New gas producing regions located in the sea of Okhotsk offshore Russia

Victor Gavrilov, Victor Martinov,
Mikhail Tsemkalo, Valentin Holodilov, Yury Shamalov
(Gubkin RSU of oil and gas, Co Ltd "Gazflot")
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Development of the Russian petroleum production within the Far East is connected with development of hydrocarbon resources of the Sea of Okhotsk with the area of 1580 thousand km^2. Most perspective areas are located within the limits of Okhotsk Sea shelf occupying 520 thousand km^2. General estimation of oil and gas resources of the Sea of Okhotsk, according to various sources, makes 11,890 to 14,5 billion ton of oil equivalent, from which 75% are concentrated within the shelf zone. Therefore in intermediate and distant terms Okhotsk sea shelf becomes the arena of purposeful exploration on oil and gas, as well as the whole development process of marine hydrocarbon deposits.

By present time geological-geophysical level of investigation within the Sea of Okhotsk is rather insignificant, despite more than fifty years' history of its geological-geophysical studying. The density of seismic 2D observations, basic method of investigations, is extremely non-uniform. The most studied is the northeastern shelf of Sakhalin island where the density of seismic surveys reaches 5 km/km^2 in a number of sites. Within the Magadan shelf it amounts 0,7 km/km^2, within the Western Kamchatka – 0,7-0,85 km/km^2. The central marine areas aren't practically studied, they are crossed just by several regional seismic profiles (general density of seismic survey – less than 0,2 km/km^2). Nevertheless, it is considered that the regional stage of geological-geophysical investigations of the Sea of Okhotsk is already finished.

The main achievement of more than a semicentenial history of region studies is creation of the first Russian center of Marine petroleum development in the Far East on the basis of the shelf of Sakhalin island deposits. Its extraction possibilities are estimated in 20 million t of oil and 50 billion m^3 of gas per year. Revealing of large and unique petroleum fields within the Sakhalin shelf proves regional petroleum-bearing capacity of the Sea of Okhotsk.

The Okhotsk Sea region refers to a transitive area from the Euro-Asian continent to the Pacific Ocean. Its borders are: in the north and the west – continental edge volcanic-plutonic belts of Late Cretaceous (Okhotsk-Chukchi and Sikhote-Alin), in the southeast – the Kuril deep-water trough. Deep seismic survey allowed to establish presence of a rather thin (within 10 km) "granite" layer (layer speed - 5,8-5,9 km/s) practically within the whole Okhotsk Sea shelf. The layer is thinning to the south and is incining only within the South Okhotsk Sea depression (fig. 1).

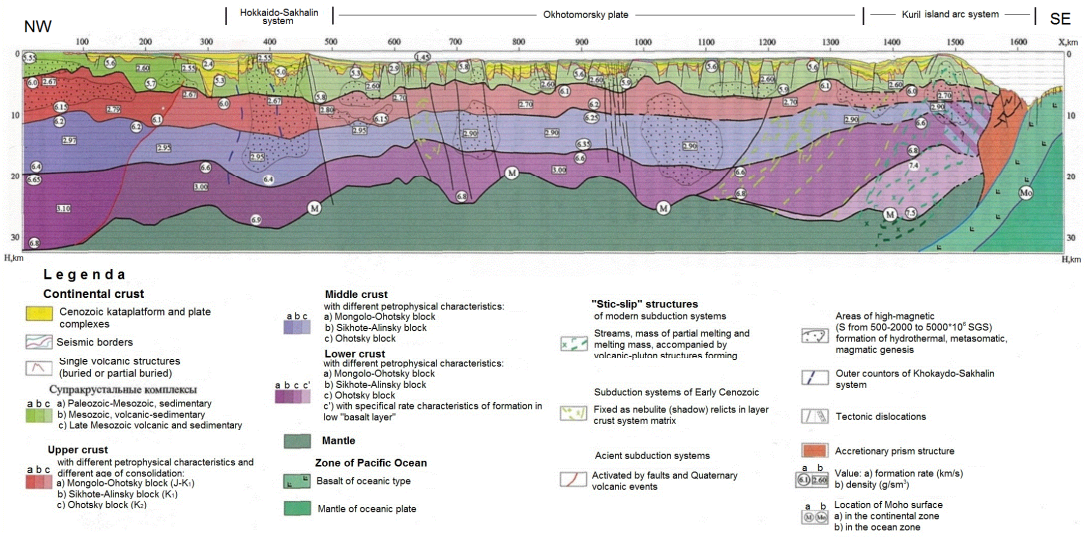

Figure 1 – Geology-geophisical section across Okhotsk sea

Four basic structural-tectonic systems could be allocated within the studied region: Hokkaido-Sakhalin accretion-collision system, Koryak-Kamchatka accretion-collision system, Kuril island arch system and the Okhotsk Sea subcontinental plate (fig. 2).

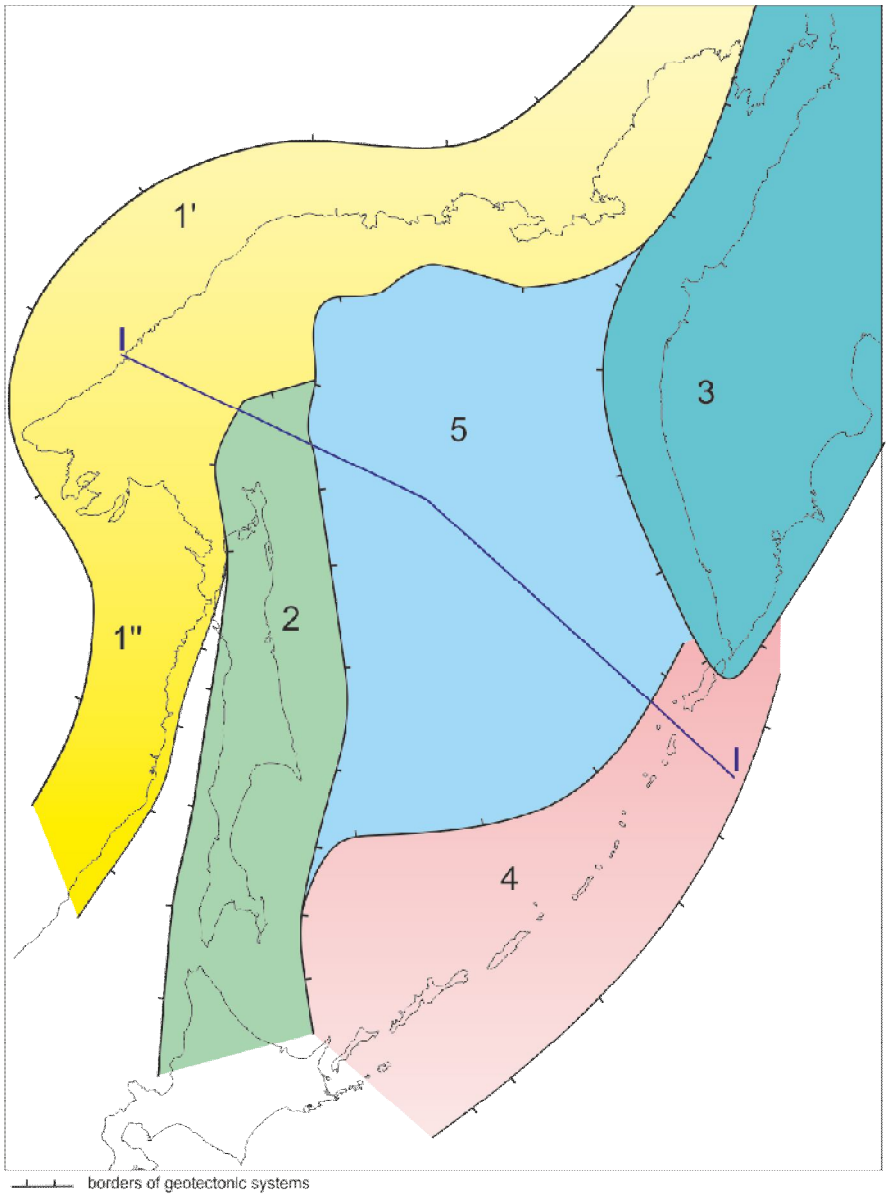

Figure 2 – Principle tectonic scheme of Okhotsk sea

Hokkaido-Sakhalin accretion-collision system includes folded zones of Hokkaido and Sakhalin, is submeridionally extended to the distance of 1500 km. Shifting faults had great value at formation of its structure. It is considered that the modern structural-tectonic skeleton of the system has become a result of shifting movements along the submeridional faults.

Koryak-Kamchatka accretion-collision system – is a complex mountain-folded construction extended from Koryak High in the south to the southern extremity of Kamchatka peninsula to the distance of more than 2000 km. The system includes a number of folded

areas: North Kamchatka, South Kamchatka, East ridges of Kamchatka, West Kamchatka, etc.

Kuril island arch system represents a classical triad: deep-water trough, island arch and back-arch deep-water depression with maximal depths of the Sea of Okhotsk up to 3374 m. The system is morphological expression of subduction zone of the Pacific lithosphere under the Kuril island arch.

The Okhotsk Sea subcontinental plate consists of a complex system of uplifts and graben-like troughs. The plate basement is composed of metamorphic formations of Carboniferous to Triassic age. It is overlain by rather thin cover (within 2 km) represented by volcanic-sedimentary and siliceous rocks, in a number of places broken by granite intrusions. It is considered that the modern Okhotsk Sea plate consists of several terrains, largest of which is the Central Okhotsk uplift (arch). Moving of the plate to the Late Cretaceous edge of the Asian continent roused formation of a modern transition zone.

The following types of sedimentary basins are allocated in the Okhotsk Sea region:

- Continental;
- Folded (edge-like and periclinal troughs);
- Intra-mountain depressions;
- Deep-marine depressions;
- Grabens inside the Okhotsk Sea plate;
- Back-arch depressions (South-Okhotsk);
- Intra-arch troughs.

From the point of view of petroleum content continental and folded basins represent the greatest interest.

Continental basins (Gizhigin, North Okhotsk, Lisyansk, Kuhtujsk and Shantarsk troughs) are extended along the Magadan coast to the distance of around 1500 km. These are the post-collision troughs formed at the folded basement of Mesozoic age. The sedimentary cover has a two-story structure: syn-rift (Paleocene – Lower Oligocene) and post-rift (Upper Oligocene – Quaternary) complexes. The general thickness of the cover reaches 10 km. Well Magadan-1 drilled within the border part revealed the basement rocks presented mainly by tuffs of the Okhotsk-Chukchi volcanic-plutonic belt. The sedimentary cover consists of intercalation of silica clays, diatomites and terrigenous material with prolayers of coals. Satisfactory reservoirs have not been revealed in the well. The similar section was revealed by wells Magadan-2 and Hmitjevsk. Practical absence of reservoirs, difficult natural-climatic conditions essentially reduce the prospects of petroleum-bearing capacity of the continental basins.

Folded basins represented by edge-like and periclinal troughs (North Sakhalin and Okhotsk - Western Kamchatka basins), have asymmetric structure: the internal border is abrupt and folded, external (more marine) is flat and also less deployed. The sedimentary cover also consists of syn-rift (pre- Upper Oligocene) and post-rift (Upper Oligocene – Quaternary) complexes. The general thickness of the cover reaches 10-13 km.

From the point of view of petroleum potential the folded basins are most attractive.

North Sakhalin petroleum basin covers northern Sakhalin and the adjoining shelf. The basement is represented by strongly dislocated pre-Cenozoic formations; sedimentary cover – by Eocene – Pliocene terrigenous complexes with the common thickness of up to 10 km. The section is characterized by sharp facial variability. Various rocks of the orogenic periphery of the basins towards the deep-marine depressions are replaced by clayey-siliceous rocks, rather deep-marine and homogeneous by the structure (fig. 3).

The structural-tectonic architecture of the basin is defined by kinematics of the largest East Sakhalin and Central Sakhalin faults of shifting character. 13 large and unique oil and gas fields are already revealed in the marine part of the North Sakhalin basin an around 60 brachianticlinal folds are mapped.

Okhotsk - Western Kamchatka basin with the thickness of the sedimentary cover up to 13 km is the largest depression of the eastern part of the sea. Litho-facies structure of the sedimentary cover is analogous to the Northern Sakhalin basin. Number of potential petroliferous areas is allocated within it, from which the largest and highly perspective is

Western Kamchatka. Most active geological-prospecting surveys are conducted within its limits. More than 150 local structures are allocated within the Okhotsk – Western Kamchatka basin from which almost 50 settle down in the marine part. The area of some local uplifts reaches 900 km^2 (Central Krutogorovsk), with the amplitude of 500 m.

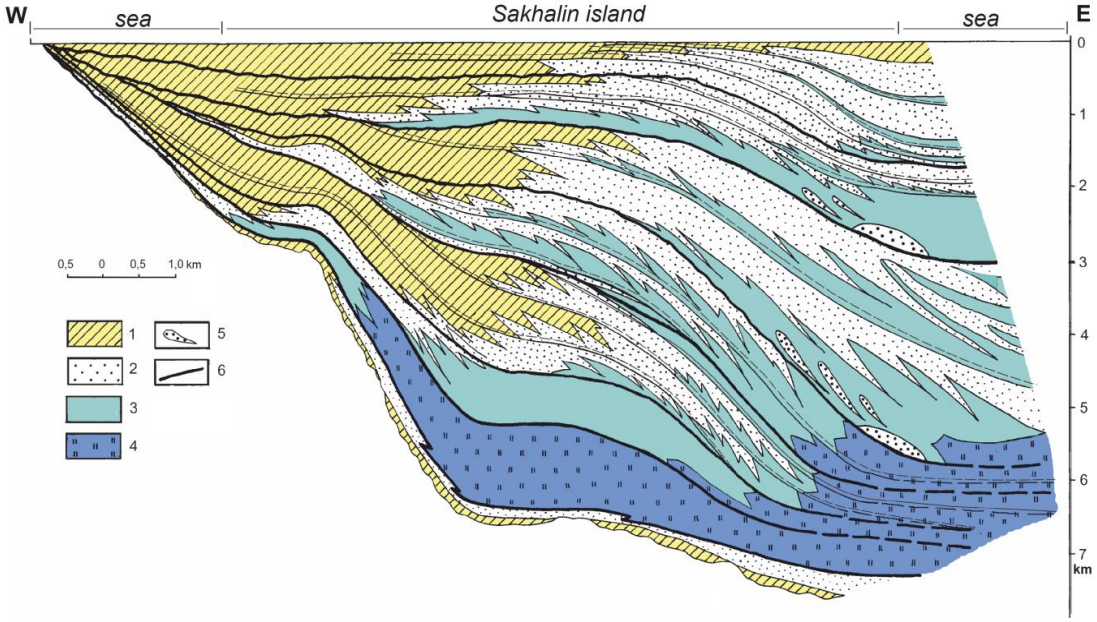

Figure 3 – Cenozoic deposits lithologic model of Sakhalin
1-5 – rocks assosiations, 6 – stratigraphic horizons borders

The geological history of Okhotsk Sea region development has been mostly predetermined by the geodynamic processes proceeding on a joint of the Euro-Asian continent and the Pacific Ocean. Beginning of this history could arouse from the approach of the Okhotsk Sea subcontinental plate to the continent and "jamming" of the subduction zone to the Okhotsk-Chukchi volcanic belt at the end of Cretaceous time that led to formation of the modern shape of the oceanic suburb. It is supposed that this process has been finished in Late Senonian, that is proven by the changes of accretionary-marine and oceanic deposits in the Sakhalin, Penzhin regions and western Kamchatka by the shallow-marine and paralic formations.

Early Cenozoic (Paleocene - Eocene) rifting stage of the geological history of the region was characterized by development of graben-rifts which were filled by subcontinental terrigenous deposits with prolayers of greywackes and effusives. Thicknesses of deposits reach 5-7 km.

The boundary of Eocene and Oligocene (around 34 million years ago) was expressed in changes of terrigenous formations onto volcanic-sedimentary, essential expansion of the sedimentation area. Character of interaction of the Pacific plate with Eurasia was changed and has led to formation of the modern Kuril island-arch system.

Further geological history of region development is considered as the post-rift stage consisting of three sub-stages.

Upper Oligocene – Middle Miocene (Late Voyampolian) substage is characterized by the beginning of formation of a continuous sedimentary cover within the limits of whole Okhotsk Sea region which has been subdivided from the main Pacific space by the Kuril islands. Original deep-marine clayey-siliceous formation enriched in organic matter was deposited extensively. Its thickness changes from 500 m to 3-4 km. These deposits, especially within the Sakhalin shelf, are observed as the main source rock formation.

In the middle of Early Miocene (burdigalian time) Okhotsk Sea region has influenced sharp decreasing of the sea level. In the Northern Sakhalin it has led to formation of an extensive shelf terrace and formation of a large deltaic system of paleo-Amur. New decrease

in the level of the World Ocean occurred at the end of Middle Miocene (11,7 million years ago).

Late Miocene substage was marked by active formation of a prograding deltaic system. Deltaic fans have overlain the Oligocene – Middle Miocene deep-marine cover, having created favorable conditions for emigration of hydrocarbons into the reservoirs.

Marine transgression and accumulation of rather deep-marine sandy-clayey deposits occurred in Late Miocene. Thickness of Upper Miocene deposits reaches 3,5 km, and sedimentation rates become avalanche, reaching for separate areas 500-600 m/million years.

At the end of Late Miocene there is marine regressing, drainage of shelf terraces and their escalating at the expense of deltaic progradation. Formation of one of the main reservoirs of the Okhotsk petroliferous province – Nut formation of Sakhalin – is dated by this age.

Pliocene – Quaternary substage is characterized by the establishment of modern sedimentation conditions.

From the point of view of petroleum-geological divisions the Okhotsk Sea region corresponds to the Okhotsk Sea petroliferous province. 3 petroliferous areas (Northern Sakhalin, Southern Sakhalin and Western Kamchatka) and 7 potentially petroliferous areas (Gizhigin, North Okhotsk, Kuhtuj, Shantarsk, Tinrovsk, Central Okhotsk, Derjugin and South Okhotsk) are allocated there. 81 oil and gas fields, including 13 within the shelf zone are discovered in the province. From them 73 deposits are in the Northern Sakhalin petroliferous region, 4 – in the Southern-Sakhalin petroliferous region (coast of gulf of Aniva) and 4 – in the Western Kamchatka petroliferous region (coast of Kolpakov region).

Northern Sakhalin petroliferous region is located within the Northeastern Sakhalin and adjoining shelf. The area is 120 thousand km^2, including 95000 km^2 in the marine part. 60 oil and gas fields including 13 within the shelf are discovered there. Among the last is unique Lunsky oil-gas-condensate field and seven large oil-gas-condensate deposits: Odoptu-more, Piltun-Astoh, Arkutun-Dagin, Chajva, Kirin, South Kirin, and probably Myngin. Last three gas condensate deposits have been discovered in 2010-2011 by the Open Company "Gazflot".

Kirin gas condensate field is studied by three wells. The well №2 is most indicative by which it has been tested by three objects in the sandstones of Upper Dagin horizon. At nipple of 15,88 mm in diameter following results have been received:

I object, interval 2959-2984, gas yield 520 thousand m^3/day, condensate – 85 m^3/day.

II object, interval 2933-2949, gas yield 492 thousand m^3/day, condensate – 70 m^3/day.

III object, interval 2882-2903, gas yield 502 thousand m^3/day, condensate – 70,8 m^3/day.

Common gas reserves are preliminary estimated as 150 bln m^3.

South-Kirin gas condensate field is discovered by a single well with three object tested in Upper Dagin sandstones:

I object, interval 2655-2669, gas yield 540 thousand m^3/day, condensate – 150 m^3/day.

II object, interval 2680-2697, gas yield 560 thousand m^3/day, condensate – 140 m^3/day.

III object, interval 2750-2760, gas yield 389 thousand m^3/day, condensate – 100 m^3/day.

Preliminary reserves estimation – 260 bln m^3 of gas.

Myngin field is discovered by the first prospecting well with the bottom at 3600 m. Gas condensate deposit is revealed in the depth interval of 2488-2514 m (sandstones of Upper Dagin horizon). Gas inflow with the yield of 300 thousand m^3/day and condensate with the yield of 88,2 m^3/day was obtained while testing (d_{nipple}=17,46 mm). Preliminary estimated reserves amount around 30 bln m^3 of gas.

Best reservoir properties within the limits of the Northern Sakhalin petroliferous region are observed for the sandstones of Dagin and Nut formations (open porosity 20-30%, permeability more than 100 mD). Fractured-cavernous reservoir type is characteristic for Daehurin and Yujntin horizons (open porosity up to 18%, fractured permeability up to 100

mD). Regional seals are practically absent. Zonal seals are clayey layers of Okobykaj and Nut formations.

Main oil-gas-generating strata are deep-marine siliceous-clayey and clayey layers of daehurin horizon of Oligocene and Miocene deposits. They are characterized by heightened TOC values, 1.5% at average, genetic type of oM is presumably sapropelic.

4 chambers of HC generation are established in the North-Sakhalin petroliferous region: Piltun-Chaiva, Baikal-Pomorsky, Eastern-Sakhalin and Pogranichny with the Cenozoic deposits thickness up to 7-10 km. Highest generation potential is observed in Piltun-Chaiva depression characterized by highest heat flow of the sedimentary sequence (geothermal gradient – 35-40oC). It is assumed that deposits of the lowermost part of the sedimentary sequence are heated up to the temperature of 200oC and more. Towards Piltun-Chaiva HC generation chamber density of resources increases up to 1-1,5 mln.m^3 for km^2, up to 95% of preliminary estimated reserves of HCs are located there.

Reservoir properties of Miocene petroliferous complexes within the observed petroliferous region are significantly defined by prograding of the deltaic paleo-Amur system. Sandy compounds of the sedimentation flows decrease towards the eastern boundary of the region and, as a result, accumulation possibilities of the petroliferous system are reducing.

20 structures are studied by drilling within the shelf zone of Norhern-Sakhalin petroliferous region. 13 of them discovered oil and gas deposits. Coefficient of success is 0,7. Quantity of undrilled structures is 67, their localized resources by the data of public corporation “Trest Dalmorneftegeophyzika” reach 5-7 bln t of oil equivalent. If to take coefficient of success 0,5 – then undeveloped resources of the observed marine part could reach 3,6 bbtoe. Average density of HC resources in the northern Sakhalin area are estimated as 65000 t/km^2 within the onshore part and 70-100 thousand t/km^2 within the shelf zone.

W e s t e r n - K a m c h a t k a petroliferous region ha the area of 105 thousand km^2 including 80 thousand km^2 within the shelf occupying three main troughs – Shelikhov, Western-Kamchatka and Voyampolian. Four small gas condensate fields are discovered in the onshore part of the Western-Kamchatka trough. Reservoir horizons are present in Paleogene deposits (porosity up to 15%), Miocene deposits (porosity from 20 to 35%, permeability up to 380 mD). Most sustained clayey seals are Kovykta formation (Eocene) and Vyventek formation (Miocene).

Most of Cenozoic deposits are located in the oil window zone. Kolpakov region with geothermal gradient of up to 62oC/km is most heated.

Most of perspective structures of the Western Kamchatka shelf have complex composition with divergence of the structural plans of different horizons. 14 zones of possible oil-gas accumulation are revealed within the shelf zone, 10 of which are located in the southern part of Western-Kamchatka petroliferous region to the south of Ovra uplift.

45 local structures with the summary results by the data of public corporation “Trest Dalmornetegeophyzika” of 3-5 bbtoe are estimated within the shelf part of Western Kamchatka. Most perspective objects for exploration are structures Pervoocherednaya, Northern Kalavayamskaya, Kalavayamskaya and Kisunskaya.

In the end of 2011 first exploration well with the depth of 3000 m was drilled within the Pervoocherednaya structure by public corporation “Gazflot”. The well drilled volcanogenic-sedimentary deposits of Neogene - ermanovskaya (N_1er), etolonskaya (N_1et) and kuluvenskaya (N_1kl) formations; of Paleogene - combined viventskaya and ukhtolskaya (P_3vv+ut) formations and snatolskaya (P_2sn) suite, consist of intercalation of sandstones and tuff-sandstones, siltstones and tuff-siltstones, consolidated sandstones, clays and argillites, coals.

Two deposits were allocated by well logging data. The first one consists of two layers and defines within the combined viventskaya and ukhtolskaya (P_3vv+ut) formations. The second pool is of massive type, represented by layer 3 P_2sn within snatolskaya suite that is of great interest as possible efficient object. Their testing is planned for the summer of 2012.

Preliminary estimations show that expected gas and condensate reserves amount 4,958 bln m^3.

N o r t h e r n - O k h o t s k potential petroliferous region elongated along the Magadan coast of the Okhotsk Sea to the distance of 350 km has the area of around 50 thousand km^2 and includes Northern-Okhotsk and Pyangin troughs with the sedimentary sequence of up to 9-10 km. 36 local structures are established in the shelf zone. To regret three wells drilled within the magadan shelf (Magadan 1, 2 and Hmetjevsk) showed practical absence of reservoir horizons that sharply decreased the license interest to this area from the site of petroleum companies.

Rest potential petroliferous regions based on the geological-geophysical data have less practical interest than the observed three areas.

Analysis of the petroliferous systems of the Okhotsk petroliferous province shows that all revealed fields and perspectives are connected mostly to Upper Oligocene – Miocene deposits. The deposits are dated to the porous terrigenous reservoirs often with admixture of pyroclastic material. All revealed deposits are connected with the rocks which accumulation mainly occurred in the periods of lowstand and are concentrated under the shales and claystones of marine transgressive cycles (Early Miocene, Middle Miocene and Early Pliocene). By phase composition combined deposits (39), gas and condensate (30) and oil deposits (12) prevail.

By density of initial reserves dominating are small (70 fields, 86%). Average are 3 fields, large - 4 oil fields and 6 gas, unique – Lunskoe gas condensate field (530 bln m^3 of gas).

Perspectives of further development of HC resources within the shelf part of Okhotsk Sea are connected with 2 petroliferous regions – Northern Sakhalin and Western Kamchatka.

If to take estimations of initial summary resources of the Sea of Okhotsk proposed by VNIGRI as 11745 mln t of oil equivalent the part of Northern Sakhalin region is 6558 mln t of oil equivalent (55,8%), part of Western Kamchatka region – 3559 mln t of oil equivalent (30,3%), in the sum it is 86,1% from all the resources of the Okhotsk Sea region.

It is worth to be noted that Sakhalin region is far long representing a unique Centre for oil and gas exploration within the Far East of Russia. Accumulated production of oil amounts 41 mln t of oil, 13,1 bln m^3 of gas. Level of investigation of Sakhalin resources amounts 35% and their reclamation – 52%. In medium-term perspective this region will increase their production possibilities predominantly for gas. In long-term perspectives concurrence for this region could become western-Kamchatka shelf where geological-prospecting surveys should be activated in the nearest future and a significant resource basis of HC stock should be created. Potential possibility for that is present.

Average density of resources within the Northern Sakhalin petroliferous region amounts 63 thousand t/km^2 including 68 thousand t/km^2 in the marine part. More than 60 perspective structures are revealed there, localized geological resources are estimated approximately in 5 btoe.

Average resource density in the Western-Kamchatka perspective petroliferous region amounts 38 thousand t/km^2, at that in the southern most perspective part it is estimated in 50-75 thousand t/km^2. 42 local structures are mapped within the shelf part of Western Kamchatka, one third of them is expected to obtain discoveries of large oil and gas deposits. Summary localized resources of the most perspective structures are estimated in not less than 2 btoe, and common localized resources exceed 3 btoe.

Defined perspectives could also be connected with the Northern-Okhotsk perspective petroliferous region where 36 perspective structures are revealed, initial summary resources are estimated in 1351 mtoe or 11,5% of the initial resources of the whole Okhotsk Sea.

Therefore it could be confidently stated that in the Far East of Russia in the long-term perspective (in 15-20 years) minimum one new Western Kamchatka producing region will be added to the Sakhalin petroleum-producing region that will create additional possibilities for commercial development of Far East of Russia and increasing of its export possibilities.