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Southeastern Eurasian Basin Termination: Structure and Key Episodes of Tectonic History

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THEME 15: Geodynamics of the Arctic Region

Summary: Multichannel seismic reflection data, obtained by MAGE in 1990, reveal the geological structure of the Arctic region between 77-80 °N and 115-133 °E, where the Eurasian Basin joins the Laptev Sea continental margin. South of 80 °N the oceanic basement of the Eurasian Basin and the continental basement of the Laptev Sea deep margin are covered by sediments varying from 1.5 km to 8 km in thickness. The seismic velocities range from 1.75 km/s in the upper unit to 4.5 km/s in the lower part of the section. Sedimentary basin development in the area of the Laptev Sea deep margin started from continental rifting between the present Barents-Kara margin and the Lomonosov Ridge in Late Cretaceous time. Since 56 Ma the Eurasian Basin opened and sea-floor spreading continues till today. The north western Laptev Sea continental margin is of the Atlantic type. Upper Cretaceous-Lower Paleocene terrigeneous synrift sediments fill depressions of the Pre-Cambrian basement on the continental slope and at the continent/ocean crust transition. The Cenozoic syn-oceanic cover of the Laptev Sea deep margin and the south eastern Eurasian Basin consist of a few structural successions, deposited by several submarine fans. An analysis of the basement morphology allows to trace the location of the buried Gakkel Ridge more precisely from 77 °N to 80 °N, which divides the Eurasian Basin into the Nansen and Amundsen Basins. The total thickness of Cenozoic sediments over the flanks of Gakkel Ridge varies from 2-3 km to 4-5 km, increasing southward. It reaches up 6 km in the central rift valley. The Gakkel Ridge is about 55-60 km wide. There is an apparent asymmetry in the structure of the Eurasian Basin on either side of Gakkel Ridge, as the Nansen Basin is shallower and narrower. It has a thicker sediment cover and a deeper basement. South of 78,5 °N, the Gakkel Ridge spreading centre changes its strike and bends eastward. At 77,5 °N between 128-131 °E the Gakkel Ridge oceanic rift meets the Laptev Sea continental margin. The tectonic relationship between the Gakkel Ridge spreading centre and the Laptev Sea continental rift system can probably be explained by a transform fault at the ocean/continent crustal boundary. The extremely low tectonic activity of Gakkel Ridge becomes completely extinct southward. At least south of 78.5 °N there was an apparent cessation in the ridge evolution approximately from 30 Ma until 3-1 Ma. The author assumes that all oceanic crust within the Eurasian Basin south east of 78 °N was formed from 56 Ma to 33 Ma.

The Eurasian Basin in the Arctic Ocean extends from the Spitsbergen Fracture Zone to the Laptev Sea continental margin for a distance of about 2000 km. It is bordered by the Lomonosov Ridge in the north and the Barents–Kara shelf in the south. The Eurasian Basin narrows in a south eastern direction from 900 km close to Greenland to 300 km near the Laptev Sea. The Gakkel Ridge forms an active spreading center in the middle of the Eurasian Basin. The ridge separates the Eurasian Basin into the Nansen and Amundsen deep-water basins and terminates at the Laptev Margin continental slope. Aeromagnetic surveys revealed that the opening of the Eurasian Basin started at 56 Ma or possibly earlier because there is an area of 50-100 km between the oldest identified spreading anomaly (Chron 24) and the morphological borders of the basin (KARASIK 1968, 1980, VOGT et al. 1979, KRISTOFFERSEN 1990). The analysis of the magnetic anomaly pattern shows that Gakkel Ridge is one of the slowest spreading ridges in the world. As asymmetry in spreading rates has persisted througout most of Cenozoic, the Nansen Basin has formed faster than the Amundsen Basin. The lowest spreading rates, less than 0.3 cm/yr, occur at the southeastern end of Gakkel Ridge in the vicinity of the sediment source areas. In this area close to the Laptev Sea, thick sediments cover the oceanic basement.

Due to unique ice conditions in August-September 1990, the Marine Arctic Geological Expedition (MAGE) from Murmansk on R/V „Professor Kurentsov" succeeded to carry out the first regional 2D seismic survey in the deep-water part of the Laptev Sea and the adjoining area of the Arctic Ocean. More than 1700 km of seismic reflection lines were acquired north of the Laptev shelf (Fig. 1). Seismic reflection profiling was based on a standard technique with a 24-fold CDP coverage. Seismic shots were generated by a linear airgun array and a seismic streamer of 2400m active length was used as receiver.

The multichannel seismic reflection data on profiles 90700, 90701, 90702, 90704 and 90707 reveal the geological structure of the Arctic region between 77-80 °N and 115-133 °E, where the Eurasian Basin reaches the passive-transform continental margin of the Laptev Sea (Fig. 1). After seismic data processing and interpretation, a structural map was produced as well as an isopach map for the sedimentary cover (Fig. 2). South of 80 °N the oceanic basement of the Eurasian Basin and the continental basement of the Laptev Sea deep margin are covered by sediments with thicknesses varying from 1.5 km to 8 km. The seismic velocities range from 1,75 km/s in the upper unit to 4.5 km/s in the lower part of the section. Since no information from boreholes in this area is available, the seismic sequence boundaries were tied to the stratigraphic model of the Laptev shelf of IVANOVA et al. (1989) and SEKRETOV (1993) as well as to the global sea level curve for the Cenozoic (Fig. 3). The stratigraphic interpretation of the key seismic reflectors „S" and „U" is supported by eustatic factors and possibly tectonic events. It coincides with the seismic stratigraphy correlation chart for the Laptev Sea (IVANOVA et al. 1989, SEKRETOV 1993), where the respective reflectors are named „I" and „L". The key seismic reflector „S" correlates with the Early Paleocene Danian top of an unconformity (58.5-60 Ma). The key seismic reflector „U" is identified as the Late Oligocene top of another unconformity (30 Ma). The seismic reflectors „U*" (55 Ma), „U3" (21 Ma),

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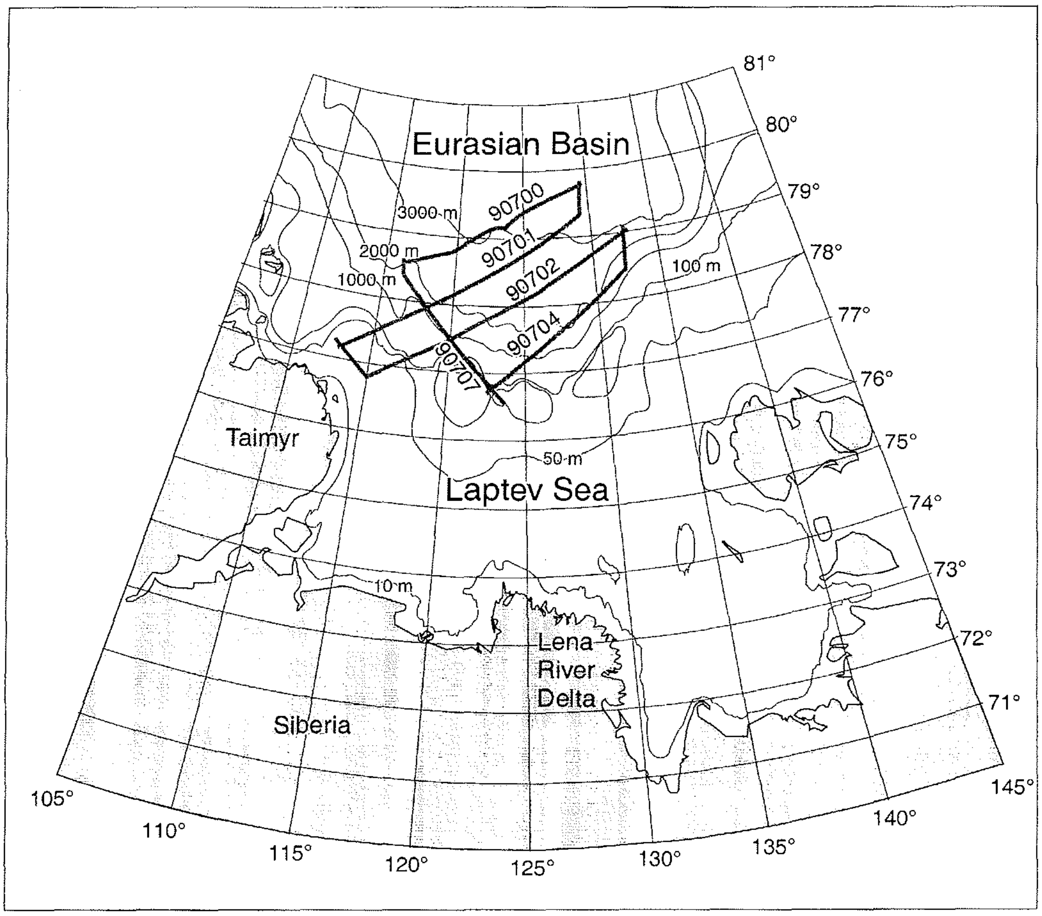

Fig. 1: Bathymetric chart of the Laptev Sea and adjacent part of the Eurasian Basin and location of the MAGE seismic lines 90700, 90701, 90702, 90704 and 90707. Bathymetric contours are given in metres. Map produced with GMT software (WESSEL & SMITH 1995).

„U2" (10.5 Ma), „U1" (5.5 Ma) and „U0" (2.9 Ma) correspond with eustatic changes of sea level in the Cenozoic (Fig. 3). The sediment cover of the Laptev Sea deep margin includes most likely Upper Cretaceous-Cenozoic deposits, but the cover of the Eurasian Basin probably contains Cenozoic sediments only (Figs. 4, 5, 6, 7). Seismic reflector „VI" is the top of the Archean-Early Proterozoic crystalline continental basement. Seismic reflector „B" is the top of the Cenozoic oceanic basement.

The development of a sedimentary basin in the area of the Laptev Sea deep margin started during continental rifting along the axis between the present Barents–Kara margin and the Lomonosov Ridge in Late Cretaceous time. Since 56 Ma the Eurasian Basin opened and sea-floor spreading continues till today. From the seismic data interpretation the author assumes that, within the studied northwestern part of the Laptev Sea continental slope between 116 °E and 127 °E, the continental basement is formed by Karelian crystalline rocks of the Laptev massif of the Siberian platform. The sediment cover on the slope comprises most likely Upper Cretaceous to Cenozoic deposits. The sediment thickness shows large lateral variations from 1.5-8 km. Two structural successions can be distinguished: an Upper Cretaceous-Lower Paleocene rift succession and a Cenozoic oceanic sequence. The rift succession with seismic velocities of 3.2-4.0 km/s and a maximum thickness of 2-3 km probably represents sandy-clayey deposits of subcontinental origin. Upper Cretaceous-Lower Paleocene terrigeneous rift sediments fill depressions of the Archean-Early Proterozoic basement on the continental slope and at the transition between continental and oceanic crust (Fig. 4). The oceanic cover is made up of submarine fan deposits with different orientations and characterized by a variable thickness of 1.5-6 km. Turbidity current sequences are identified with some certainty in the seismic stratigraphy. Seismic velocities in the sandy-argillaceous cover of turbidity sediments increase with depth from 1.8 km/s to 3.2-3.4 km/s (Fig. 4: Line 90700, I INT., II INT., SP 0-600; Fig. 7: Line 90704, II INT., SP 3000-4600). Structurally, the continental basement shows a block appearance comparable to that of the passive margins of the Atlantic. The observed dipping of pre-Cambrian blocks of the continental basement next to the oceanic trough of the Eurasian Basin is caused by a complicated system of normal faults. This study suggests that the tectonic development of the northern segments of the slope (Fig. 4) occurred in Late Cretaceous to Early Paleocene times, but the southernmost segment (Fig. 7), probably, in Paleocene to Eocene times. The width of the continental slope, measured from the modern shelf edge to the continent/ocean crustal boundary, changes from 120-130 km on the north to 60-100 km in the south (Fig. 2).

Due to the limited geophysical data, the continent/ocean transition can be defined only tentatively. Along lines 90700 (II INT., SP 200-600) (Fig. 4), 90701, 90702, 90704 (II INT., SP 2900-3100) (Fig. 7), the top of the basement cannot be identified due to the occurence of multiple reflections. The width of this unresolved areas varies from 28 km along 90700, 61 km along 90701, 39 km along 90702 to 11 km along 90704. The boundary between continental crust of the Laptev Sea continental slope and oceanic crust of the Nansen Basin is shown

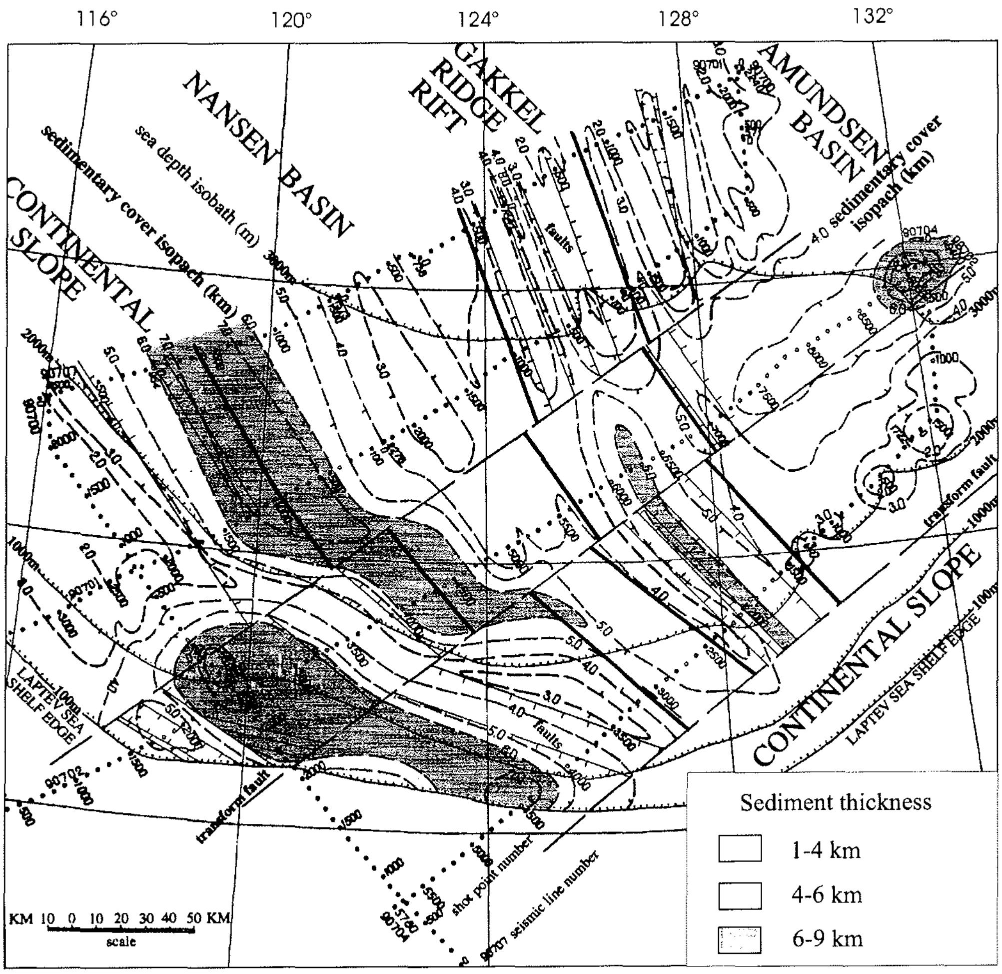

Fig. 2: Isopach map for the sedimentary cover of the southeastern Eurasian Basin termination and Laptev Sea continental slope. Thick lines mark the boundaries between main structural elements: Laptev Sea continental slope, Nansen Basin, Gakkel Ridge Rift and Amundsen Basin. Seismic line number, shot point number, water depth in metres and sediment thickness in kilometers are marked.

by a thick line on the map (Fig. 2). It has been drawn at the middle of the unresolved areas. The step-like morphology of the continent/ocean transition may indicate the presence of transform faults.

In the adjoining Eurasian Basin of the Arctic Ocean, the Cenozoic syn-oceanic cover consists of several successions deposited by submarine fans. The total thickness of the syn-oceanic sequence ranges from 1.5-8 km. The sediment thickness of each of the successions varies from several hundred metres to 2-4 km. Seismic velocities in the sandy-argillaceous turbidity sequences increase from 1.75 km/s in the upper part to 4.1-4.5 km/s at the top of the oceanic basement (Figs. 4, 5, 6, 7).

The morphology of the oceanic basement is complex. An analysis of basement morphology allows to trace more precisely the location of the buried Gakkel Ridge rift from 77 to 80 °N. The water depth varies from 2-3.5 km with only little topography above the assumed Gakkel Ridge. The Gakkel Ridge rift is about 55-60 km wide (Fig. 2). There is an apparent asymmetry in the structure of the Eurasian Basin on either side of Gakkel Ridge (Figs. 4, 5, 6, 7): The width of the Nansen Basin changes abruptly from 120 to 25-30 km in the direction of the Laptev Sea, but the width of the Amundsen Basin does not become narrower than 100 km, even in its southernmost part. South of 80 °N, the asymmetry is clearly expressed in bathymetry, basin width, sediment distribution and depth to top of the basement. The Nansen Basin is shallower and narrower. It has a thicker sediment cover and a deeper basement. It is necessary to note that south of 80 °N the spreading half-rates on the south-western side of Gakkel Ridge were lower, in contrast to the rest of the Eurasian Basin. The Nansen Basin formed slower than the Amundsen Basin.

The data presented show the geological structure at the junction of the mid-ocean Gakkel Ridge with the Laptev Margin (Fig. 2). The Gakkel Ridge rift valley and the oceanic crust of the Eurasian Basin can be followed 50-60 km farther south than previously interpreted by Karasik (1968, 1980) on the basis of magnetic anomalies. South of 78.5 °N, the Gakkel Ridge spreading centre changes its strike and bends eastward. This change in direction of the axis of the spreading centre and the supposed offsets of its segments are inferred from the system of northeast trending transform faults. The southernmost segment of the oceanic rift is crossed by the line 90704 (Fig. 7). The East Laptev horst, 150 km towards the southeast along strike of Gakkel Ridge, appears to be an uplifted block of Late Cimmerian continental basement under a thin sedimentary cover (0.3-1 km). The structure of the East Laptev horst can be identified at the shelf edge with some certainty by its large positive gravity anomalies (Sekretov 1993). At 77.5 °N between 128 and 131 °E, the Gakkel Ridge oceanic rift reaches the Laptev Sea continental margin. At this point, the oceanic rift alignes with the Late Cimmerian East Laptev Horst on the shelf, which may be an obstacle for along-strike rift propagation. Cenozoic rift structures, formed on the

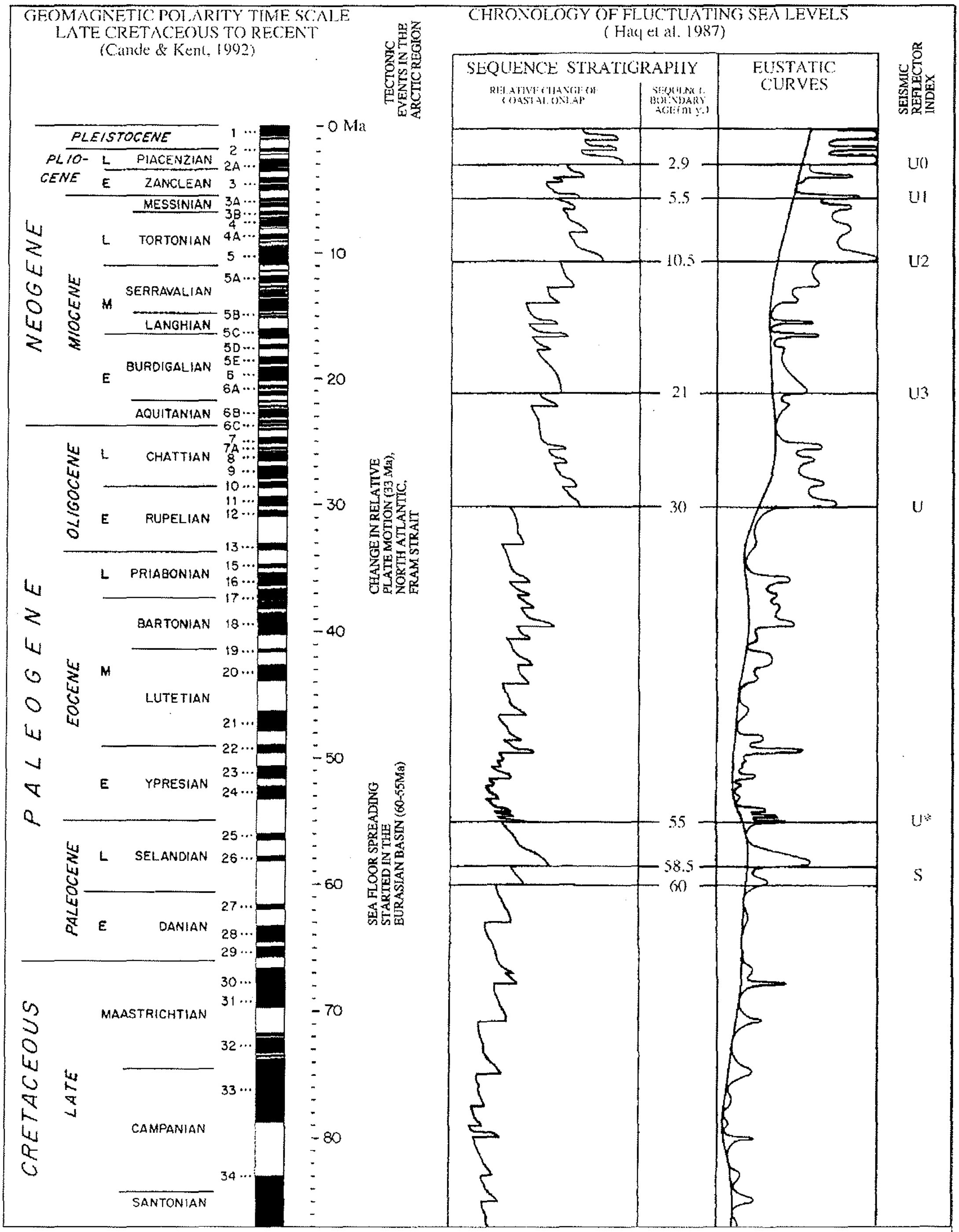

Fig. 3: Seismic stratigraphy correlation chart for the southeastern Eurasian Basin termination and Laptev Sea continental slope.

Laptev shelf basically in the Paleogene, have been delineated from seismic and gravity data and described earlier (IVANOVA et al. 1989, GRAMBERG et al. 1990, SEKRETOV 1993). The tectonic boundary between the Gakkel Ridge spreading centre and the Laptev Sea continental rift system can probably best be seen as a transform fault at the ocean/continent crustal boundary accompanied by large-scale shear faults to the north of the shelf.

The basement morphology and structure of the sedimentary cover across Gakkel Ridge allows to define with a sufficient degree of confidence the subdued oceanic rift valley north of 78 °N (Figs. 4, 5). The anomalous slow spreading and the high sedimentation rates caused the burying of Gakkel Ridge and the formation of syndepositional anticlines over the rift flanks and a central depression in the rift valley. The total thickness of Cenozoic sediments over the flanks of Gakkel Ridge varies from 2-3 km to 4-5 km, increasing southward. It reaches up to 6 km in the rift valley. The extremely low tectonic activity of Gakkel Ridge becomes extinct southward (Figs. 4, 5, 6, 7). South of 78.5 °N, Upper Oligocene, Miocene, Pliocene and Pleistocene deposits cover the oceanic basement of the Eurasian Basin and Gakkel Ridge (Figs. 6, 7). There is only a single funnel-shaped small graben bounded by two converging curvilinear faults, in the Upper Pliocene-Quaternary sediment units over the rift zone (Fig. 7). Thus, at least south of 78.5 °N,

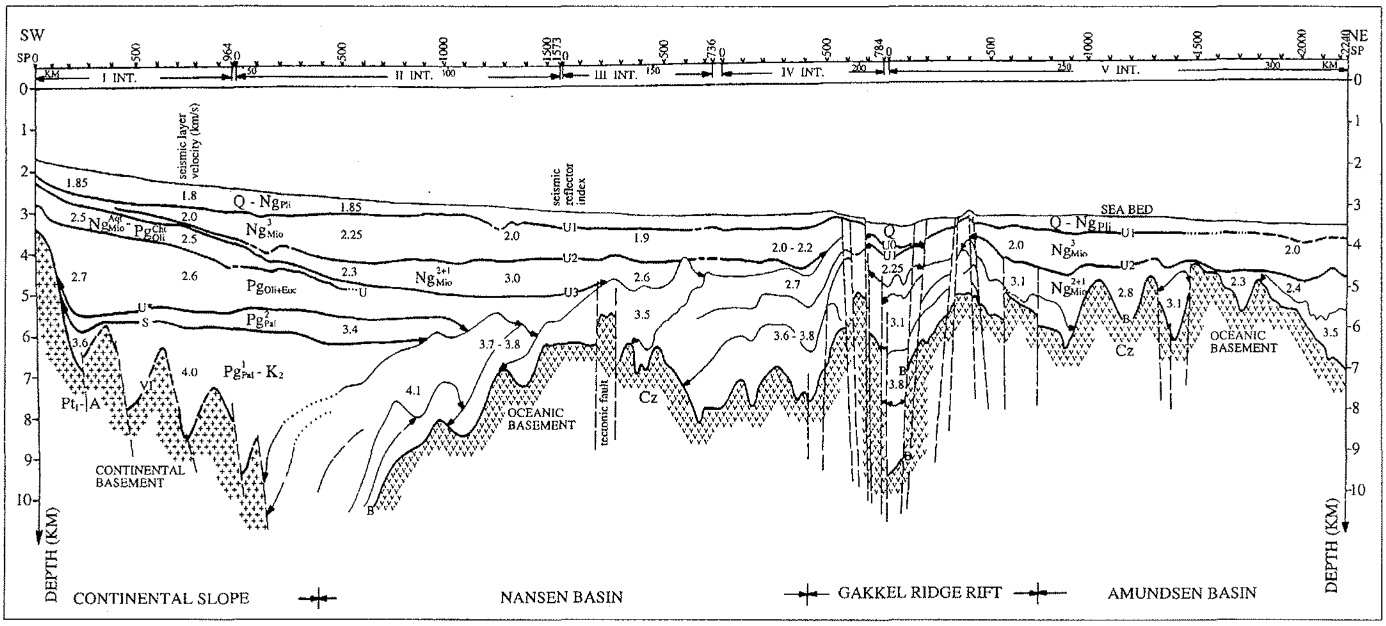

Fig. 4: Seismic line 90700. Depth section. According to the data acquisition the whole transect consists of five parts with shot point sequences: I INT, II INT, III INT, IV INT, V INT. On top the shot points (SP) and their numbers as well as the horizontal scale in kilometers. The seismic units accordingly to Figure 3 are included as well as their seismic velocities in km/s. Assumed stratigraphic ages based on these studies are indicated.

there was a complete break in the tectonic evolution of the Gakkel Ridge rift from approximately 30 Ma to 3-1 Ma and there was no sea-floor spreading in the Eurasian Basin during the last 30 m.y. This corresponds with the convergence of the magnetic anomalies 4-12 reported by KARASIK (1968, 1980) and the formation of the Neogene to Quaternary sediment cover on the Laptev shelf. Neogene to Quarternary sediments represent a post-rift sequence for the Laptev Sea rift system. The author has repeatedly called attention to this issue (IVANOVA et al. 1989, GRAMBERG et al. 1990, SEKRETOV 1993). This event is related to significant changes in the geodynamic situation in the Arctic region close to Chron 13 (33 Ma) involving the North Atlantic, Fram Strait and western Eurasian Basin (KRISTOFFERSEN & TALWANI 1977, VOGT et al. 1979,

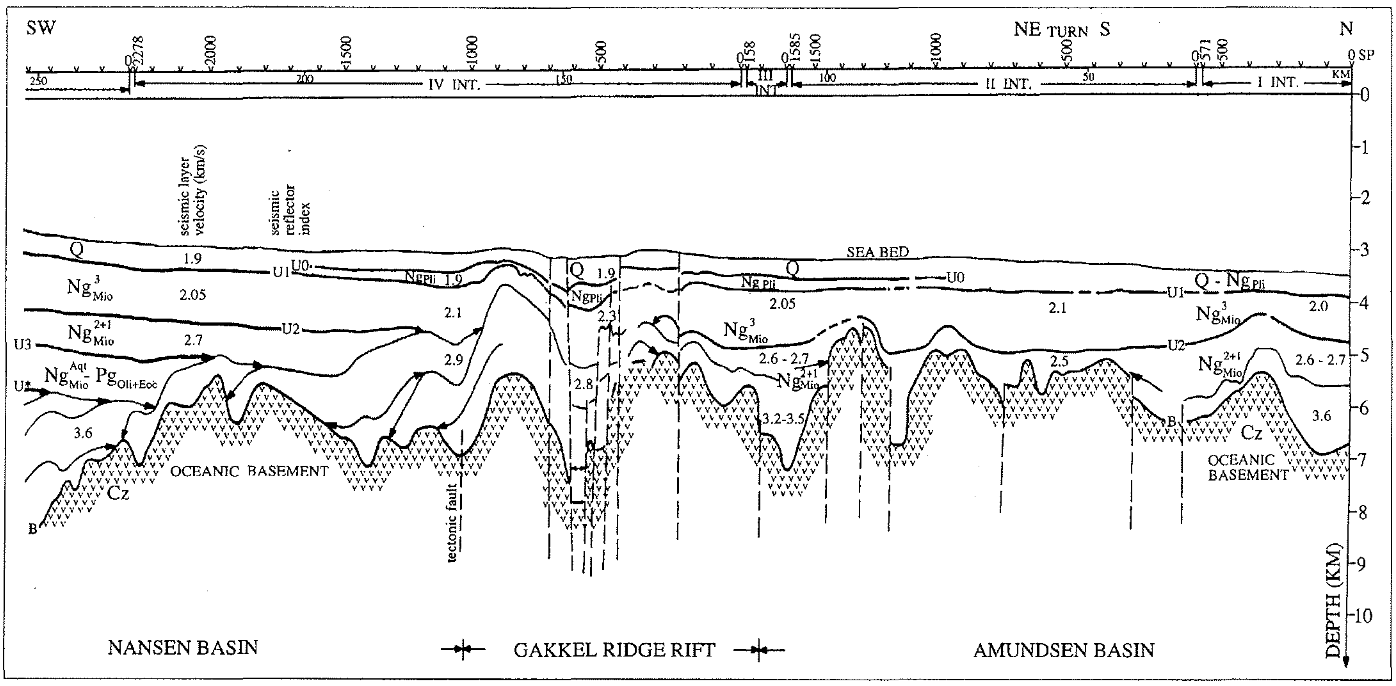

Fig. 5: Fragment of the seismic line 90701. Depth section. According to the data acquisition the whole transect consists of five parts with shot point sequences: I INT, II INT, III INT, IV INT, V INT. On top the shot points (SP) and their numbers as well as the horizontal scale in kilometers. Seismic units according to Figure 3 are included as well as seismic velocities in km/s. Assumed stratigraphic ages based on these studies are indicated.

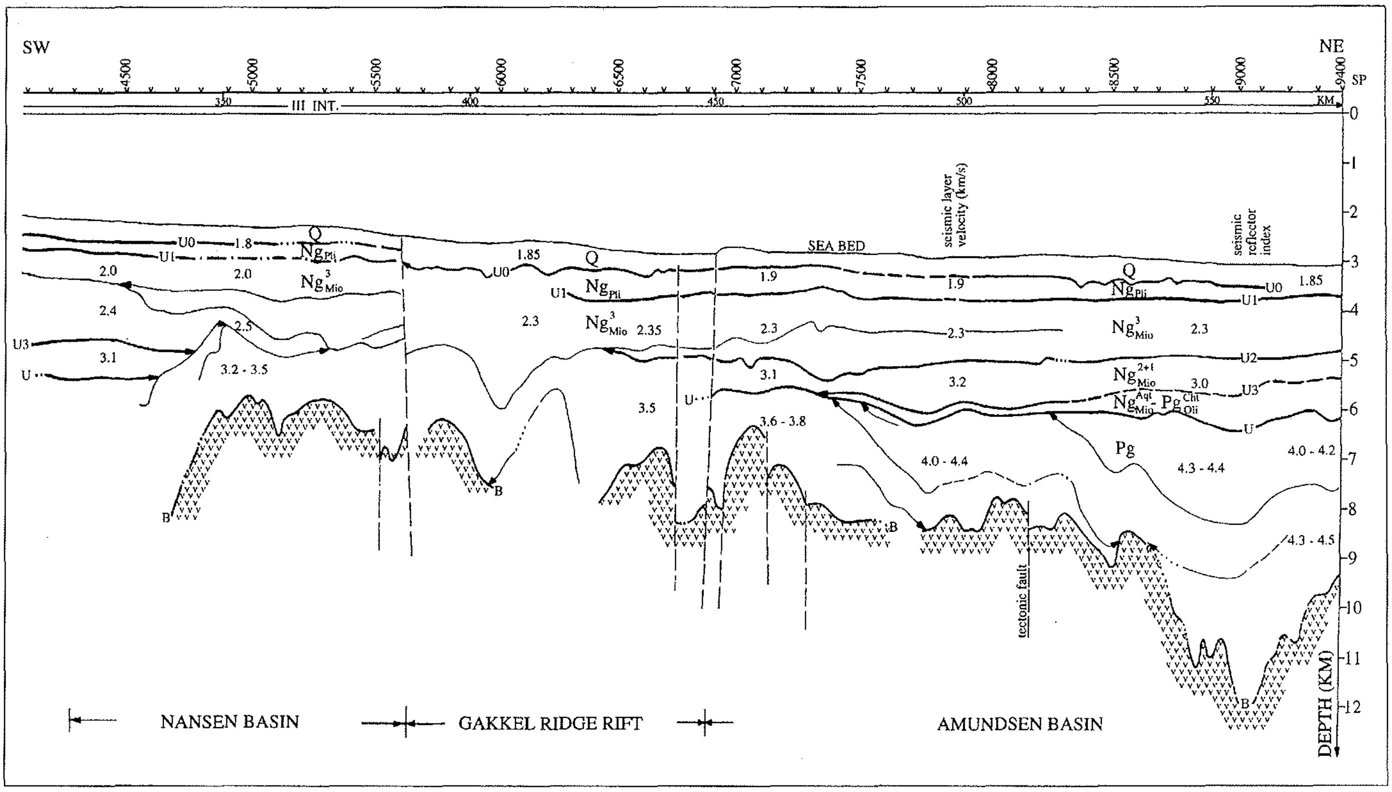

Fig. 6: Fragment of the seismic line 90702. Depth section. According to the data acquisition the whole transect consists of three parts with shot point sequences: I INT, II INT, III INT. On top the shot points (SP) and their numbers as well as the horizontal scale in kilometers. Seismic units according to Figure 3 are included as well as seismic velocities in km/s. Assumed stratigraphic ages based on these studies are indicated.

SRIVASTAVA 1985, JOKAT et al. 1995). Sea-floor spreading in the Fram Strait started at about 33 Ma. At the same time the spreading rate in the western Eurasian Basin decreased by 50 %. Therefore the author assumes that all oceanic crust within the southeastern Eurasian Basin south of 78.5 °N was formed from 56 Ma to 33 Ma.

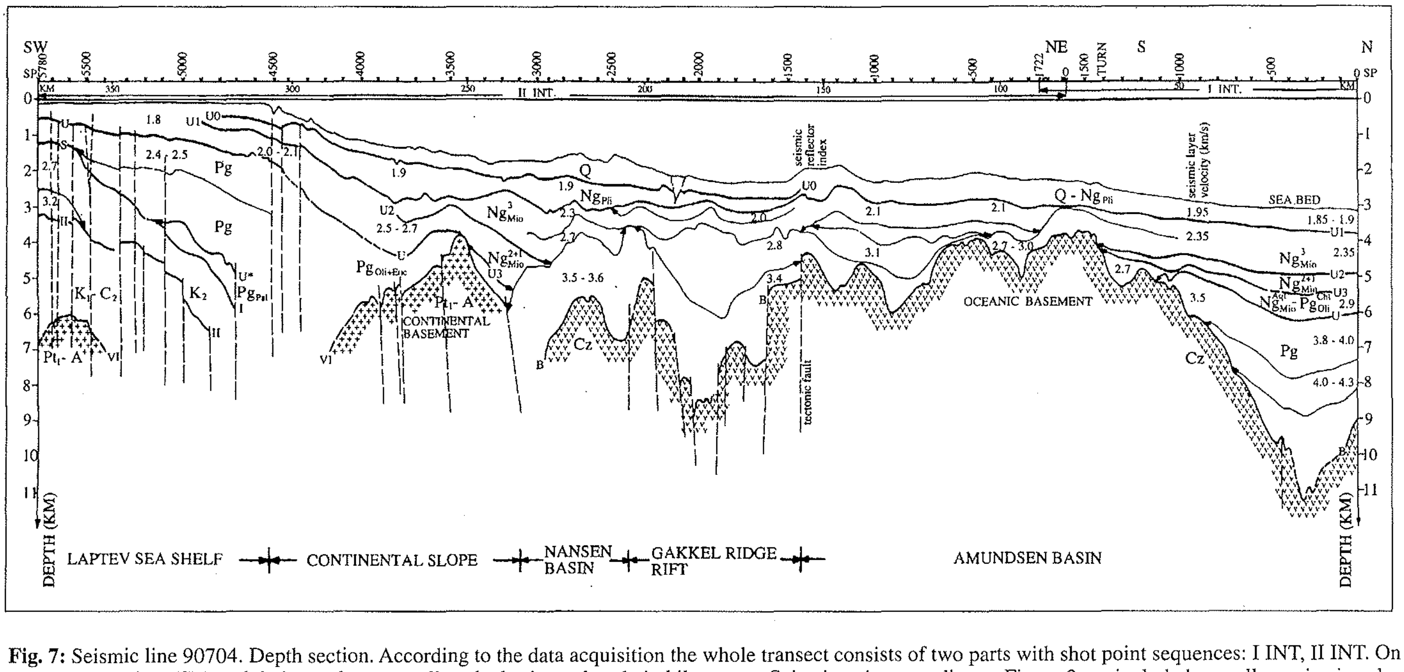

Fig. 7: Seismic line 90704. Depth section. According to the data acquisition the whole transect consists of two parts with shot point sequences: I INT, II INT. On top the shot points (SP) and their numbers as well as the horizontal scale in kilometers. Seismic units according to Figure 3 are included as well as seismic velocities in km/s. Assumed stratigraphic ages based on these studies are indicated.

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