S. Government Printing Office, 1256 pp.

Talwani, M. and Udintsev G.B., 1982. Tektonika dna okeana. In: Geologia dna Mirovogo okeana. Atlantika. Biostratigrafia i tektonika (rezul'taty bureniya v 38-m reise "Glomar Chellendzher"). Nauka, Moscow, pp. 155-182 (in Russian).

Verba, M.L., 1984. Barentsevo More. In: I.S. Gramberg, and Y.E. Pogrebitsky (Editors), Geologicheskoe Stroenie SSSR i Zakonomernosti Razmeshcheniya Poleznykh Iskopaemykh, v. 9, Morya Sovetskoi Arktiki. Nedra, Leningrad, pp. 11-39.

Vinogradov, V.A., 1984. More Laptevykh. In: I.S. Gramberg and Y.E. Pogrebitsky (Editors), Geologicheskoe Stroenie SSSR i Zakonomernosti Razmeshcheniya Poleznykh Iskopaemykh, v. 9, Morya Sovetskoi Arktiki. Nedra, Leningrad, pp. 50-60.

Vogt, P.R., Johnson, G.L. and Kristjansson, L., 1980. Morphology and magnetic anomalies north of Iceland. J. Geophys., 47: 67-80.

Weber, J.R. and Sweeney, J.F., 1990. Ridges and basins in the central Arctic Ocean. In: A. Grantz, L. Johnson, and J.F. Sweeney (Editors), The Geology of North America, v. L., The Arctic Ocean Region: Geological Society of America, Boulder, pp. 305-336.

Yanshin, A.L., 1988. Evolution of geological processes in the history of earth. *Nauka, Leningrad, 39 pp. (in Russian).*

Zverev, S.M., Kosminskaya, I.P., Krasil'shchikova, G.A. and Mikhota, G.G., 1977. Deep structure of Iceland and the Iceland-Faeroe-Shetland region based on seismic studies (NASP-72). Int. Geol. Rev., 19: 11-24.

Phase I (pre-Oligocene) was characterized by the