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Abstract

The Russian Western Arctic Basins cover the huge area including the Barents and Kara seas, the western part of the Laptev sea and adjacent territories with some archipelagoes and islands (Spitsbergen, Franz Josef Land, Severnaya Zemlya, Novaya Zemlya, etc.). They comprise the Barents and Kara Basins, the northern areas of the Timan-Pechora Basin, the North West Siberia, including Yamal and Gidan peninsulas and the Yenisey-Khatanga Basin. Within the Russian Western Arctic basins the following main tectonic elements can be identified: extensional depressions (Central-Barents, Yenisei-Khatanga, West Siberia, East Urals) with sedimentary thickness is more than 12- 14 km; platform massives with average thickness of sediments of 4 – 6 km, monoclines and tectonic steps, like transition zones between extensional depressions and platform massives. Western Arctic basins are filled by mainly Palaeozoic and Mesozoic sedimentary successions. In the sedimentary cover of this large region, many common stratigraphic complexes and unconformities can be traced within Palaeozoic and Mesozoic complexes that show similarity of geological conditions of their formation. Analysis of the Russian Western Arctic basins, their structures and hydrocarbon prosepctivity shows the areas, which are favourable for hydrocarbon accumulations. Deep depressions, as areas of long-term and stable sinking, are highly promising zones for the accumulation of predominantly gas fields. They form regional gas accumulation belts, extending for thousands of kilometres, where the largest fields can be expected in the zones of their intersection with the major tectonic elements of another strike. Within the Barents-Kara shelf, the large belt of predominantly gas accumulation extends from the north of the West Siberian province through the South Kara basin and into the Barents Sea. The second potential belt of predominantly gas accumulation may be associated with the North Barents ultra-deep depression. On the flanks of the depressions the sedimentary cover profile does not contain the complete set of oil-and-gas-bearing complexes, identified in the central parts of the extensional depressions. The reservoirs can be filled by HC due to the lateral migration of fluids from the neighbouring kitchens or from their own dominant oil-and-gas source rock strata. For the formation of oil accumulations, the most favourable are platform massifs and ancient uplifts areas.

Introduction.

The Russian Western Arctic Basins cover the huge area including the Barents and Kara seas, the western part of the Laptev sea and adjacent territories with some archipelagoes and islands (Spitsbergen, Franz Josef Land, Severnaya Zemlya, Novaya Zemlya, etc.). They comprise the Barents and Kara Basins, the northern areas of the Timan-Pechora Basin, the North West Siberia, including Yamal and Gidan peninsulas and the Yenisey-Khatanga Basin (Fig.1,2).

Exploration of the Russian West Arctic shelf has been conducted for many years. Geological surveying of the Russian sector of the Barents Sea began in 1970s when the first forecast estimation of oil and gas resources revealed high potential of the Russian Arctic Offshore. In the 1978 government of the USSR appointed Ministry of gas to develop the Arctic shelf with focusing on the exploration in the Barents and Kara Seas. During the decade (1980 to 1990) intensive exploration studies resulted in several discoveries in the Russian Barents sea. In 1980 – 1994 in the course of geological and geophysical surveys in the Barents, Pechora and Kara Seas Russian survey companies, , processed over 300,000 km of seismic profiles, conducted gravity and magnetic maps, revealed 101 prospective areas and discovered 10 oil and gas fields. Since that time 61 wells have been drilled in the Barents and Kara Seas. Most of the wells discovered hydrocarbons.

The first well in the Barents Sea was drilled in 1981 and the second well in 1983 made a discovery in the Murmaskaya prospect. In 1985 Pomorskoye gas field in the south part of the Pechora Sea and Severo-Kildinskoye gas field in the south Barents Sea were discovered. During 1988-1989 the gas condensate fields – Rusanovskoye in the Kara Sea and Shtokmanovskoye in the Barents Sea were discovered. The discovery of the Shtokmanovskoye field with the capacity of 3.9 billion m³ of gas and 37 mln. ton of condensate was of vital significance as it drastically changed the

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attitude of world oil and gas companies towards the Russian Arctic Offshore.

In 1990 two discoveries have been made, Ludlovskoye gas field in the Barents Sea and Leningradskoye gas condensate field in the Kara Sea. In 1992 Ledovoye gas condensate field has been discovered near the Shtokman giant field.

The Prirazlomnoye oil discovery (1989) in the Pechora offshore area was a prominent achievement followed by other oil discoveries; Varadey More (1995), Medyn More (1997) and Dolginskoye (1999). From the period of 1981 – 2008 in the Barents Sea 33 offshore wells were drilled.

Besides exploration wells several parametric wells have been drilled to evaluate stratigraphy, structures and connection between onshore and offshore areas of the Barents Sea. The drilling parametric wells in the archipelagoes of Frantz Josef Land, Svalbard and onshore Pechora Sea gave some ideas on hydrocarbon prospectivity of the whole area. These years Pagurskaya, Severnaya, Kheisa wells were drilled in the Frantz Josef Land. Grumman, Vassdalen, Raddedalen and Iskhegda wells were drilled in the Svalbard archipelago. In the early eighties the first wells were drilled in the mouth of the Pechora Sea.

In the period from 2000 till present day there were no any new discovery in the Barents Sea, mainly because of absence of drilling. Several new well have been drilled in the Shtokman gas condensate field and in the Pechora Sea fields to re-estimate the reserves. The only one new Pakhanchevskaya prospect in the Pechora Sea has been drilled on the Silurian carbonates in in 2009 but the well gave only oil shows.

Structure of the Russian Western Arctic Shelf basins.

Within the Russian Western Arctic basins the first-order tectonic elements can be identified: extensional depressions (Central-Barents, Yenisei-Khatanga, West Siberia, East Urals) with sedimentary thickness is more than 12-14 km; platform massives with average thickness of sediments of 4 – 6 km, monoclines and tectonic steps, like transition zones between extensional depressions and platform massives. In the main tectonic elements the *second order structures* have been formed: aulacogens, grabens and linear inverted swells (Fig.1).

Petroleum potential.

There are not many fields discovered on the Barents-Kara shelf, but all discoveries were made by the first wells and are classified as large and unique gas fields. In the Barents Sea, the unique Shtokman gas-condensate field was discovered, as well as gas-condensate fields Ledovoe, Ludlovskoe, Murmanskoe and North Kildinskoe, the total gas reserves of which are 4.4 tcm. According to official estimates of JSC Gazprom, major part belongs to the unique Shtokman gas field with reserves of over 3.9 tcm of gas and 39 million tons of condensate. In the Kara Sea, Leningradskoe and Rusanovskoe gas-condensate fields are discovered with proven gas reserves of 311 bcm and with expected gas reserves of 1.5 tcm. Today, large gas fields are discovered in the Ob and Taz Bays on the Yamal shelf. Petroleum potential of the offshore area in the Timan-Pechora basin (Pechora Sea) is proved by discoveries of medium-size gas-condensate Pomorskoe and North Gulyaevskoe fields and of large oil fields Prirazlomnoe, Varandey-more, Medynskoe-more and Dolginskoe. The largest reserves of hydrocarbons, mainly gas, are concentrated in the north of Western Siberia, Nadym-Pur-Taz, Yamal and Gydan petroleum regions, where the total proven gas reserves amount to 43.5 tcm, most of which is concentrated in the unique fields.

Large gap in the total proven reserves of the north of Western Siberian province and of the Barents-Kara shelf is related to the exploration maturity of mineral resources. The petroleum potential distribution in the well-explored part of the West Siberian basin shows that the main gas accumulations are concentrated in the extensional parts of the Western Siberian basin. Large and unique accumulations are associated with the structures of linear inverted swells within the extensional sag basins. Unique fields are often concentrated in saddles, formed at the intersection of regional linear depressions of different directions. The examples may be the unique Urenogoy (with initial proven gas reserves of 11.4 tcm) and Yamburg (with initial proven gas reserves of 6.5 tcm) gas fields. These fields are grouped in the area of the intersection of West Siberian deep depression, Yenisei-Khatanga trough and troughs in the East-Pre Ural zone of the Western Siberia. Another group of unique fields is concentrated in the Yamal-Gydan saddle at the intersection of West Siberian depression and extensional structures of the Taimyr fold system. In this zone, the unique Kharasavey gas field is discovered with initial proven gas reserves 1.5 tcm, Tambey group of gas-condensate fields and Bovanenkovo gas-condensate field with initial proven gas reserves of 4.8 tcm. As we move to the marginal zones of the West Siberian basin, the share of liquid hydrocarbons increases in the deep horizons, which is reflected in the gradual replacement of pure gas pools by oil-gas-condensate accumulations. Oil-gas-condensate pools dominate in the fields of the Nurminsky swell in the west and in the fields of the Vankor group. The share of liquid hydrocarbons increases also from north-west to south-east towards the closure zone of deep troughs and decreased depth of the basement (Kharampurskoe, Yuzhno-Russkoe fields). Major oil accumulations of the West Siberian basin are concentrated in the area of Mid-Ob, where the sedimentary cover, including the Palaeozoic strata, rarely exceed 4-6 km, compared with the area of ultra-deep depression, where the total thickness of Palaeozoic-Mesozoic sedimentary cover attains 12-14 km and more.

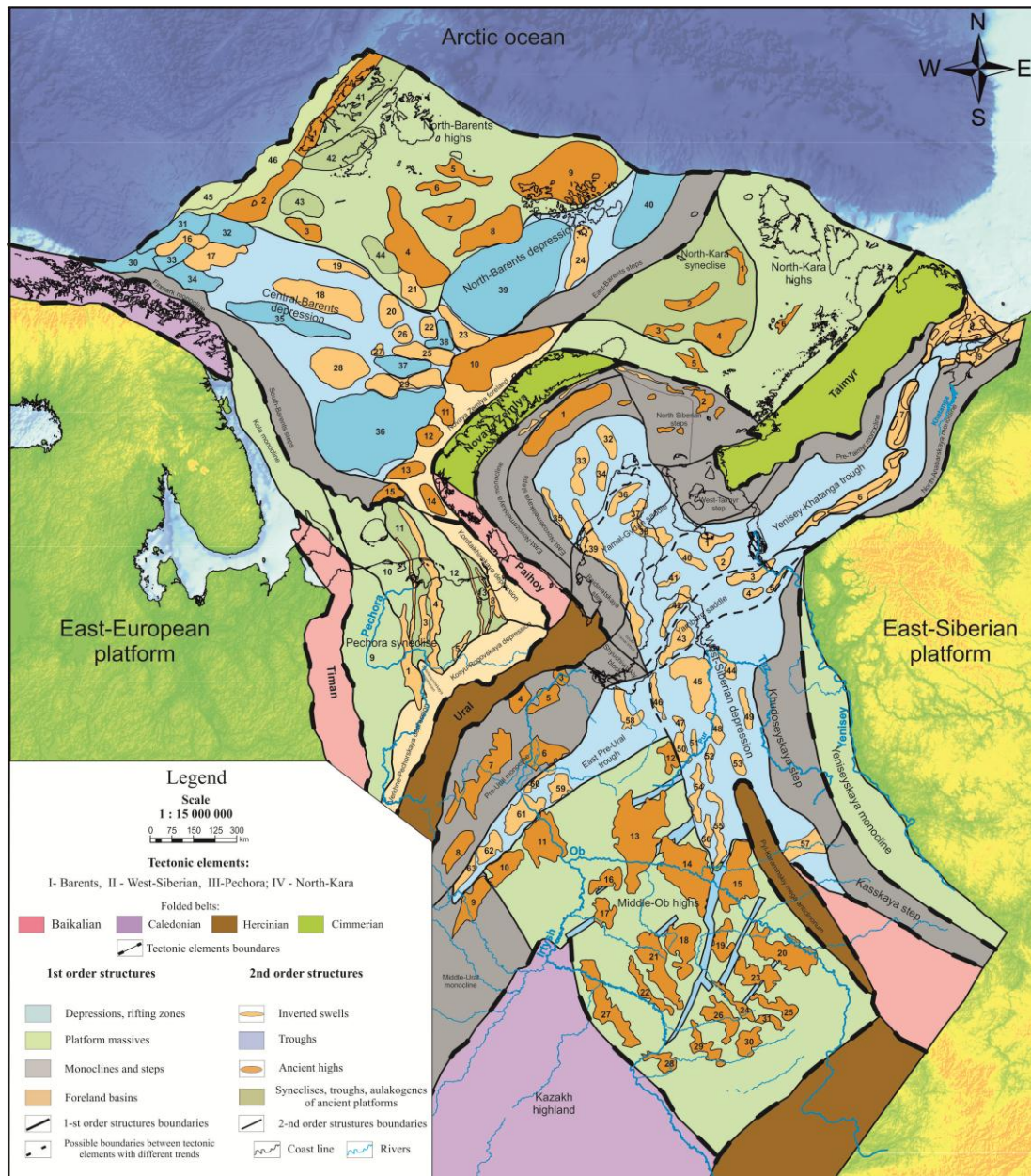


Fig. 1. Main tectonic elements of the north Eurasian basins (Western Arctic and West Siberia).

Modified from Surkov&Zhero (1981), Kontorovich&Surkov (2000), Kontorovich et al. (2001), Skorobogatov et al (2003), Timonin (1998), Ulmishkev (1986), Bogdanov& Khain (1996), Gabrielsen (1990), Johansen (1994), Brekhuntsov, Bitukov (2005), Rudkevich (1986), Kalenich et al. (2004), Martirosyan, Vasilyeva (2004) and Bochkarev 2004.

Legend: Barents Sea: 1 – Western Svalbard uplifts; 2 – Stappen High; 3 – Gardarbanken high; 4 – Vernadskiy high; 5 – Belyi Island High; 6 – Viktoria high; 7- Persey High; 8 – Pinegin high; 9 – Frantz Josef Land high; 10 – Admiraltey high; 11 – Mityushikhinskoye high; 12 – Bezimyannoye high; 13 – Gusinozemelskoye high; 14 – Mezhdusharskoye high; 15 – Severo-Pechorskoye high; 16 – Senja ridge; 17 – Loppa high; 18 – Bjarmeland platform; 19 – Sentralsbanken high; 20 – Mlovitskiy high; 21 – Medvezhinskaya saddle; 22 – Shatskiy swell; 23 – Lunin saddle; 24 – Albano-Gorbovszkaya saddle; 25 – Demidov-Ludlov saddle; 26 – Fersman high; 27 – Demidov high; 28 – Fedinskiy high; 29 – Shtokman saddle; 30 – Harstad basin; 31 – Sorvestnaget basin; 32 – Bjornaya basin; 33 – Tromso basin; 34 – Hammerfest basin; 35 – Nordkapp basin; 36 – South-Barents trough; 37 – North-Shtokman trough; 38 – South-Luninskiy trough; 39 – North-Barents trough; 40 – North-Barents trough; 41 – Devonian graben; 42 – Sturfjord graben; 43 – Sorkapp basin; 44 – Olga trough; 45 – Vestbakken volcanic province; 46 – Hornsun fault zone. **Timan-Pechora:** 1 – Pechora-Kozhva megaswell; 2 – Shapkin-Yurjakha swell; 3 – Layskiy swell; 4 – Kolva swell; 5 – Salyuka swell; 6 – Sorokin swell; 7 – Gamburtsev swell; 8 – Saremboi-Lekkeyaginskiy swell; 9 – Izhma-Pechora depression; 10 – Malozemelsko-Kolguevskaya monocline; 11 – Denisov depression; 12 – Khoreyver depression; 13 – Varandey-Adzva structural zone.

West Siberia: 1 – East-Pre-Novozemelskoe high; 2 – Sverdrupskoe high; 3 – Salekhardskiy high; 4 – Tilminskiy high; 5 – Hashgorskiy swell; 6 – Chylskiy high; 7 – Visimskiy swell; 8 – Pelymskiy high; 9 – Tavdinskiy high; 10 – Shaimskiy swell; 11 – Krasnoleninskiy high; 12 – Severniy high; 13 – Surgutskiy high; 14 – Nizhnevartovskiy high; 15 – Aleksandrovskiy swell; 16 – Salymskiy swell; 17 – Verkhnesalymskiy swell; 18 – Kaimysovskiy high; 19 – Srednevasyuganskiy swell; 20 – Parabelniy swell; 21 – Demyanskiy swell; 22 – Pologrudovskiy swell; 23 – Pudinskiy swell; 24 – Tarskiy swell; 25 – Kazanskiy high; 26 – Mezhdovskiy swell; 27 – Starsoldatskiy swell; 28 – Nizhneomskiy swell; 29 – Tebisskiy swell; 30 – Novotroitskiy high; 31 – Kalganskiy high; 32 – Beloostrovskiy swell; 33 – Rusanovskiy swell; 34 – Skuratovskiy swell; 35 – Obruchevskiy swell; 36 – North-Yamalskiy swell; 37 – Sredne-Yamalskiy swell; 38 – Tambeyskiy swell; 39 – Nurminskiy swell; 40 – Gydanskiy high; 41 – Geofyzicheskiy

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high; 42 – Aderpayutinskiy swell; 43 – Yamburgskiy swell; 44 – Russkiy swell; 45 – Urengoyskiy swell; 46 – Medvezhiy swell; 47 – Yamsoveyskiy swell; 48 – Pyreynaya saddle; 49 – Russko-Chaselskiy swell; 50 – Gubkinskiy swell; 51 – Tarkosalinskiy swell; 52 – Yetypurskiy swell; 53 – Kharampuskiy swell; 54 – Vyangpuskiy swell; 55 – Tagrinskiy swell; 56 – Varyeganskiy swell; 57 – Lineynaya saddle; 58 – Yarudeyskiy swell; 59 – Polyuskiy high; 60 – Radomskiy swell; 61 – Serginskoe high; 62 – Tursunskiy swell; 63 – South-Iusskiy high. *Yenisey-Khatanga*: 1 – Gydoymanskaya group of highs; 2- Salpadinskaya group of highs; 3 – Tanamskiy swell; 4 – Messoyakhskiy swell; 5 – Malokhetskiy swell; 6 – Rassokhinskiy swell; 7 – Balakhninsky swell; 8 – Kiryako-Tasskaya group of highs; 9- Belogoro-Tigyanskaya group of highs.

A similar situation can be observed on the Barents-Kara shelf. In the Kara Sea, Rusanovskoe and Leningradskoe gas fields were discovered in the linear inverted structures of the mostly sagged offshore part of the West Siberian basin. In the Barents Sea, the unique Shtokman field is located in the Central Barents depression, in the zone of its intersection with the North Barents deep trough. Oil hydrocarbons in the Central Barents depression appear in its western closure (new field Skrugard, discovered in 2011 in the Norwegian sector of the Barents Sea on the western slope of the Loppa uplift). Large oil fields are discovered in the offshore extension of the Pechora syncline. Oil shows in the Barents Sea peripheral areas are known in Spitsbergen and Franz Josef Land.

The comparative analysis of the structural layout and distribution of oil and gas fields in the well-studied West Siberian province and on the poorly explored Barents-Kara shelf enables to identify in the basins of Barents and Kara Seas the most promising areas of oil and gas accumulation (Fig. 2). These are, first of all, *predominantly gas-accumulating zones of the central extensional parts of the deep depressions in the Barents and Kara seas*. They form the large oil and gas accumulating belt, which extends from the north of the West Siberian province through the South Kara depression into the Barents Sea and further through the South Barents depression into the Norwegian sector of the Barents Sea, including Nordcap and Hammerfest troughs, Loppa uplift and Harstad trough. The second possible belt of predominantly gas accumulating may be associated with the central part of the North Barents deep depression and the Yenisei-Khatanga trough.

High heat flux and the presence of several source rock strata – dominants in various horizons of the sedimentary cover are responsible for the multi-phase generation of gas and oil hydrocarbons. Gas hydrocarbons predominate, capturing during their migration liquid fractions; they form the intense vertical fluid flow, which is replenished with new portions of hydrocarbons from the upper horizons. Gas accumulates in the inversion structures located directly above the epicentre of the basin sinking. The fields are located in chains within the swells and form linear oil-and-gas accumulating zones. These promising areas in the Central Barents depression should include all inverted structures (Demidov uplift, Shtokman and Ludlovskoe saddles, Fersman uplift). In the offshore area of the West Siberian depression, most promising for gas and gas-condensate fields are the inversion swells (Nurminsky, Rusanovsky, Leningradsky, Beloostrovsky, Anabar, Preobrazhensky, Tambeysky swells and others).

If the volume of hydrocarbons coming from the deep horizons exceeds the rate of their migration and accumulation in the reservoir, then the abnormally high reservoir pressure may arise. The vertical gas flow pushes the liquid hydrocarbons into marginal zones of depression and under conditions favourable for lateral migration of fluids, hydrocarbons from the downwarps of the basin move to the marginal zones, where they undergo the differentiation by phase composition. Liquid hydrocarbons accumulate in pools as dissolved in gas, or as oil rims of gas pools at reduced reservoir pressure. For the formation of gas-oil or oil-gas accumulations, the most favourable are marginal areas of large troughs, zones of tectonic stages or individual arched uplifts within the ultra-deep depressions. If arched uplifts or margins of large deflections experienced a significant rise repeated over time, the quality of caprocks could be disturbed, gas accumulations could dissipate, and oil accumulations could reform. These promising oil structures include the Fedynsky high and margins of the Admiralty swell.

Maximum productivity within the ultra-deep depressions is associated with “*tectonic nodes*”, i.e. areas that fall within the intersection of tectonic elements with different directions, and possibly different ages. These “tectonic nodes” reflect the intersection of zones with high core energy, which causes the abnormality of all the processes occurring in them, including oil-and-gas generation and the subsequent migration of hydrocarbons. These areas include the intersection of the Palaeozoic sublatitudinal Central Barents and of younger North Barents depression. This area includes a unique Shtokman gas field and two large gas fields, Ludlovskoe and Ledovoe. Within the South Kara depression, such tectonic nodes can include the zone of West Siberian ultra-deep depression intersection with the structures of the Eastern Novaya Zemlya zone.

The mapped *uplift zones associated with large platform massifs* are favourable for the formation of mainly oil hydrocarbon accumulations. In these areas, usually one source rock stratum dominates, although other associated strata, rich in organic matter, may be involved into the hydrocarbons generating process. The source rock strata on platform massifs, due to the relatively shallow depth of their occurrence and lower heat flux compared with the ultra-deep depressions, often are still in the oil-and-gas window and generate liquid fluids that accumulate in the vicinity of the kitchen. An example of such a vast area of predominantly oil accumulation, which the unique oil fields are discovered, is the zone of Mid-Ob uplifts in the Western Siberia. In Palaeozoic basins, the oil potential of domed uplifts is proved at the Bolshezemelsky crest of the Timan-Pechora basin. One of the reasons for the lack of gas accumulations in the platform massifs may be the lack of reliable caprock, which ensures gas preserving in the reservoir. Such conditions, favourable for the formation of oil accumulations, can exist in the structures of the North-Barents uplifts zone and of the North Kara plate. On the monocline slopes, the producing interval is thinner, the number and amplitude of structural traps are dramatically reduced; and the formation of hydrocarbon accumulations in non-anticlinal traps becomes more favourable.

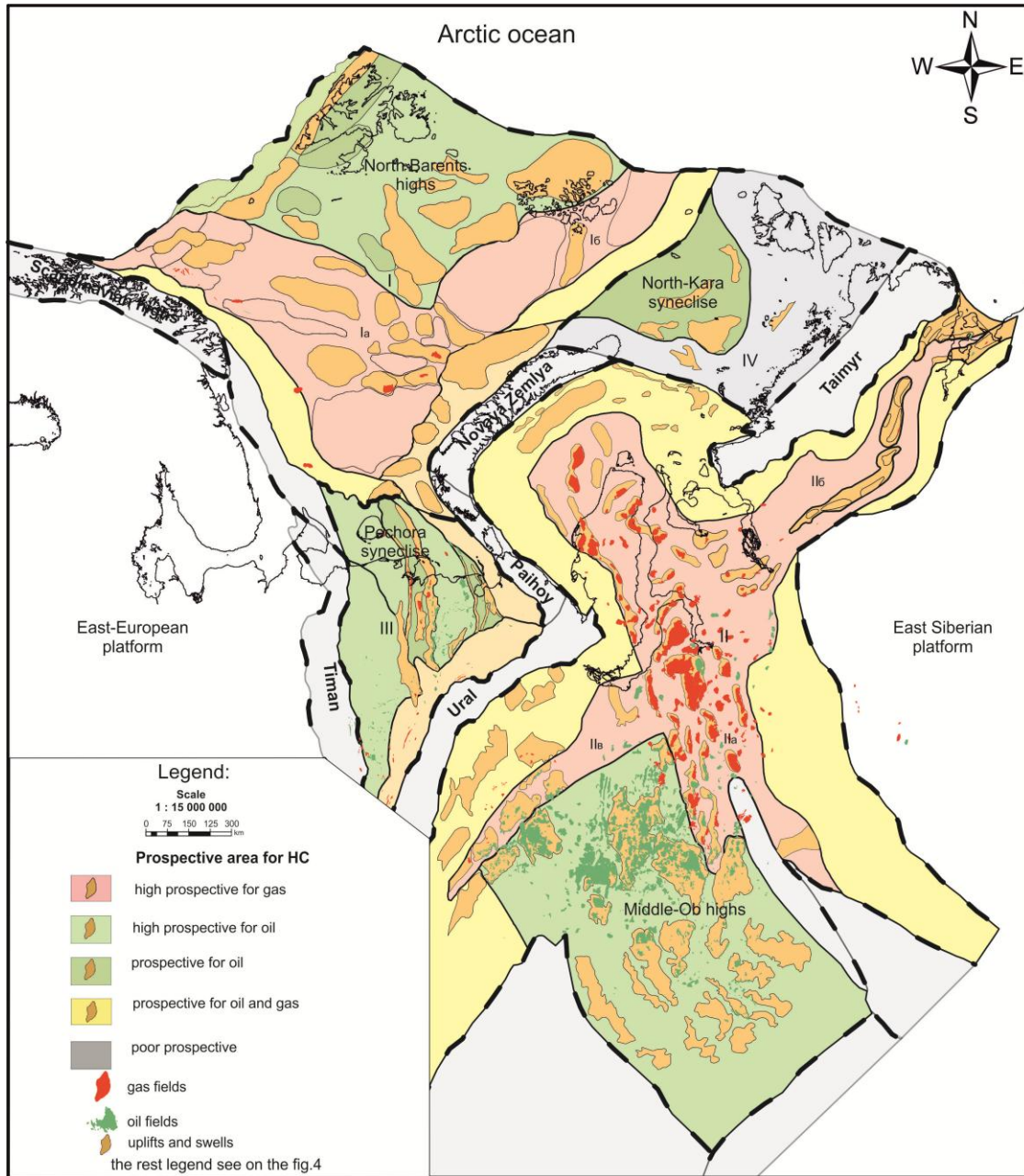


Fig. 2. Oil and gas prospects trends in the Western Arctic basins and adjacent acreages

Prospective plays in the Eastern Barents Sea.

Within the western part of the Barents Sea, drilling was performed in fourteen areas and gas-condensate fields were discovered; the unique Shtokmanovskoye field is among them. Oil and gas-condensate fields were discovered in the Pechora Sea. Drilled wells in the different parts of the Barents Sea determined wide stratigraphic range of oil-and-gas reservoirs.

The discovered gas and gas-condensate reservoirs in the Barents Sea are associated with Jurassic and Triassic reservoirs. Oil bearing capacity of the Pechora Sea is established in the Palaeozoic section and in Triassic rocks. The potential to discover pools in the Palaeozoic reservoirs are also associated with the Barents Sea basin. In the Barents Sea following petroleum complexes are identified: terrigenous-carbonate Silurian-Ordovician, terrigenous Middle Devonian-Lower Frasnian, terrigenous-carbonate Lower Frasnian-Tournaisian, Upper Carboniferous-Lower Permian carbonates; terrigenous complexes of Upper Permian-Triassic, Lower-Middle Jurassic, Lower Cretaceous and Upper Cretaceous.

The Ordovician-Silurian complex occurs predominantly on the flanks of the Barents Sea basin – on the Kola monocline, on the Novaya Zemlya archipelago and in the Timan-Pechora basin. In the Timan-Pechora basin the main producing horizons are associated with carbonate strata. The best reservoirs are associated with the bioherms and biostromes. The reservoirs are dolomitized limestones of Wenlockian and Ludlovian age, fissured-cavernous, fissured-porous and porous types; their open porosity varies from 0.5 to 20.0%, in average 8%, permeability – up to 10 mD. Some permeable beds are 50-100-m thick. Caprocks are shaly-carbonate of the upper part of the Ludlovian stage. According to seismic data, the anomalies of “reef” type are identified. The assumed reef buildups are mapped in the transition zone

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between Timan-Pechora and Barents Sea plates and might be associated mainly with the ancient basement highs.

Lower Devonian – Frasnian complex. Reservoirs of the Lower Devonian-Frasnian age in the Timan-Pechora basin are represented by sandstone horizons in the stratum of shaly low-permeable rocks. Sandstones are poorly sorted, quartzous with various degrees of cementation. Several productive layers are identified in the terrigenous complex under Domanic unconformity of the Late Devonian age, associated with the strata in Eifelian, Givetian and the lower part of Frasnian stages. Their thickness varies from 20 to 70 m, reservoirs porosity – 10-13%, up to 23%, permeability varies from 0.07 to 0.8 mD. The caprock is represented by shaly rocks of the Frasnian age and occurs practically over the whole territory of the Timan-Pechora basin. Reservoirs are massive with tectonic faults and also stratigraphically and lithologically sealed. According to seismic data, there are lithological traps, isolated by local shaly beds and associated with clinofold progradational complexes. The main producing horizon in the Timan-Pechora basin is the Givetian strata. Oil fields Inzyreiskoye, Sarutayuskoy, Rossikhina, Kharyaginskoye et al. are associated with these strata, as well as stratigraphically and lithologically screened (Inzyreiskoye, and Rossikhina fields).

The Upper Frasnian – Lower Carboniferous complex is represented by carbonate strata, predominantly limestones of various types. Reef buildups can form the chains of barrier reefs and isolated bioherm buildups. Reservoirs of this complex in the Timan-Pechora basin are represented by dolomites and limestones with 11-20% porosity, up to 15 mD permeability, which increases sharply in fractured zones. Porosity of the buildups increases to 30% and more. Wells' production rates are from one to several tens of tons per day. The caprock of the pools is beds of shale, dense limestones and dolomites. The bed of Viséan shales, quite consistent in thickness, also can be a good sealing. The main oil pools are established in zones of reef massives and in bioherm bodies (Fig. 3).

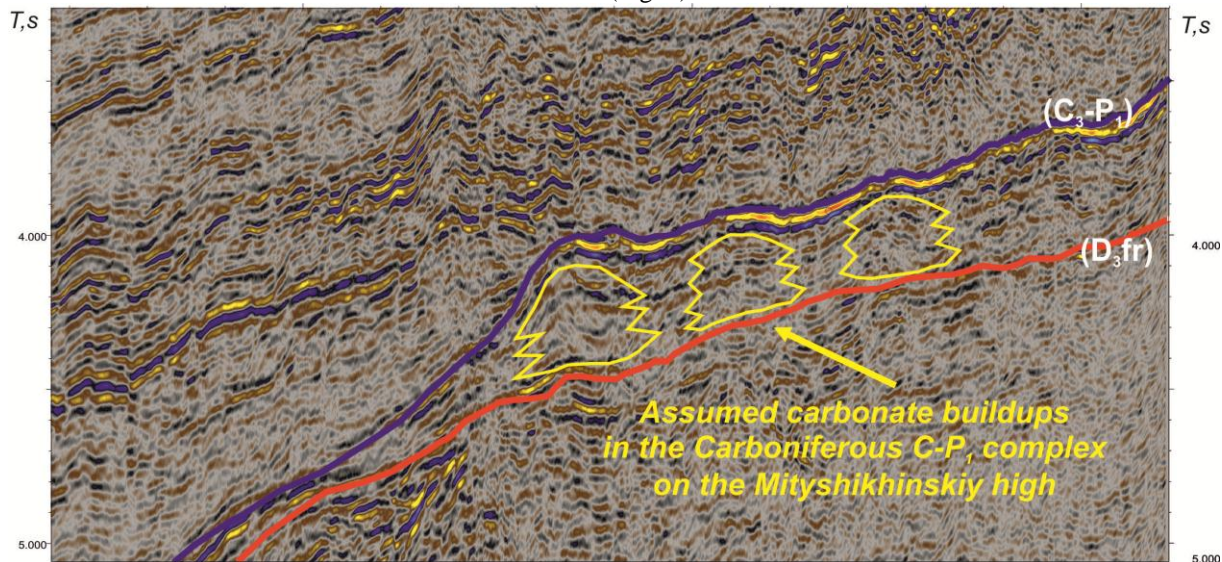


Fig. 3. Carbonate build-ups in the Upper Frasnian – Lower Carboniferous complex.

Upper Carboniferous – Lower Permian carbonate complex. The reservoirs are of massive and layered-massive types. In the western part of the Pechora syncline territory, the chain of Asselian-Sakmarian buildups age was determined, elongated in submeridional direction. It is traced from onshore to the offshore area and to Kolguev Island. Further, it is traced along the Kola monocline, where it is confirmed by the presence of “Reef”-type anomalies on seismic profiles. Oil and gas pools can be associated with this complex in the Pechora Sea in the structures of the inverted swells like Sorokin, Gulyaevsky and Medynsky. In the Admiralteyskiy uplift of the Barents Sea basin only shows (gas with water) are found so far. The Kungurian age sealing occurs over the whole territory of the basin. It is built by predominantly shaly and shaly-silty rocks, sometimes shaly-sulphate (within the western part of the Barents Sea).

Lower – Upper Permian terrigenous petroleum complex consolidates terrigenous strata of Artinskian, Kungurian and Ufimian stages, Lower Permian and Kazanian-Tatartian stages of Middle-Upper Permian series. This petroleum complex has regional occurrence. In the eastern part of the Barents Sea, it is represented by shaly-silty-sandy stratum with variable thickness from 0.4 to 4 km, increasing in some places up to 7 km towards the Novaya Zemlya. Sandstone reservoirs of the Lower – Upper Permian petroleum complex were studied by the wells on the Murmanskaya, Peschanoozerskaya and Admiralteiskaya areas, onshore and offshore wells in the Timan-Pechora basin and outcrops at Novaya Zemlya and Polar Ural. The Lower – Upper Permian petroleum complex at the western part of the Barents Sea shelf is represented by siliceous, shaly-siliceous and siliceous-carbonate strata. It is penetrated by many wells and outcrops at the Spitsbergen Archipelago and on the Nadezhda Island. Several hydrocarbon fields are discovered in the Lower – Upper Permian petroleum complex in the Timan-Pechora petroleum basin. In the Upper Permian strata in wells drilled at the southern flank of the Southern Barents depression and at the Admiralteiskaya area detected the luminescence of hydrocarbons [Semenovich, Nazaruk, 1992]. The Permian reservoirs are represented by quartzo-feldspathic sandstones with intergranular voidness. Sandstones are not consistent and associated mainly with the upper part of the Permian section. Sandstone beds are 20-40 m thick; in the north at Severo-Gulyaevskoye and Dolginskoye fields they are 13-35 m thick.

The porosity varies from 12-13% in the Ufimian strata to 12-17% in the Kazanian-Tatarian strata. Lower porosity of the Upper Permian reservoirs is observed in deeper strata. Shaly Upper Permian and Lower Triassic beds can act as local seals. The pools are structural-lithologic, lithologic and stratigraphic.

The occurrence of Upper Permian sandstone reservoirs in the Barents Sea is closely linked with cyclic changes of the sea level and, accordingly, with the internal structure of the Lower – Upper Permian sedimentary complex. The best reservoir properties are found in sandstones of alluvial fans and in nearshore-marine and shoal-marine sandstones of low stand sea tracts. Both sandstones can be identified in the seismic profiles by bright high-amplitude reflections, generated due to the differences of acoustic impedance of these sandstones and enclosing rocks or their possible saturation by fluids. At that, sandstones of the alluvial fans are less consistent and more fragmented. The occurrence zone of sandstone reservoirs with nearshore-marine and shoal-marine origins of the second sequence low stand sea tracts expands towards the north, compared with the first sequence. This is linked with gradual clinof orm filling of the South Barents and Novaya Zemlya basins.

In the strata of high stand sea tracts, the best reservoir properties characterize shoal-marine sandstones, accumulated on the edge of the shelf. They are identified by bright high-amplitude reflections in the turns of clinof orms (Fig. 4). As for deltaic and shoal-marine reservoirs, they have lower potential, because they are often mudded by clay material or eroded during the subsequent drop of the sea level. However, possible structural and structural-lithologic traps are observed on seismic profiles in the southern part of the pre-Novaya Zemlya uplifts zone. During high stand sea tract, predominantly shaly condensed profile is accumulated in central parts of the basin; the probability to find here good sandstones with high reservoir properties is low. The zone of shoal-marine sandstones in the second sequence of low stand sea tract becomes narrower in the south and somewhat shifts to the north compared with the first sequence. But due to an appearance of additional source area in the east, these sandstones of the second sequence of high stand sea tract are probably widespread in the Novaya Zemlya foredeep.

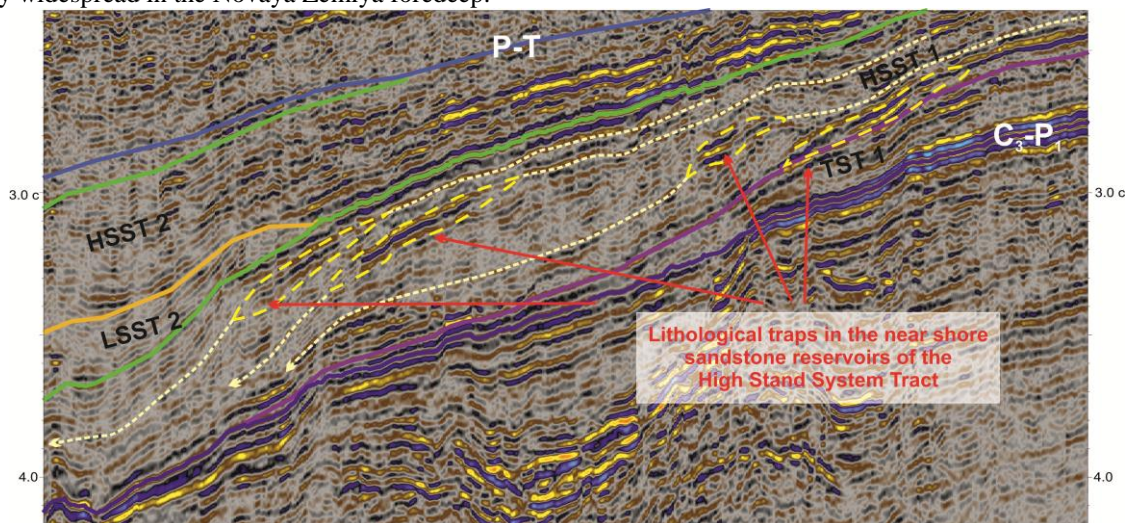


Fig. 4. Lithological traps in the Lower – Upper Permian terrigenous complex.

Triassic petroleum complex. This petroleum complex is also widespread in the Barents Sea and is represented by terrigenous strata of the Triassic age. Its thickness varies from 0.5 km in the Pechora Sea to 5 km in the centre of the South-Barents depression, increasing also to the west from 1.3 to 7.5 km, accordingly. In the north of the Barents Sea this petroleum complex is 4-km thick, and in the Norwegian sector it is 1-3-km thick.

Fields in the Triassic petroleum complex are discovered both in the Timan-Pechora basin and on the Barents Sea shelf. In the Timan-Pechora basin, the main part of the Triassic petroleum complex's pools occurs in the Lower and Middle Triassic reservoirs. Discovered fields are located within high-amplitude onshore swells. The Peschanoozerskoye oil-gas-condensate field, associated with the Peschanoozerskoye high, is discovered on the eastern margin of the Kolguev Island in lenses of greywacke sandstones of the Lower Triassic Charkobozhskaya formation.

On the Russian Barents Sea shelf in the Lower Triassic strata, the Severo-Kildinskoye gas field was discovered, and in the Lower – Middle Triassic sandstones – the Murmansk gas field. Gas composition is methane with low content of non-hydrocarbon components. Gas shows were detected in parametric wells on the Heiss Island (Frantz-Josef Land) and on the Western Spitsbergen. Reservoir properties deteriorate due to plunging of the complex and facies change to prodeltaic and shoal-marine ones. So at the Murmanskaya area, the open porosity of the Upper Triassic sandstones is 14-16% and permeability does not exceed 18-20 mD. Porous and porous-fractured reservoirs are developed in the Upper Triassic strata. The regional seal is not identified in this petroleum complex's strata, but local shaly caprocks are developed [Lindquist, 1999]. The Triassic petroleum complex is characterized by the formation of structural-lithologic and lithologic-stratigraphic traps [Stoupakova, 2001].

The structure of the *Jurassic petroleum complex* is practically uniform over the whole territory of the eastern part of the Barents Sea basin. It occurred in a relatively stable marine environment that enabled forming of reservoir rocks with high and medium storage potential and shaly caprocks. The thickness of the complex is 700-1500 m; it

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regularly increases from south towards the central part of the South Barents depression.

The Jurassic reservoirs within the eastern part of the Barents Sea shelf are studied by wells in Ledovoe, Ludlovskoye, Shokmanovskoye, Arcticheskoye, Fersmanovskoe, Kurentsovskoe, Murmanskoe, Severo-Murmanskoe and Severo-Kildinskoe fields. The regional seal is the Upper Jurassic and partially Lower Cretaceous mudstones. The regional seal is 30-70-m thick in average. Reservoirs have good properties and high potential. Average porosity is 20-25%. Permeability varies within wide limits – from 0.5 to 1.5 mD. Reservoirs are in the anticline traps consistent at long distances and in the lithological traps. Gas and gas-condensate pools are discovered in the strata that are controlled by large anticline structures.

Cretaceous potential petroleum complex is most widely developed within the central part of the offshore area. They are represented by marine sandy-clayish formation. Sandy beds are quite consistent in the lower part of the section/ The most part of sandy varieties concentrates in the foundation of the Aptian stage. The maximum depth of the Cretaceous complex top is 800 m; it is easily accessible by drilling. The petroleum complex thickness varies from 700 to 900 m. Well logging often gives high gas indications. During Luninskaya-1 well drilling, the water-gas blowout happened from 612-m deep regional caprock. The traps of lithologic and structural-lithologic types have insignificant amplitude and wings inclination angles.

Prospective plays in the northern West Siberia basin

The northern West Siberia basin includes Yamal – Gydan petroleum region and its offshore extension. The sedimentary cover of the region is composed of terrigenous rocks of Mesozoic and Cenozoic age. To date, in the offshore area of the southern Kara Sea, only 4 exploratory wells have been drilled (2 in each of Rusanovskaya and Leningradskaya structures), which penetrated the strata of the Lower Cretaceous Barremian section. Results of regional geophysical surveys of the shelf and deep wells drilling along the coast of the Yamal Peninsula show that the Jurassic and Cretaceous oil/gas-bearing strata in the fields of the Nurminsky megaswell and other uplifts extend to the Kara Sea shelf; this confirms the high oil/gas-bearing potential of the offshore area.

Geological and geophysical exploration maturity and infrastructure development of the northern part of Western Siberia is highly non-uniform. The most studied territories are Nadym-Pur-Taz region and Yamal petroleum region, but the latter still remains insufficiently explored and requires additional studies. Most of the fields, discovered in the region, are associated with the reservoirs of the Cretaceous complex. The main volumes of production belong to giant accumulations of the Cenomanian-Aptian and Neocomian complexes, reserves of which appear to be significantly depleted in the next 15-20 years. Geological-geophysical and especially the geochemical maturity of underlying Jurassic, Triassic and Palaeozoic strata remain extremely low. However, depletion of the resource base of the Cretaceous complex in the northern areas of the West Siberian petroleum basin raises the question of the need for new discoveries of hydrocarbons in the lower horizons of the sedimentary cover, and in the first place – in the Jurassic complex. The least studied territories of the Western Siberian petroleum basin are the Gydan petroleum region, the north-east of the Pur-Taz petroleum region (Bolshekhetskaya depression) and the Ust-Yenisei petroleum region, located in the northeast, the most remote area from the existing gas transport infrastructure.

The Jurassic complex. The Jurassic petroleum complex corresponds to a sedimentary cycle during which the sedimentary environment changed from continental to coastal-marine. In the rhythmically-layered a middle Jurassic formation, the combination of reservoirs and seals is a factor which favours hydrocarbon pool formation and preservation. The development of Jurassic sedimentary complexes is the result of alternating transgressive and regressive sedimentation cycles that are determined in the Jurassic strata as alternating shaly and silty-sandy sequences (Fig.5).



Fig. 5. Stratigraphic tie of intra-formation discontinuities in the Jurassic complex

Transgressive system tracts were formed at the sharp rise of the sea level above the shelf edge. They characterize Jurassic transgressions of the marine basin into the drained shelf and into the littoral plain, when the shaly consolidated column was formed in a relatively submerged part of the shelf due to the deficit of sedimentations. The transgressive stages are short in terms of geological time. They are fixed in the wellbore data as sharp changes of lithology and in SP and gamma-ray logs.

Cretaceous complex contains the main reservoirs in the northern West Siberian and Kara Sea basin. The huge resources are associated with Cenomanian and Apt-Albian reservoirs. The Albian-Cenomanian succession comprises a regressive sequence ranging from coastal-marine to deltaic and alluvial facies upwards in the sequence. It is a coal bearing succession represented by irregular interbedded sandstone, siltstone and shaly rocks with prevailing sandy and silty varieties. The reservoirs are sandstone and siltstone; their net gas-saturated thickness varies from 1.2 to 6 m, the average open porosity is 25- 29%. Neocomian clinofolds are potential reservoirs in the northern areas of the West Siberia and Kara basins. Neocomian succession is represented by a rhythmically-layered, pre-coal-bearing, coastal-continental formation.

One of the examples of the multi reservoirs fields is Geophysicheskoye gas condensate field located in the Gydan petroleum region. The western part of the field is located in the Obskaya Bay. The field was discovered in 1975 which in accidental blowout produced the fountain of gas-condensate mixtures with absolutely free flow rate of 519.417 Mcm/day. The maximum penetrated interval is Middle Jurassic strata. The Geophysicheskoye field has a complex geological structure, within which a number of faults are mapped, and therefore there are tectonically screened accumulations. There are 17 accumulations identified in the field: 3 – oil accumulation, 11 – gas accumulations and 3 gas-condensate accumulations in the Cenomanian to Middle Jurassic strata.

The largest reserves of natural gas are in the *Cenomanian reservoirs*, which contains 39% of them. Productive Cenomanian strata are represented by irregular alternating sandstones, silty-shaly rocks. Reservoirs are sandstones and siltstones; their net gas-saturated thickness varies from 22.8 m to 32.4 m; the average open porosity is 29.7%, gas saturation factor is 67.7%. Gas flow rates vary from 210.0 Mcm/day at the 14-mm choke to 310.0 Mcm/day at the 24-mm choke. The reservoir pressure is 9.5-9.7 MPa; this corresponds to the hydrostatic pressure; the reservoir temperature is +24 °C. Methane dominates (98.808%) in the gas composition. The ethane content is 0.097% propane content is 0.007%, nitrogen - 0.741%, carbon dioxide - 0.32%, helium - 0.011%, argon - 0.017%, hydrogen sulphide is absent. The gas density compared to that of air is 0.562. Gas-water contact in the accumulation is accepted at the absolute depth mark -987.8 m. Gas accumulation is massive and waterfowl.

Aptian-Albian reservoirs (The TP group) are represented by interbedded sandstone, siltstone and shaly varieties (Fig. 3.10). Net gas-saturated thickness of the reservoirs varies from 1.0 m to 10.5 m, oil-saturated thickness - from 1.0 m to 3.0 m. The average open porosity is 18-27%; gas saturation factor is 52-65% oil saturation factor is 60%. Gas flow rates during well testing range from 40.5 Mcm/day at the 5-mm choke to 519.417 Mcm/day at the 12 mm choke, oil flow rates range from 2.7 m³/day at a dynamic level 598 m to 4.4 m³/day at a dynamic level of 588 m. The reservoir pressure is 17.1-25.8 MPa, the reservoir temperature is +44...72 °C. The average content of methane is 89.75%, ethane - 5.03%, propane - 1.39%, butanes - 0.38%, higher C₆₊ - 2.78%, nitrogen - 0.25%, carbon dioxide - 0.42%. The gas density compared to that of air is 0.571-0.653. The oil density is 0.843-0.870 g/cm³. Accumulations contain gas, gas condensate and oil; they are massive, waterfowl, sometimes bedded, arched, tectonically and lithologically screened.

The Middle Jurassic reservoirs are represented by interbedded sandstones, siltstones and mudstones. The net gas-saturated thickness of reservoirs is 6.0 m, the average open porosity is 18%, the gas saturation factor is 65%. As a result of J₂ testing, the gas fountain was obtained with flow rate of 68.0 Mcm/day at 15-mm choke. The relative gas density compared to that of air is 0.691. The reservoir temperature is +89 °C. Gas-condensate accumulation is massive, waterfowl.

Yenisei – Khatanga trough is an extensional depression, located in the northern flank of the East Siberia platform. It is considered as a part of the Russian Western Arctic basins because its western and eastern flanks are extended to the Kara and Laptev Seas correspondently. Tectonically it is a foreland of the Taimyr folding belt. Yenisei-Khatanga trough was formed on the top of intra-continental paleorifting system of Pre-Jurassic age. The thickness of sedimentary cover is more than 10 km.

Junction zones between the Taimyr fold system and West-Siberian basin, East Siberian platform and Laptev Sea are of particular interest for hydrocarbon prospectivity of the region. The junction zone between the Taimyr fold system and the West Siberian basin contains the deep rift system filled with Palaeozoic and possibly Riphean-Vendian and Triassic successions. In the junction zone between the Taimyr fold area, East Siberian platform and the Laptev Sea the salt Anabara-Khatanga Palaeozoic basin is located. Of particular interest is the Anabar-Khatanga salt basin, where possible hydrocarbon accumulations are associated with pre-salt and post-salt complexes. In the western part of the Yenisei-Khatanga trough, in addition to prospective Jurassic-Cretaceous reservoirs, a special attention should be paid to the Palaeozoic carbonate build-ups in the junction zone between the Taimyr fold system and the Gydan region of the Western Siberia Basin. For this evaluation the regional seismic lines acquired by Rosnedra (Yuzhmoregeologiya) in 2007 – 2011 have been used.

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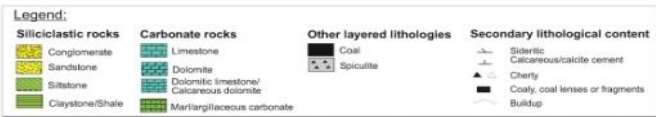
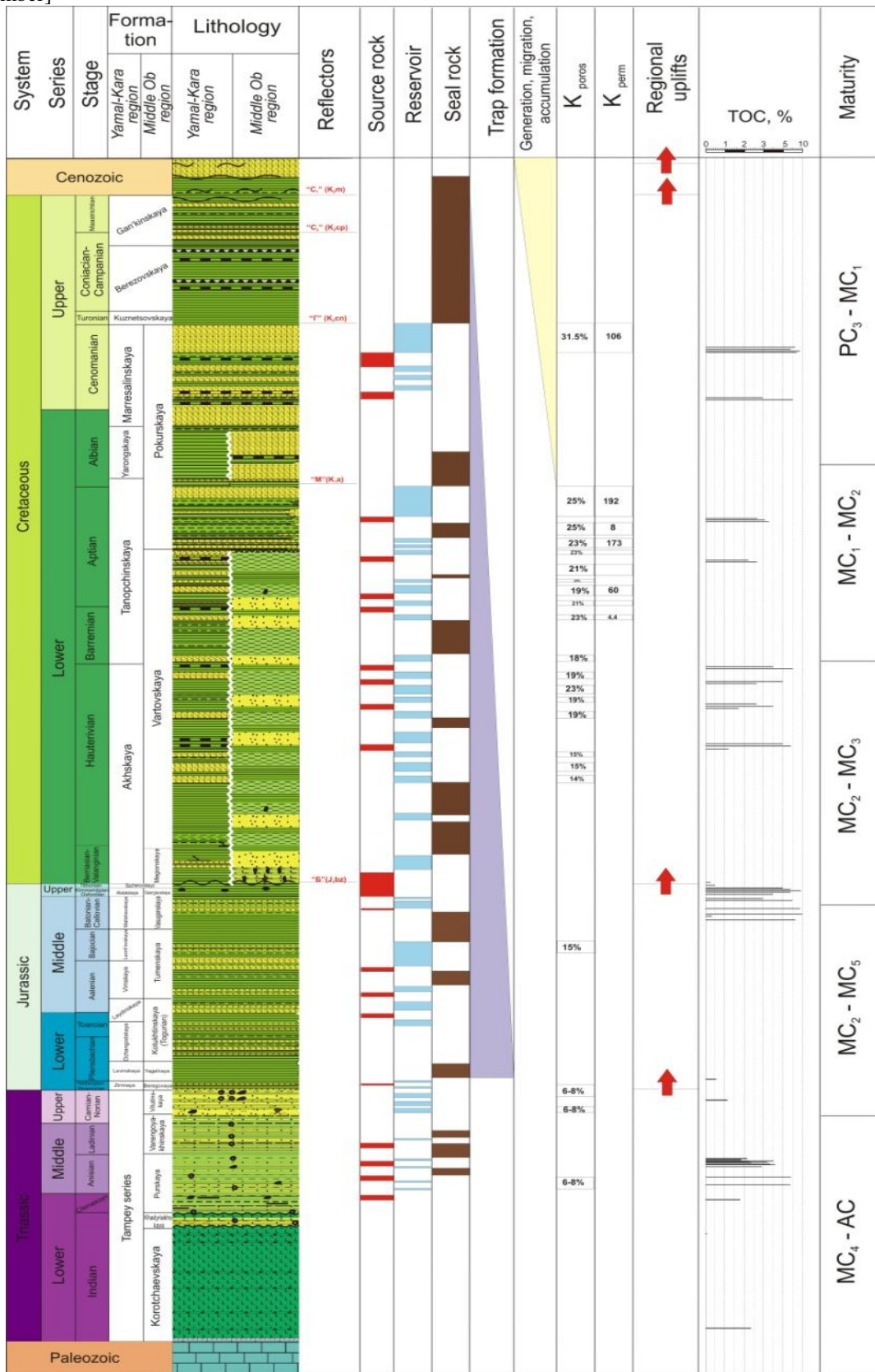


Fig. 6. Composite lithological colu[m] of northern West Siberia with main seals, source rocks and reservoirs

Prospective plays in the offshore Yenisey-Khatanga basin

In the western offshore flank of the Yenisei-Khatanga trough in the Enisei Gulf there is no one well drilled. Age and lithology of major pre-Jurassic SSC identified in the sections of the Yenisei Bay can be assumed only by analogy with the Taimyr sections and based on general concepts concerning the structure and development history of the sedimentary basin. The total thickness of the pre-Jurassic sedimentary complexes is more than 8 – 10 km.

Several regional reflectors can be marked quite confidently at depths of 3 – 5 km, these are the top of carbonate complex, base and top of the Jurassic complex, and a number of reflecting horizons above the top of the carbonate complex. The top of the acoustic basement has block structure and is well traced on seismic. The depth of the top of the acoustic basement ranges from 3 km in elevated northern blocks to 14 – 15 km in the central part of the Palaeozoic trough (Fig.7). Elevated basement blocks are overlaid by the Jurassic-Cretaceous strata that have a specific form of seismic records, similar to the corresponding strata of the Western Siberia and adjacent part of the Yenisei-Khatanga trough. In the area of maximum presence of the Palaeozoic strata, the Jurassic complex reduces in thickness up to complete absence. Age of the basement is taken as Archean-Proterozoic by analogy with the East Siberian platform and the northern slope of the Taimyr Peninsula at the junction with the North Kara syncline.

Dating of the carbonate complex is essential for forecasting of the stratigraphic section in the region. By analogy with sections of the Yenisei-Khatanga trough and of the western Taimyr, the regional reflector, corresponding to the top of the carbonate complex may be associated with the top of the Devonian carbonate platform, represented in most parts of the central and southern Taimyr by shallow-marine detrital dolomitic limestone. Only in the northern Taimyr, the Upper Devonian (Domanic) strata are represented by black and lime shales and by limestones, similar to the section of the Timan-Pechora basin and the eastern part of the Barents Sea.

All build-ups mapped in the area of the Palaeozoic trough could be formed as a barrier structures on the boundary between of shallow-water shelf in the north of the East Siberian platform and of the deep-sea environment that prevailed in the northern Taimyr. The first inversion occurred in the Early Permian time; this is reflected in the regional unconformity. Above the extensional part of the basin tuff molasses complex can be traced by electro-magnetic data. At the boundary of the Triassic-Jurassic time, during one of the stages of the Taimyr fold area formation, western extension of the Taimyr region was uplifted. Most of the inverted swells extend to the west and may have a structural extension in the north of the Western Siberia.

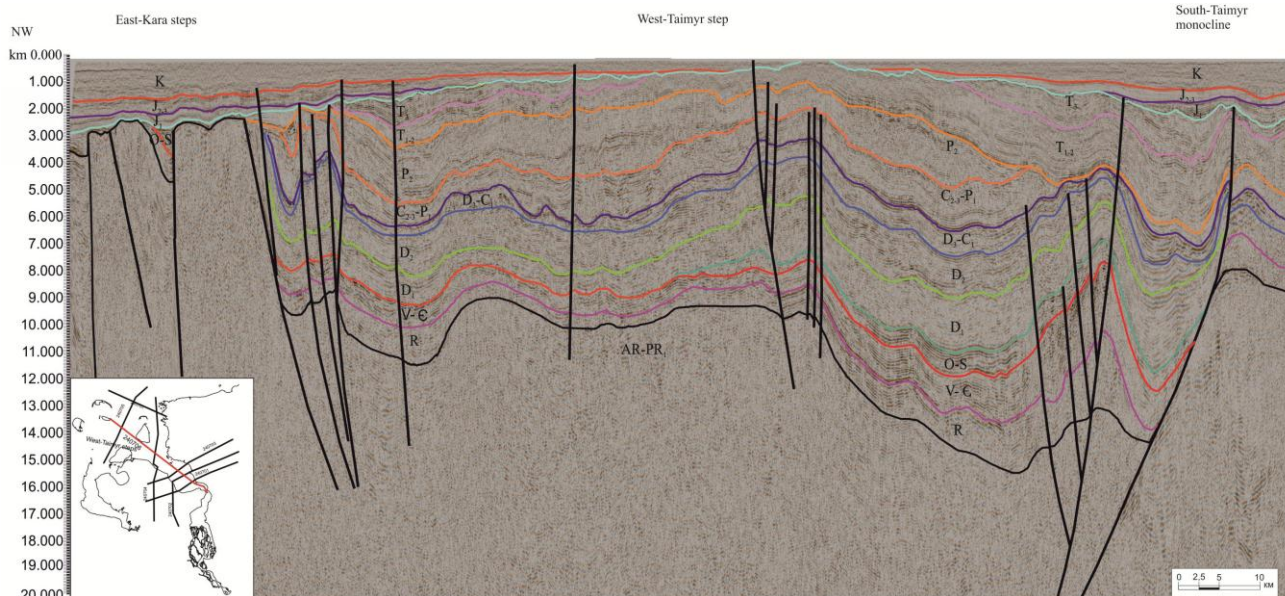


Fig. 7. Geo-seismic profile along the Yenisei Bay (based on Yuzhmorgeologia seismic data)

In the central Palaeozoic zone of the Western Taimyr step, the petroleum potential may be associated with the complex of Palaeozoic strata. It can be considered as a separate Palaeozoic petroleum basin with high prospects for the hydrocarbon accumulations exploration. Potential oil source rock strata of the basin may be Domanic-like facies, widely represented in the northern Taimyr, possible analogues of the Domanic strata of the Timan-Pechora basin. In addition, the strata of Silurian-Lower Devonian and Lower Permian ages may have potential oil source rock properties. Large Devonian carbonate build-ups can be prospective reservoirs; they are drillable at depths of 4 - 5 km. Carbonate build-ups of the barrier reefs type range as a chain along the extension of the Taimyr structures in the direction of the Yamal-Gydan area (Fig.8).

At some profiles "bright spots" can be seen within reef build-ups. In addition to carbonate reservoirs Permian clastic sandstone reservoirs may be interesting in the area of deltaic or nearshore-marine facies. Jurassic reservoirs may be prospective, only where they are located at depths more than 1 km and covered by the regional Upper Jurassic seal. Traps that are favourable for the preservation of accumulations in the Permian and Jurassic potential petroleum complexes will be located within the inversion swells, extending in the direction of the Yamal-Gydan anticline. The northern zone is interesting for hydrocarbons prospecting in the Jurassic-Cretaceous and Palaeozoic sedimentary

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complexes. High potential can be associated with the Jurassic-Cretaceous complex where accumulations can be formed by vertical migration from the lower potential source rock strata, and by lateral migration of hydrocarbons into the Jurassic-Cretaceous reservoirs from adjacent oil kitchens of the South-Kara Basin.

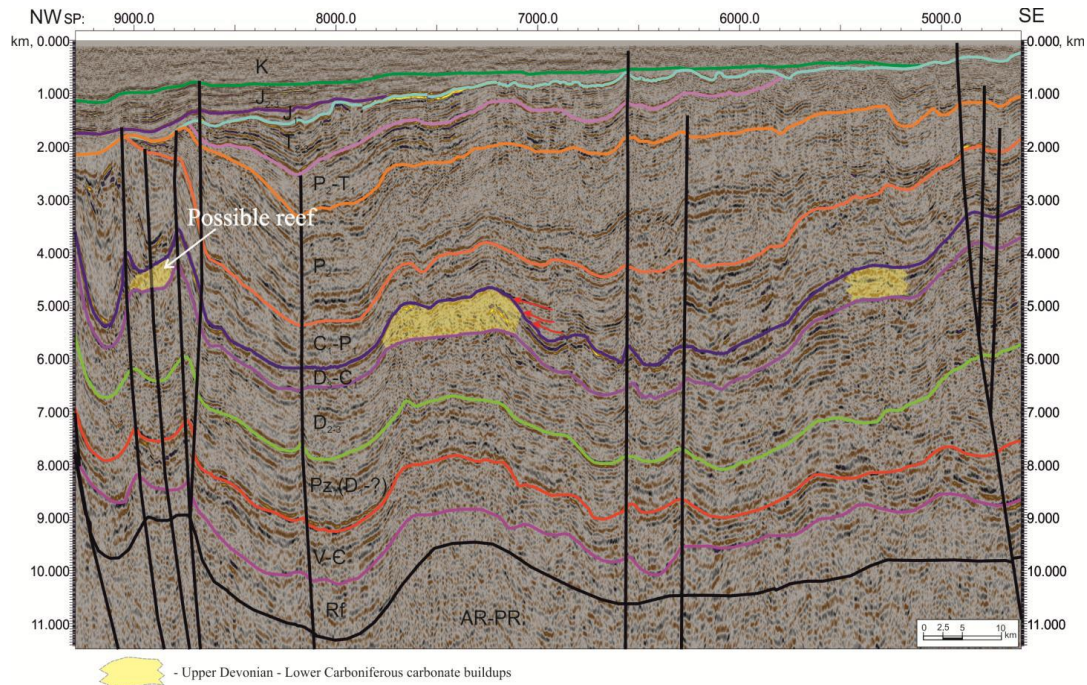


Fig. 8 Carbonate build-ups in the Palaeozoic complex of the Yenisei-Khatanga western flank.

Within the junction zone of the Taimyr fold system and the East Siberian platform, three possible petroleum accumulation zones are also observed: the southern zone of the East Siberian platform, the central zone of the Anabar-Khatanga salt trough and the northern Pre-Taymyr fold-thrust zone of Kiryako-Tasskaya highs. Each of them has its own specifics of the petroleum potential development. In the southern zone, which occupies the northern slope of the Anabar anticline, possible petroleum potential is related mainly to the Riphean-Vendian and Cambrian sedimentation complexes. The properties and composition of the potential source rock strata and the reservoirs may be similar to those, which have already generated hydrocarbon accumulations in the Eastern Siberia. Petroleum potential of halogenic Anabar-Khatanga trough is associated with pre-salt and post-salt sedimentation complexes. The presalt complex probably contains significant potential resources of oil and gas, but they are occurring at the depths more than 5 - 7 km and are classified as difficult to access by drilling. Since salt is an excellent seal, the migration of hydrocarbons from subsalt complex into suprasalt complex is possible only along the salt stocks; such process observed in the Nordvik field, or in the trough margins, significantly complicated by tectonic faults. In the postsalt complex, in addition to hydrocarbons migrated from under the salt, the hydrocarbons generation by potential oil source rocks of Carboniferous and Permian age is also possible. Because of the insufficient knowledge about the petroleum-generating potential of the Upper Palaeozoic coal-bearing strata, the quantities of expected generated hydrocarbons remain a matter of discussion.

The Northern Pre-Taimyr fold-thrust zone of the Kiryako-Tasskaya highs also has some potential for the hydrocarbon accumulation discoveries. Potential source rock strata may occur within the entire section of the sedimentary cover, and hydrocarbon accumulation may form or reform after the final phase of folding at the end of the Cretaceous period in the fold-thrust structures. Thus, the potential to discover new oil and gas accumulation zones is high enough. Their resource potential can be significant and attractive from an economic point of view.

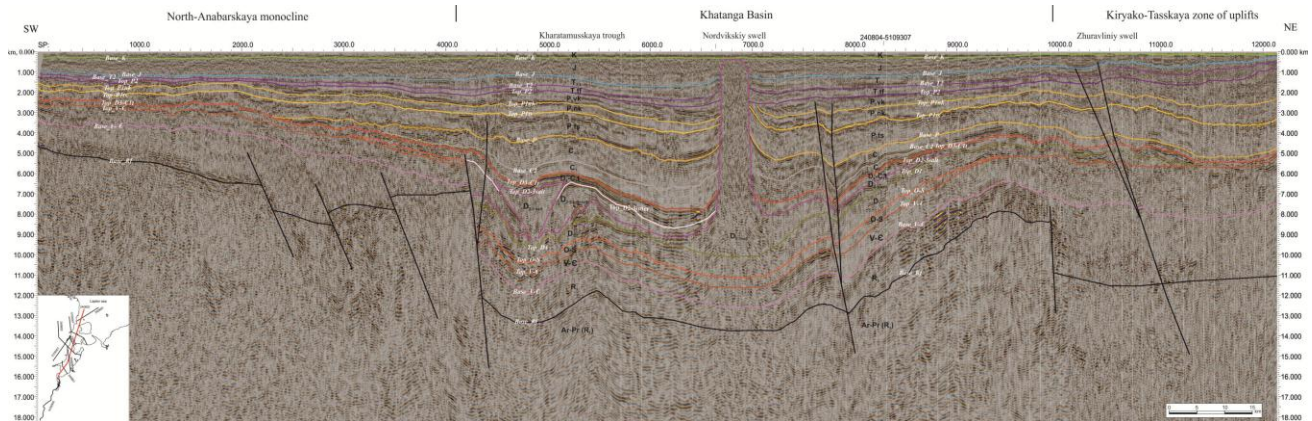


Fig. 9. Geo-seismic profile along the Anabaro-Khatanga Basin (based on Yuzhmorgeologia seismic data)

Conclusion.

Western Arctic basins are filled by mainly Palaeozoic and Mesozoic sedimentary successions. In the sedimentary cover of this large region, many common stratigraphic complexes and unconformities can be traced within Palaeozoic and Mesozoic complexes that show similarity of geological conditions of their formation. Analysis of the Russian Western Arctic basins, their structures and hydrocarbon prosectivity shows the areas, which are favourable for hydrocarbon accumulations. Deep depressions, as areas of long-term and stable sinking, are highly promising zones for the accumulation of predominantly gas fields. They form regional gas accumulation belts, extending for thousands of kilometres, where the largest fields can be expected in the zones of their intersection with the major tectonic elements of another strike. Within the Barents-Kara shelf, the large belt of predominantly gas accumulation extends from the north of the West Siberian province through the South Kara basin and into the Barents Sea. The second potential belt of predominantly gas accumulation may be associated with the North Barents ultra-deep depression. On the flanks of the depressions the sedimentary cover profile does not contain the complete set of oil-and-gas-bearing complexes, identified in the central parts of the extensional depressions. The reservoirs can be filled by HC due to the lateral migration of fluids from the neighbouring kitchens or from their own dominant oil-and-gas source rock strata. For the formation of oil accumulations, the most favourable are platform massifs and ancient uplifts areas.

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