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Russian Arctic Sedimentary Megabasin and Its Reflection in Oil and Gas Properties of Its Borderlands

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THEME 9: Hydrocarbon Potential of the Eurasian Margins: Geological and Tectonic Factors

Summary: The Russian Arctic shelf and continental slope belongs to the giant Arctic superbasin. This superbasin can be divided into an eastern and a western segment with an apparently different structure and history. The Norvegian - Barents platform is the main element of the western segment. Several large sedimentary basins filled with kilometres of Paleozoic and Mesozoic strata had formed here. Seismic reflection data and the geology of neighbouring areas show that the platform apparently existed from the earliest Paleozoic. A significant stage in the development of the western segment was the Permian to Triassic, when intensive subsidence and corresponding accumulation of sediments took place. It was the principal period for organic material transformation and hydrocarbon generation. The source rocks subsided into the gas window very fast. Gas production in the deep zones of the basins resulted in the formation of supergiant gas-condensate fields in the Barents and Karsa seas. Evidence for the existence of oil fields at earlier times in the periphery of the basins has been discovered recently.

The eastern segment is separated from its western counterpart by the Lomonosov ridge. The situation is different in the eastern segment, which has a complex structure consisting of blocks and linear zones. Most blocks have a Precambrian basement that has been reactivated in the Mesozoic. These blocks form a tectonic collage of massifs divided by mobile linear zones.

Sedimentary basin development was controlled by processes of reconstruction of the continental crust, the Mesozoic tectogenesis playing a significant role. Analyses of seismic data show six main successive units in the northern part of the Chukchi Sea, with a total thickness exceeding 10 km. The lowermost unit F apparently has an Upper Paleozoic - Triassic age. The next complex E has the greatest thickness, exceeding 3-4 km. It consists of terrigenous material. After a regression the lacustrine and shelly marine strata (unit D) were deposited. The complexes E and D apparently have a Jurassic - Cretaceous age. The units C and B represent alluvial or paralic deposits and have a Paleogene - Lower Miocene age. The unit A shows the character of strata deposited in modern marine conditions. In the southern part of the Chukchi Sea, the three lower complexes are included in the basement or transitional zone.

The Russian Artic basins have a great hydrocarbon resource potential.

THE RUSSIAN SHELF AND NEIGBOURING AREAS – INTRODUCTION

The western and eastern part of the Russian shelf belongs to the Arctic superbasin. The history and structure of these two segments divided by the Lomonosov Ridge are different. The western segment is separated from the eastern segment by the subsea Lomonosov Ridge. The eastern segment consists of the Lomonosov and Mendeleev ridges separated by the Makarov and Tollya depressions (Fig. 1).

The western segment consists of the Norvegian-Barents platform, and the Nansen and Amundsen deepwater depressions which are separated by the Gakkel Ridge rift. The platform underwent rifting processes. The significant rifting, fast subsidence and corresponding accumulation of sediments took place at the end of Paleozoic and beginning of Mesozoic eras, so that there are several large basins filled with kilometres of Paleozoic and Mesozoic sediments. These events had important consequences for hydrocarbon generation, distribution, and accumulations. The Mesozoic strata have been drilled and studied, and giant gas-condensate fields were discovered. The upper Paleozoic part of the succession is supposedly oil bearing, while the upper part of the Mesozoic strata is gas bearing.

The eastern segment including the Asian-Alaskan sector was located on a continental crust first. Then destruction by rigid mass processes played a significant role. Now the eastern part of the Russian Arctic shelf is a collage of rigid blocks divided by folded Mesozoic zones. In the sedimentary basins, Mesozoic and Cenozoic sediments attain the greatest thickness of the succession. Analogs to the oil bearing structures of Alaska are present here. Different development histories in the western and eastern segments are the reason why some areas are gas bearing and others oil bearing.

The Western Segment

A marine terrigenous-carbonate Paleozoic complex covers wide areas on the Barents shelf. Lacustrine and alluvial deposits are found along the shelf periphery in Svalbard (Spitsbergen) in the northwest and Pechora Sea in the south. Paleozoic rocks on the shelf were deposited as platform facies, which was followed by Late Paleozoic - Triassic rifting. I. Gramberg noted that the Permian-Triassic rifting manifested the reconstruction of the Earth's Crust between the Paleozoic and Mesozoic eras (GRAMBERG 1997). Rifting is suggested by magnetic anomalies identified in the meridional zone of the Barents Sea (FICHLER et al. 1997). Simultaneously folding and orogenesis was initiated in the Urals and West Siberian regions. The denudation of associated rising mountains in these zones provided abundant quantities of terrigenous material. Streams from the new uplifts flowed westward and northward filling the South and North Barents depressions and Karsa Sea depression in Permian and Triassic time. This was a significant stage in the development of the basins. The thickness of Permian and Triassic deposits in the Barents Sea is as much as 9-10 km.

One significant event was the forming of the Novaya Zemlya

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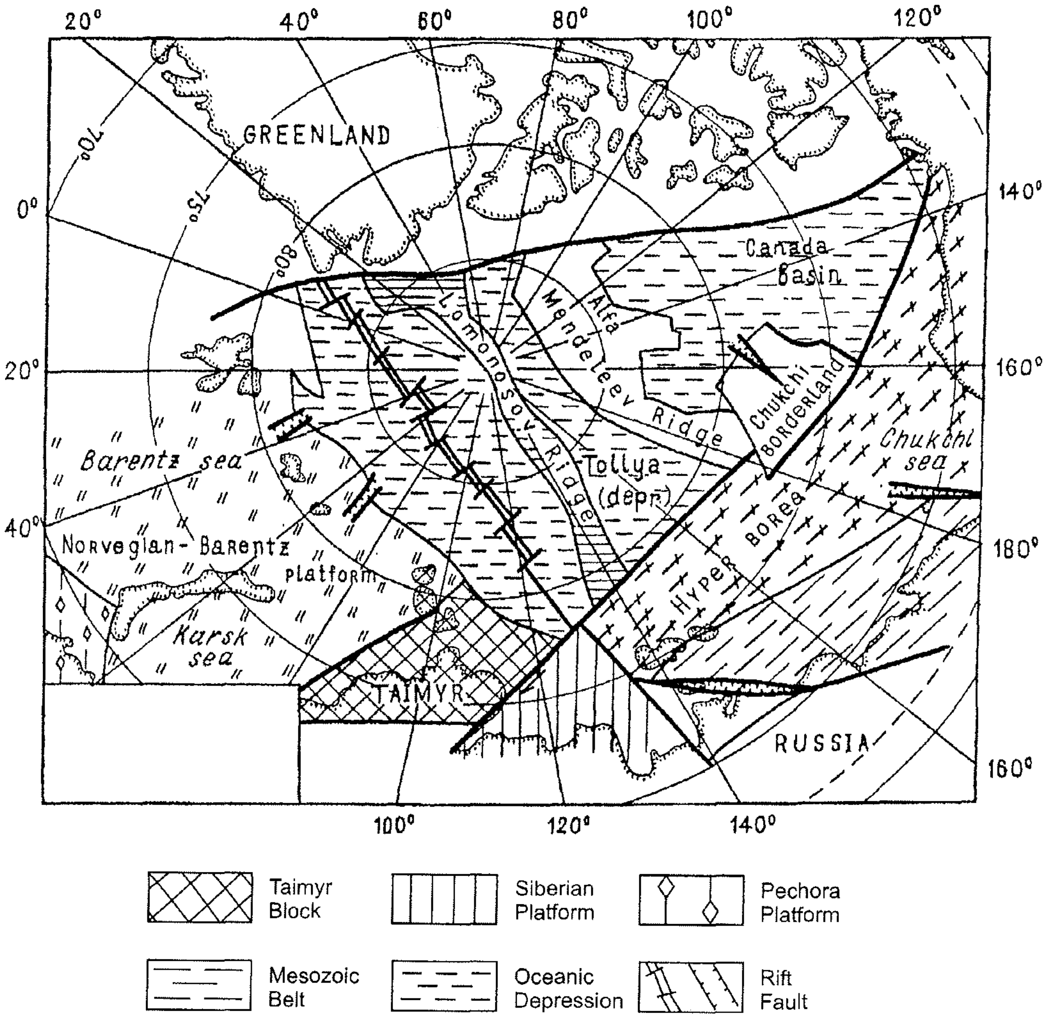

Fig. 1: Tectonic sketch of the Arctic megabasin

arc (now archipelago) at the end of the Triassic. As MARTIROSYAN et al. (1998) noted, the Late Paleozoic - Early Mesozoic uplift of the Urals and the Novaya Zemlya orogen changed the regional picture dramatically. The influx of terrigenous material into the Barents depressions was stopped by this barrier, but material continued to flow into the Kara Sea depression. Because of strong subsidence and sediment accumulation and organic transformation there was a period of significant petroleum hydrocarbon generation at depths corresponding to the „oil window". Following this the source rocks subsided and the maturation level increased into the gas window and gas generation dominated at these deeper levels.

Gas production in deep zones of the basins resulted in the formation of supergiant gas-condensate fields in central parts of the basins like Shtokmanskoe and others in the Barents Sea, Leningradskoe and Rusanovskoe in the Kara Sea (Fig. 2). Oil on the other hand migrated to the basin peripheries to form deposits in the Pechora Sea and Timan- Pechora depression onshore. Evidence of previous oil bearing strata are found on Svalbard, Franz-Joseph Islands and Novaya Zemlya where numerous places with petroleum saturated rocks are known (KLUBOV 1997).

The Eastern Segment

The situation is different in the eastern polar segment, which has a complex structure consisting of blocks and linear zones (GRAMBERG et al. 1997). These blocks are predominantly rigid massifs of different age and structure surrounded by fold belts. The Chukchi-Eskimo massif is the oldest and most blocks have a Precambrian basement that has been reactivated in the Mesozoic. Some of them had been rifted away from the ancestral Hyperborean platform or from the North American craton at different times. These blocks generally moved from east to west. They had formed a tectonic collage of massifs divided by mobile linear zones filled with Upper Mesozoic and Cenozoic deposits.

The block embraced by Taimyr and the southern part of Severnaya Zemlya archipelago played an important role as a tectonic boundary between the western and eastern parts of the Russian Arctic. The Precambrian basement of the North Taimyr zone began to rise and Paleozoic strata overlying the basement on the Severnaya Zemlya archipelago were weakly deformed. It may have been the margin of the Barents platform which was later destructed. From the end of Devonian times on, the North Taimyr block stood high above large depressions on the east and west.

The eastern part of the Russian sector is less well studied than the western part. During the last 60 Ma, rifting was apparently an important process with spreading axes forming the Alfa Ridge, rifts near the New Siberian Islands and Vrangel Island, and the Gakkel Ridge.

The Gakkel rift zone pinches out southward. Apparent continuations of this zone are two branches on the Laptev Sea shelf: the Lena-Taimyr in the west and Oloy in the southeast. Pure spreading dominates the Lena-Taimyr branch, while subhorizontal tension and displacement dominated in the Oloy branch (PISKAREV et al. 1997).

Sedimentary basin development was controlled by processes of reconstruction of the deep continental crust. The Amerasian basin opened in Jurassic-Cretaceous time (150-110 Ma). The Russian part of the Amerasian basin is subdivided into four subbasins, Laptev Sea subbasin, East Siberian Sea subbasin and North- and South-Chukchi Sea subbasins (Fig. 2). The basement in the southwestern part of the Laptev Sea is a continuation of the Siberian platform. The basement under the eastern part of Laptev Sea, and basins east of it, is heterogeneous and was re-activated during the Mesozoic. Sediment fills in these basins vary in age. The majority of basin sequences start with Devonian strata which crop out along the southern periphery of the Amerasian basin, in northern Alaska and Chukotka. Devonian and younger strata are more ubiquitous than older deposits (THURSTON & THEISS 1987). Terrigenous-carbonate rocks of the Upper Devonian, Carboniferous and Permian seem to correlate with the Lower Ellesmerian in Alaska. Upper Permian and Lower Triassic strata are generally terrigenous in composition and are about 3 km or more thick. The clastic material was transported from the north.

The intensive subsidence took place all over the Arctic during the Mesozoic. Tectonic reconstruction resulted in changing terrigenous source areas during the Cretaceous. The bulk of Mesozoic strata are marine and near shore facies of Upper Triassic, Jurassic and Cretaceous ages. Fluvio-deltaic formations are recognized and are the reservoirs in Prudoe Bay oil field of Alaska. Volcanic activities influenced the deposition and character of sedimentary rocks in the Cretaceous and Paleogene.

SEISMIC FACIES UNITS

Figure 3 shows a proposed correlation between sequences of North Alaska and the North Chukchi basin in the Chukchi Sea. There are six units in the North Chukchi basin with a total thickness exceeding 10 km (Fig. 4). The greatest thicknesses are found in the northern part of the Chukchi Sea in the Cretaceous and Jurassic (units F and E). Apparently they consist of predominantly terrigenous material, but they may also include carbonate and volcanic rocks. These deposits may be correlated with the upper Ellesmerian sequence of Alaska.

The Vrangel Island block was elevated at this time, and Jurassic and Cretaceous strata pinch out toward the island. After a regression the lacustrine and shelly marine strata were deposited over a wide area representing marginal marine or nonmarine facies. These strata are in unit D, where low-amplitude parallel reflectors are typical.

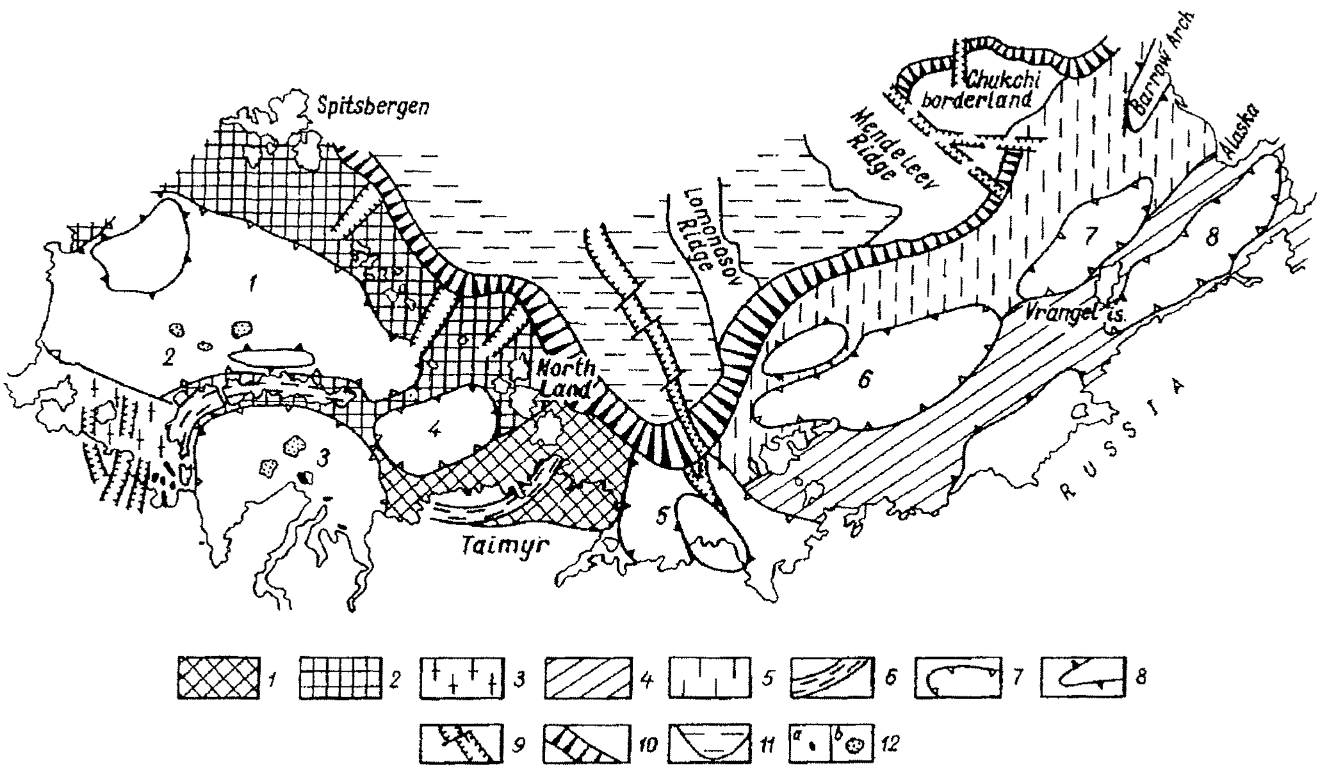

Fig. 2: Big sedimentary basins on Russian Arctic shelf. 1: Taimyr block, 2: Norvegian-Barents platform, 3: Pechora platform, 4: Mesozoic folding zone, 5: Activated platform, 6: Early Kimmerian tectogenesis zones, 7: Sedimentary basins, 8: Big highs, 9: Riftgenesis zones, 10: Continental slope, 11: Deepwater oceanic depressions, 12a: oil and 12b: gas fields. Basins: Barents Sea 1: North Depression, 2: South Depression), 3: Kara Sea, 4: North Kara Sea, 5: Laptev Sea, 6: East Siberian Sea, 7: North Chukchi , 8: South Chukchi (basin Hope in eastern part)

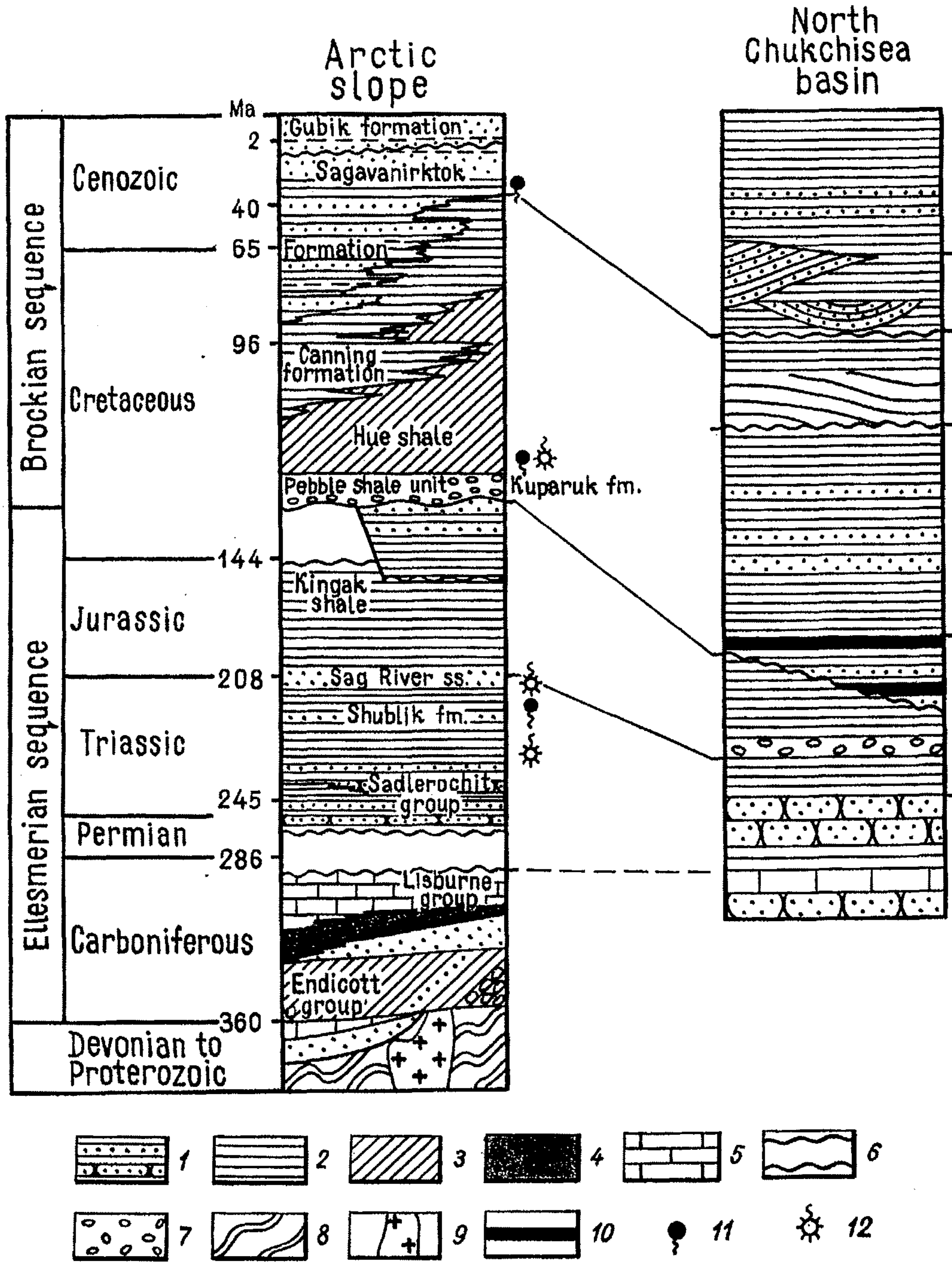

Fig. 3: Correlation scheme of Arctic slope on Alaska and North Chukchi Sea basin. 1: Clastic deposits, 2: Marine clays, 3: Condensated marine shale, 4: Argillite, 5: Limestone and dolomite, 6: Hiatus or erosion, 7: Coarse deposits, 8: Folded basement, 9: Granite, 10: Coal, 11: oil show, 12: gas show.

In the Paleocene there was a transformation in the tectonic regime. Northern Chukotka underwent orogenesis and became a source of terrigenous material. Continental facies is assumed for Latest Eocene and Oligocene strata. A marginal marine lowland was limited by uplift in the South. Rivers cut the previously formed plain delta complexes. The seismic facies configuration is typical of a progradational shelf or platform. Variable seismic characteristics of seismic sequences C and B suggest that they represent an alluvial plain or paralic deposits (Fig. 5). To the north, reflectors in these units become more continuous and parallel indicating that the sequence is possibly marine in that area.

The land area became subdued in Early and Middle Miocene, but was rejuvenated at the end of Miocene. Seismic unit A shows the character of strata deposited in modern marine conditions. The sediments consist mainly of silt, mud and sand, its seismic characteristics suggest a marine depositional setting, the seismic reflectors are parallel and of low-amplitude. The large seismic disruption that begins from unit D and continues into younger units is interpreted to represent either a stream of gas or the margin of a diapir.

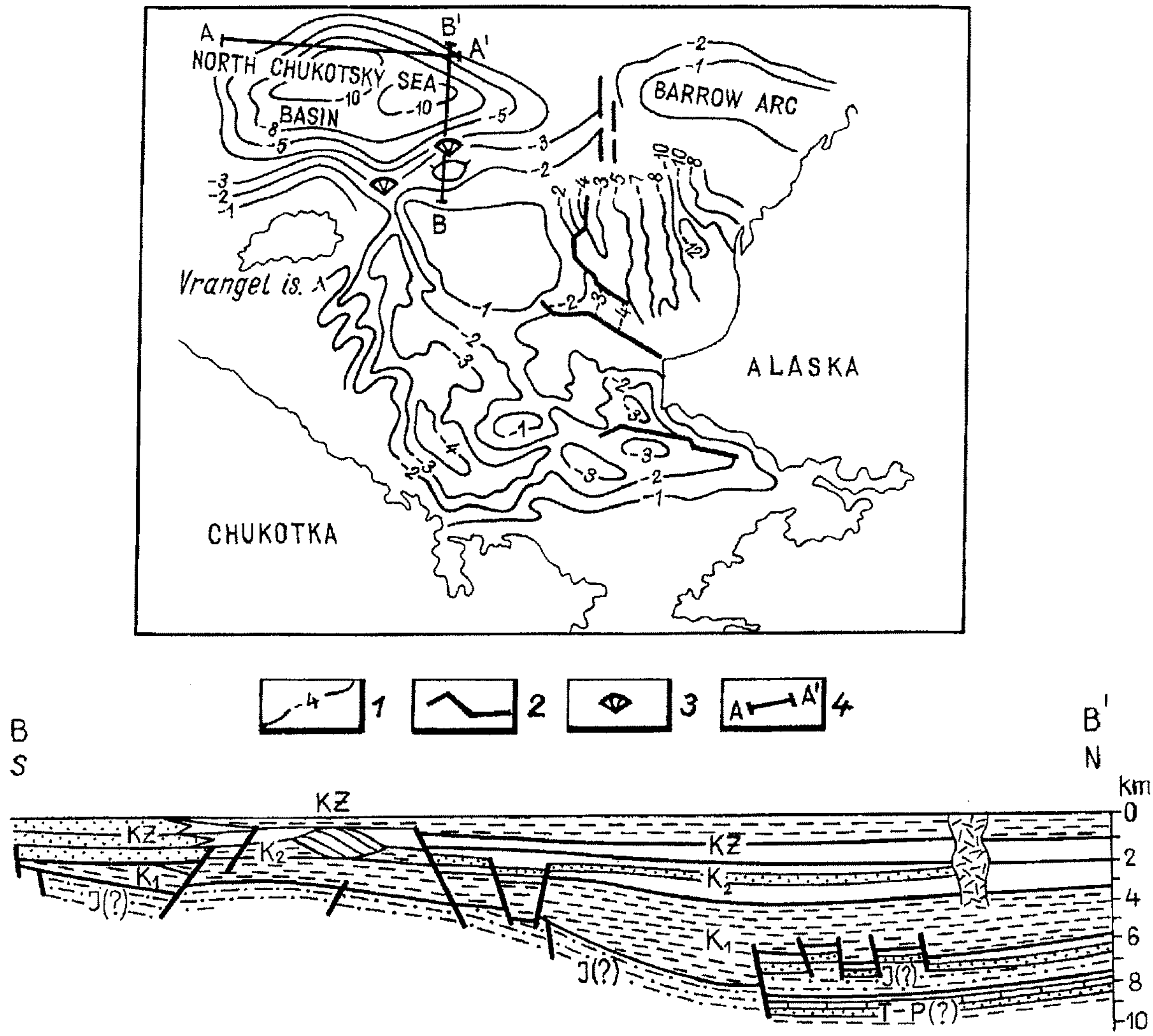

Fig. 4: Structural scheme and geological profile. 1: Acoustic basement counter line, 2: Fault, 3: Delta cone, 4: profile line.

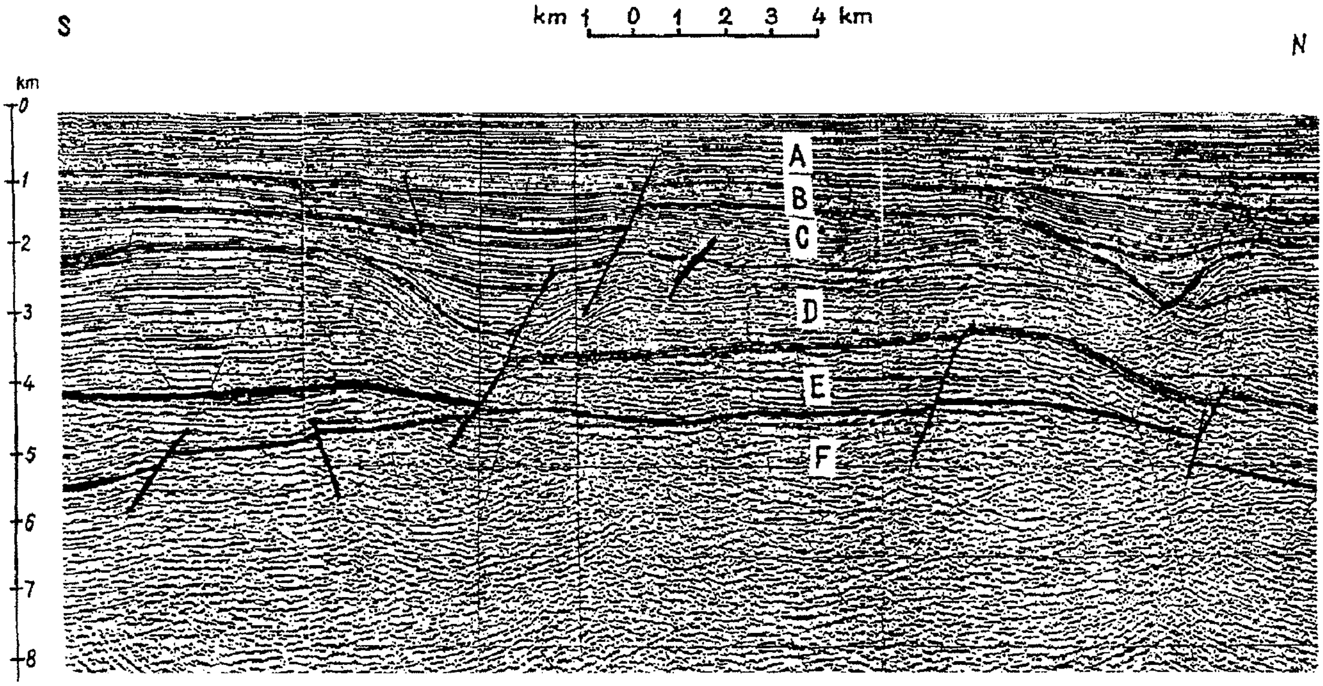

Fig. 5: Fragment of seismic profile showing seismic facies units.

DISCUSSION

The eastern part of the Russian Arctic shelf has a very big potential for hydrocarbons; predominantly oil in upper Paleozoic and Triassic strata and gas in younger deposits. The substantial thickness of sedimentary strata, and a favourable Mesozoic to earliest Paleogene geothermal regime made for a very good environment for hydrocarbons generation.

Conditions in the Russian Arctic sector are different. The western part apparently had a relatively stable platform regime at the beginning of Paleozoic time, but rifting accompanied by intense subsidence took place in the Permian-Triassic. The large quantity of terrigenous material was transported from the east and southwest. It affected hydrocarbon generation and determined the distribution of oil and gas. Gas bearing strata in the upper part of the stratigraphic succession in the central part of the Barents Sea are correlated with oil bearing upper Paleozioc strata in marginal parts of this area (Pechora Sea). A similar situation is interpreted for the margin of the Karsa Sea where the giant gas-condensate fields are located and evidence of previous oil bearing in Paleozoic strata are found on the surrounding islands.

The eastern Russian Arctic shelf is part of the Asian-Alaskan sector of the Arctic where oil fields were found in Alaska. The main stratigraphic complexes are common or similar (ORUDJEVA et al. 1999). There are two wide strips in the Asian-Alaskan sector of the Arctic. One strip which is more gas bearing than oil bearing extends from east to west, i.e. from Cape Lisburn to Gerald Island, Vrangel Island and farther west into the Vostochno-Siberian Sea This strip is dominated by young orogen molasse complexes. The second strip is north of the first one. Here it is believed that there is the possibility of discovering oil in the large sedimentary basins, because they have some similarity to the Alaskan Arctic slope. The difference in structure and sedimentary history determines the main reason for the difference in hydrocarbon occurrences in the west and east. The oil-bearing reservoirs are more common in the east than in the west, particularly on the Russian Arctic shelf. This shelf and continental slope belong to the circum-polar marginal zone system with big oil and gas bearing basins, have high hydrocarbon potential and deserve special attention. The Russian Arctic basins is a great oil and gas province for the twenty-first century.

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