Polarforschung 68: 41 - 50, 1998 (erschienen 2000)

Laptev Sea Rifted Continental Margin: Modern Knowledge and Unsolved Questions

By Sergei S. Drachev[1]

THEME 3: Plate Boundary Problems in the Laptev Sea Area

Summary: The Laptev Sea is one of a few unique places where an active oceanic spreading axis approaches a continental edge causing specific structural style dominated by extensive rift structures. In such a place one can study the geodynamics of the initial breakup of the continents that was playing an important role in creating the past and present-day oceans. The modern understanding of the Laptev continental margin geology resulted from multichannel seismic (MCS) surveys carried out since 1986 by Russian and German research institutions as well as from seismological observations and satellite marine gravity data. These investigations led to outlining an earlier predicted extensive rift system formed at visible continuation of the Gakkel Ridge. However, despite the obvious achievements some very important questions concerning the geology of this region still remain to be answered. These are related to the structure of the basement of the shelf, geometry of the rift system, seismic stratigraphy and age of the rift sedimentary infill, paleogeodynamics and modern geodynamics of the plate boundary in the Laptev Sea.

INTRODUCTION

The Laptev Sea lies in the Russian Arctic between Taimyr Peninsula and New Siberian Islands (Fig. 1). It is one of a few unique places on the Earth where an active oceanic spreading axis approaches a continental edge causing a specific structural style dominated by an extensive rift structure. In such a place one can study the process of an initial breakup of continents that was playing an important role in creating the past and modern oceans.

For a long time the Laptev continental margin (LCM) was an enigmatic area of continental margin/spreading ridge interaction. Prior to the 60s knowledge of its geology was mainly based on geological surveys of the coastal areas and New Siberian Islands. The tectonic concepts of that period represent the extrapolation of the continental structures onto the shelf. First offshore geophysical studies were begun by the Research Institute of the Arctic Geology (NIIGA) in 1955 with an aeromagnetic survey at 1 : 5 000 000 scale. At the beginning of the 60s they were followed by gravity field studies and in 1963-1969 by aeromagnetic surveys, both at a scale of 1 : 2 000 000. Further, in the period 1973-1988, more detailed potential studies were carried out. They included a gravity survey of 1 : 1 000 000 scale of the whole shelf and an aeromagnetic survey of 1 : 200 000 scale for some parts of the area.

Seismic investigations were initiated in early 70s with using the emergence angles of seismic waves from earthquakes and near-receiver P to S conversions (AVETISOV 1983). In 1973 the first refraction and deep seismic sounding test experiment was carried out in the southern Laptev Sea. These works were continued in 1979 with joint reflection and refraction studies along a line in the western part of the shelf. Subsequently, in 1985-1986, refraction experiments were conducted annually by the Polar Geological Expedition of State Enterprise "SEVMORGEO".

Shipboard multichannel reflection studies were begun by Marine Arctic Geologic Expedition (MAGE), Murmansk, in 1984 in the area of Khatanga Bay. In 1986 they were extended eastward and the first grid of regional profiles was surveyed in the central and eastern Laptev Shelf. In the following years LCM was investigated by several Russian and German institutions: the Moscow Laboratory of Regional Geodynamics (LARGE) and Sevmorneftegeofisika (SMNG), Murmansk, in 1989, MAGE in 1987, 1988 and 1990, the German Federal Institute for Geosciences and Natural Resources (BGR), Hannover, in cooperation with SMNG in 1993, 1994 and 1997 and in the frame of the Russian-German cooperative program "Laptev Sea 2000" by the Alfred Wegener Institute for Polar and Marine Research (AWI) in 1998. Today the total length of MCS lines amounts to about 25 000 km. Figure 1 summarises almost all offshore MCS lines carried out since 1986. These studies allowed the delineation of an earlier predicted (GRACHEV et al. 1970, PATYK-KARA & GRISHIN 1972) rift system and the seismic stratigraphic features of rift sedimentary infill (IVANOVA et al. 1990, DRACHEV et al. 1995b, 1998, RÖSER et al. 1995, HINZ et al. 1998). Although, an obvious breakthrough in understanding of the LCM geology was achieved owing to MCS surveys, some very important questions still remain to be answered. This paper is an attempt to highlight such unsolved questions and to point out what can be done in the future toward a better understanding of this unique tectonic fabric.

STRUCTURE OF THE BASEMENT

The Laptev continental margin occupies an area where the East Siberian Craton, the Early Mesozoic Taimyr Fold Belt, and the Late Mesozoic New Siberian-Chukchi and Verkhoyansk fold belts come together. These structural elements are well-studied onshore and many facts suggest that they continue offshore

[1] Sergei S. Drachev. P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, 36 Nakhimovski Av., 117851, Moscow, Russia.

Manuscript received 19 January, accepted 25 October 1999

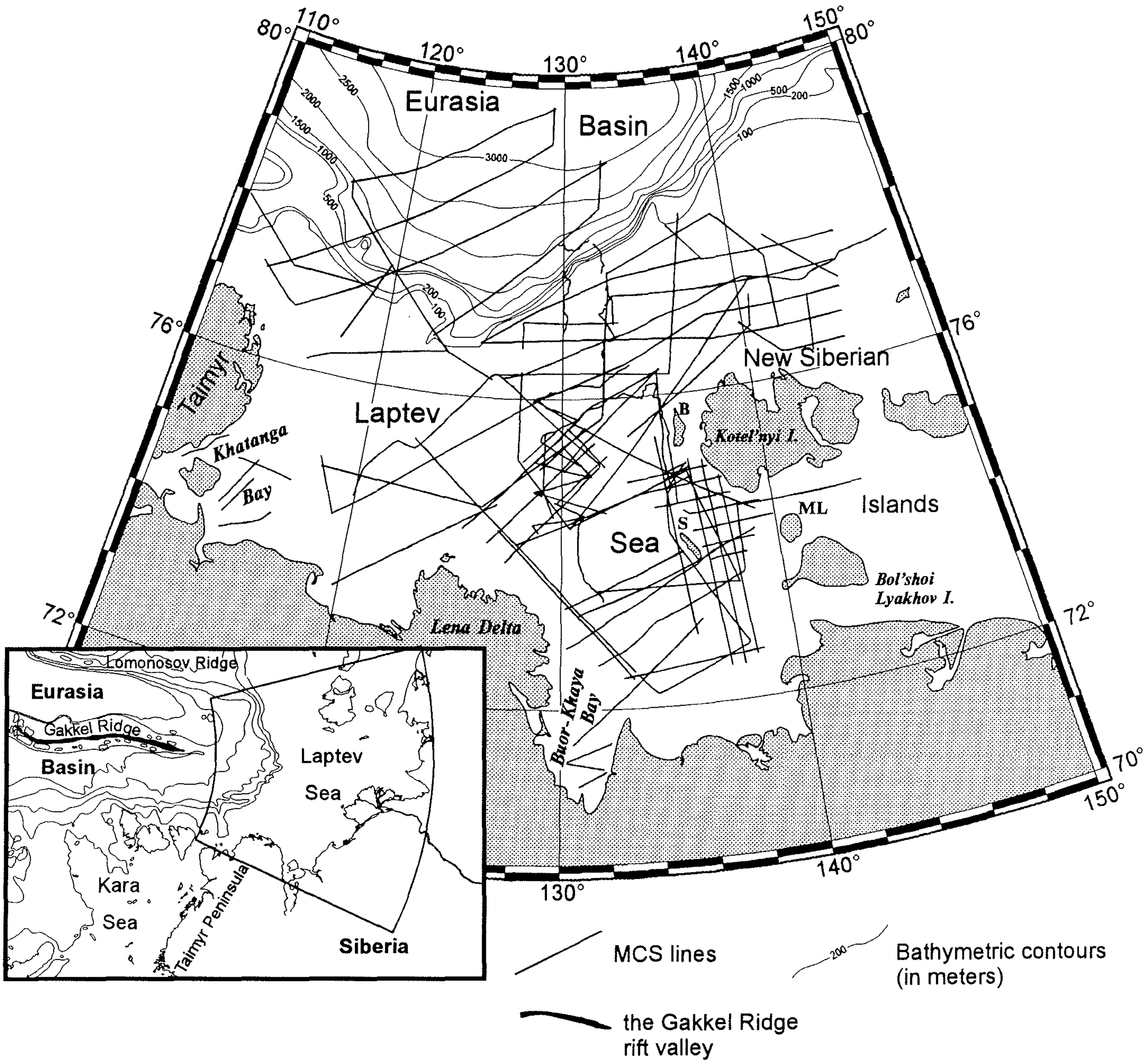

Fig. 1: Index map of the Laptev Sea continental margin showing location of the multichannel seismic reflection profiles. Polar stereographic projection. The small-scale insertion shows the location of the studied area. B = Bel'kov Island, S = Stolbovoi Island, ML = Malyi Lyakhov Island

forming the basement of the shelf sedimentary basins. But their exact limits within the shelf are not detected and there exist as many points of view as there are investigators.

In the earliest publications LCM as well as the whole continental margin of the North-East Asia was suggested to be underlain by East Siberian and Hyperborean cratons slightly separated by a miogeosynclinal fold belt (Ermolaev 1933, Arkhangel'skii & Shatski 1933, Atlasov et al. 1964, etc.). The most extreme expression of this idea was given by Obruchev (1934), Litinskii (1967) and Muratov (1981) who believed the entire East Arctic continental margin and adjacent continental areas to be occupied by an ancient platform.

An opposite point of view was proposed by Kropotkin & Shatalov (1936), Saks et al. (1955), Mokshantsev et al. (1964), Pol'kin & Gaponenko (1967), Egiazarov (1969), etc. These authors considered the structure of the Arctic continental margin of North-East Asia to be mainly composed of Mesozoic fold belts. It was suggested that several solid, intermediately folded massifs were located inside the fold belts and these latter themselves were bounded on the south-west and north by East Siberian and Hyperborean cratons respectively. This concept was completely presented by Vinogradov and co-workers who summarized the results of geophysical studies conducted by NIIGA (Vinogradov et al. 1974, 1977, Vinogradov 1984). According to these publications, the major part of the shelf represents a continuation of the East Siberian Craton and has a platformal structural style. This offshore cratonic province, usually called the Laptev block (massif) is suggested to be separated from East Siberian Craton by the Olenek Fold Zone. The latter is presumed to coincide with an inverted Riphean or Late Paleozoic aulacogen. In the east the Laptev Block is surrounded by a region of Late Mesozoic folding, and both these provinces become complicated by several grabens which developed during the Cenozoic. Comparing offshore seismic refraction horizons with unconformities known within the sedimentary cover of the craton, VINOGRADOV (1984) describes the shelf as consisting of three main sedimentary megasequences overlying an Archean to Lower Proterozoic crystalline basement: Riphean to Middle Paleozoic, Upper Paleozoic to Lower Cretaceous, and Upper Cretaceous to Quaternary. The total thickness of the sedimentary cover of the shelf was postulated to vary from about 8 km within the most subsided, southwestern part (South Laptev Basin), to 0.1-0.2 km on the uplifted blocks.

Vinogradov's concept was further developed by MAGE's geophysicists who accepted it as a basis for interpretation of the offshore MCS data (IVANOVA et al. 1990, ALEKSEEV et al. 1992). These authors postulated the Laptev paraplatformal block to underline the whole western part of the shelf (Fig. 2).

However, the presence of a large undeformed cratonic block within the LCM is poorly supported by the geological data. These show that the shoreline of the Laptev Sea is approached by several fold belts at different angles which appear to extend offshore, surrounding the northeastern edge of the East Siberian Craton and joining each other within shelf. The formation of this

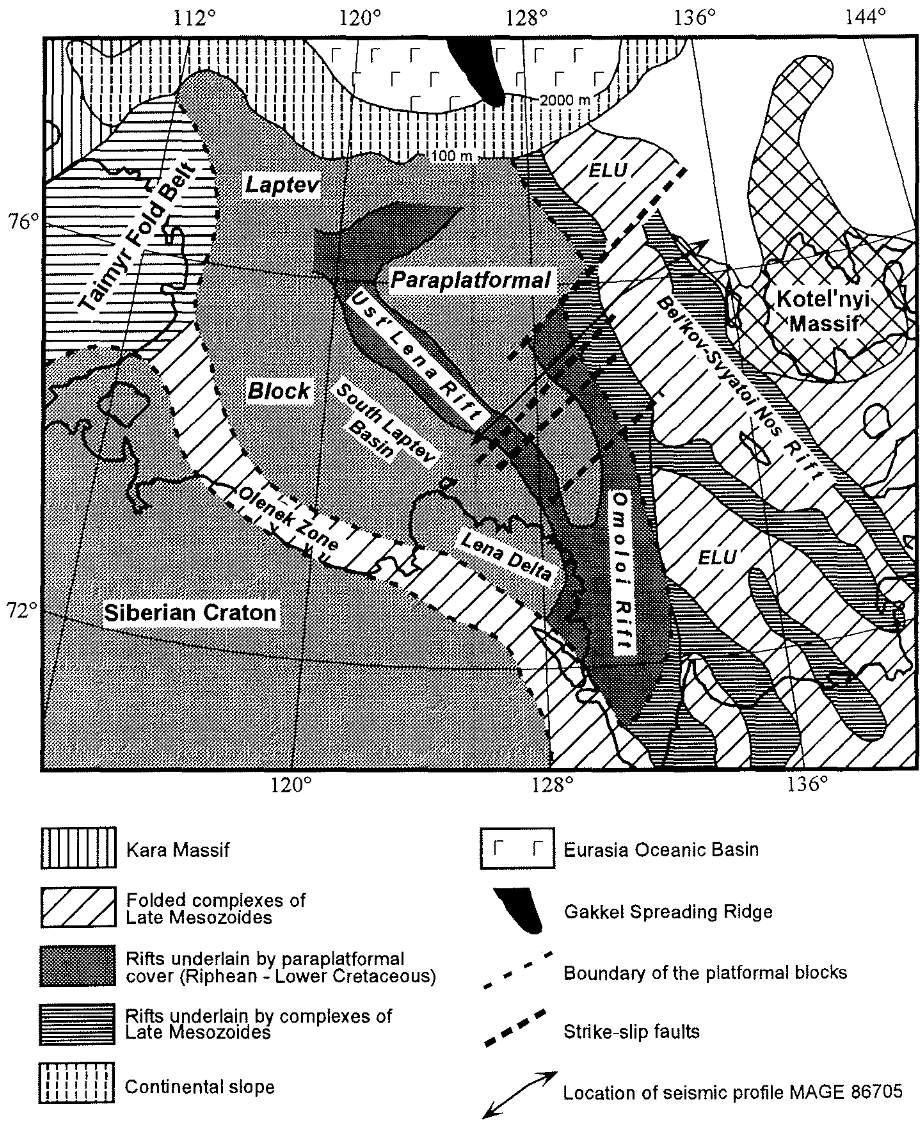

Fig. 2: Tectonic zonation of the Laptev Shelf (simplified from ALEKSEEV et al. 1992). ELU denotes the East Laptev Uplift.

junction is related to accretion of several tectonostratigraphic terranes to the paleo-Siberian continental margin and was completed in Mid-Cretaceous with extensive compression of the South Taimyr, Verkhoyansk and New Siberian-Chukchi fold belts (SAVOSTIN et al. 1984b; PARFENOV 1991, ZONENSHAIN et al. 1990, FUJITA et al. 1997). This fact allows to assume that the basement of LCM is affected by Late Mesozoic folding and has a folded structure rather than a platformal one. Even if there are some solid blocks in structure of LCM, they would form part of the basement affected by folding and therefore would not contain a pre-Late Cretaceous undeformed cover.

STRUCTURE OF THE RIFT SYSTEM

Although the rift structure of the LCM was inferred in early 70s (GRACHEV et al. 1970, PATYK-KARA & GRISHIN 1972), the first reliable structural scheme was published by VINOGRADOV (1984) mainly on the base of potential field studies. He delineated a horst-and-graben structure of the shelf basement and outlined several extensional basins: the South Laptev and Anisin basins, Ust' Lena and Bel'kov troughs.

The present-day MCS data show the structure of the LCM as consisting of several asymmetric rifts and high-standing normal faulted blocks (IVANOVA et al. 1990, DRACHEV et al. 1995b, 1998; HINZ et al. 1998). However, despite the considerable amount of MCS surveys, the structure of the rift system is not completely deciphered yet. The seismic profiles are mainly located in the central and eastern LCM (Fig. 1) whereas its northern and southwestern parts are less studied. There is no general agreement among the researchers regarding either presence and geometry of one structural element or another, or structural style and mechanism of formation of the rift system as a whole.

The Ust' Lena Rift, East Laptev and Stolbovoi horsts, and Bel'kov-Svyatoi and Anisin rifts are the most pronounced among the structural elements of the rift system (Fig. 3). The existence of the Omoloi Rift and South Laptev rift basin was subjected to doubt (DRACHEV et al. 1998; HINZ et al. this volume). The former was proposed by KIM (1986), IVANOVA et al. (1990) and SEKRETOV (1998) as a principal north-south trending axial graben which coincides with a fractured boundary between the New Siberian-Chukchi Fold Belt and the Laptev Block (Fig. 2, 4A). Subsequently, it was speculated that the Omoloi Rift is a direct continuation of the Gakkel Ridge spreading zone onto LCM. However as shown, for example, by MCS line MAGE 86705, the area of the inferred Omoloi Rift represents a transitional zone of crustal partitioning between the Laptev Horst and Ust' Lena Rift (Fig. 4). Even if this rift had existed it would hardly have been a shelf continuation of the spreading axis as proposed by KIM (1993) and IVANOV et al. (1994). The Gakkel Ridge had to migrate eastward with respect to the Laptev Shelf with a half rate of the spreading, and obviously reached its present-day position somewhere in the Late Miocene phase of extension. This, in turn, requires a transform faulting between southern termination of the Gakkel Ridge and the Laptev Shelf. Existence of such a fracture was first inferred by GALABALA

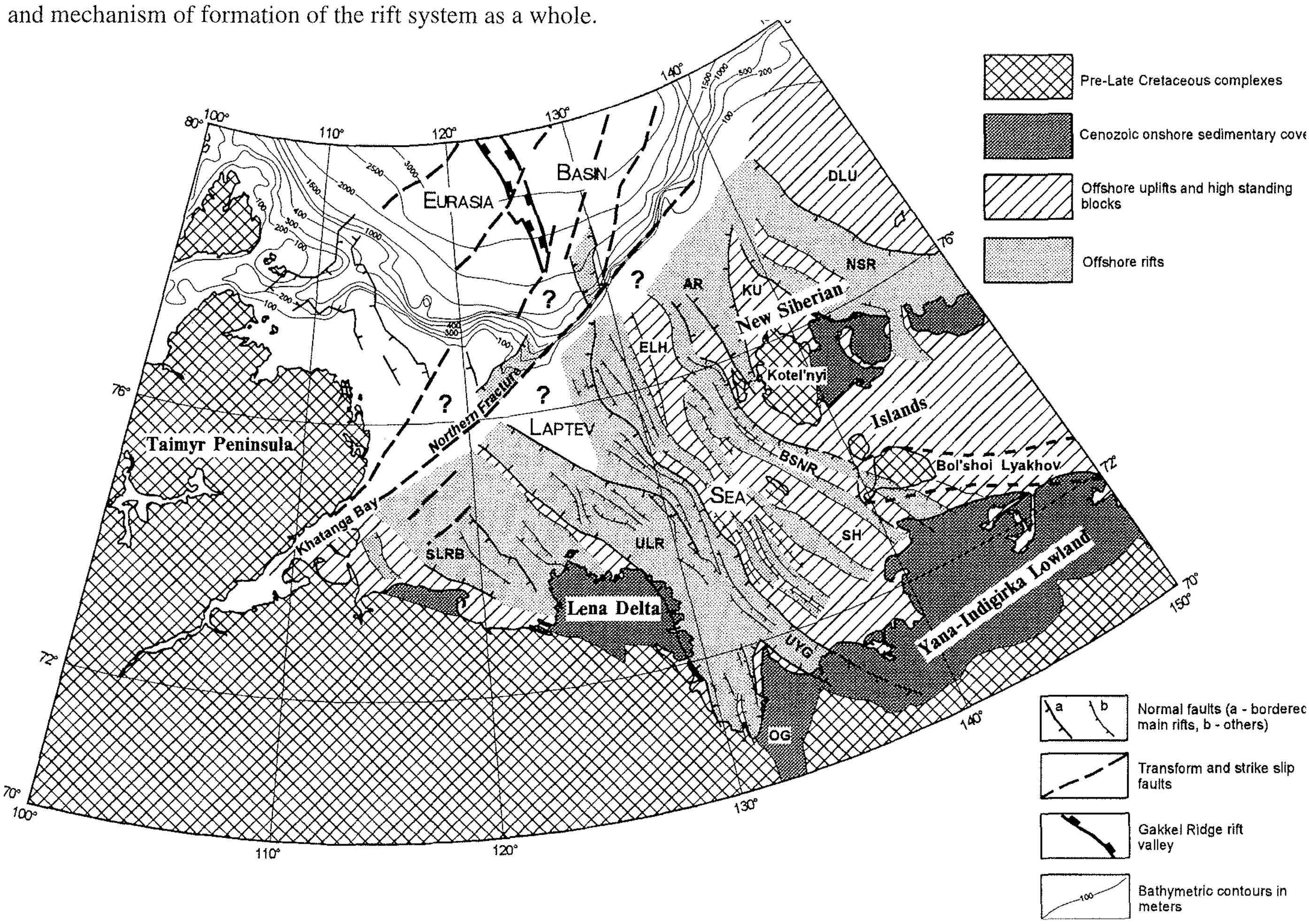

Fig. 3: Main structural elements of the Laptev Shelf (after DRACHEV et al. 1998). Polar stereographic projection. Capital letters denote: SLRB = South Laptev Rift Basin, ULR = Ust' Lena Rift, UYG = Ust' Yana Graben, OG = Omoloi Graben, ELH = East Laptev Horst, AR = Anisin Rift, BSNR = Bel'kov-Svyatoi Nos Rift, SH = Stolbovoi Horst, KU = Kotel'nyi Uplift, NSR = New Siberian Rift, DLU = De Long Uplift.

(1983) and then by VINOGRADOV et al. (1974), FUJITA et al. (1990a) and DRACHEV et al. (1998) who described it as Khatanga fault zone, Severnyi Graben, Severnyi Transfer and Northern Fracture (Fig. 3) respectively. This fault could have acted as a transform fault during opening of the Eurasia Basin and be responsible for displacement of the Lomonosov Ridge with respect to the Laptev Shelf. This fault is well-expressed in the potential fields, however, up to date no evidences in favor of it were detected by MCS data.

The BGR 1997 survey also did not reveal the Omoloi Rift. According to its results, the area westward of the East Laptev Horst is occupied by the very broad Ust' Lena Rift which reaches about 300 km in width and extends for more than 500 km from north to south. This rift encompasses the area of the formerly postulated South Laptev rift basin which is not distinguished as an individual structure on the BGR profiles. After careful analysis of published Russian data FUJITA et al. (1990a) inferred the structure of the Laptev Shelf to be consistent with an asymmetric, simple shear, extensional system. In many cases the BGR profiles demonstrate the deeply penetrating listric normal faults which may act as the main detachments at the base of the rift system. The major west dipping detachments reaching down to Moho are the M/V Academik Lazarev and IB Kapitan Dranitsin faults in the eastern sides the Ust' Lena and Anisin rifts respectively. By opinion of HINZ et al. (1988), the simple shear mechanism is a dominant extension process responsible for the origin of the LRS. However the existing data are not sufficient to follow the details of the crust deformation of the LCM.

SEISMIC STRATIGRAPHY OF THE SEDIMENTARY COVER

The dating of the seismic stratigraphic units is the most controversial point of the LCM geology. The absence of deep offshore wells causes much uncertainty about the nature and age of the seismic markers and there is no unified seismic stratigraphic scheme of the LCM. Two main concepts were proposed.

Basing on Vinogradov's tectonic concept IVANOVA et al. (1990) admits the presence of a paraplatformal sedimentary cover composed of Riphean to Lower Cretaceous successions in the Laptev Sea. According to this point of view, the Late Cretaceous to Cenozoic sediments rest on the Late Mesozoic folded

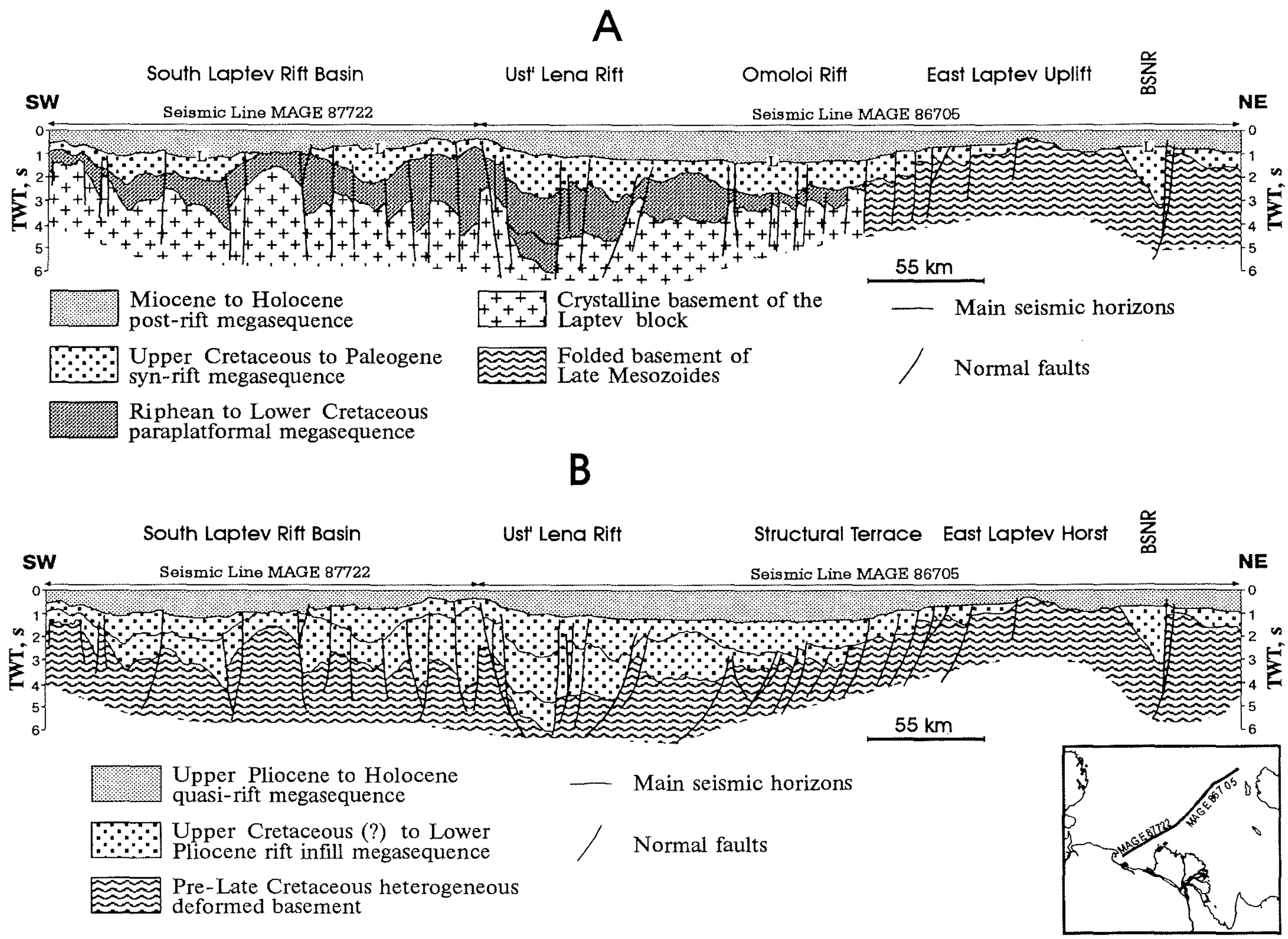

Fig. 4: Two versions of geological interpretation of MAGE 86705 and MAGE 87722 MCS lines according to (A) IVANOVA's et al. (1990) and (B) DRACHEV's et al. (1998) tectonic and seismic stratigraphic concepts. The vertical scale is in seconds TWT (Two Way Travel Time). BSNR denotes Bel'kov-Svyatoi Nos Rift.

basement in the eastern part of LCM only. The abrupt increase of the sedimentary thickness within the axial part of the Omoloi Rift, Ust' Lena Rift and South Laptev Basin are considered to result from the appearance of older successions ranging from the Riphean to Early Cretaceous in age (Fig. 4A). The Riphean to Mesozoic complexes are believed to build up a quasi-platformal sedimentary cover of the Laptev Block.

A different seismic stratigraphic approach is developed by DRACHEV et al. (1998) and HINZ et al. (1998). According to these authors, the whole LCM was affected by Late Mesozoic folding, and strongly eroded and peneplained prior to onset of the rifting at the end of the Late Cretaceous/beginning of the Paleocene. Thus, the complexes of pre-Late Cretaceous age form the substratum which appears in MCS records as acoustic basement. in adjacent onshore areas and New Siberian Islands and by correlating regional seismic horizons to the major plate tectonic and paleogeographic reorganizations. Comparison of the proposed seismic stratigraphic schemes is given in Fig. 5.

PALEOGEODYNAMICS

There is no doubt that the LCM has been affected by the opening of the Eurasia Basin. The spreading began at 56-58 Ma with a rate about 2.2 cm/yr. and continues today but with a very low rate of about 0.13 cm/yr. In spite of such a long period of extension, the LCM is underlain by a continental crust that is strongly thinned, but did not loose its continuity within the

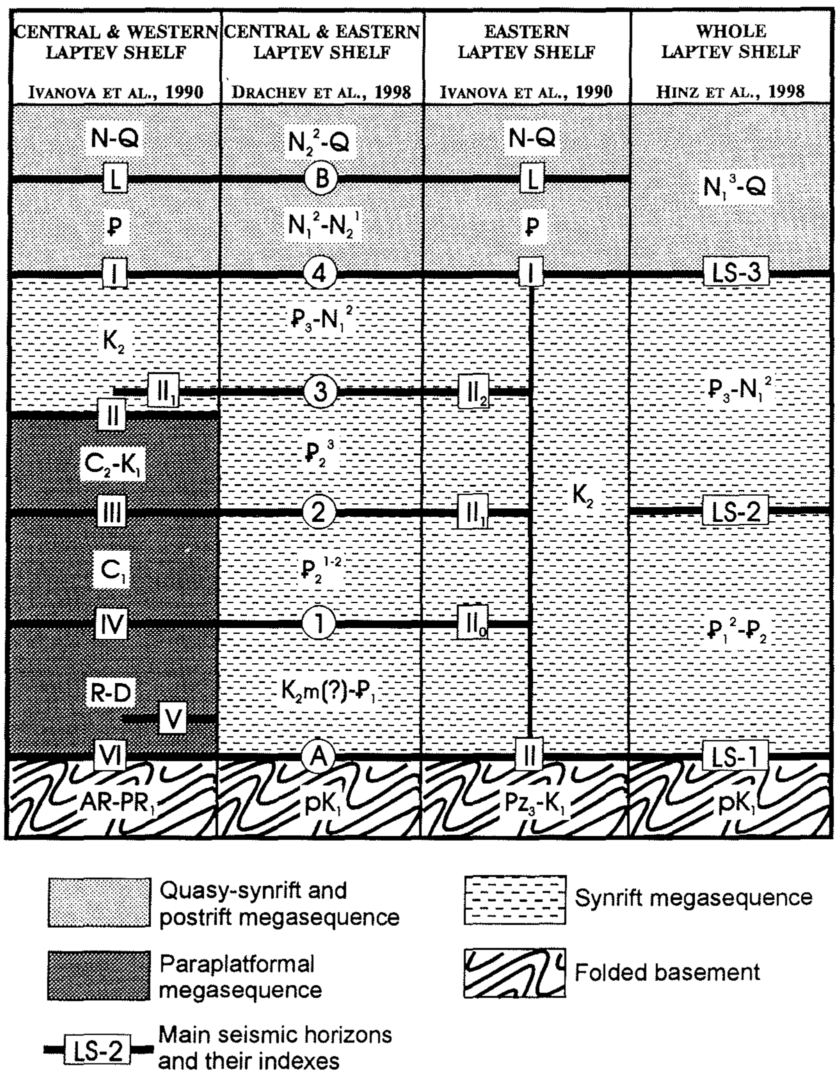

Fig. 5: A comparison of the seismic stratigraphic models proposed for the Laptev Sea margin.

Consequently, the seismic units with mostly coherent reflection pattern resting on the basement range in their age from Late Cretaceous to Quaternary in all parts of the LCM studied so far. Three (HINZ et al. 1998) to five (DRACHEV et al. 1998) main seismic unconformities, respectively, were recognized by comparison of MCS data with the results of geological studies deeply subsided rifts. It may indicate that the value of crustal stretching in LCM is not enough to compensate the total opening of the Eurasia Basin. This, in turn, leads to a supposition that the Gakkel Ridge has never been propagating directly into LCM and its spreading axis terminates against the Khatanga transform fault undergoing eastward slipping relative to LCM with the half spreading rate. This phenomenon might lead to a rejuvenation of the rifts in the same direction.

From the above stated one can infer that the geometry of Tertiary plate boundary could be different from what is observed now in Northeastern Asia. As it is shown by SAVOSTIN et al. (1984a), during Early Tertiary the pole of North American/Eurasian plate rotation was located somewhere near Japan. By the end of this time most of the Eurasia Basin was opened and, as shown by MCS data, the Laptev Shelf was strongly affected by extension.

However, there is no evidence of simultaneous rifting in areas southeastward of the Laptev Sea. The Moma Rift, the only extensional feature of internal Northeastern Asia, was initiated only in Late Miocene (ZONENSHAIN et al. 1978; GRACHEV 1983). To explain this we have to admit that the main plate boundary in Paleogene and Eocene had a complex character. Probably one of its extensional segments can be found in the easternmost part of the Chukchi Peninsula near the Anadyr River and further to the south in the Koryak Highland where extensive fields of the Late Cretaceous to Early Tertiary rift related basalts are known (FILATOVA 1987).

MODERN GEODYNAMICS

The present-day tectonics and geodynamics of the LCM also represent important and, at the same time, poorly studied questions. COOK et al. (1986), based on seismological data, calculated the present-day Euler Pole of the Eurasian and North American plates to be near the coast of Buor-Khaya Bay (Fig. 6). This result was recently supported by GPS data (ARGUS & HEFLIN 1995). This northern position of the pole implies a very slow, probably less than 0.35 cm/yr., spreading and deceleration of the plate divergence within the LCM that is recorded by a degeneration of most of the normal faults in the uppermost sedimentary succession (Fig. 4). Using this fact, SEKRETOV (1993, 1998) even suggests that about 30 my ago the LCM came into the stage of a post-rift thermal subsidence, and reflector "L" (Fig. 4A) is a rift-cessation unconformity. However, a rather high level of seismicity shows that the extension of the LCM lithosphere is still active. Although seismicity and modern geodynamic of the LCM was a subject of several publications (SAVOSTIN & KARASIK 1981, COOK et al. 1986, PARFENOV et al. 1988, FUJITA et al. 1990a,b, AVETISOV 1993, DRACHEV et al. 1995a), the kinematics of this plate intersection is still mainly unknown.

The seismological data base for the LCM, including the southern Gakkel Ridge, consists of more than 40 focal mechanism solutions for about 20 events. The majority of them is characterized by two different solutions and for some of them up to five different mechanisms were calculated. Such a strong diversity was mainly the result of two factors: a sparse local seismological network and an uncertainty in orientation of the nodal planes, as almost all solutions were calculated before MCS results became available. Later it was recognized that the main features of the seismicity are well-corresponding to major structural elements of LRS (AVETISOV 1993, DRACHEV et al. 1995a). The linear band of seismicity follows the axial zone of the ridge and turns to northern part of the Bel'kov-Svyatoi Nos rift which is seismically active up to 74° N and can be considered as a present-day continuation of the extension axis of the Gakkel Ridge on the shelf (FUJITA et al. 1990b, AVETISOV 1993). Another linear zone of earthquakes reveals an extension along Ust' Lena Rift, and the third one coincides with the Lena-Olenek structural line representing left-lateral movements. These zones of seismicity separate almost aseismic blocks and do not cross the whole shelf while terminating against the Khatanga-Lomonosov Transform.

Thus, combining seismological data with seismic reflection results, it may be concluded that the boundary between the Eurasian and North American plates is not integral within the LCM. Figure 6 shows two rather speculative models of the modern plate tectonic situation in this area with different configuration of two microplates: Ust' Lena Microplate (Lena Delta and western part of the shelf) and East Laptev Microplate (eastern and northern parts of the shelf). These models need to be proved more carefully. Several probably existing microplates within the Laptev Shelf can significantly affect the present-day geodynamics of the Arctic.

CONCLUSION

During the last decade the LCM was intensively studied by offshore MCS surveys. Revealing the main structural elements of the rift system formed under influence of opening of the Eurasia Basin is the main result of these studies. However, presently this region keeps many geological puzzles, and an unified model of its tectonic evolution is still far from being constructed. Some of such unclear questions were discussed in this paper. They are related to the structure of the shelf basement, geometry of the rifts, seismic stratigraphy and age of the rift sedimentary infill, paleogeodynamics and modern geodynamics of the plate boundary in the Laptev Sea. To solve some of them it is necessary to carry out specific investigations as, for instance, deep seismic refraction profiling for studying lower stages of LCM down to the crust/mantle transition, and high resolution multichannel seismic reflection profiling to study the uppermost level of the LCM structure in more detail that is difficult on deep MCS profiles. But there are other questions which can be solved using already existing data. To achieve this, we need an integration of the different data sets available in several institutions. The following is one of possible ways which can help to answer some of the remaining questions of LCM geology in cooperative studies:

- to distinguish the different types of the basement using seismic velocities from the BGR 1997 survey, ERS-1 and ERS-2 altimeter gravity data as well as Russian gravity and magnetic data;
- to define geometry and kinematics of the present-day plate boundary or boundaries using the high resolution seismic data and acoustic survey of the POLARSTERN 1998 cruise and

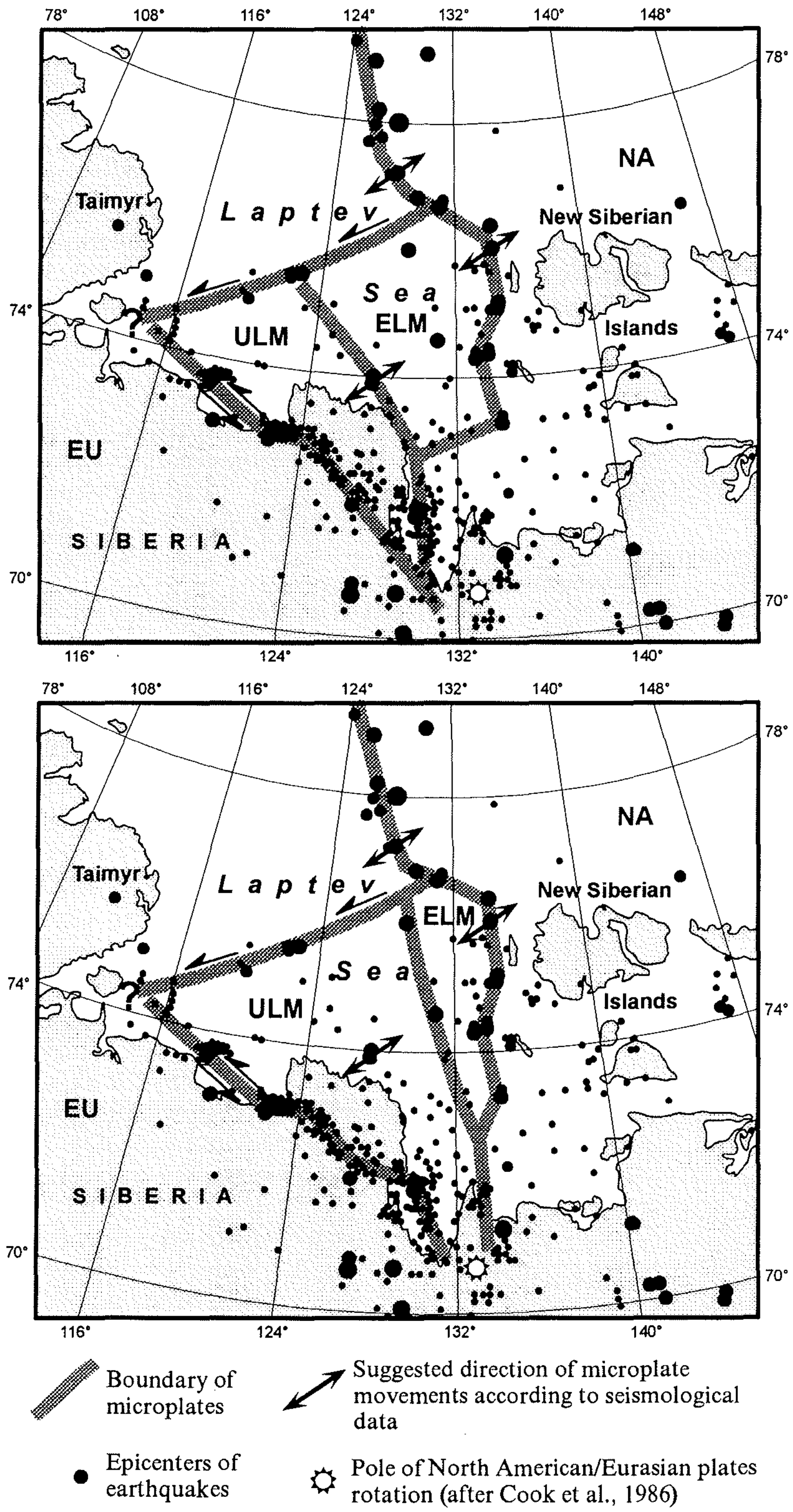

Fig. 6: Two possible models of plate boundary geometry and kinematics in the Laptev Sea. The earthquake epicenters location is given after AVETISOV (1993). Bold capital letters denote EU Eurasian and NA North American lithospheric plates, ULM Ust' Lena and ELM East Laptev microplates.

incorporating the Russian-American and international data base on seismicity;

- to construct an integral geological model of the rifting using all available seismic reflection and refraction data as well as gravity and magnetic data.

ACKNOWLEDGMENTS

The author is most grateful to the Organizing Committee of ICAM III for providing him with a support to travel to Celle and to attend such an important scientific meeting. The whole paper was improved after a careful reviewing by Dr. M.K. Kos'ko and an anonymous reviewer.

References

Alekseev, M.N., Arkhangelov, A.A., Ivanova, N.M., Kim, B.I., Patyk-Kara, N.G., Plakht, I.R., Reinin, I.V., Sekretov, S.B. & Shkarubo, S.N. (1992): Laptev and East Siberian Seas. Cenozoic. In: Palaeogeographic Atlas of the Shelf Regions of the Eurasia for the Mesozoic and Cenozoic.- Vol. 1, the text. Robertson Group plc, UK, and Geological Institute, Academy of the Sciences, USSR, 1-14 - 1-33 (in Russian).

Argus, D.F. & Heflin, M.B. (1995): Plate motion and crustal deformation estimated with geodetic data from the global positioning system.- Geophys. Res. Letters 22: 1973-1976.

Arkhangel'skii, A.D. & Shatskii, N.S. (1933): Tectonic Scheme of U.S.S.R.- Bulleten' MOIP, Nov. Seriya, v. 11, 4: 323-348 (in Russian).

Atlasov, I.P., Vakar, V.A., Dibner, V.D., Egiazarov, B.Kh., Zimkin, A.V. & Romanovich, B.S. (1964): The New Tectonic Map of the Arctic.- Doklady AN SSSR, v. 156, 6: 1341-1342 (in Russian).

Avetisov, G.P. (1983): Seismological data on the deep structure of the New Siberian Islands and adjacent sea areas.- Internat. Geol. Review 25: 651-660.

Avetisov, G.P. (1993): Some problems of lithospheric dynamics of the Laptev Sea.- Fizika Zemli 5: 28-38 (in Russian).

Cook, D.B., Fujita, K. & McMullen, C.A. (1986): Present-day plate interactions in Northeast Asia: North American, Eurasian, and Okhotsk plates.- J. Geodyn. 6: 33-51.

Drachev, S.S., Baranov, B.V., Dozorova, K.A. & Pristavakina, E.I. (1995a): Structure, seismicity and present-day geodynamics of Laptev Sea.- In: Programme and Abstracts of 5th Zonenshain Conf. on Plate Tectonics, Moscow, RF, November, 1995, 41.

Drachev, S. S., Savostin, L.A. & Bruni, I.E. (1995b): Structural pattern and tectonic history of the Laptev Sea Region.- Reports Polar Res. 176: 348-366.

Drachev, S.S., Savostin, L.A., Groshev, V.G. & Bruni, I.E. (1998): Structure and Geology of the Continental Shelf of the Laptev Sea, Eastern Russian Arctic.- Tectonophysics 298: 357-393.

Egiazarov, B.Kh. (1969): Arctidy as a particular geostructure of the Earth.- In: Mesozoic tectogenes (Tezisy dokl VII sessii Nauchnogo Soveta po tektonike Sibiri i Lal'nego Vostoka). Magadan: 17-20 (in Russian).

Ermolaev, M.M. (1933): Geology and mineral resources of the New Siberian Archipelago.- Leningrad, Izdatel'stvo AN SSSR: 157-182.

Filatova, N.I. (1987): Tectonic setting of Maastrichtian to Eocene basalt magmatism in northeastern part of the Pacific Fold Belt.- Geotektonika 4: 85-101 (in Russian).

Fujita, K., Cambray, F.W. & Velbel, M.A. (1990a): Tectonics of the Laptev Sea and the Moma rift systems, northeastern USSR.- Mar. Geol. 93: 95-118.

Fujita, K., Cook, D.B., Hasegava, H., Forsyth, D. & Wetmiller, R. (1990b): Seismicity and focal mechanisms of the Arctic region and the North American plate boundary in Asia.- In: A. GRANTZ, L. JOHNSON & J. F. SWEENEY (eds.), The Geology of North America. Vol. L., The Arctic Ocean region. Boulder, Co.: Geol. Soc. of Amer., 79-100.

Fujita, K., Stone, D.B., Layer, P.W., Parfenov, L.M. & Koz'min, B.M. (1997): Cooperative program helps decipher tectonics of Northeastern Russia.- Eos, Trans. Am. Geophys. Union 78: 245, 252-253.

Galabala, R.O. (1983): Some aspects of the recent tectonics of Yakutia.- In: N. A. LOGACHEV & S.I. SHERMAN (eds.), Regional tectonics of Siberia. Novosibirsk: Nauka, Siberian Branch, 51-59 (in Russian).

Grachev, A.F. (1983): Geodynamics of the Transitional Zone from the Moma Rift to the Gakkel Ridge.- In: J.S. WATKINS & C.L. DRAKE (Editors), Studies in Continental Margin Geology. Am. Assoc. Pet. Geol. Mem. 34: 103-114.

Grachev, A. F., Demenitskaya, R. M. & Karasik, A. M. (1970): Mid Arctic Ridge and its continental continuation.- Geomorphologiya 1: 42-45 (in Russian).

Hinz, K., Block, M., Delisle, G., Franke, D., Kos'ko, M.K., Neben, S., Reichert, C., Roeser, H.A. & Drachev, S. (1998): Deformation of Continental Lithosphere on the Laptev Sea Shelf, Russian Arctic.- In: Abstracts of the 3rd International Conference on Arctic Margins (ICAM III), Celle, Germany, October, 1992, 85.

Ivanov, V.L., Gramberg, I.S., Pogrebitsky, Y.Y., Lazurkin, D.V., Kim, B.I., Yashin, D.S. & Avetisov, G.P. (1994): Evolution peculiarities of the Laptev Sea geosystem as s key region in the Arctic.- Reports on Polar Res. 144: 107-110.

Ivanova, N.M., Sekretov, S.B. & Shkarubo, S.N. (1990): Geological structure of the Laptev Sea shelf according to seismic studies.- Oceanology, 29: 600-604.

Kim, B.I. (1986): Cenozoic history of the development of the East Arctic shelves and paleoshelves.- In: B.KH. EGIAZAROV & Y.B. KAZMIN (eds.), Structure and History of Development of the Arctic Ocean. Leningrad: Sevmorgeologiya, 105-119 (in Russian).

Kim, B.I. (1993): Seismic zones of the Laptev margin plate and their continental and ocean projection.- In: Programme and Abstracts of 4th Zonenshain Memorial Conference on Plate Tectonics, Moscow, RF, November 1993, 78.

Kropotkin, P.N. & Shatalov, E.T. (1936): Essay on geology of the Northeast of USSR.- Materialy po izucheniyu Okhotsko-Kolymskogo kraya, Seriya 1, Vypusk 3. Moscow: ONTI, 147 pp. (in Russian).

Litinskii, V.A. (1967): Geological and tectonic structure of shelf of Eastern Siberia and Far East's Arctic seas.- In: Tesisy dokladov V sessii Nauchnogo soveta po tektonike Sibiri i Dal'nego Vostoka. Novosibirsk: 151-154 (in Russian).

Mokshantsev, K.B., Gornshtein, D.K., Gusev, G.S., Den'gin, E.V. & Shtekh, G.I. (1964):Tectonic structure of Yakut ASSR.- Moscow:, Nauka, 240 pp. (in Russian).

Muratov, M.V. (1981): The old and young platforms.- In: Tectonics of the platforms and tectonic maps in studies of Geological Institute of Academy of Sciences of USSR. Moscow: Nauka, 6-97 (in Russian).

Obruchev, C. V. (1934): Data on tectonics of Northeastern Asia.- Problemy Sovetskoi Geologii 6: 182-220; 7: 7-78.

Parfenov, L.M. (1991): Tectonics of the Verkhoyansk-Kolyma Mesozoides in the context of plate tectonics.- Tectonophysics 199: 319-342.

Parfenov, L.M., Koz'min, B.M., Grinenko, O.V., Imaev, V.S. & Imaeva, L.P. (1988): Geodynamics of the Chersky seismic belt.- J. Geodyn. 9: 15-37.

Patyk-Kara, N.G. & Grishin, M.A. (1972): Position of the Polousnyy Range in the structure of the northeast USSR and its most recent tectonics.- Geotectonics, 6: 242-245.

Pol'kin, Ya.I. & Gaponenko, G.I. (1967): Tectonics of the Arctic Shelf of the East Siberia and Far East.- In: Tesisy dokladov V sessii Nauchnogo soveta po tektonike Sibiri i Dal'nego Vostoka. Novosibirsk: 180-182 (in Russian).

Roeser, H.A., Block, M., Hinz, K. & Reichert C. (1995): Marine Geophysical Investigations in the Laptev Sea and the Western part of the East Siberian Sea.- Report. Polar Res. 176: 367-377.

Saks, V.N., Belov, N.A. & Lapina N.N. (1955): Modern ideas about geology of the central Arctic.- Priroda 7: 13-22.

Savostin, L.A. & Karasik, A M. (1981): Recent plate tectonics of the Arctic basin and of northeastern Asia.- Tectonophysics 74: 111-145.

Savostin, L.A., Karasik, A.M. & Zonenshain, L.P. (1984a): The history of the opening of the Eurasia basin in the Arctic.- Trans. USSR Acad. Sci., Earth Sci. Sect., 275: 79-83.

Savostin, L.A., Natapov, L.M. & Stavsky, A.P. (1984b): Mesozoic paleogeodynamics and paleogeography of the Arctic region.- In: Proceedings of 27th International Geological Congress. Arctic geology. Reports. V. 4 Moscow: Nauka, 217-237.

Sekretov, S.B. (1993): Junction of Gakkel oceanic ridge and Laptev Sea continental margin: General features of tectonics according to the data of multichannel seismic profiling.- In: Programme and Abstracts of 4th Zonenshain Memorial Conference on Plate Tectonics, Moscow, RF, November 1993, 124-125.

Sekretov, S.B. (1998): Southeastern Eurasian Basin termination: Structure and key episodes of tectonic history.- In: Abstracts of 3rd International Conference on Arctic Margins (ICAM III), Celle, Germany, October 1992, 165.

Vinogradov, V.A. (1984): Laptev Sea.- In: I.S. GRAMBERG & Y.E. POGREBITSKII (eds.), Geologic Structure of the USSR and its Relationship to the Distribution of Mineral Resources. Vol. 9, Seas of the Soviet Arctic. Leningrad: Nedra,pp. 51-60 (in Russian).

Vinogradov, V.A., Gaponenko, G.I., Rusakov, I.M. & Shimaraev, V.N. (1974): Tectonics of the eastern Arctic shelves of the USSR.- Leningrad: Nedra, 144 pp. (in Russian).

Vinogradov, V.A., Gaponenko, G.I., Gramberg, I.S. & Shimaraev, V.N. (1977): Structural-associational complexes of the Arctic shelf of the eastern Siberia.- International Geological Review 19, 1331-1343.

Zonenshain, L.P., Natapov, L.M., Savostin, L.A. & Stavsky, A.P. (1978): Recent plate tectonics of the northeastern Asia in connection with the opening of North Atlantic and the Arctic Ocean basins.- Oceanology 18: 550-555.

Zonenshain, L.P., Kuz'min, M.. & Natapov, L.M. (1990): Geology of the USSR: A Plate-Tectonic Synthesis.- In: B. M. PAGE (ed.), Geodynamics Series, 21. Washington DC: Amer. Geophys. Union, 242 pp.