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Eurasian Arctic Margin: Earth Science Problems and Research Challenges

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Invited Plenary Lecture

Summary: The fundamental features of evolution and hydrocarbon potential of the Eurasian continental margin are considered in the light of structure and geological history of major shelf basins whose level of exploration and geodynamic position vary from west to east. The best studied Barents-North Kara Basin is a typical passive margin which borders the Eurasian oceanic opening and displays a prolonged pre-breakup depositional history spanning almost the entire Paleozoic and Mesozoic eras and resulting in a great thickness of sediments with positively proven oil and gas potential. Unique gas condensate fields have also been discovered in the South Kara Basin, although the accumulation of cover sequences did not begin here until about the Paleozoic/Mesozoic time boundary and was probably more influenced by the events in the West Siberian province than in the central Arctic. The location of the Laptev Basin at a unique structural T-junction between continental margin and the Eurasian spreading axis accounts for a specific geodynamic environment leading to post-breakup extension and associated formation of unusually stretched and thinned continental crust beneath a substantial thickness of predominantly latest Mesozoic and Cenozoic sediments. Although the least explored East Siberian and Chukchi Basins represent an apparent morphostructural transition from north-eastern continental Asia to the central Arctic Ocean, their designation as a typical passive margin may, perhaps, be questioned until evolutionary links between the formation of the Amerasian oceanic deep seabed and late Mesozoic - Cenozoic processes of subsidence and sedimentation in eastern basins are established with greater confidence.

Because of an outstanding oil and gas potential of the Eurasian continental margin, the fundamental and applied dimensions of its earth science exploration have always been closely interrelated. Of particular interest in a fundamental context are
- the examination of the structural and evolutionary continuity between the Eurasian Arctic margin and its neighboring crustal assemblages on both the mainland and the oceanic sides;
- unraveling the formation of different parts of this margin in relation to Cenozoic geodynamic processes in the Arctic Ocean;
- the issues related to expansion of continental crust in the course of its extensional stretching;
- palinspastic reconstructions accounting for the changes in dimensions of continental masses in the course of their pre- and post-breakup evolution,
- and studies of deep interior processes causing reorganizations at the upper level of the lithosphere.

Among more specific research objectives are
- the recognition of syn-oceanic structural elements and tectonic events as opposed to features inherited from the pre-oceanic evolution;
- determining the lithostratigraphic composition of the sedimentary cover and developing tectono-stratigraphic concepts for basin modeling;
- identifying the factors influencing generation and preservation of hydrocarbons and the criteria for discriminating between predominantly oil- and gas-bearing basins.

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INTRODUCTION

The Eurasian Arctic margin faces the Arctic Ocean between 10 °E and 170 °W. By far the largest part of this margin pertains to the Russian exclusive economic zone. Consequently, earth science studies on the Eurasian Arctic margin have been predominantly performed by Russian research institutions and industrial groups, except for the western part of the Barents Sea which is covered mainly by Norwegian surveys. Major contributions to the exploration of the Laptev, East Siberian and Chukchi Seas were also made by German institutions (BGR) and North American companies (Western Geophysical) by contracting Russian vessels for seismic reconnaissance surveys; in the East Siberian and Chukchi Seas these surveys provided the bulk of all existing seismic data.

The current level of exploration of the Eurasian Arctic margin decreases dramatically from west to east. The Barents Sea is relatively well surveyed by seismic investigations accompanied by stratigraphic and exploration drilling. In the South Kara Sea both seismic and well data are less abundant, whereas the existing knowledge in the North Kara and Laptev Seas is mainly based on as yet limited seismic evidence not verified by drilling results. Aeromagnetic and gravity surveys of varying scales cover the entire Eurasian Arctic margin; in the East Siberian and Chukchi Seas, where Russian seismic data available to the authors are very scarce, the potential field evidence provided the main source for geological interpretations (e.g. GRAMBERG et al 1997).

The Eurasian Arctic margin is one of the largest continental margins in the world and is also leading in the amount and size of shelf/slope sedimentary basins whose outstanding oil and gas potential was predicted by VNIIOkeangeologia specialists more than 30 years ago. Since then it has been positively confirmed by discoveries of giant offshore fields (GRAMBERG & SUPRUNENKO 1995, GRAMBERG et al. 1983, OSTISTY & FEDOROVSKY 1993). The main basins traditionally recognized on the Eurasian Arctic margin are the Barents - North Kara Basin, the South Kara Basin, the Laptev Basin, and the eastern basins underlying the shelves of the East Siberian and Chukchi Seas; the first two are the apparent offshore continuations of well known highly productive onshore provinces. This paper attempts to highlight the key geological features of each of these subdivisions with a view to identify fundamental concerns relevant to better understanding of crustal evolution of the entire Eurasian Arctic margin and improved assessment of its hydrocarbon potential.

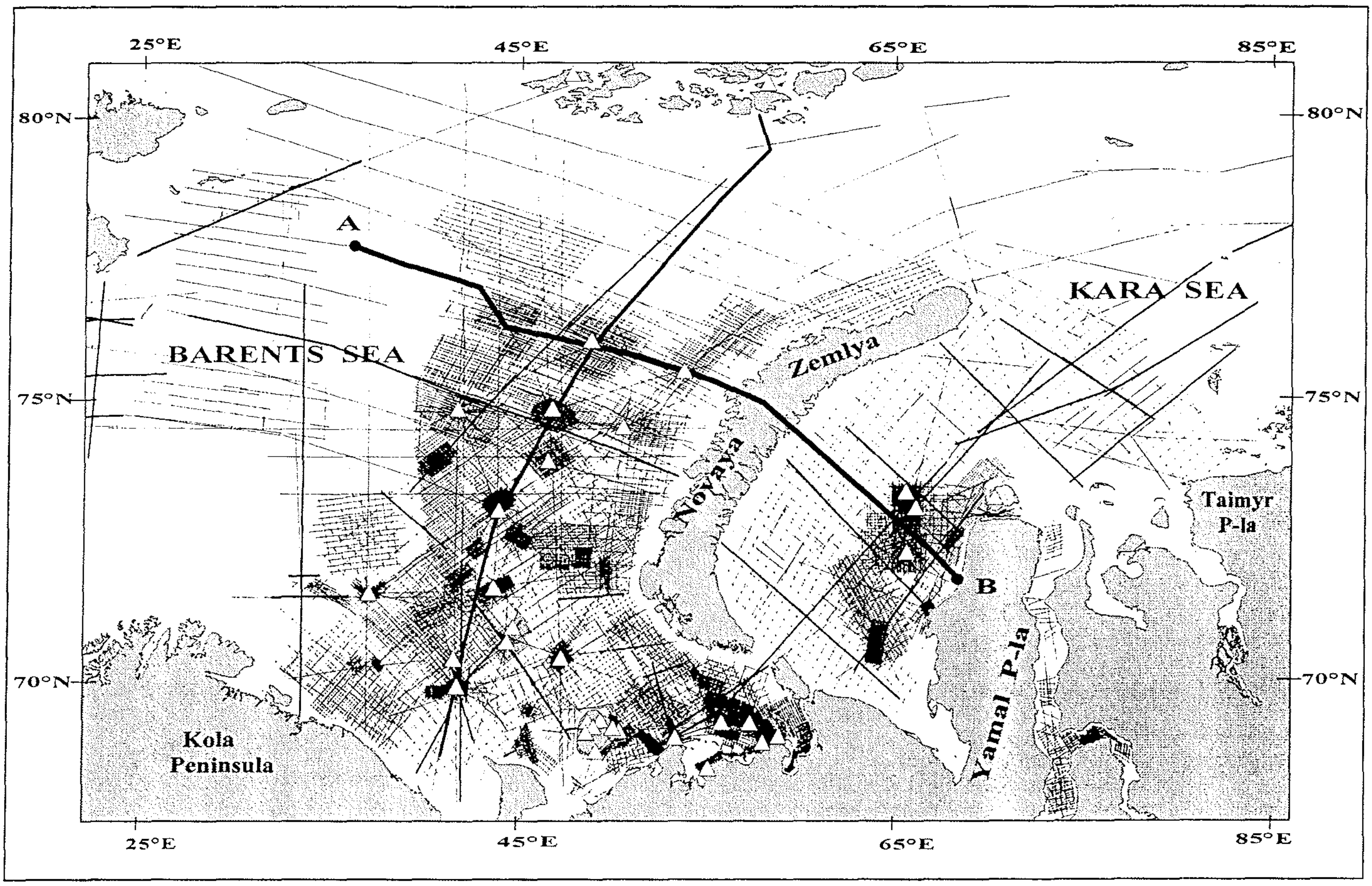


Fig. 1: Russian seismic and well data coverage in the Barents and Kara Seas. Thin lines = MCS lines and refraction lines; bold lines = wide-angle seismic reflection lines; line A - B geological profile shown in Figure 4; triangles = main stratigraphic and exploration wells.

SUMMARY OF EXISTING KNOWLEDGE

The Barents - North Kara Basin

Within the Barents - North Kara Basin, earth science activities were concentrated mainly in the Barents Sea shelf, whereas the North Kara Sea shelf remains relatively poorly studied. In the course of several decades the Russian seismic surveys concentrated predominantly in the eastern Barents Sea where a few hundred thousand kilometers of reflection and refraction lines were acquired mainly by SMNG Trust and MAGE. The distribution of these surveys is shown on Figure 1. Only those lines that were shot during the last 20-25 years using modern CDP methods (ca. 250,000 km) are depicted. Special technologies, such as wide angle seismic reflection profiling, were applied along several of these lines. In the deepest parts of the basins, they enabled the recognition of ancient cover sequences previously not distinguished from the basement (PAVLENKIN et. al 1998). Aeromagnetic surveys (Fig. 2) were another major tool in earth science investigations. Together with systematic gravity observations at 1 : 1,000,000 and more detailed scales, they constituted an important contribution to verifying the position of the basement, developing models of the Earth's crust and identifying the nature of its individual layers. Finally, the ground truth control of geophysical data was provided by direct geological evidence derived from numerous onshore and offshore wells and bedrock outcrops on the surrounding archipelagoes and mainland.

Based on the presence of ancient crystalline complexes, late Precambrian low grade sequences and late Vendian to Cambrian undeformed strata on the surrounding archipelagoes and mainland, the entire Barents - North Kara Basin is commonly believed to be underlain by a heterogeneous Baikalian basement whose cratonization is attributed mainly to the latest Precambrian orogeny caused by convergence of older continental blocks; this event was, perhaps, locally superseded by a Caledonian reactivation. The basement structure is dominated by a major trough running parallel to Novaya Zemlya in the eastern Barents Sea shelf (Figs. 3, 4). This feature is in marked contrast to the western Barents Sea where the basement surface generally lies at much shallower depths.

Despite apparent variations in total thickness, the lithostratigraphic composition of the basin fill is rather uniform and characterized by the presence of four principal sequences thought to extend more or less continuously over the entire Barents-North Kara Basin (GRAMBERG & SUPRUNENKO 1998). The lowermost basin sequence has an Ordovician to early Devonian age and commonly rests directly on the basement, though it may locally be underlain by older cover strata of limited thickness and distribution. The unit consists of terrige-

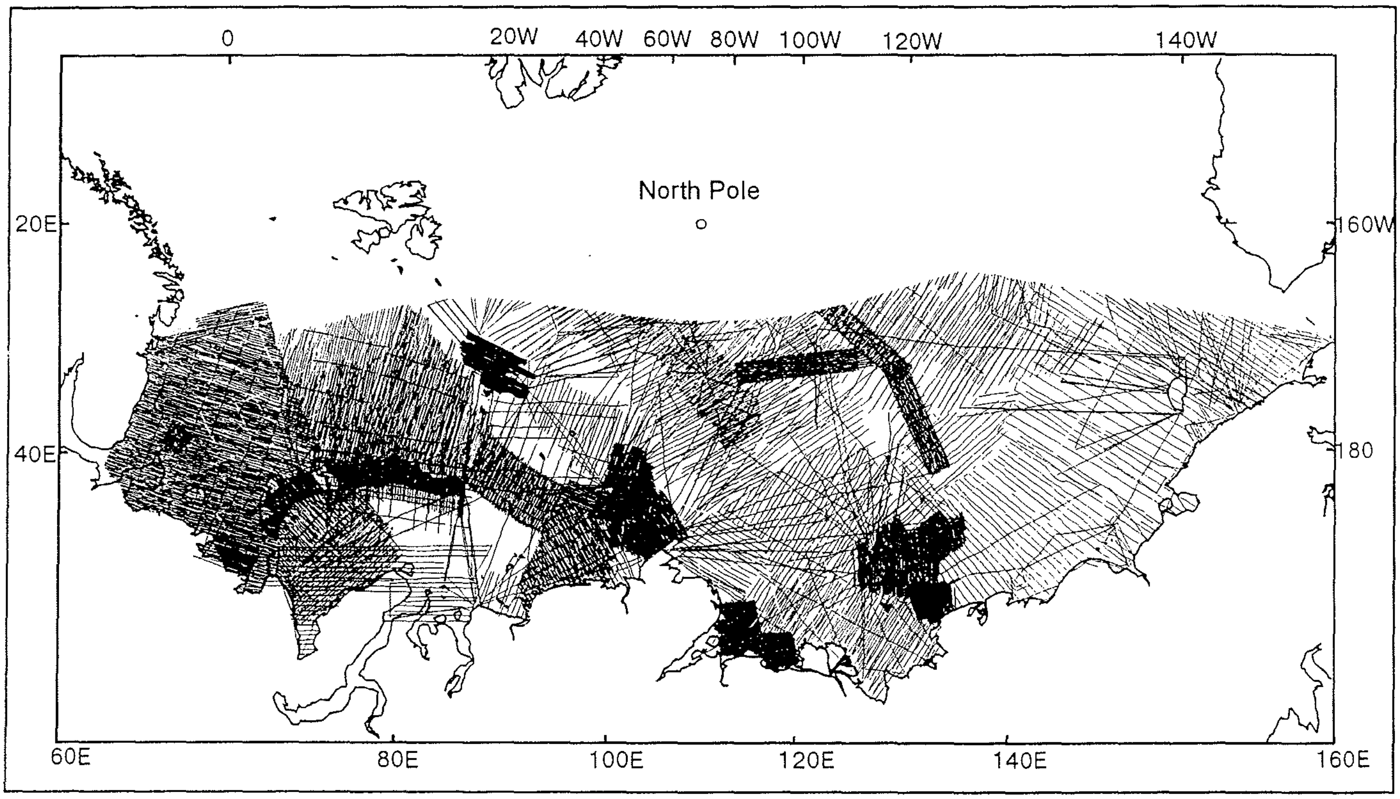


Fig. 2: Russian aeromagnetic tracklines on the Eurasian Arctic margin.

nous-carbonate deposits with a conspicuous proportion of coarse clastic rocks; numerous internal disconformities account for strong variations in its composition and thickness. The mid-Devonian to early Permian sequence is much more persistent in lateral distribution and lithology. It is dominated by carbonate platform strata with prominent reef formations and intercalations of salt-bearing rocks. The Late Permian to Triassic clastic sequence in the East Barents trough reaches 10-12 km in thickness and constitutes here more than a half of the total sediment fill which in the deepest depocenters may exceed 20 km; the depositional features indicate very high sedimentation rates in shallow marine to lacustrine, locally continental environments. Jurassic-Cretaceous marine, shallow marine and lacustrine sediments form the uppermost, relatively uniform regional sequence which, however, still exhibits gentle thickness gradients consistent with the underlying major structural features. Only a minor late Cenozoic veneer is observed at the top of the section.

At least three upper sequences with their great thickness of sediments are apparently favourable for generating and trapping hydrocarbons. This is confirmed by a very wide stratigraphic interval of oil and gas occurrences currently known in the Barents - North Kara Basin and ranging from oil accumulations of variable size in the Carboniferous to lower Permian beds to the giant gas condensate fields Shtockmanskoye and Ledovoye in the Jurassic deposits. On the whole, the great majority of proven oil and gas fields and prospects is concentrated predominantly in the eastern Barents Sea, but it remains uncertain to what extent the present-day position of hydrocarbons (in both vertical and lateral dimensions) reflects the pattern of their generation and original distribution (see discussion section). Despite the unquestionable great resource potential of the eastern Barents Sea, only the Prirazlomnoye oil field in the Pechora Sea is currently approaching production stage, whereas the economic and environmental constraints are as yet prohibitive for exploration and development activities in more remote offshore targets, including those with proven unique reserves.

Igneous rocks in the cover sequences are the products of pulses of extensional trap magmatism recorded in mid-late Devonian, latest Permian to early Triassic, and late Jurassic to early Cretaceous time intervals. The magmatic activity must have been one of the important factors for the generation and preservation of hydrocarbons, but only first approaches have so far been made towards a solution of this problem.

The South Kara Basin

The distribution of seismic and aeromagnetic investigations within the South Kara Basin is very uneven (Figs. 1, 2): the south-western part of the basin (between Novaya Zemlya and the Yamal Peninsula) is much better surveyed, especially near the Yamal Peninsula, whereas north and east of the Yamal Peninsula, the seismic coverage is less systematic, and aeromagnetic data are virtually missing. About 60,000 km of MCS lines shot over the South Kara Basin using modern technologies resulted in the discovery of 16 large prospects. Only two of them were drilled, and both turned out to be unique gas condensate fields in the lower Cretaceous sequences (Leningradskoye and Rusanovskoye).

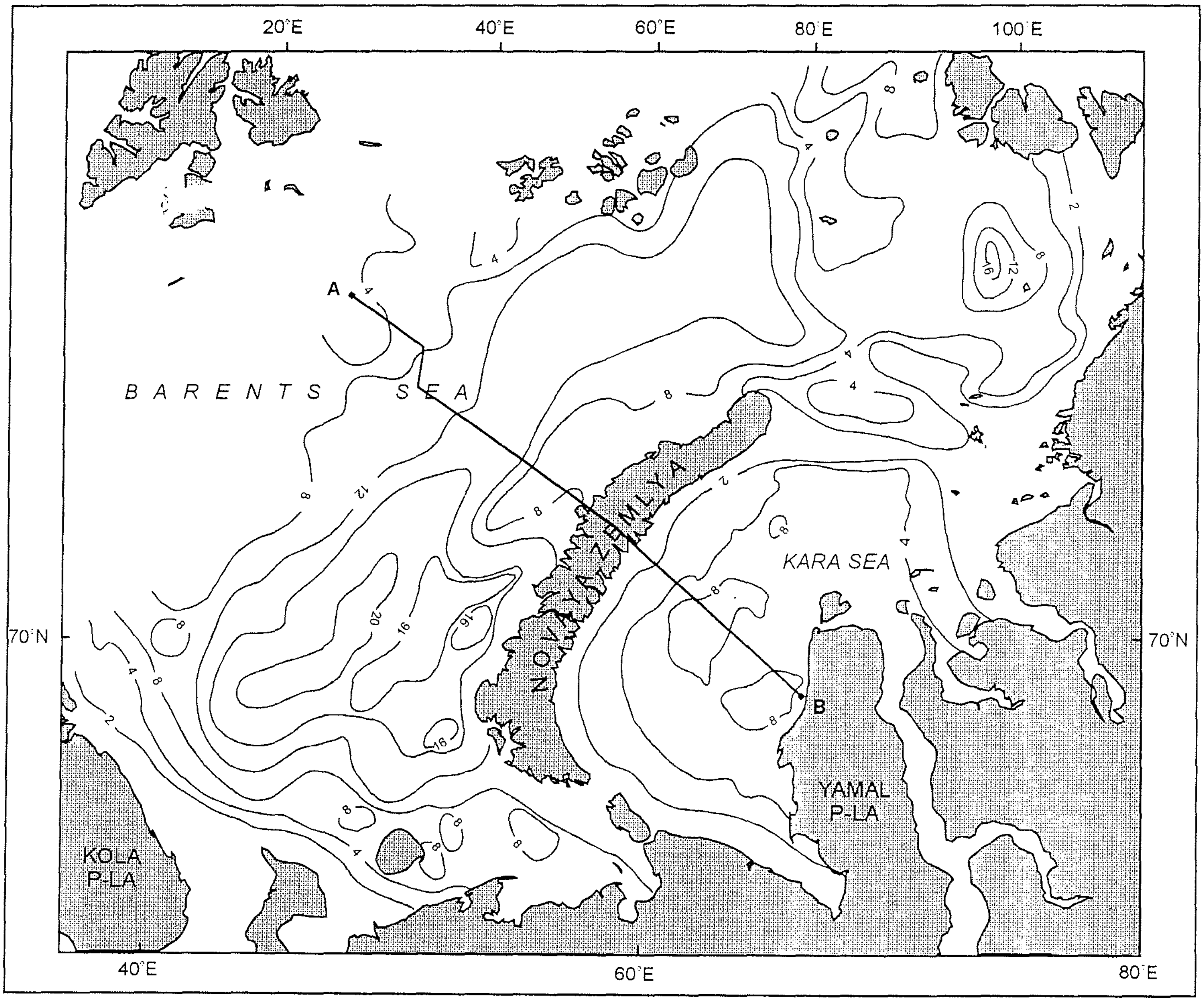


Fig. 3: Depth to basement in the Barents – North Kara and the South Kara Basins (km); from GLEBOVSKY et al. (1997) and VNIIOkeangeologia archive data. Line A – B = location of geological profile shown in Figure 4.

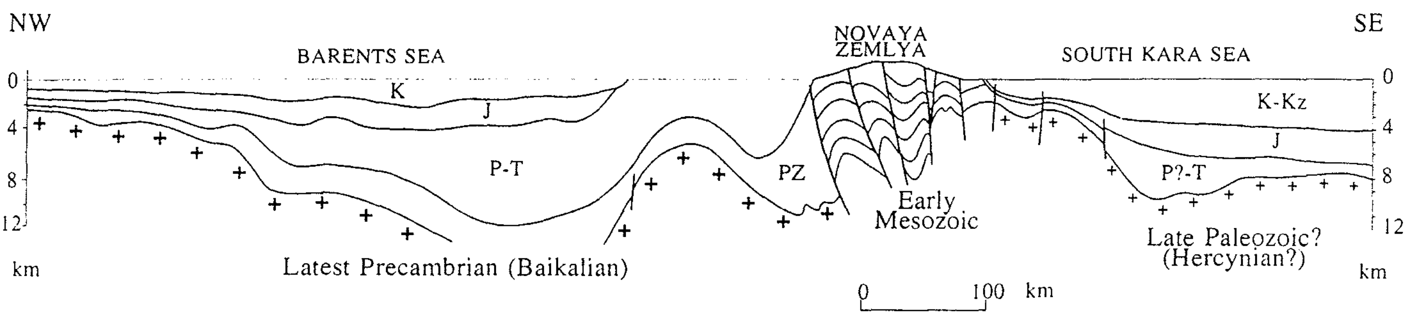


Fig. 4: Schematic geological profile along line A - B across the Barents Sea, Novaya Zemlya and the South Kara Sea (for location see Figs. 1 and 3). Geological age symbols indicate the stratigraphic range of major sequences established and/or presumed in the Barents – North Kara and the South Kara basins. Inscribed ages refer in basin areas to the final cratonization event in the tectonic basement, and on Novaya Zemlya – to the main deformational event in the epicratonic sequences broadly coeval with the adjacent basin fill. Generalized from MAGE data (e.g. IVANOVA & KAVUN 1997) and VNIIOkeangeologia numerous archive reports.

The striking discovery by the very first wells of these two giants occurred in the same stratigraphic interval that yields the bulk of production on the adjacent mainland. This positively suggests that the South Kara Basin represents an offshore frontier continuation of the extremely rich West Siberian hydrocarbon province and must therefore have much in common with the latter. This is particularly true for the upper part of the sedimentary cover which accommodates the major reservoirs (GRAMBERG & SUPRUNENKO 1995), but evidence is not yet sufficient to apply this similarity concept to the earlier basin history.

Indeed, drilling in the South Kara Basin was stopped at the base of the Aptian at approximately 2.0-2.5 km depth after penetrating a continuous upper early Cretaceous to Quaternary succession of predominantly marine terrigenous sediments with appreciable proportions of siliceous rocks. The drilled interval is practically identical in composition and thickness with coeval sequences on the Yamal Peninsula where similar lithologies were cored for another 2-3 km further down the section, through lowermost Cretaceous (pre-Aptian) and Jurassic strata. Units of this age evidently continue offshore the Yamal Peninsula and can reliably be traced by seismic data throughout much of the South Kara Basin; however, correlation of older (pre-Jurassic) units which make up the lower 5-6 km of the basin fill and the nature of the basement remains ambiguous.

The Laptev Basin

Seismic coverage in the Laptev Sea is much less dense than in the western seas (Fig. 5a). It amounts to 22,000 - 23,000 km of MCS lines with about half of their total length acquired by BGR. The data are mostly wide-spaced regional profiles measured with different acquisition parameters by several organizations, almost completely without refraction control. Together with the lack of borehole evidence and a high degree of variability of the seismic-geological environments, this creates ground for a variety of interpretations of even those distinct reflectors which are identified in all data sets, and certainly precludes the recognition of individual oil and gas prospects. The interpretation of aeromagnetic data from widely spaced flight-lines (Fig. 2) enabled the compilation of a rough depth to basement sketch (Fig. 6), which appeared generally consistent with seismic information. Repeated attempts to use potential field evidence for better perception of the nature of the basement and the age of basin fill did not, however, appear particularly conclusive. Hydrocarbon expectations in the Laptev Basin are quite optimistic due to the presence of a thick sedimentary cover the accumulation of which was probably in large part associated with depositional processes in the latest Mesozoic and Cenozoic paleodelta of the Lena River. Resource motivations are, however, as yet too weak to stimulate offshore drilling in the harsh natural and logistic environment of the Laptev Sea shelf, and the existing views on its tectonic structure and history are still essentially based on speculative concepts rather then on direct geological evidence; the process of adaptation of these views to more recent geophysical data and associated modern ideas is just beginning.

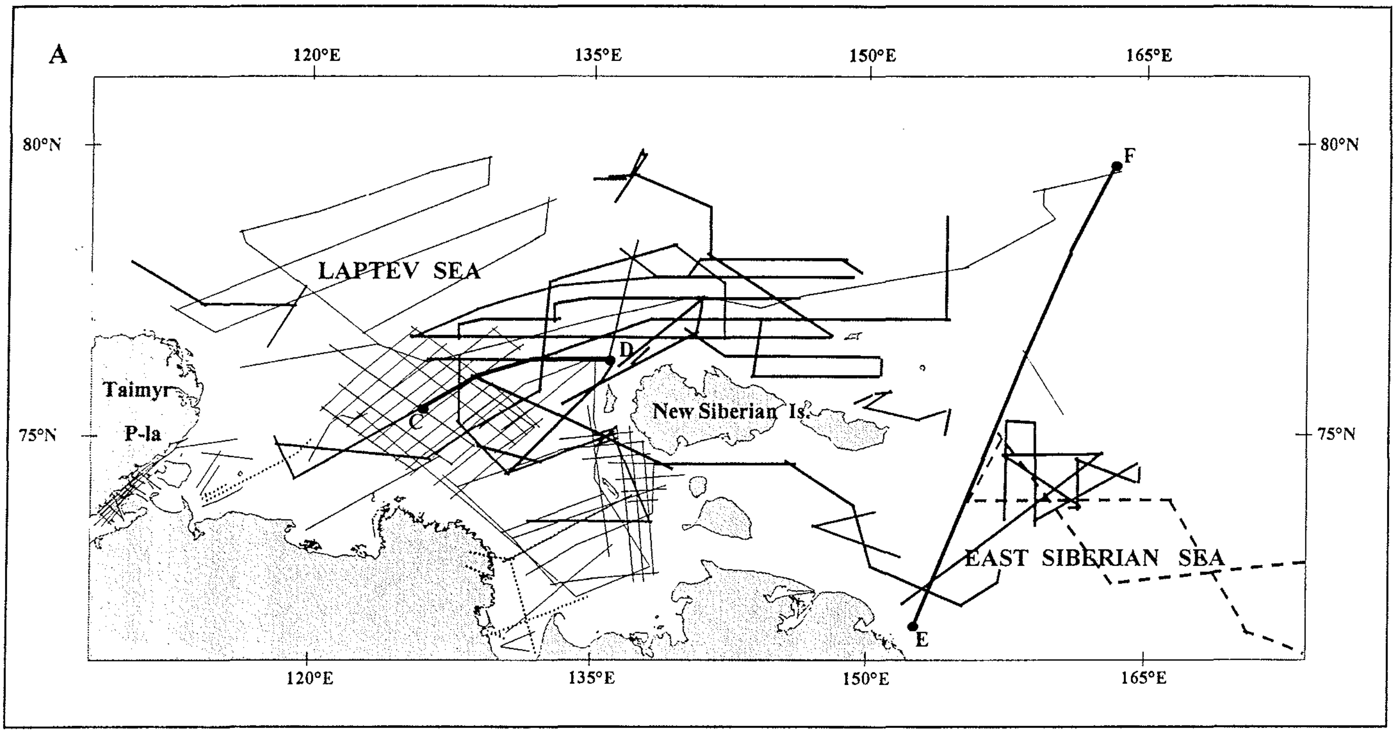
Even from currently available reconnaissance data the Laptev Basin emerges as one of the world's most intriguing tectonic sites, first of all because of the specific nature of its junction with the Eurasian oceanic basin whose spreading lineaments abut almost orthogonally against the base of the Laptev Sea slope. An evident manifestation of this structural coupling is the configuration of the Laptev Basin with its general seaward dipping morphology, emphasized by the absence of island-capped basement highs in the outer shelf. In this respect, the Laptev Basin is markedly different from the western Eurasian Arctic margin. Another major distinction is a much more variable depth of the acoustic basement which in the eastern Laptev Basin forms a prominent high, whereas the western Laptev Basin is dominated by a major basement depression. Within the latter, most Russian authors tend to recognize individual relative highs and lows believed to mark different structural units (DRACHEV 1998a, 1998b, IVANOVA et al. 1989, VINOGRADOV 1984); however, recent seismic evidence obtained by BGR (HINZ et al. 1997, 1998) suggests the presence of a single, relatively flat-floored depression with a rather constant depth to basement in the 4-5 s TWT interval.

On Figure 7, the main structural elements mentioned above are named the West Laptev Deep and the East Laptev High; the former corresponds to the Ust' Lena rift, and the latter to the East Laptev uplift of HINZ et al. (1997, 1998). The profile shown in Figure 7 traverses these major structures only in their boundary zone, but it nevertheless illustrates the principal crustal characteristics observed across their entire extent. Extensional faulting is quite evident in the East Laptev High which is dissected into the Laptev and the Kotel'nyi Horsts by the Anisin Basin. A "crustal partition zone" recognized by HINZ et al. (1997) in the Laptev Horst is particularly spectacular in this respect. A more subdued, relatively simple seismic structure in the much deeper Ust' Lena Rift is traditionally explained in terms of longer subsidence history. However, it could also represent the result of greater degree of extensional stretching and accompanying reworking of continental crust within a relatively short length of geological time. A brief review of the main existing concepts and a stratigraphic interpretation proposed for the observed seismic features are given in discussion section.

The Eastern Basins in the East Siberian and Chukchi Seas

Aeromagnetic data obtained along wide-spaced flight lines (Fig. 2) provided the source for depth to basement calculations indicating the existence of very deep depressions of the magnetic basement in the Eastern Basins, descending below 16 km (Fig. 6). Seismic data obtained by western companies are proprietary, whereas Russian seismic profiles in the Eastern Basins are too few (Figs. 5a, b), and in most cases have insufficient depth resolution to enable reliable verification of the aeromagnetic evidence and/or gravity modeling. Direct geological correlation is hampered by the scarcity of onshore bedrock outcrop and the total absence of deep stratigraphic wells in the area. The lack of ground truth for geophysical data permits only hypothetical interpretations of the geological structure of the Eastern Basins. An example of such a largely presumptive model for the structure of the East Siberian shelf is given in Figure 8.

The principal structures recognized in this profile are a large



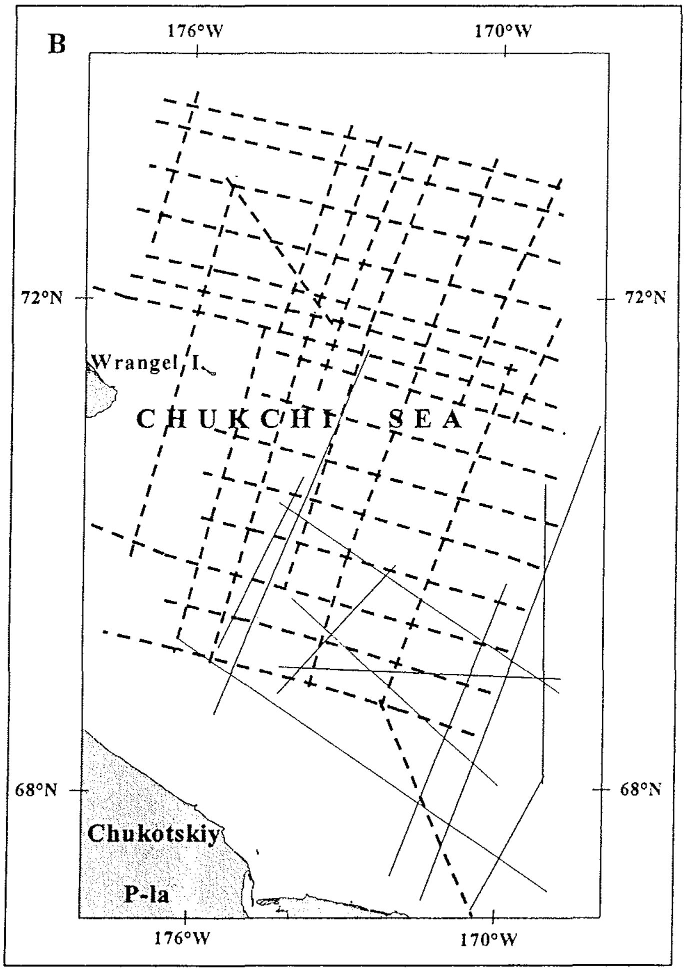


Fig. 5: Seismic data coverage in the Laptev Sea and East Siberian Sea (A) and Chukchi Sea (B). Dotted lines = refraction lines; thin and bold lines = MCS lines acquired by Russian expeditions and by BGR; broken lines = MCS lines acquired by Western Geophysical; bold lines C - D and E - F show locations of geological profiles on Figures 7 and 8.

depocenter called in this paper the New Siberian Deep, a prominent basement high underlying the De Long Islands, and another unnamed major sedimentary basin associated with the outermost shelf and continental slope. A noteworthy feature of the New Siberian Deep is the marked difference between the acoustic and magnetic basement surfaces (see also Fig. 6) although their positions are more similar beneath the slope basin. In the New Siberian Deep, the thickness of indisputable cover sequences overlying the acoustic basement varies from 1-2 to 5-6 km; the greatest part of this section is believed to consist of Cretaceous and Tertiary sediments, whereas a latest Miocene to Quaternary age is assigned to the uppermost thin, relatively persistent veneer. Ages given to older cover sequences which are assumed to be present beneath the acoustic basement in the New Siberian Deep, as well as to the even deeper magnetic basement, are purely speculative.

It appears highly probable that the structural pattern inferred in the western part of the East Siberian Sea (Fig. 8) extends into its eastern and north-eastern parts which are almost completely unstudied by seismic methods but are also characterized by alternating large elevations and depressions of the magnetic basement. Preliminary analysis of limited seismic and potential field data in the Chukchi Sea suggests its probable structural continuity with the North Slope of Alaska which gives reasons for a positive assessment of the hydrocarbon prospects of the Eastern Basins.

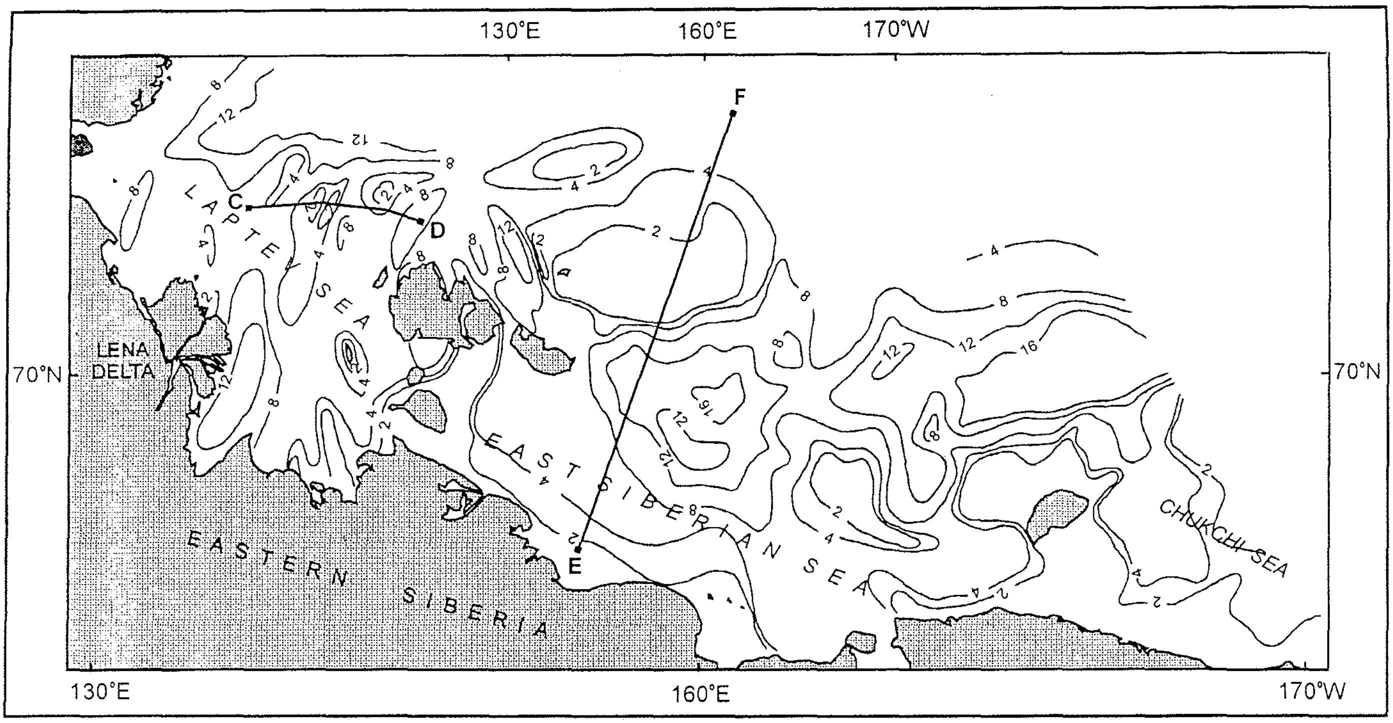


Fig. 6: Depth to basement in the Laptev and Eastern Basins (km) from VNIIOkeangeologia archive data; lines C - D and E - F show locations of geological profiles on Figures 7 and 8.

DISCUSSION

The Barents-North Kara Basin

The shelf edge of the Barents and Kara Seas is almost strictly parallel to the spreading axis of the Eurasian Basin which agrees with the definition of the Barents - North Kara Basin as a "classic" passive continental margin. Like many other passive margin basins associated with the evolution of modern oceans, the Barents - North Kara Basin displays a prolonged pre-breakup depositional history apparently unrelated to the Eurasian opening. Indeed, formation of the sedimentary cover in the Barents - North Kara Basin began, perhaps, close to the Precambrian/Paleozoic boundary and therefore preceded the onset of spreading in the Eurasian Basin by almost 500 Ma. On the contrary, Cenozoic sequences which would be expected to accumulate on the Barents-North Kara margin synchronously with the deepening of the Eurasian Basin, are virtually absent. These evolutionary peculiarities of the Barents-Kara sector of the Eurasian Arctic margin are impor-

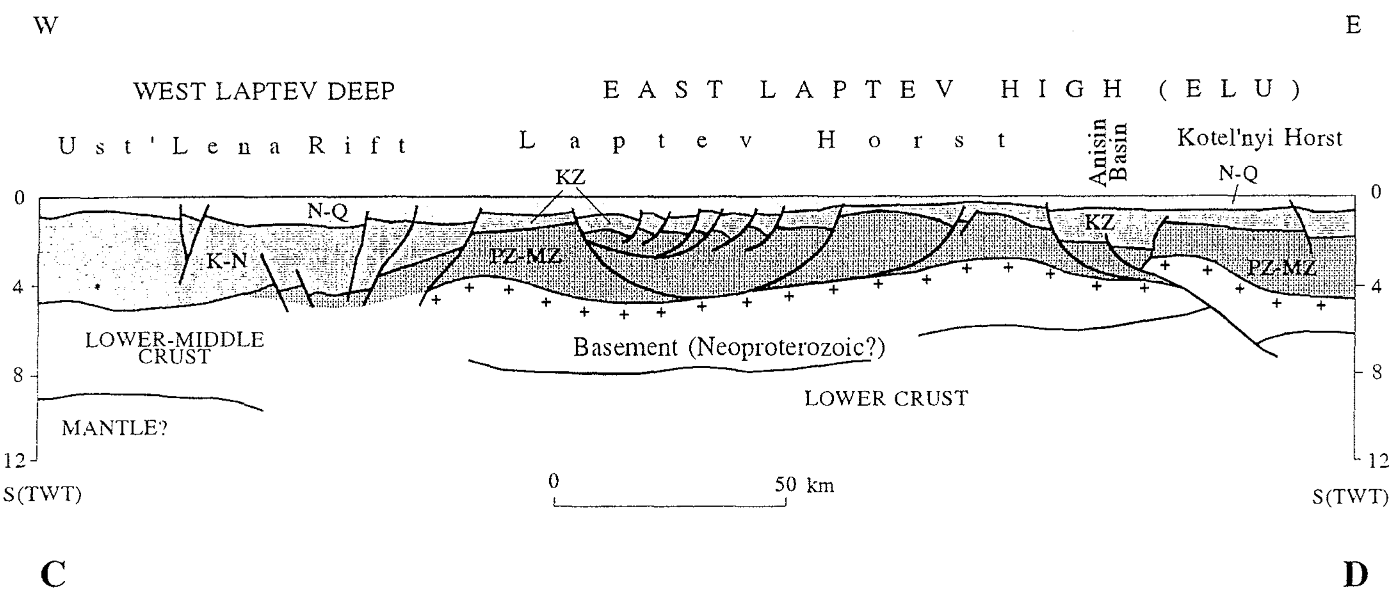


Fig. 7: Schematic geological profile along line C - D in the Laptev Sea (for location see Figs. 5 and 6). Seismic boundaries are synthesized from interpreted BGR lines 97-01 (eastern end) and 97-20 (HINZ et al. 1997). Geological age symbols indicate stratigraphic range assigned to basin fill sequences and/or to older cover units believed to occur in the acoustic basement. For further explanation see text in discussion section. ELU = East Laptev Uplift.

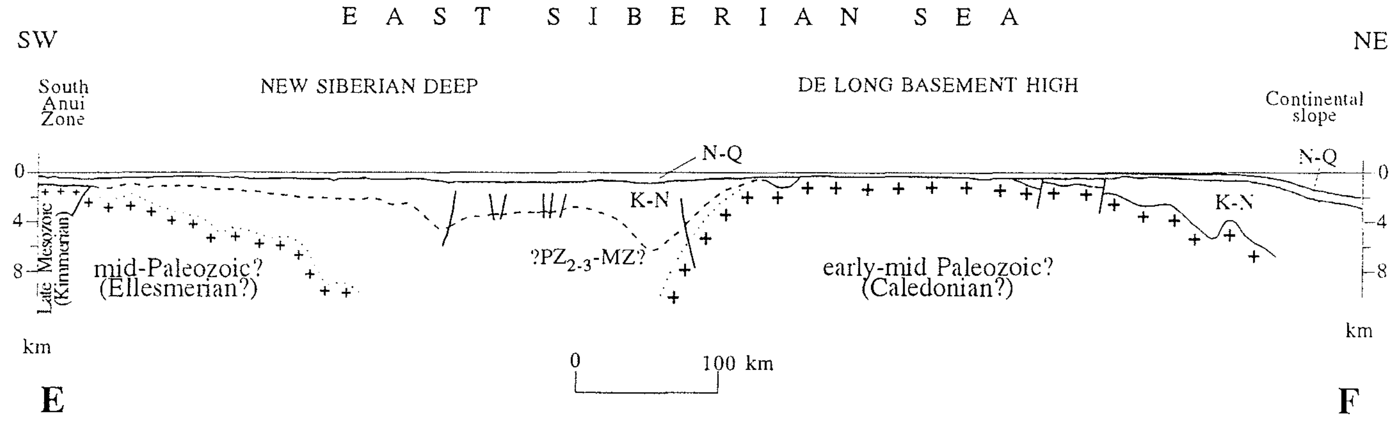


Fig. 8: Schematic geological profile along line E - F in the East Siberian Sea (for location see Figs. 5 and 6). Note difference in position of magnetic basement surface (dotted boundary) and of acoustic basement (dashed boundary) in the New Siberian Deep. Geological age symbols indicate stratigraphic range provisionally assigned to basin fill sequences and/or to older cover units believed to occur in the acoustic basemeent. Insccibed ages refer to tectonic events thought to be responsible for basement cratonization in different zones. Adapted from DRACHEV et al. (1995, 1998), KOS'KO (1984), and VNIIOkeangeologia archive data.

tant both in a fundamental context and for resource evaluations.

A very prolonged sedimentation history spanning the greatest part of the Phanerozoic is commonly interpreted in terms of the Barents - North Kara Basin evolution on the ancient East European platform. This concept is most readily applied to the western part of the Barents Sea shelf where a moderate thickness of Paleozoic and Mesozoic sequences is consistent with low sedimentation rates characteristic for stable tectonic regimes. In the eastern Barents Sea Shelf, however, a very thick latest Permian-Triassic succession indicates vigorous accumulation in a graben-like trough most likely associated with intense intracratonic extension and thinning of the Earth's crust at about the Paleozoic/Mesozoic boundary. Such activation of a hitherto quiet geodynamic environment could, perhaps, indicate the appearance of initial extensional stresses the effects of which were restricted at this early stage to the formation of the East Barents failed rift. It was not until about 200 Ma later when these stresses culminated in the separation of the Lomonosov Ridge and the opening of the Eurasian Basin.

The notion that the East Barents depression was formed by extensional stretching of the continental lithosphere is primarily based on geophysical evidence suggesting that up to 20 km and more of sediments rest here directly on a high-velocity lower crust. This type of structure is encountered in many major continental rift grabens and usually attributed to compensation processes beneath rapidly subsiding sedimentary basins. Alternative interpretations deny extensional rifting and propose that the lower crustal layer beneath the East Barents basin fill represents a deeply buried oceanic basement, a relic of an ancient ocean that existed in the place of the East Barents and North Kara Seas in late Precambrian and early Paleozoic times. In the absence of direct ground truth, both models remain largely speculative, though in our view the second concept is deliberately conjectural and more difficult to reconcile with the existing geological data and isostatic considerations.

Regardless of the difference in opinions on the tectonic nature of parts of the Barents - North Kara Basin basement, it is clear that a vast sedimentary basin existed here long before the Eurasian opening and the formation of the modern continental margin. There is no reason to believe that this pre-Cenozoic depositional area was limited to the present-day Barents - North Kara shelf: more likely it encompassed the Lomonosov Ridge in its pre-drift position and, perhaps, even partly extended over the region which is now occupied by the Alpha-Mendeleev bathymetric highs. It is not clear whether this presumably continuous basin marked a continental margin of an already existing hypothetical Arctic paleo-ocean, or represented an intracontinental depression completely surrounded by source areas. In either case, it appears that spreading of the Eurasian Basin seafloor must have begun across a mature depositional depression and continued for a lengthy period beneath a substantial thickness of pre-breakup sediments, including not only a pre-rift graben fill but also older sequences of wide stratigraphic range (POSELOV et al. 1998). Since the latter are known to include Paleozoic and Mesozoic platform strata in the Barents - North Kara Basin, the presence of deposits of similar age on the conjugate Lomonosov Ridge margin is a logical assumption. However, their tectonic position on the ridge may differ from the structurally undisturbed platform units in the Barents - North Kara Basin and may display more similarities with deformed sequences of Novaya Zemlya and/or fold belts of Northeast Russia.

The prolonged depositional history resulting in the accumulation of a great thickness of sediments on both passive margins of the Eurasia Basin and also in its oceanic core suggests that this entire part of the Arctic region may possess a high oil and gas potential as already positively proven in the Barents - North Kara Basin. Further assessments and related prospecting and exploration activities may profit from the consideration of some additional factors that were likely to influence the formation and distribution of hydrocarbons.

Indeed, the absence of early Cenozoic cover sequences in the Barents - North Kara Basin and the very limited occurrence of late Cenozoic strata mark a pronounced Tertiary erosional episode associated with an elevated position of the entire Barents - North Kara lithosphere. The cause and mechanism of this upheaval, which occurred synchronously with the deepening of the adjacent oceanic basin, are poorly understood. It is conceivable that this major tectonic event could have caused a considerable redistribution of initial hydrocarbon accumulations. Only few of them probably retained their original stratigraphic position, whereas many others were, perhaps, partly or completely destroyed or, on the contrary, remobilized to produce major secondary fields. The Prirazlomnoye oil field in the Pechora Sea is an example of original accumulation, but the Shtockman and Ledovoye giant gas condensate fields could have been formed by an upward migration of hydrocarbons into the Jurassic sequence (GRAMBERG & SUPRUNENKO 1998).

One of the crucial scientific concerns in the Barents-North Kara Basin is a better understanding of the transition from undeformed Paleozoic and early Mesozoic cover units on the eastern Barents shelf to coeval folded sequences on Novaya Zemlya. A possible solution of the problem is schematically presented in Figure 4, mainly on the basis of a common understanding that the Mesozoic deformation on Novaya Zemlya was caused by SE-NW lateral tectonic transport. Field evidence, however, suggests that at least in some parts of the archipelago the structure is simpler and forms an almost symmetrical anticlinorium (TRUFANOV et al. unpubl. data).

Among other controversial issues is the nature and the scope of Alpine tectonism in West Spitsbergen. Some recent publications (e.g. DARAGAN-SUSCHEV & EVDOKIMOV 1998) claim that transpressional stresses related to the Cenozoic plate motions caused the first major structural distortion in the entire, hitherto undisturbed area, but conventional concepts associating the main deformational event with the Caledonian orogeny remain by far more commonly accepted.

The South Kara Basin

The ambiguity in identification of age and composition of the base of the cover gives rise to different tectonic concepts of the early basin history and the nature of the basement. A more commonly accepted interpretation is based on analogy with northern West Siberia and assumes that pre-Jurassic units are represented by latest Paleozoic(?)-Triassic volcanic-sedimentary molasse deposits in graben-like depressions of the basement. The latter is believed to represent an offshore continuation of the Hercynian continental crust which was stretched and submerged to 10-12 km depth (Figs. 3, 4) in the floor of major rift-related grabens underlying the deepest parts of South Kara Basin. As the result of these extensional events, originally mid-upper crustal layer acquired the position and velocity parameters usually encountered in lower crust. This concept is essentially based on the similarity with the East Barents depression in the mechanism proposed for the modification of continental crust by extensional stresses, as well as in the latest Paleozoic-Triassic age assigned to the formation of the main graben-controlled sequences (SHIPILOV et al. 1998).

USTRITSKY (1985, 1998) stresses the similarity between the South Kara Basin and East Barents depression from a different angle. He attributes the apparent absence of a "granite layer" in the South Kara Basin to an initial lack of continental crust and assumes that the high-velocity crustal layer at the base of the sedimentary fill represents a "basalt window" inherited from the Riphean to early Paleozoic Uralian Ocean. According to this concept, a hypothetical ocean was not closed in this area during the Hercynian Orogeny, and the oceanic floor was preserved after the cratonization of the West Siberian basement. During much of Paleozoic time this oceanic depression accumulated mostly thin deep-water sediments. After the emergence of Hercynian denudation sources farther to the south, it was rapidly filled by thick clastic sequences and converted into a shallow water basin. The latter continued its gradual subsidence in late Mesozoic and Cenozoic time as the South Kara part of the Eurasian Arctic margin continental shelf.

The presence of Paleozoic, relatively deep-water lithologies on the east coast of Novaya Zemlya is the main geological argument used by USTRITSKY (1985) who interpretes these rocks as lower slope facies, transitional from a continental margin to an oceanic environment. However, other authors (e.g. KORAGO et al. 1998) believe that these rocks could equally likely indicate an uncompensated sedimentation in a deep intracratonic trough which was formed east of Novaya Zemlya in the course of mid-Paleozoic crustal extension and associated initial rifting of an ancient continental lithosphere.

To gain insight into the whole South Kara Basin history, it is obviously crucial to explain the nature of folding in the Paleozoic and lower Triassic sequences on Novaya Zemlya and to document their transition to the South Kara basement and basin units. These goals may, perhaps, be achieved by dedicated geological and geophysical studies on the archipelago and in the nearby Kara Sea shelf, without waiting for further stratigraphic drilling which in the present-day economic situation appears a very remote possibility.

The Laptev Basin

Unlike the Barents - Kara Seas sector, the Laptev Sea continental margin cannot, strictly speaking, be regarded as "passive" with respect to the Eurasian oceanic basin. The spreading lineaments of this basin abut orthogonally against the base of the Laptev Sea slope and form one of the world's most enigmatic T-junctions of that type. The abrupt termination of the oceanic features is explained by the existence of a prominent linear divide recognized from morphostructural and potential field evidence. This divide is described in the literature as Khatanga-Lomonosov zone, or Severnyi Transfer, or Charlie Transform Fault. Most authors agree, however, that this major boundary did not prevent the further propagation onto the Laptev Sea upper slope and shelf of the extensional tectonic regime resulting in the formation of rift-related horst and graben assemblages.

The opinions about the preceding basin history and the nature of the substratum affected by rifting are less unanimous. A more traditional view implies that the West Laptev Deep and the East Laptev High are the offshore portions of the ancient East Siberian craton and the adjacent Late Mesozoic fold belt, respectively. In late Mesozoic and Cenozoic time, both provinces underwent extensional downfaulting and were buried under young basin sequences. The accumulation of these sequences in the West Laptev Deep was merely a continuation of a preceding lengthy platform history but in the east it marked the change from a compressional tectonic regime in the fold belt to an extensional one. Consequently, a much greater total sediment thickness in the West Laptev Deep is attributed mainly to the presence of thick undeformed pre-late Mesozoic platform strata (probably as old as Riphean), whereas in the eastern Laptev Basin the base of the sedimentary cover is correlated with a peneplained surface of the late Mesozoic orogen. The extremely long depositional history and the much wider stratigraphic range of the cover sequences assumed by this concept for the western Laptev Basin provide the basis for a much more optimistic hydrocarbon evaluation than for the less mature eastern Laptev Basin (KIM 1998).

More recent interpretations postulate that throughout the greatest part of the Laptev Sea shelf the base of the basin sequences is represented by a distinct, relatively young, seismic boundary. This boundary is assumed to be associated either with a structural unconformity post-dating the late Mesozoic deformations, or with a prominent erosional discontinuity believed to accompany the major re-orientation of plate motions at about the Mesozoic/Cenozoic time boundary, or with a superposition of these stratigraphically close surfaces (DRACHEV 1998a, 1998b, DRACHEV et al. 1998, HINZ et al. 1997, 1998). Consequently, the main distinction between the western and eastern Laptev Basin is seen in the intensity of rift-related crustal extension and the subsidence reflected in the thickness of the latest Mesozoic and Cenozoic basin fill sequences. This approach provides less optimism for hydrocarbon evaluations because it reduces the probability of generation and preservation of hydrocarbons from organic sources in pre-rift sequences. At the same time, very active geodynamic environments and vigorous Cenozoic clastic sedimentation could facilitate the appearance of relatively young primary accumulations, and/or the remobilization and redistribution of older organic matter leading formation of major secondary fields.

Elements of both approaches were used for the geological solution proposed in Figure 7. Already "partitioned" but not yet appreciably thinned crust underlying the East Laptev High is interpreted as consisting of three layers: a supracrustal sedimentary layer, a mid-crustal infrastructural layer, and a lower crustal layer. Only the upper part of the supracrustal sedimentary layer is represented by high-reflectivity units forming the latest Tertiary-Quaternary post-rift veneer and the main Cenozoic syn-rift basin fill. The lower part of the supracrustal sedimentary layer is believed to be concealed beneath the acoustic basement where a pattern of scattered reflectors suggests the presence of pre-rift sedimentary sequences probably correlative with the thick, moderately folded Paleozoic-Mesozoic succession on Kotel'nyi Island. The assignment of the underlying mid-crustal layer to a Neoproterozoic(?) crystalline infrastructure follows a commonly accepted interpretation of the Kotel'nyi crustal block as an epi-continental "median massif". Extensional faulting is most evident in the supracrustal sedimentary layer, except in its uppermost part which must have accumulated after the main phase of stretching. The configuration of faults in the upper crust and their apparent absence at deeper levels suggest that the top and the base of the mid-crustal layer may delineate major detachment surfaces accommodating the extensional stress.

Beneath the Western Laptev Deep these two mid-crustal reflectors and the descending base of the basin fill seem to merge into one main interface separating the sedimentary layer from its "solid" base. The latter appears to have been reduced by stretching to a thickness of only 4-5 s TWT (about 10 km?). The composition and properties, as well as the primary nature of this mid-lower crustal layer are open for assumptions and may, perhaps, be regarded as a tectonic collage of heavily reworked infrastructural crustal assemblages and suprastructural sequences. Deepening of the basin from the East Laptev High westwards is shown in Figure 7 (after BGR seismic data, HINZ et al. 1997, 1998) as caused mainly by Cenozoic extensional faulting. However, a slightly broader stratigraphic range is assigned to the Ust' Lena Rift fill to indicate that in this part of the Laptev Basin subsidence and sedimentation could have already begun in Cretaceous time. The possibility that older cover sequences are also present in this basin fill is certainly not ruled out by the existing data, although some geological evidence seems to indicate that the entire area presently occupied by the Laptev Basin may have been affected by late Mesozoic folding.

The leading role of Cenozoic rifting in the formation of the Laptev Basin is challenged by some authors who question the close connection between the evolution of the Eurasian and Laptev basins. According to USTRITSKY (1998), the Laptev Basin basement was largely formed during the late Mesozoic orogeny as the result of accretion of allochthonous continental terranes in the process of closure of a hypothetical pre-existing ocean whose relics may still be present in the deepest parts of the Laptev Basin.

Apart from such ultramobilistic views, the main scientific questions related to the Laptev Basin formation can be summarized as follows:

(i) the stratigraphic range of the basin fill in the Ust' Lena Rift and the nature of the crustal substratum affected by Cenozoic rifting, or in other words, the credibility of the traditional concept of an essentially epi-platform evolution of the western Laptev Basin versus its more recent interpretations as a deeper and more strongly stretched portion of a single Laptev shelf basin that evolved on a more or less uniform late Mesozoic fold basement, and

(ii) the mechanism of interaction between the Eurasian oceanic basin and the Laptev shelf basins within the Khatanga-Lomonosov ("Severnyi Transfer") zone , or the validity of the speculation by HINZ et al. (1997, 1998) that south of the Charlie Transform Fault the Eurasian opening was compensated by an equivalent amount of lateral stretching of the continental crust. According to this model, the intensity of extensional deformation in the Laptev Basin gradually shifted from the Ust' Lena Rift to younger grabens between the Anjou and De Long Islands, following an eastward migration of the Gakkel Ridge spreading axis.

The Eastern Basins

The lack of accessible seismic data precludes a substantial debate of the geological structure and history of the Eastern Basins. At this stage, they can only be discussed in a very preliminary manner, mainly on the basis of indirect evidence including the consideration of general analogies, remote correlations or geodynamic reconstructions. The southernmost periphery of the New Siberian Deep is believed to be underlain by the late Mesozoic South Anui Fold Zone and the west-north-west continuation of the Chukchi Fold Belt exposed in onshore outcrops on the mainland and the Lyakhovsky Islands and traced by potential field data within a near-coastal offshore strip. The Lower Cretaceous unconformity (LCU) which truncates the top of this basement and manifests the main compressional event throughout much of the Russian North East is believed to form the acoustic basement in the entire Eastern Basins. This fundamental assumption underlies the majority of commonly accepted seismic stratigraphic interpretations.

Northward from the South Anui Zone a gentle descent of the acoustic basement is accompanied by a much steeper downward offset of the magnetic basement. Based predominantly on an assumed structural continuity of the latter with Paleozoic complexes on the mainland and on Wrangel Island, we propose a late mid-Paleozoic to early lower Cretaceous age for the units between the magnetic and acoustic basements in the New Siberian Deep. Whether these units are structurally more comparable with moderately deformed Paleozoic-Mesozoic succession on Anjou Islands or with much stronger folded pre-late Mesozoic units on Lyakhovsky and Wrangel Islands is open for assumptions.

An older (Caledonian?) basement beneath the De Long High is indicated by the presence of flyschoid sediments in island outcrops intruded by mafic sills and dikes; the latter yielded late Ordovician isotopic ages probably corresponding to the time of the main tectonic event.

In our view, the lack of direct evidence for a late Mesozoic plate convergence anywhere within the vast East Siberian and Chukchi Sea shelves may indicate that over the greatest part of the Eastern Basins the mid-Cretaceous compressional event was limited to structural reworking of the pre-existing crust and probably mainly consisted of refolding of early-mid Paleozoic basement complexes and/or initial deformation of the pre-Late Mesozoic cover. Nevertheless, mid-Cretaceous orogenic assemblages are widespread on the mainland and the Lyakhovsky Islands, and compressional features of presumably the same age have been documented on Wrangel Island (Kos'ko et al. 1990, 1993). This makes some authors (e.g. Ustritsky 1998) believe that geodynamic models postulated for the Russian North East and the Alaska North Slope may also apply to the entire area occupied by the Eastern Basins. According to this concept, the latter are underlain by a relatively young crust which was accreted in the form of exotic terranes and cratonized as late as in late Mesozoic time.

Whichever scenario of the Eastern Basins pre-Cenozoic crustal history finds better support from future investigations, the post-mid Cretaceous geodynamic evolution of the eastern Eurasian Arctic margin and its present-day structural relationship with the Amerasian Basin present a separate problem, since they seem to exemplify a peculiar setting not readily matched elsewhere in the world, namely, a modern extensional margin evolving on the periphery of a „non-spreading“ oceanic basin. A plausible explanation of this unusual combination may not be achievable without better understanding of the nature and origin of the Amerasian Basin deep seabed.

CONCLUSIONS

Vast sedimentary basins underlying the Russian Arctic shelf and the basement highs which delineate and separate these basins are the principal components of the crustal structure of the Eurasian Arctic margin. Because of an outstanding oil and gas potential of these basins, the fundamental and applied dimensions of earth science exploration on the Eurasian Arctic margin have always been closely interrelated. Research interest in this field ranged from understanding the broad regularities of crustal evolution of the entire Eurasian Arctic margin to more specific objectives, such as

- the recognition of syn-oceanic structural elements and tectonic events as opposed to features inherited from pre-oceanic evolution;
- the correlation of such syn-oceanic structures/events with the peculiarities of geological history of the Eurasian and Amerasian oceanic basins, and of pre-oceanic features with the evolution of the adjacent mainland;
- the determination of the lithostratigraphic composition of the sedimentary cover and development of tectono-stratigraphic concepts for basin modeling;
- the identification of the factors influencing the generation and preservation of hydrocarbons and of the criteria to discriminate between predominantly oil- and gas-bearing basins.

Despite the apparent progress achieved during the past decades in the exploration of the Eurasian Arctic margin, especially in its western sector, most of these problems continue to stand out as priority research challenges requiring further dedicated investigations. Of particular interest in a fundamental context is the examination of the structural and evolutionary continuity between the Eurasian Arctic margin and the adjacent crustal assemblages on both the mainland and the oceanic sides with a view to unravel the formation of different parts of the Eurasian Arctic margin in relation to Cenozoic geodynamic processes in the Arctic Ocean.

From this angle, the Barents - North Kara Basin fully corresponds to the definition of a typical passive margin whose outer edge is almost strictly matched by the shape of the active Gakkel Ridge oceanic rift and the conjugate slice of continental lithosphere underlying the Lomonosov Ridge. The pre-breakup depositional record of the Barents - North Kara Basin suggests a prolonged extensional subsidence within a much larger basin which probably extended from the East European platform to far beyond the Lomonosov Ridge in its pre-drift location. The geodynamic positon of this vast area of sedimentation must have been wholly intracontinental at least until late Mesozoic time when its most distal part was probably converted into a continental margin bordering the inferred opening of the Canada Basin. An unexplained feature of the history of the Barents - North Kara Basin is the Tertiary uplift which seems inconsistent with either the preceding subsidence history or with the Cenozoic deepening of the rest of the Arctic geodepression.

The geodynamic setting of the South Kara Basin is obscured by its evident continuity with the West Siberian province. This is emphasized by the separation from the Barents-North Kara Basin by a prominent suture extending from the Polar Urals through Vaigach Island, the Novaya Zemlya Archipelago to the North Siberian Ramp. This suture probably started to develop in the Polar Urals - Vaigach Island segment during Hercynian events, culminated in the emergence of the early Mesozoic Novaya Zemlya fold system, and completed its evolution in the course of the Tertiary uplift of the North Kara shelf. However, this growing isolation of the South Kara Basin from the Barents - North Kara Basin did not seem to radically influence the obvious similarities in their Mesozoic pre-breakup evolution which could also be characteristic of a considerable part of the West Siberian province. Consequently, the apparent lack of a direct present-day connection with the Arctic Ocean deep seabed does not preclude an assignment of the South Kara Basin to the passive margin of the Eurasian Basin.

The "classic" parallelism between the spreading lineaments of the Eurasian Basin and the western part of the Eurasian Arctic margin changes in the Laptev Sea to a peculiar T-junction characterized by the propagation of extensional stress from the Eurasian Basin almost orthogonally across the continent-ocean boundary. This geodynamic setting caused noticeable lateral expansion of thinned continental crust beneath the western Laptev Basin but not to the extent of breakup and separation by newly-formed oceanic lithosphere. In contrast to the Barents-Kara margin, the evidence of a preceding long-term extensional history in the Laptev Basin is by far less convincing. Here, the rapid transformation of normal continental crust into an "overstretched" margin seems to have occurred shortly after the late Mesozoic compressional event that probably affected, at least to some degree, much of the area presently occupied by the Laptev shelf. Such structural relationships are certainly not usual in typical passive margins and not really covered by the commonly accepted terminology.

The conventional classification of the Eastern Basins as the eastern sector of the Eurasian passive margin, transitional from north-eastern continental Asia to the central Arctic oceanic core, is consistent with the present-day morphostructural evidence, but not, perhaps, as yet sufficiently well understood in a historical context, namely, how the latest Mesozoic - Cenozoic subsidence of the Eastern Basins was related to the formation of the adjacent Amerasian deep seabed. Within the latter neither the presence of continuous oceanic crust, nor the mode and the age of its formation have been reliably established. An old view that relative bathymetric highs in the Amerasian Basin might reresent a submerged continuation of the eastern Eurasian Arctic margin has never been decidedly invalidated. The history of the Eastern Basins is also not adequately known to allow a confident interpretation of alternating compressional and extensional environments caused by the interaction of lithospheric plates and/or intraplate tectonic events.

A common need in all Eurasian Arctic margin basins is the improvement of information on the basement assemblages, particularly on age and geodynamic mechanism of their formation. In the western Eurasian Arctic margin the final cratonization of the basement is believed to have been associated with its last recorded deformation (Baikalian in the Barents-North Kara Basin, Hercynian in the South Kara Basin) succeeded by the beginning of accumulation of undeformed platform sequences. In the eastern Eurasian Arctic margin the initial, latest Precambrian or early-mid Paleozoic folding failed to cause basement cratonization. Instead, after a lengthy period of cover sedimentation, the late Cimmerian reactivation lead to various degrees of superposed deformation in the earlier basement complexes and/or to initial disturbance in the cover rocks. In both the western and eastern Eurasian Arctic margin, there are deep basement depressions characterized by the apparent absence of the "granite" crustal layer (the so called "basalt windows"). Extensional stretching and thinning of continental crust is seen as the main mechanism forming such a low in the Laptev Sea basement. It is not clear, however, to what extent this model, proposed for a specific Cenozoic geodynamic environment, can be applied to other similar hollows, especially in the western Eurasian Arctic margin where their formation is referred to a much earlier period of basin history.

A prolonged epi-continental depositional history which is reliably documented in the western Eurasian Arctic margin and can be assumed in the eastern Eurasian Arctic margin and, perhaps, also in much of the adjacent Arctic Ocean, underlies the concept of an Arctic geodepression advanced by POGREBITSKY (1984). It also agrees with the observation by GRAMBERG (1998) that the youngest ocean of the planet is framed by the oldest passive margin environments. A further development of the theoretical basis for studying the evolution of the Arctic Basin in general and the Eurasian Arctic margin in particular will require much closer focusing on issues related to expansion of continental crust in the course of its extensional stretching. At present, this problem is obviously neglected, and most palinspastic reconstructions seem to disregard the increase in lateral dimensions of continental masses in the course of their pre- and post-breakup history, most notably within extensional continental margins forming around late Mesozoic and Cenozoic oceans. Another major shortcoming of current fundamental thinking is its overconcentration on modeling the changes on the Earth's face as the main instrument of discerning global evolution, whereas the studies of deep interior processes causing reorganizations at the upper level of lithosphere are not sufficiently encouraged.

It is believed that answers to these and other unsolved questions can best be achieved through an unbiased balance between rational ideas contained in both modern plate tectonic hypotheses and alternative approaches to interpretation of crustal history based on more traditional concepts.

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References

Daragan-Suschov, Yu.I. & Evdokimov, A.N. (1998): Caledonides of the North Atlantic: fold belt or epiplatform orogen.- III International Conference on Arctic Margins, Celle, Abstracts: 45.

Drachev, S.S. (1998a): Sub-bottom structure of the Laptev Sea.- In: N.A. BOGDANOV & V.E. KHAIN (eds.), Explanatory notes to the Tectonic map of the Kara and Laptev Seas and North Siberia.- Inst. Lithosphere of Marginal and Interior Seas, RAS, Moscow, 87-96 (in Russian).

Drachev, S.S. (1998b): Laptev Sea rifted continental margin: modern knowledge and unsolved questions.- III International Conference on Arctic Margins, Celle, Abstracts: 48-49.

Drachev, S.S., Savostin, L.A., Elistratov, A.V. & Brun, I.E. (1995): New multichannel seismic results from East Siberian Sea: Indigirka Bay - Jeannette Island profile.- Programme and Abstracts, 5th Zonenshain Conf. Plate Tecton., Shirshov Inst. Oceanol. RAS Moscow, 42-43.

Drachev, S.S., Johnson, G.L., McAdoo, D., Laxon, S. & Kassens, H. (1998): Main structural elements of eastern Russian Arctic continental margin derived from satellite gravity and multichannel seismic reflection data.- In: H. KASSENS et al. (eds.). Land-Ocean Systems in the Siberian Arctic: Dynamics and History. Springer Verlag, 667-682.

Glebovsky, V.Yu., Kieniewiez, P.M. & Maschenkov, S.P. (1997): Geophysical signatures of basement topography in the Eastern Barents and Kara Seas.- Technical Abstracts, Int. Geosci. Conf. and Exhibition, European–Asian Geophysical Society / European Association of Geoscientists and Engineers / Society of European Geophysicists, Moscow, 15-18 September 1997, E3.1 (in Russian).

Gramberg, I.S. (1998): Sedimentary basins on continental margins of the World Ocean (age of origination, stages of evolution, scope of oil and gas potential).- Doklady Akad. Nauk, 362 (4), 525-529 (in Russian).

Gramberg, I.S. & Suprunenko, O.I. (1995): The future of the Russian oil and gas industry lies with the Arctic shelf.- Development of the Russian Arctic seas shelf. Abstracts, II Int. Russian Arctic Offshore Conf. RAO-95, State Techn. Univ., St. Petersburg, 18-22 September 1995, 49-52 (in Russian).

Gramberg, I.S. & Suprunenko, O.I. (1998): Barents Sea oil and gas sedimentary basin - major stages of formation.- Development of the Russian Arctic seas shelf. Proc. III Int. Russian Arctic Offshore Conf. RAO-97, Central Res. Inst., St. Petersburg, 23-26 September 1997, part 1, 204-209 (in Russian).

Gramberg, I.S., Kulakov, Yu.N. & Pogrebitsky, Yu.E. (1983): Arctic Oil & Gas Superbasin.- Proc. XI World Petrol. Congr., London, 93-99.

Gramberg, I.S., Piskarev, A.L. & Belyaev, I.V. (1997): Block tectonics of the East Siberian and Chukchi Seas bottom according to gravity and magnetic anomaly analysis.- Doklady Akad. Nauk, 352 (5), 656-659 (in Russian).

Hinz, K., Delisle, G., Cramer, B., Franke, D., Fieguth, U., Lindemann, F., Neben, S., Tostmann, H. & Zeibig, M. (1997): Marine seismic measurements and geoscientific studies on the slope and shelf of the Laptev Sea and east Siberian Sea/Arctic with M.V. "Akademik Lazarev" and I.B. "Kapitan Dranitzin".- Unpubl. Cruise Report, Part II: preliminary scientific results.- BGR Report 116.693: 51-161.

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

Ivanova, N.M., Sekretov, S.B. & Shkarubo, S.I. (1989): Geological structure of the Laptev Sea shelf from seismic data.- Oceanology, XXIX (5), 789-795 (in Russian).

Ivanova, N.M. & Kavun, M.M. (1997): Main geological results of geophysical investigations along geotransects Vaigach I. - Severnaya Zemlya and Yamal P-la - Edge I.- Abstracts, Int. Workshop: Key problems of regional geology of the Barents-Kara shelf and adjacent land, EUROPROBE - VNIIOkeangeologia, St. Petersburg, 13-17 February 1997, 19-20.

Kim, B.I. (1998): The sedimentary cover thickness, structure and petroleum potential of the Laptev Sea shelf.- Programme and Abstracts, 6th Zonenshain Conf. Plate Tecton., Shirshov Inst. Oceanol. RAS, Moscow, 49-50.

Korago, E.A., Kovaleva, G.N. & Pogrebitsky, Yu.E.(1998): The fold system of Novaya Zemlya as an intracratonic continuation of the Urals suture.- III International Conference on Arctic Margins, Celle, Abstracts: 100.

Kos'ko, M.K. (1984): The East Siberian Sea.- In: I.S. GRAMBERG & YU.E. POGREBITSKY (eds.), Geological structure of the USSR and regularities in distribution of mineral resources, vol. 9: The seas of the Soviet Arctic. Leningrad, Nedra, 60-67 (in Russian).

Kos'ko, M.K., Lopatin, B.G. & Ganelin, V.G. (1990): Major geological features of the islands of East Siberian and Chukchi Seas and the northern coast of Chukotka.- Marine Geol. 93: 349-367.

Kos'ko, M.K., Cecile, M.P., Harrison, J.C., Ganelin, V.G., Khandoshko, N.V. & Lopatin, B.G. (1993): Geology of Wrangel Island, between Chukchi and East Siberian Seas, Northeastern Russia.- Geol. Surv. Canada Bull. 461, 102 pp.

Ostisty, B.K. & Fedorovsky, Yu.F. (1993): Main results of oil and gas prospecting in the Barents and Kara Seas inspire optimism.- Arctic Geology and Petroleum Potential. Proc. Norw. Petrol. Soc. Conf., Tromso, 15-17 August 1990, 243-252.

Pavlenkin, A.D., Poselov, V.A., Daragan-Suscheva, L.A., Pogrebitsky, Yu.E., Butsenko, V.V. & Bulatkina, K.I. (1998): Lithospheric structure of the Barents shelf and the continent-ocean passive margin transition zones from DSS data.- In: F.P. MITROFANOV & N.V. SHAROV (eds.). Seismogeological Model of the Lithosphere of Northern Europe: the Barents Region, Part 2, Chapt. 7, Geol. Inst. Kola Sci. Center RAS, Apatity, 5-40 (in Russian).

Pogrebitsky, Yu.E. (1984): The Arctic segment of the Earth and its tectonic evolution.- In: I.S. GRAMBERG & YU.E. POGREBITSKY (eds.). Geological structure of the USSR and regularities in distribution of mineral resources, vol. 9: The seas of the Soviet Arctic. Leningrad, Nedra, 246-253 (in Russian).

Poselov, V.A., Butzenko, V.V., Grikurov. G.E. & Pavlenkin, A.D. (1998): Seismic profile between the Gakkel and Lomonosov Ridges and its bearing on the nature of the Eurasia basin.- III International Conference on Arctic Margins, Celle, Abstracts: 149.

Shipilov, E.V., Kuz'michev, F/D. & Bogdanov. N.A. (1998): Sub-bottom structure of the Kara Sea: South Kara Basin- In: N.A. BOGDANOV & V.E. KHAIN (eds.), Explanatory notes to the Tectonic map of the Kara and Laptev Seas and North Siberia, Inst. Lithosphere of Marginal and Interior Seas, RAS, Moscow, 77-81 (in Russian).

Ustritsky, V.I. (1985): On the relationships between the Urals, Pai-Khoi, Novaya Zemlya and Taimyr.- Geotectonics.1: 51-61 (in Russian).

Ustritsky, V.I. (1998): The history of development of present geological structure in the Russian Arctic.- Programme and Abstracts, 6th Zonenshain Conf. Plate Tect., Shirshov Inst. Oceanol. RAS, Moscow, 57.

Vinogradov, V.A. (1984): The Laptev Sea.- In: I.S. GRAMBERG & YU.E. POGREBITSKY (eds.), Geological structure of the USSR and regularities in distribution of mineral resources, vol. 9: The seas of the Soviet Arctic. Leningrad, Nedra, 60-67 (in Russian).