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Potential Field Studies on the Crustal Structure of the Laptev Sea and the Western Part of the East Siberian Sea

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THEME 3: Plate Boundary Problems in the Laptev Sea Area

Summary: By a synthesis of data of many surveys, gravity and magnetic maps were prepared. The density of gravity measurements is about one point per 100 km²; the usual spacing of the lines of the aeromagnetic surveys is 10 km in the southern part of the area investigated, and 20 km north of 76 °N.

The potential field maps were analyzed by double Fourier spectrum analysis, transformations, filtering, moving windows analysis and inversions. The results are used to establish a scheme of tectonically relevant lines and structural units of the Laptev Sea and the western East Siberian Sea. Shaded relief maps demonstrate the pattern of the potential fields in the investigated shelf area and a part of the oceanic Eurasia Basin north-west of the Laptev Sea.

The Eurasia Basin shows linear magnetic and gravity anomalies parallel to the spreading axis, the Nansen-Gakkel Ridge. In the central Laptev Sea, weak NNW striking anomalies indicate that the main structures strike in the same direction. They show offsets at ENE trending fault zones which may be transfer faults. According to the interpretation of the reflection seismic measurements and gravity modeling the mostly NNW striking M/V A.Lazarev Fault separates the Ust'-Lena Rift Basin from the Laptev Horst. It corresponds to a change in the gravity pattern, but not in the magnetic pattern. Strong magnetic anomalies indicate shallow basic rocks for the De Long Plateau and deep-lying basic rocks beneath Kotelny Island. From southwest over west, northwest and north to northeast, the New Siberian Islands are surrounded by a nearly 50 km wide strip of intense gravity gradients. They may be caused by differential vertical movements.

The Khatanga-Lomonosov Zone separates the Laptev Sea from the oceanic Eurasia Basin. Pronounced earthquake epicenters mark the Belkovsky graben and the southwestern Laptev Sea coast. The potential field maps do not indicate oceanic crust for any parts of the Laptev Shelf and the western East Siberian Sea.

INTRODUCTION

Until about 1965, the understanding of the geology and the tectonics of the Laptev and East Siberian Seas was based on data gathered in the neighbouring coastal regions and the islands. When the areas of geophysical surveys expanded, the understanding relied more and more on the geophysical data. KARASIK (1968) discovered the seafloor spreading origin of the Eurasia Basin by a study of the magnetic anomaly pattern. It was first supposed that the Nansen-Gakkel Ridge continued along the Omoloj graben on the Laptev shelf to the Lena mouth and further to the Moma rift (GRACHEV 1973). How ever, there is no geophysical evidence for a continuation of the spreading axis onto the Laptev Sea shelf. Instead the tectonic map that was issued after the first regional geophysical surveys, indicates pre-Cambrian platform areas and Mesozoic fold belts (VINOGRADOV et al. 1974).

An analysis of the aeromagnetic anomalies revealed that spreading in the Eurasia Basin began in the Paleocene and continued until now (KARASIK 1980). A tentative identification of magnetic lineations in the Makarov Basin indicates that there spreading took place in Late Cretaceous - Eocene (TAYLOR et al. 1981). The Canadian Basin developed by seafloor spreading in the Late Jurassic to Early Cretaceous (155-115 Ma, VOGT et al. 1982). The tectonic events in the shelf areas are related to these spreading phases.

VERBA et al. (1986) and GRAMBERG et al. (1986) considered the northeastern Russian shelf as a single marginal continental plate with folded series from Proterozoic till Mesozoic. Paleomagnetic data indicate increased major tectonic events between Early and Late Cretaceous and in Paleocene-Eocene (GRAMBERG & POGREBITSKY 1989). It was established that the age of the flat sediment layers on the Laptev shelf is Upper Cretaceous-Cenozoic.

An alternative hypothesis proposed formation of the northeast margin of the Siberian continent by accretion. NATAPOV (1988) stated that before Middle Jurassic the New Siberian Islands area, the De Long area and the Chukchi microcontinent were parts of a continent Arctida which was separated from Siberia by the Anuj Ocean. The South-Anuj suture zone is the trace of the closed Anuj Ocean.

A following geophysical study suggested an offset of the Nansen-Gakkel Ridge near the shelf edge, and a continuation of the spreading axis into the eastern Laptev Sea in the form of Cenozoic grabens (GRAMBERG et al. 1990). Cenozoic compression was documented in the sediments at the New Siberian Islands, probably simultaneously with extension on the Laptev Sea shelf (SAVOSTIN & DRACHEV 1988). Later, AVETISOV (1993) derived from an investigation of earthquake epicenters a division of the plate boundary on the Laptev shelf into two branches. In the eastern zone extension dominates whereas in the Lena-Taimyr zone subhorizontal compression dominates.

Many papers on the nature of the Laptev and East Siberian Sea floor and the stages of their formation were published during the last years. JOHNSON et al. (1994) proposed a multi-stage Cenozoic history of the Arctic ocean. It was supposed that the basic basement layers were just below the sediment cover in the central Laptev Sea area, forming a „basalt window" in the basement (PISKAREV et al. 1997). On the base of a seismic data analysis Sekretov (1998) concluded that the crust of the deep basins of the Eurasia Basin had formed at 56-33 Ma, then a 30

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Ma long break followed after which spreading commenced at 1-3 Ma. Analysis of reflection seismic data from the Laptev Sea, carried out in the frame of the joint Russian-German cooperative work, led HINZ et al. (1998) to the conclusion that rifting and extension (without complete break of the crust) took place in the Laptev Sea predominantly between Paleocene and Miocene. It is assumed that since the Oligocene a part of the new crust was formed in the Khatanga-Lomonosov zone, which is the southeastern boundary of the Eurasia Basin. ROESER et al. (1998) date the reactivation of spreading at the Nansen-Gakkel Ridge at 12 Ma. VERBA et al. (1998) developed similar ideas.

Our investigations rests on the digital potential field data base, that was compiled by VNIIOkeangeologia in 1993-98, and on reflection seismic lines obtained by BGR since 1993. The area of this study (Fig. 1) is as key region for the analysis of relations between oceanic and shelf structures.

THE DATA BASE

This study is based on gravity and magnetic maps that include data of many surveys. The density of gravity measurements is one point per 100 km² the accuracy of Bouguer anomalies is better than 1.2 mGal. This study uses interpolated data points on a rectangular 10 x 10 km grid.

The magnetic grid uses the same data points. It is based on the results of several aeromagnetic surveys. The mean spacing between the survey lines is 10 km in the southern part of investigated area, and 20 km north of 76 °N. The accuracy of the magnetic anomalies is better than 25 nT.

POTENTIAL FIELD ANALYSIS AND IST RESULTS

The potential field analysis consists of three groups, namely

- calculation and evaluation of two-dimensional Fourier transforms,
- analysis of gravity and magnetic maps and
- density models for selected cross-sections whose locations are shown in Figure 1.

Two-dimensional Fourier spectra

The frequency contents of the gravity and the magnetic anomalies was investigated by an analysis of the two-dimensional Fourier spectrum. The obtained diagrams show the spatial characteristics of the potential fields. The synthesis of a selected range of harmonics allows to to emphasize certain properties of the underground. Careful investigation of the spectrum helps to select appropriate parameters for an improved visualization of the potential fields.

Based on grids of 10 x 10 km two-dimensional Fourier spectra of the gravity and the magnetic anomalies were computed. For the long-wave anomalies with periods T >200 km these spectra are similar. The sources of these regional anomalies are mainly upper mantle to low crust heterogeneities. The main contribution to the regional magnetic anomalies brings the upper part of the lower crust, because magnetization of the rocks decreases strongly with depth at 15-20 km, according to the increasing temperature and pressure (PECHERSKIJ 1994, PISKAREV & PAVLENKIN 1985). The sources of the anomalies with wavelengths of 100-200 km lie mostly in the basement, i.e. in the upper crust, at the depth interval 10-20 km. The sources of the more local anomalies (T <100 km) are mainly in the sediment cover or in the uppermost part of the basement, above a depth of about 10 km. The local gravity anomalies show a remarkable maximum in NW and NE direction at the period 90-100 km.

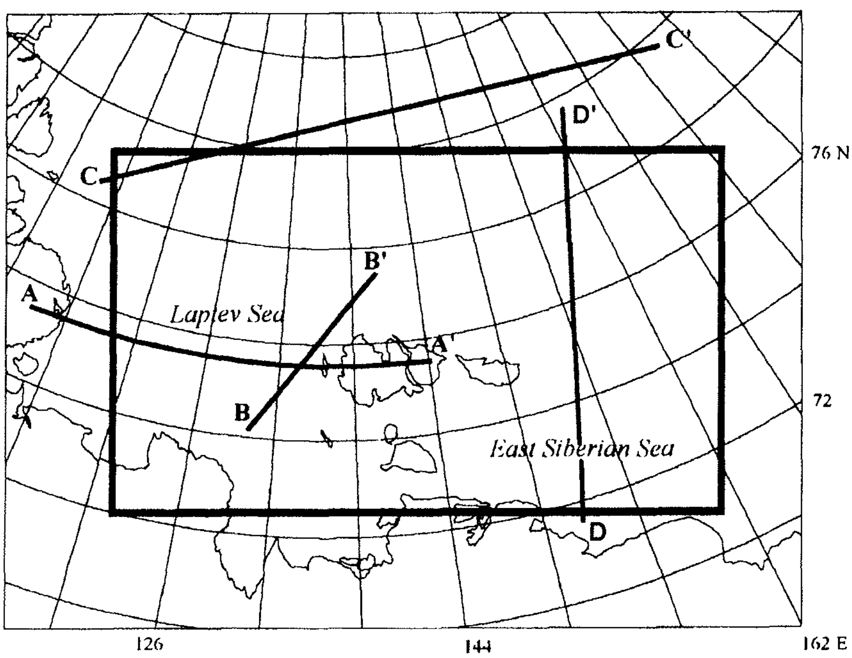

Fig. 1: The Laptev Sea and its surroundings. The heavy frame shows the bounds of Figures 2, 3, 4 and 9. A - A' etc. are locations of gravity models of Figures 5 through 8.

Gravimetric and magnetic maps

More than ten geophysical maps were produced under use of transformations, filtering, and moving windows analysis. They reflect and represent the faulted and folded structures in the basement and the sediment cover (Figs. 2, 3, 4).

Figure 2 shows the residual gravity anomalies after exclusion of the long-wave anomalies with period T >200 km as shaded relief map. This emphasizes the intermediate- and short-wavelength anomalies. The structures of the sediment cover and the upper crust are clearer in this map than in the map of Bouguer anomalies. The lighting was chosen from west because this accentuates the NW, NE and meridional orientation of the predominating gradient zones in this area. The map shows the main tectonic patterns of the shelf area and the deep ocean area north-west of the Laptev Sea. The latter is characterized by linear anomalies that parallel the Nansen-Gakkel Ridge. To the south, a zone of wide anomalies extends from the Khatanga river mouth to northeast along the continental slope. In the central Laptev Sea, weak NNW striking anomalies predominate. They show offsets at ENE trending orthogonal zones. The NNW striking M/V A. Lazarev Fault which according to the interpretation of the reflection seismic measurements (HINZ et al. 1998) separates the Ust'-Lena Rift Basin from the Laptev Horst, corresponds exactly to a change in the gravity pattern. The strongest anomalies are seen above the De-Long and the Kotelny massives. In the East Siberian Sea, the most remarkable anomalies relate to the near shore Anuj-Liakhovsky belt, and to the NNE striking zone which crosses the shelf in direction to the Mendeleev Ridge. A remarkable belt of strong anomalies extends out from the western end of the Anuj-Liakhovsky belt and the Kotelny terrain to the western Nansen-Gakkel Ridge boundary. Remarkable is also an E-W striking belt of strong anomalies in the southern part of the De-Long terrain.

Figure 3 is derived from the same residual gravity grid (T <200 km) by moving windows technique. It shows the horizontal gravity gradients summarized within windows of 40 x 40 km. The map shows a belt of intensive local anomalies around the Kotelny massive and in the southern part of the De-Long massive. The graben-shaped depressions, which are observed in the seismic profiles, are mostly within this belt. The belt of strong anomalies from the western border of Kotelny massive to the oceanic crust area stands out in Figures 2 and 3. Another anomaly zone from the Lena river mouth to Belkovsky Island appears also in both maps.

The magnetic shaded relief map (Fig. 4) shows in the northwestern corner the linear magnetic anomalies of the Eurasia Basin that are generated by seafloor spreading. Strong magnetic anomalies indicate shallow basic rocks for the De-Long plateau. They are especially strong in its southeastern part. The smoother character and the greater wavelength indicate deep lying basic rocks beneath Kotelny Island. According to calculations by PISKAREV (1977) the depths of the magnetic anomaly sources are between 8-16 km. The Khatanga-Lomo-

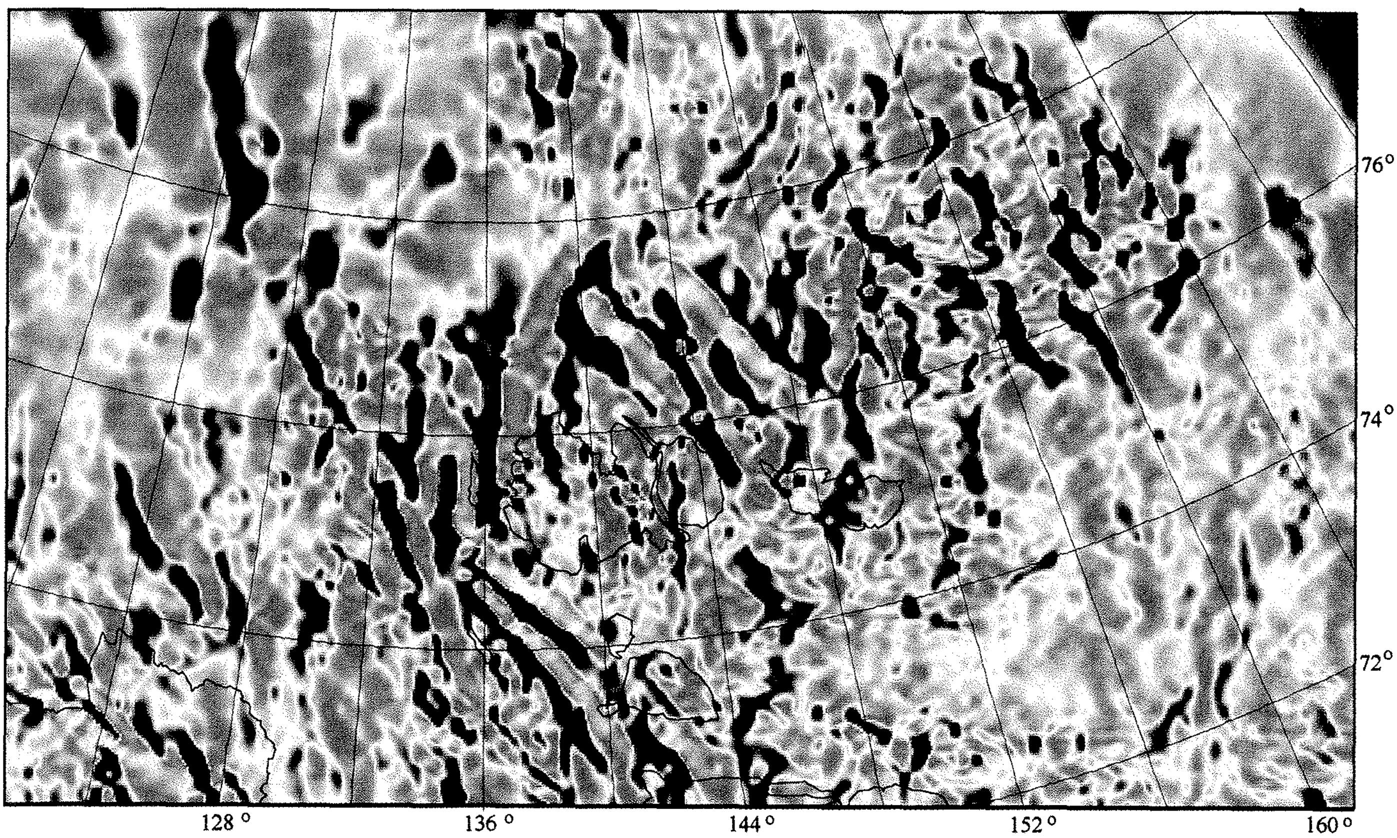

Fig. 2: Shaded relief map of the residual gravity anomalies: period of anomalies T <200 km. Light from the left side, the illuminated sides of the gradient zones are brown.

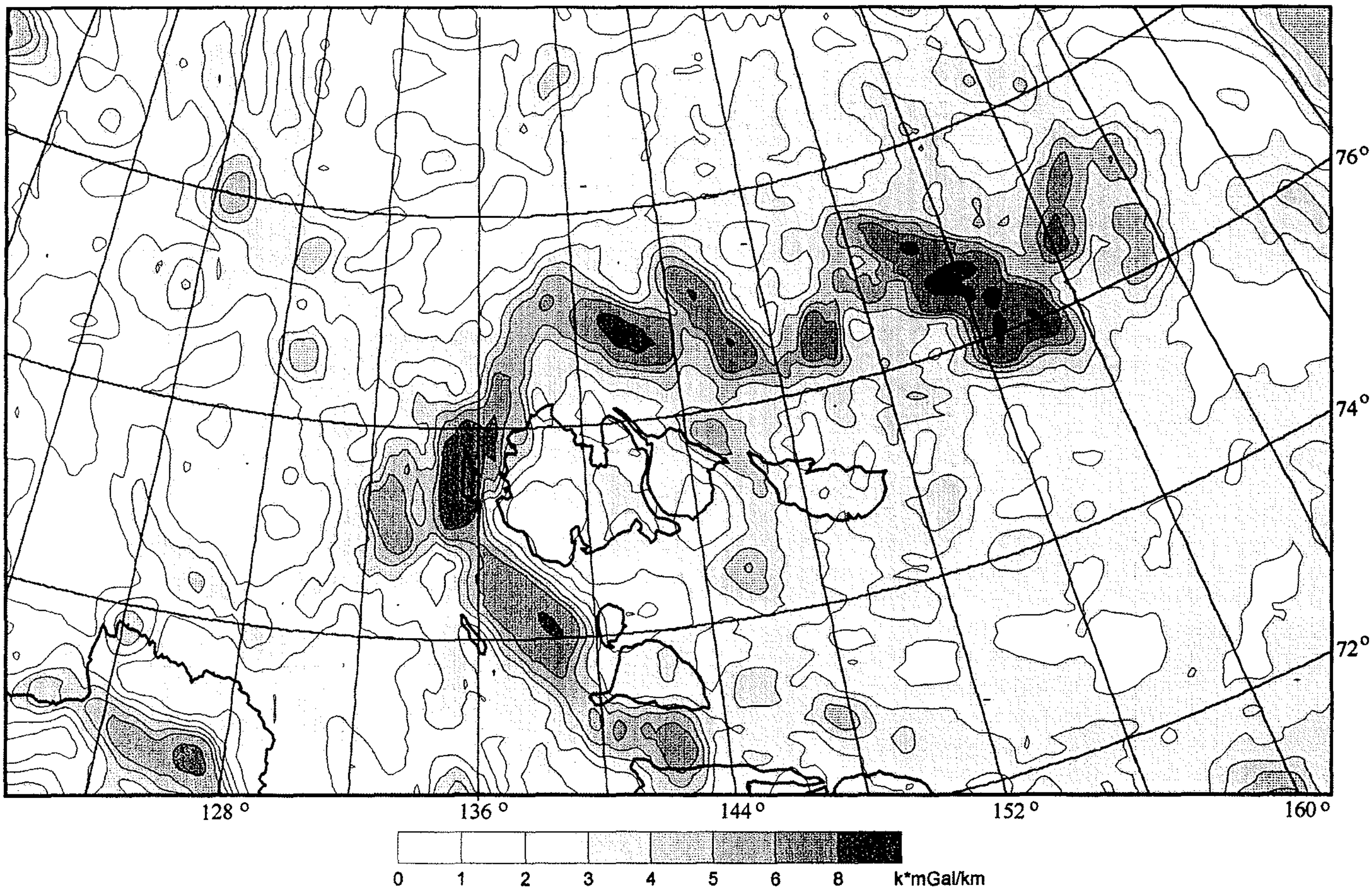

Fig. 3: Map of the summarized horizontal gradient of the residual gravity anomalies with period of anomalies T <200 km. Calculations are executed in moving window of 40 x 40 km.

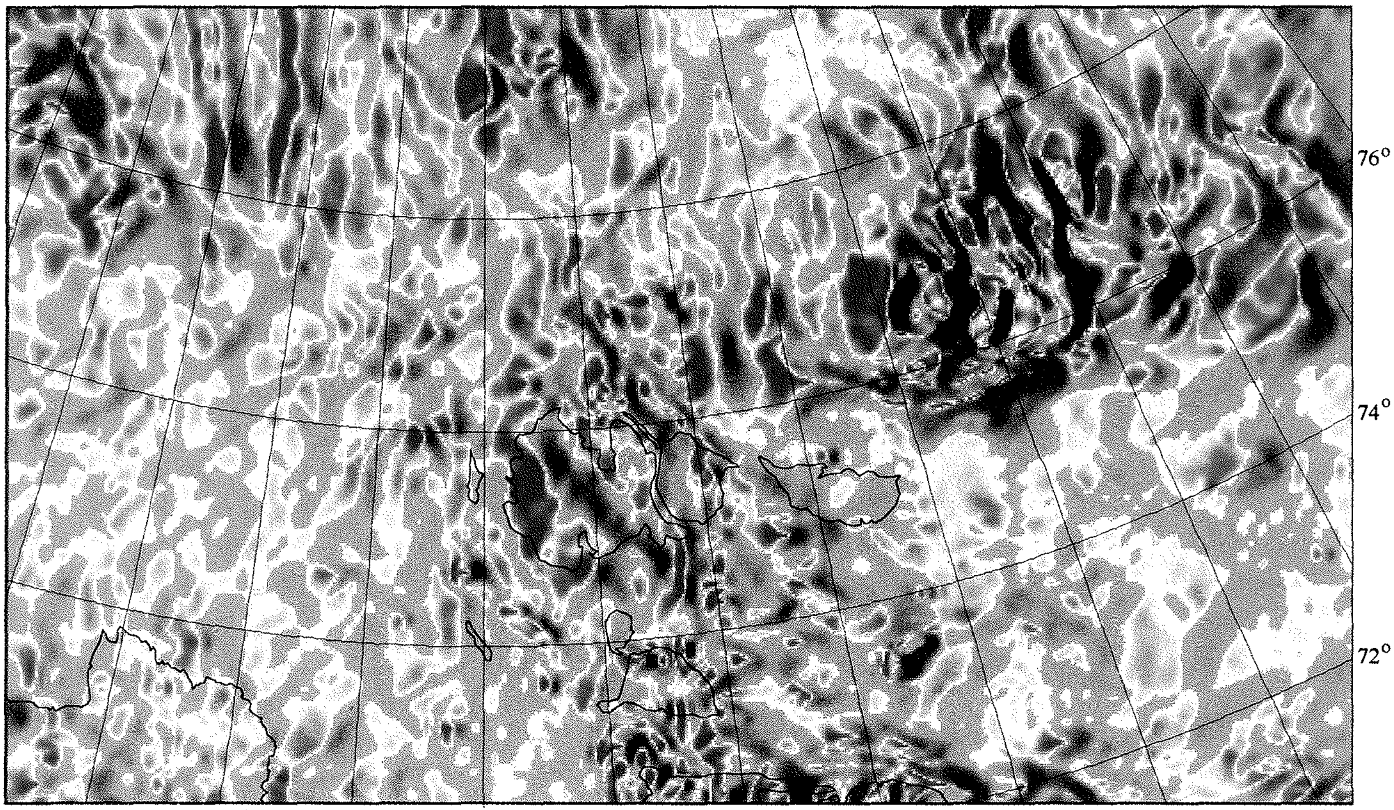

Fig. 4: Shaded relief map of the magnetic anomalies. Light from the left side. The illuminated sides are red.

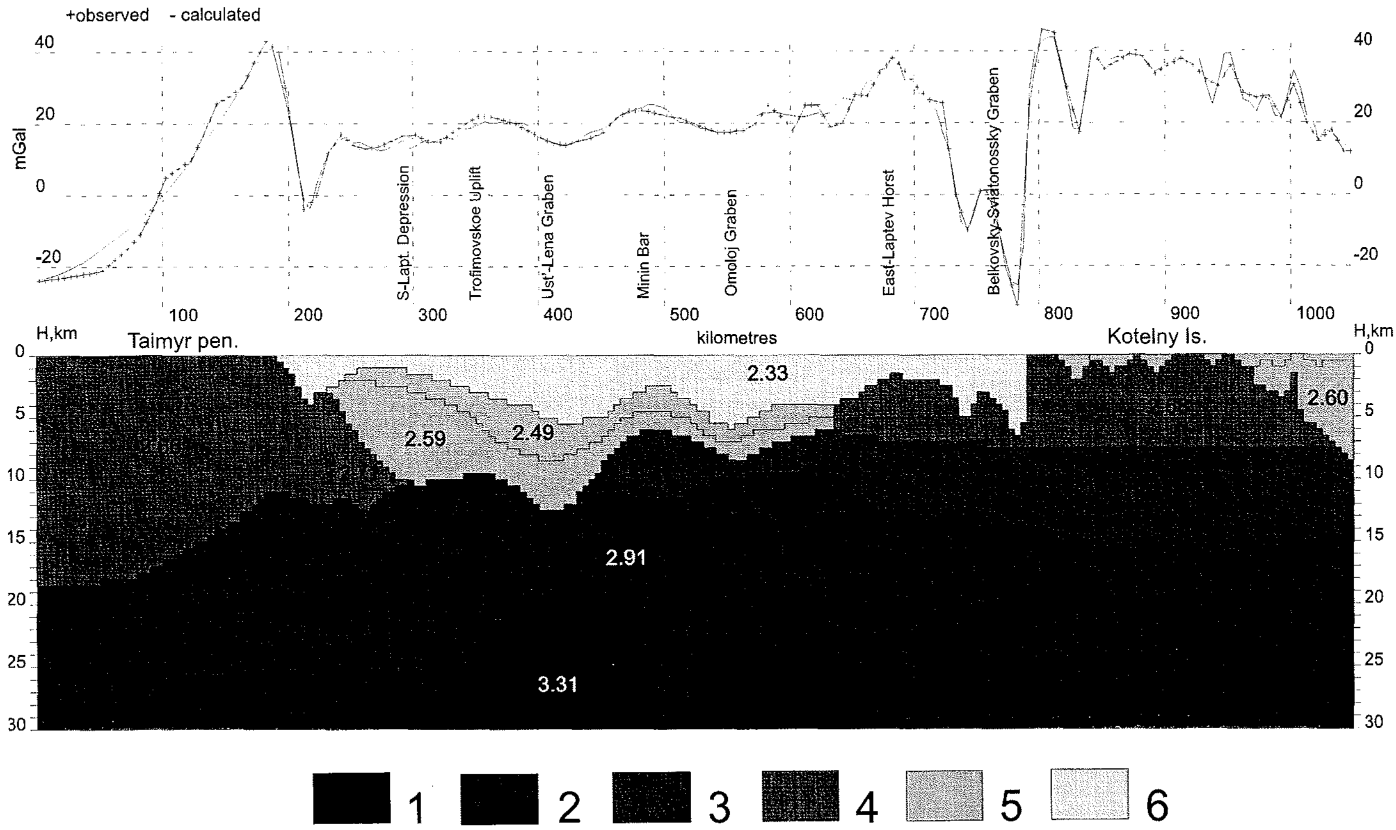

Fig. 5: Gravity model along profile A - A' in the Laptev Sea along 75.5 °N. Crosses = observed values of Δg, continuous line - calculated values. Patterns used in gravity models of Figures 5 to 8: (1) = mantle, density ρ = 3.30 - 3.32 g/cm³. (2) = lower crust, ρ = 2.91 g/cm³: (3) = upper crust of basic composition, ρ = 2.77 - 2.87 g/cm³: (4) = upper crust of granite-diorite composition, Paleozoic carbonate layers, oceanic crust of layer 2, ρ = 2.64 - 2.73 g/cm³. (5) = Mesozoic sediments, ρ = 2.41 - 2.63 g/cm³. (6) = cover sediments, Upper Cretaceous to Cenozoic, ρ = 1.89 - 2.35 g/cm³.

nosov zone is characterized by weak anomalies which strike in NE direction. The central Laptev Sea shows an orthogonal set of weak anomalies.

Model calculations for selected lines

Figures 5 to 8 show gravity models which are based on seismic and petrophysical data. That means the used densities are estimated from the seismic velocities of the sediment layers and the crustal basement under use of the knowledge of rock types and the appropriate petrophysical data. This minimizes the uncertainty of the gravity model. The crosssections in Figures 5 through 8 were computed as 2.5D solution, that means, it is taken into account that the bodies are limited in the direction perpendicular to the image plane. The Bouguer gravity anomalies were used.

In the cross-section of the gravity model A - A' along 75.5 °N, Taimyr Peninsula to New Siberian Islands (Fig. 5) the sediment layers are based on the seismic data of SEKRETOV et al. (1992). The correlation of the local gravity anomalies to the boundary between Triassic and overlying Upper Cretaceous to Cenozoic sediments, that was established during a gravity survey of the New Siberian Islands (PISKAREV et al. 1975), had been used for the model construction. The following densities were assumed in the model: Upper Cretaceous - Cenozoic 2.32-2.33 g/cm³, Mesozoic layers 2.49-2.59 g/cm³, folded Paleozoic - Triassic facies of Taimyr and New Siberian Islands 2.66-2.68 g/cm³, upper crustal series of the basement 2.76 g/cm³, basic series of the lower crust 2.91 g/cm³, mantle 3.31 g/cm³.

The thickness of the sediment layers exceeds 12 km, that of the young sediments in the Belkovsky-Sviatonossky graben 5 km. That is silimar to the sediment thickness in graben-shaped depressions studied by FUJITA et al. (1990) and ROESER & BLOCK (1994). A steep negative anomaly is found above the Belkovsky-Sviatonossky graben, west of Belkovsky Island. It relates to the density contrast between 5 km cover sediment layer (2.33 g/cm³) and carbonate Paleozoic formation (2.68 g/cm³). A similar but weaker anomaly is found near the eastern edge of the Taimyr Peninsula. Obviously, the narrow grabens, where the modern seismic activity is concentrated (AVETISOV 1996), are not compensated by elevations of deeper boundaries. Thus, isostatic equilibrium is not achieved.

Above the depressions of the central Laptev Sea, namely the Ust'-Lena and the Omoloj grabens, the negative gravity effect of 5 km of cover sediments and up to 5 km of Mesozoic layers with densities 2.49-2.59 g/cm³, is almost completely compensated, the observed Bouguer anomalies are less 10 mGal. This can only be explained by compensating uplift of the mantle surface, where the density contrast is 0.4 g/cm³. 5-8 km uplift of the Moho boundary from the regional average 30-32 km to 23-26 km can explain the absence of the negative gravity anomalies.

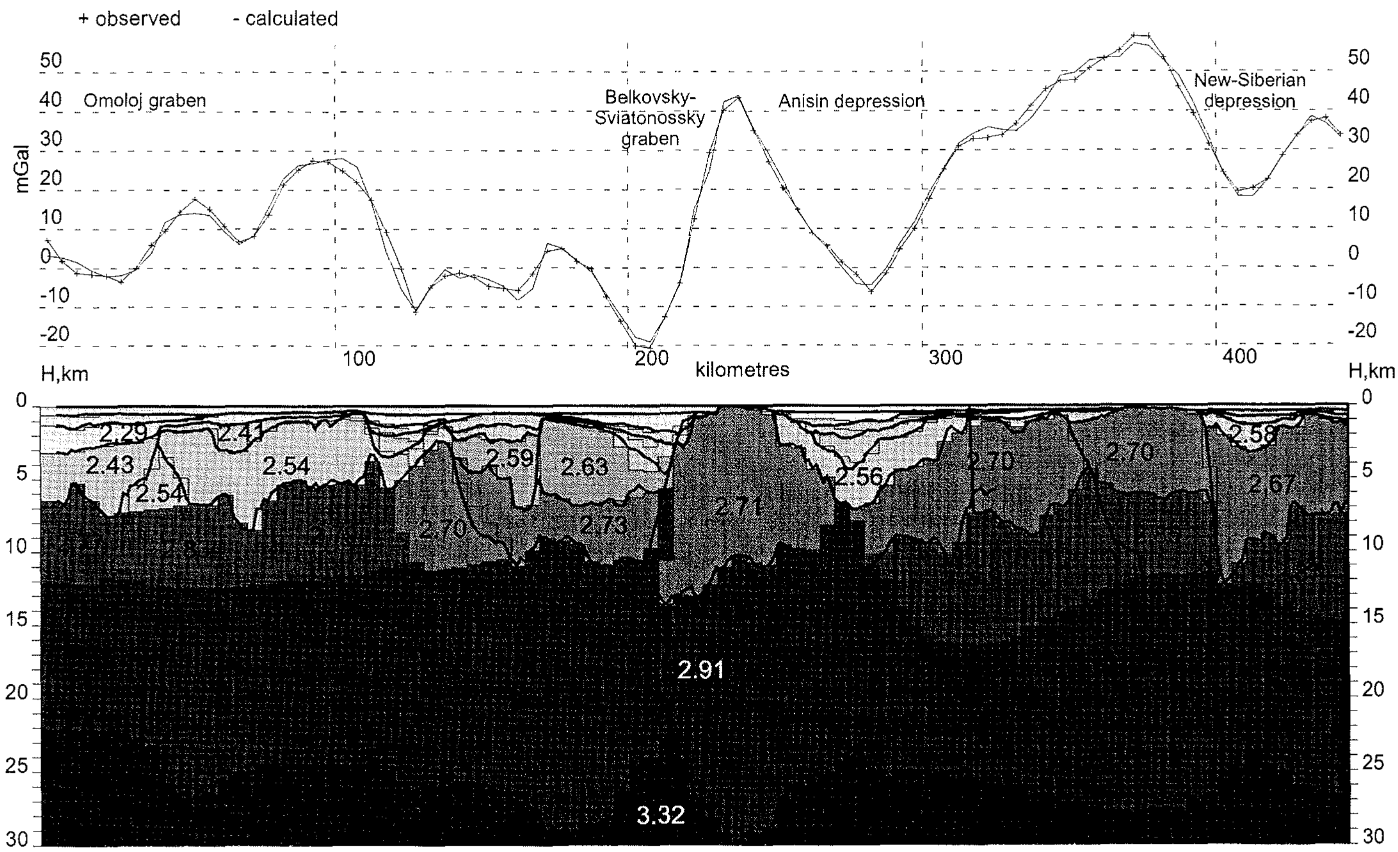

Fig. 6: Gravity model along profile B - B' (BGR94-02) in the northeastern Laptev Sea. Thick lines in the model - seismic boundaries. See Fig. 5 for legend.

According to the depths of the magnetic anomaly sources, in the eastern part of the crosssection a subhorizontal boundary divides the upper crust at 8 km depth. The lower crustal layer with density 2.91 g/cm³, which probably consists of a mixture of ultra-basic, basic, and metamorphic rocks, outcrops under the sediments in the central Laptev Sea area.

A density model B - B' along the seismic profile BGR94-02 (Fig. 6) is computed using gravity and seismic data in the eastern Laptev Sea. According to the character, the profile can be divided into several zones. Between 0-110 km (till Lazarev fault), the basement consists of basic rocks with density 2.77-2.83 g/cm³. The sources of the weak magnetic anomalies (20 nT) in this zone lie in the sediment cover with density 2.29-2.54 g/cm³. The source depths are between 1-7 km. Their magnetizations 0.1-0.2 A/m are typical for some groups of terrigenous sediments. Several sources lie in the basement at depths 8-14 km. The magnetizations of about 1 A/m are typical for crystalline basement rocks.

An isometric magnetic anomaly with an amplitude of about 90 nT near the western flank of the Omoloj graben (at 35 km) corresponds to an earthquake hypocenter (Fig. 9). It may indicate a volcanic construction (calculated density 2.54 g/cm³), because the seismically observed sharp rise of the basement is not paralleled by a positive gravity anomaly.

Between 115-210 km the basement consists of rocks of granite-diorite composition with a density of 2.70-2.73 g/cm³. The density of the thick sediment layers above the basement west of Belkovsky Island is 2.59-2.63 g/cm³ which is similar to the density of Permian-Triassic sequence in the region.

The folded basement with density 2.71-2.67 g/cm³ in the central part of the line (210-445 km) consists probably of carbonates. At 6-12 km depth it is underlain by a crustal series of basic composition with the density 2.85-2.91 g/cm³. Some magnetic anomalies indicate magmatic bodies in the folded basement. In the Anisin depression the magnetic sources lie in the lower sediment layer with density 2.56 g/cm³, which would be consistent with the density of Triassic sandstones and aleurolites in Kotelny Island.

The cross-section D - D' (Fig. 7) is based on a reflection seismic profile that was carried out by Expedition of Moscow Oceanology Institute in 1988. Down to 5 km depth, the density boundaries are selected according to the seismic data.

The southern part of the profile (0-70 km) crosses a zone of positive gravity anomalies along the southern coast of Bol'shoj Liakhovsky Island and along the northern edge of the Anuj-Liakhovsky belt. The character of the potential field anomalies and geological observations indicate that the upper crust consists of folded oceanic crust. To the north (70-230 km) the crustal basement gradually subsides to about 10 km depth. Between 230-300 km the profile transects the southern side of the New Siberian depression. The seismic section does not image the basement. The gravimetric model demonstrates

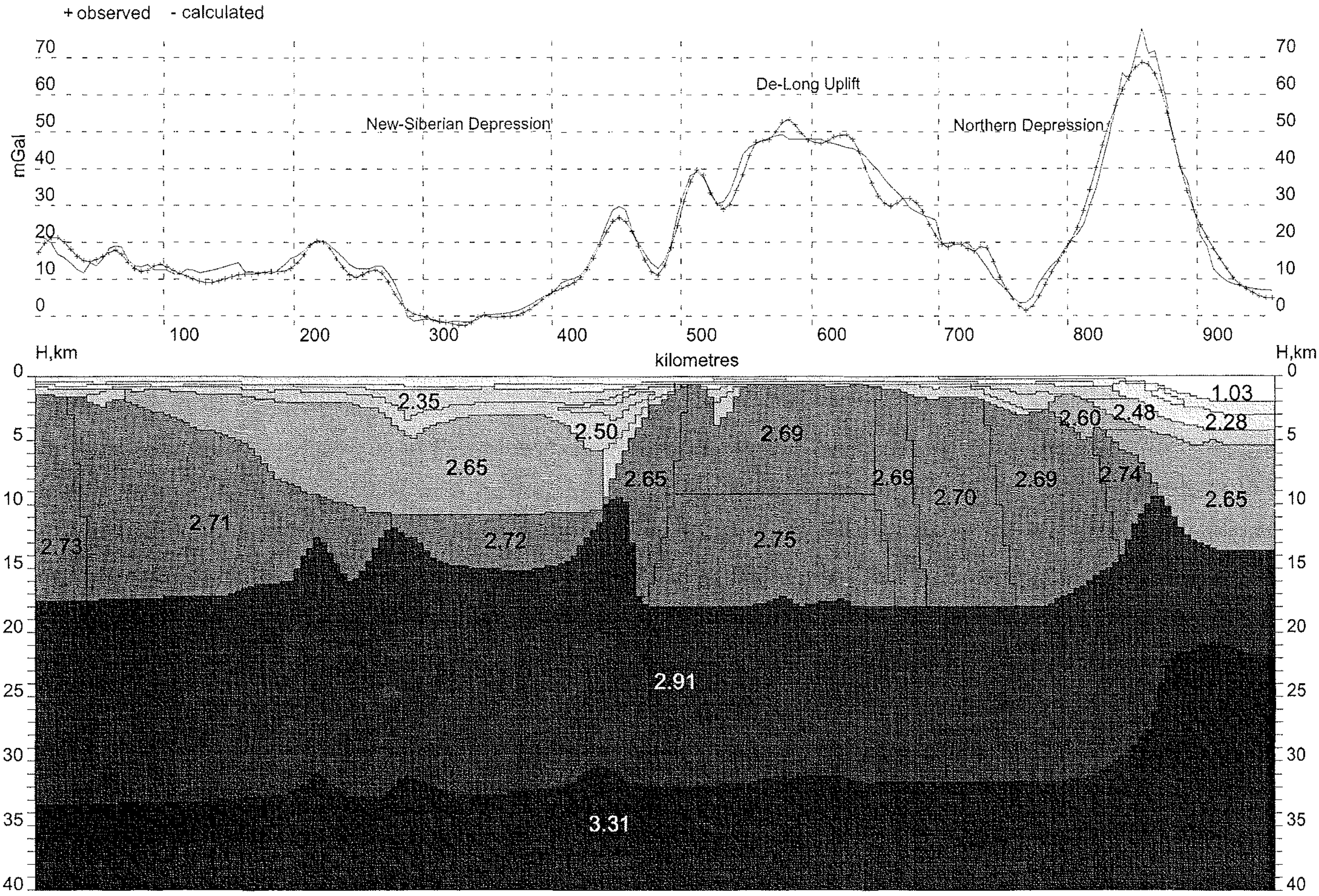

Fig. 7: Gravity model along profile D - D' in the western part of the East Siberian Sea. See Fig. 5 for legend.

uplift of the Moho and the lower crustal surfaces, which overcompensate the negative gravity effect of the increasing sediment thickness. Between 300 and 420 km the profile crosses the New Siberian depression. The supposedly folded basement with the density 2.72 g/cm³ is shown beneath the base of the sediment cover. Between 440-650 km the profile crosses the De-Long uplift. We suppose that folded basement with the density 2.69 g/cm³ reaches here down to approximately 9 km and is underlain by granitic-metamorphic upper crust (2.75 g/cm³). Between 650-740 km the profile crosses the dipping north-western part of the De-Long uplift and then the Northern depression and the continental slope.

Figure 8 provides a better understanding of the structure and the development of the Laptev Sea basin. In that order we have computed a model C - C'. It runs from the Taimyr shelf across the Nansen Basin, the Nansen-Gakkel Ridge, the Amundsen Basin, the Lomonosov Ridge, the Submariner Basin to the Mendeleev Ridge (Fig. 8). The following densities were chosen: 1.90-2.04 g/cm³ for Upper Miocene - Pliocene sediments in the Eurasia Basin, 2.38-2.40 g/cm³ for pre Upper Miocene to Cenozoic sediments, 2.75 g/cm³ as average density of the oceanic basalt layer 2 and 2.64 g/cm³ for the same layer in the central Nansen-Gakkel Ridge area.

DISCUSSION

The main results are summarized in the tectonic map of the area (Fig. 9). Several tectonic units are delimited by boundaries, which separate areas with different direction and/or amplitude-frequency characteristics of the potential fields, and which usually coincide with prominent gradient zones. Usually, these areas have uniform levels of the regional (with wavelength T >200 km) anomalies of potential fields. The second type of lines are gravity and magnetic gradient zones, which can be seen best in the maps of the intermediate class of anomalies (100< T <200 km). Examples of such type maps, derived from residual anomaly maps, are presented in Figures 2, 3 and 4. These zones represent deep faults, which root in the lower crust at 15-20 km or more.

A third type of lines, the gravity and/or magnetic gradient zones, is best revealed in the maps of local anomalies. They appear also in the residual anomaly maps (Figs. 2, 3, 4). The sources of these anomalies are in the upper crust and in the sediment cover. They show the positions and the directions of the sedimentary fold axes, the basement relief structures, and the faults in the sediment cover and upper crust.

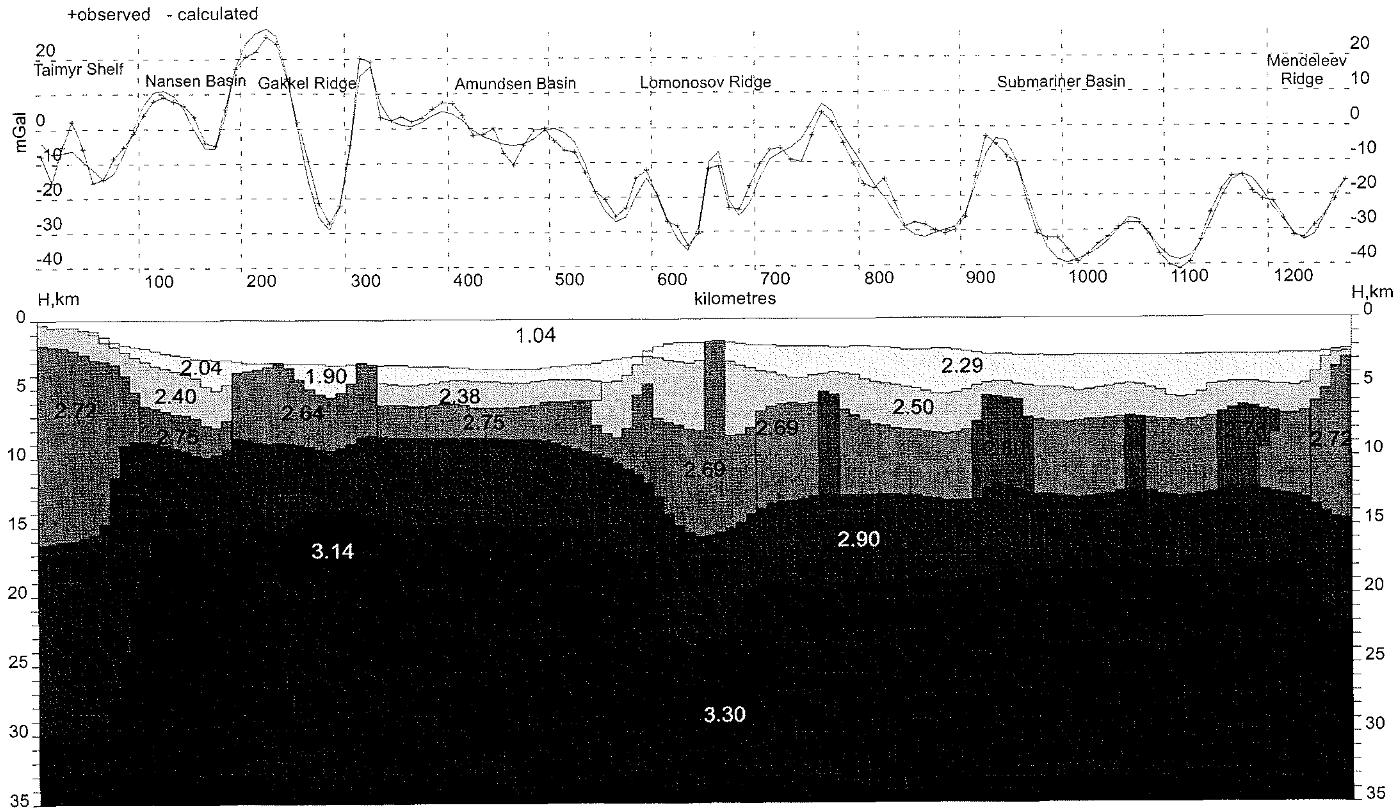

Fig. 8: Gravity model along profile C - C' in the Eurasia Basin near the Laptev shelf. The density 3.14 g/cm³ below the Gakkel Ridge corresponds to the higher temperature of the mantle at this line. See Fig. 5 for legend.

Figure 9 is a general picture of the tectonic elements of the studied area. The De-Long and the Kotelny terrains are the firstly consolidated areas in the region. In many places of the New Siberian Islands moderately folded Paleozoic carbonate sediments are exposed. In the Kotelny area the gravity anomalies are shorter than in the De-Long area, for the magnetic anomalies it is just the opposite. By analogy with well investigated regions in North Siberia we conclude that these terrains have pre-Cambrian or Caledonian crustal basement. The main sources of the observed magnetic anomalies are basic magmatic rocks (mostly basalts and dolerites) in the basement and the sediment cover, or basic metamorphic rocks within the basement. At Bennett Island on the De-Long Uplift basalts of Early Paleozoic and Late Mesozoic age are exposed. An area of the Taimyr belt in the western part of the study region became consolidated in the Paleozoic.

The folded structures of the Anuj-Liakhovsky Belt which were consolidated in the Early Cretaceous, are accompanied in the north by the Faddey zone, where the granite-dioritic basement gradually dips northward (Fig. 7). Sediments in the New Siberian depression reach a thickness of up to 12 km; the upper sediment unit (K_2-Q?) is up to 7 km thick. The greatest thicknesses are observed in two parallel grabens which accompany the boundaries of the New Siberian depression to the Kotelny and De-Long terrains (ROESER & BLOCK 1994).

The South Laptev zone and the Shelon belt in prolongation of the Verkhojansk fold belt were consolidated in the Early Cretaceous (120 Ma). The Shelon belt and the South Laptev zone show unusually weak magnetic anomalies. Their pattern reflects Cenozoic fault structures in the sediment cover. The basement is not magnetized. Density modeling (Fig. 7) indicates a basic composition of the deep lying basement. Furthermore, there is no doubt that many magmatic bodies were emplaced in the basement in an epoch of tectonic and magmatic activity, which produced a mantle uplift under the Omoloj and the Ust'-Lena grabens. The most probable cause for the low magnetization of the basement may be that the ferrimagnetic minerals in the gabbros, dolerites and basalts of this layer have a low Curie point (200 °C is not unusual for Cenozoic basalts), or very low concentration (this is usual for the basement of the Verkhojansk fold belt).

The Khatanga-Lomonosov zone separates the Laptev shelf from the oceanic Eurasia Basin. This zone lies in the prolongation of a Triassic rift, which is revealed by geophysical surveys in the basement of the Khatanga depression (GUSEV 1976). The whole zone shows seismic activity only in two places. The first consists of several epicenters at the continuation of the Ust'-Lena graben; the second is a line of epicenters between the projection of the Nansen-Gakkel Ridge to the shelf and the Belkovsky-Sviatonossky graben. The Khatanga-Lomonosov zone may be considered as a developing transform fault, that connected the Nansen-Gakkel Ridge axis with its continuation as a rift zone at a different place (the Northwind Basin?, GRANTZ 1993).

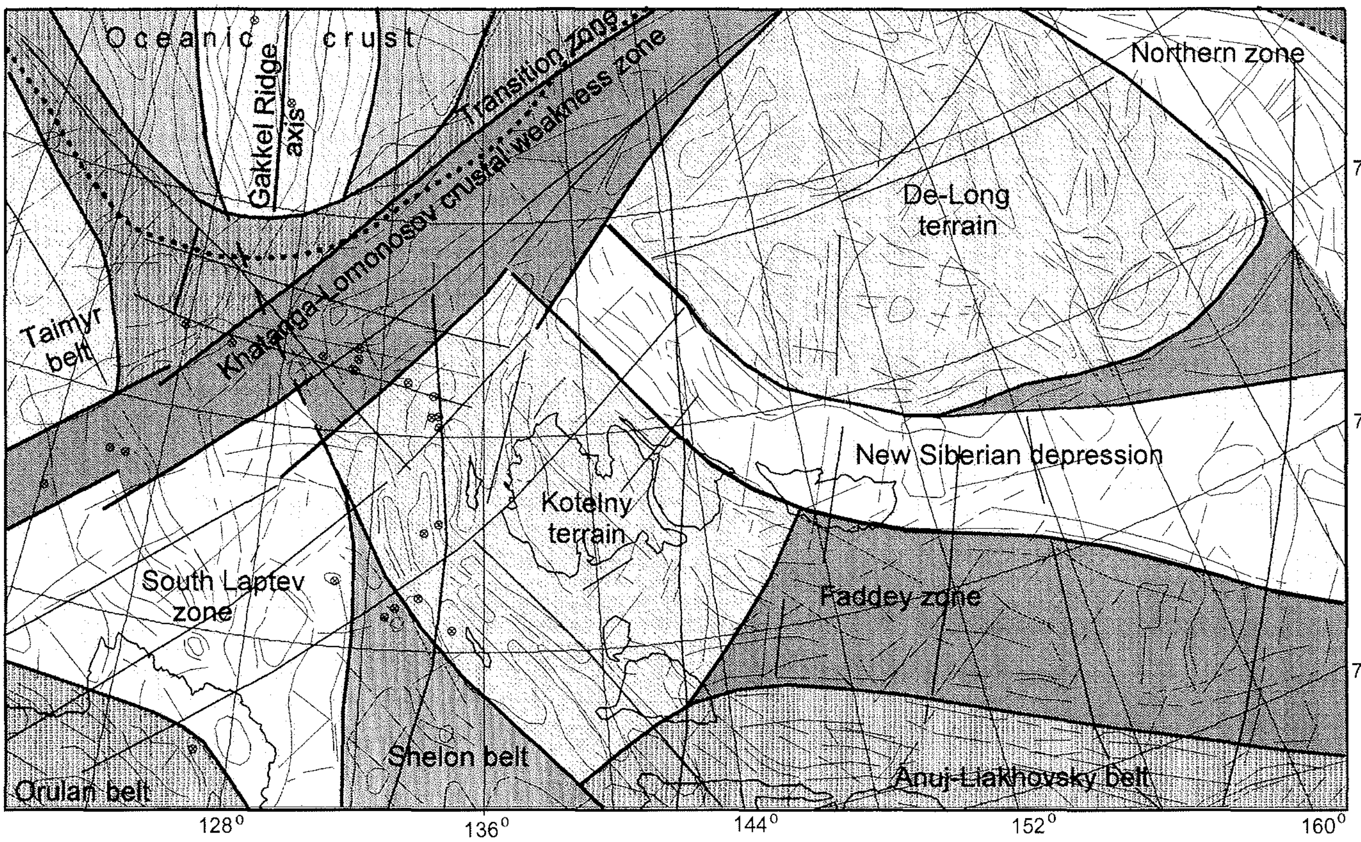

Fig. 9: Tectonic features of the eastern Laptev Sea - western East Siberian Sea region, according to potential field interpretation.

CONCLUSIONS

A detailed analysis of the potential field data allowed to derive information on the tectonic structure and the composition of the crust and the sediment cover in the Laptev Sea area. The main result is a tectonic subdivision of the eastern Laptev Sea - western East Siberian Sea, which delineates the boundaries of the tectonic units, the main fault zones, the axes and the gradients of anomalies.

The anomaly pattern indicates that since the Paleocene seafloor spreading was active in the Eurasia Basin. The Khatanga-Lomonosov zone worked as transform fault zone. Rifting but not spreading may have affected the Laptev Sea.

References

Avetisov, G.P. (1993): Geodynamics of the seismoactive zones of the Arctic region (Geodinamica seismoaktivnykh zon Arkticheskogo regiona).- Soviet Geology 10: 52-62. (in Russian).

Avetisov, G.P. (1996): The seismoactive zones of Arctic (Seismoaktivnye zony Arktiki).- SPb.: VNIIOkeangeologia, 183 pp. (in Russian).

Fujita, K., Cambray, F.W. & Velbel, M.A. (1990): Tectonics of the Laptev Sea and Moma rift system, northeastern USSR.- Marine Geology 93: 96-118.

Gramberg, I.S. & Pogrebitsky, Ju.E. (eds.) (1989): Geological construction of USSR and regularities in the deposits distribution. Soviet Arctic Seas (Geologicheskoje stroenie SSSR i zakonomernosti razmeschenija poleznykh iskopaemykh. Moria Sovetskoj Arktiki).- L.: Nedra 9: 290 pp. (in Russian)

Grachev, A.F. (1973): Moma continental rift (Momskij kontinental'nyj rift).- Geophysical Methods of Survey in Arctic L., NIIGA 8: 56-75. (in Russian)

Gramberg, I.S., Kos'ko, M.K. & Pogrebitskij, Ju. E. (1986): Tectonic evolution of the Siberian Arctic shelves in Proterozoic-Mesozoic time (Tektonicheskaja evolutsija arkticheskikh shelfov Sibiri v rifee – mezozoe).- Soviet Geology 8: 60-72. (in Russian)

Gramberg, I.S., Demenitskaja, R.M. & Sekretov, S.B. (1990): System of riftogenic grabens of the Laptev Sea shelf as a missing link of the Gakkel Ridge - Moma rift belt (Sistema riftogennykh grabenov shelfa moria Laptevykh kak nedostajuschego zvena riftovogo pojasa khrebta Gakkel'a - Momskogo rifta).- DAN RAN 311(3): 689-694. (in Russian).

Grantz, A. & Parnes, P.W. (1992): Arctic Summer West Scientific Party (1993): Cruise to the Chukchi Borderland, Arctic Ocean.- EOS 74: 249-254.

Gusev, B.V. (1976): The structures of the oceanic crust spreading in the basement of the West Siberia plate (Struktury razrastanija okeanicheskoj kory v fundamente Zapadno-Sibirskoj plity).- Geophysical Methods of Survey in Arctic L., NIIGA 10: 9-13. (in Russian).

Hinz, K., Block, M., Delisle, G., Franke, D., Kos'ko, M., Neben, S., Reichert, C., Roeser, H.A. & Drachev, S. (1998): Deformation of continental lithosphere on the Laptev Sea shelf, Russian Arctic.- III International Conference on Arctic Margins, Celle, Abstracts: 85.

Johnson, G.L., Pogrebitsky, Ju. & Macnab, R. (1994): Arctic structural evolution. Relationship to paleoceanography.- The Polar Oceans and Their Role in Shaping the Global Environment, 255-294.

Karasik, A.M. (1968): Magnetic anomalies of the Gakkel Ridge and origin of the Eurasian Basin of the Arctic ocean (Magnitnye anomalii khrebta Gakkel'a i proiskhozhdenie Evrazijskogo subbassejna Severnogo Ledovitogo okeana).- Geophysical Methods of Survey in Arctic. L., NIIGA 5: 8-19. (in Russian)

Karasik, A.M. (1980): The main peculiarities of development and structure of the Arctic Basin according to aeromagnetic data (Osnovnye osobennosti istorii razvitija i strukturi dna Arkticheskogo bassejna po aeromagnitnym dannym).- Marine Geology, Sedimentology, Sediment Petrology and Ocean Geology. L., Nedra, 178-193. (in Russian)

Natapov, L.M. (1988): The history of the accretion structure of the north-eastern frame of the Siberian continent (Istorija akkretsionnoj struktury severo-vostochnogo obramlenija Sibirskogo kontinenta).- Geology of the Seas and Oceans.- Papers of the soviet geologists at the XXVIII Session Int. Geol. Congress. L., Sevmorgeologia, 172-187. (in Russian)

Pecherskij, D.M. (ed.) (1994): Petromagnetic model of the lithosphere (Petromagnitnaja model litosfery).- Kiev: Naukova dumka, 175 p. (in Russian)

Piskarev, A.L. (1977): On the Structure of the Eastern Siberian Shelf Basement (O stroenii fundamenta Vostochno-Sibirskogo shelfa).- Tectonics of Arctic L., 86-97. (in Russian)

Piskarev, A.L., Avetisov, G.P., Genin, B.L. & Larin, S.M. (1975): Bunge Land structure and its junction with Kotelny and Faddeevsky Islands (Struktura Zemli Bunge i zon sochlenenija ee s ostrovami Kotel'nyj i Faddeevskij).- Geophysical Methods of Survey in Arctic L., 10: 35-40. (in Russian)

Piskarev, A.L., Manukhova, A.V. & Tchernychev. M.Ju. (1997): Geodynamic system of the Laptev Sea according to analysis of gravity and magnetic anomalies (Geodinamicheskaja sistema moria Laptevych po dannym analiza gravitatsionnykh I magnitnykh anomalij).- DAN RAN 354: 230-233. (in Russian)

Piskarev, A.L. & Pavlenkin, A.D. (1985): Appreciation of magnetization alteration in the deep crust conditions according to joint interpretation of magnetic and seismic data (Otsenka izmenenija namagnichennosti gornikh porod v glubinnykh uslovijakh na osnove komplexnoj interpretatsii dannykh magnitorazvedki i seismorazvedki).- DAN USSR 282: 41-44. (in Russian)

Roeser, H.A. & Block, M. (1994): Seegeophysikalische Untersuchungen der BGR in der russischen Arktis.- Nachrichten Dt. Geolog. Ges. 51, 103-107.

Roeser, H.A., Hinz, K., Piskarev, A.L. & Neben, S. (1998): Seafloor spreading at the transition from the Eurasia basin to the Laptev shelf.- III International Conference on Arctic Margins, Celle, Abstracts: 155.

Savostin, L.A. & Drachev, S.S. (1988): Cenozoic compression in the New Siberian Islands region and its link with the Eurasian Basin opening (Kajnozoiskoe szhatie v rajone Novosibirskikh ostrovov i ego sviaz' s raskrytiem Evrazijskogo subbassejna).- Oceanology 28: 775-782. (in Russian)

Sekretov, S.B. (1998): Eurasian Basin - Laptev Sea geodynamic system: tectonic and structural evolution.- III International Conference on Arctic Margins, Celle, Abstracts: 166-167.

Taylor, P.T., Kovacs, L.C., Vogt, P.R. & Johnson, G.L. (1981): Detailed aeromagnetic investigation of the Arctic Basin, 2.- J. Geophys. Res. 86: 6323-6333.

Verba, V.V., Volk, V.E., Kiselev, Yu.G. & Kraev, A.G. (1986): Deep crust construction of the Arctic ocean according to geophysical data (Glubinnoe stroenie Severnogo Ledovitogo okeana po geofizicheskim dannym).- Structure and stages of development in the Arctic ocean. L., Sevmorgeologia, 54-71. (in Russian)

Verba, V.V., Kim, B.I. & Volk, V.E. (1998): Construction of the crust of the Arctic region according to geophysical data (Stroenie zemnoj kory Arkticheskogo regiona po geofizicheskim dannym).- Geological and geophysical characteristics of lithosphere in the Arctic region. SPb., VNIIOkeangeologia 2: 12-28. (in Russian)

Vinogradov, V.A., Gaponenko, G.I., Rusakov, I.M. & Shimaraev, V.N. (1974): Tectonics of the Eastern Arctic shelf of the USSR (Tektonika Vostochno-Arkticheskogo shelfa SSSR).- NIIGA Trans., L., Nedra, 114 p. (in Russian)

Vogt, P.R., Taylor, P.T., Kovacs, L.C. & Johnson, G.L. (1979): Detailed aeromagnetic investigation of the Arctic Basin.- J. Geophys. Res. 84: 1071-1089.