Proceedings of the MSTU, Vol. 15, No. 2, 2012 pp.419-428

UDC 553.93 + 551.242.5.056(470 + 571/1-922)

Oil and gas prospects of the European part of the Arctic shelf of Russia

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Abstract. Four oil and gas generation intervals have been identified in the western part of the Arctic shelf of Russia. A number of large and unique oil and gas fields have already been discovered and partially appraised, as a result, three potential hydrocarbon areas, still insufficiently studied, have been identified within the subject area. These potential hydrocarbon areas are the northern extremity of the Murmansk region in the Rybachy Peninsula, Franz-Joseph Land Archipelago and the North-Kara shelf. The assumption has been made that detection of hydrocarbon deposits in two first of the listed areas are most actual in modern conditions.

Аннотация. В пределах западной части Арктического шельфа России выделено четыре возрастных интервала нефтегазообразования. Наряду с уже выявленными и частично разведанными крупными и уникальными месторождениями нефти и газа в пределах рассмотренных провинций выделены три потенциально богатые углеводородным сырьем и недостаточно исследованные области – северная оконечность Мурманской области в пределах п-ова Рыбачий, территория архипелага Земля Франца-Иосифа и Северо-Карский шельф. Сделано предположение, что вопросы обнаружения месторождений УВ в двух первых из перечисленных областей в современных условиях наиболее актуальны.

Key words: oil and gas occurrences, geodynamic evolution, oil and gas provinces, Arctic shelf
Ключевые слова: нефтегазоносность, геодинамическая эволюция, нефтегазоносные провинции, Арктический шельф

1. Introduction

The problem of definition of environments and conditions under which hydrocarbon raw-materials were generated and became mature, and identification of their possible spatial and temporal location is a highly important issue. It enables the estimation of their perspective resources and conditions of commercial production. It attaches a large value to the two major tasks. The first one is the deciphering of the nature of region's geodynamic evolution. The second, conjugated one is tying-up the endogenous and exogenous lithospheric processes with the formation of commercial concentrations not only of the organic matter but also of the commercial deposits as a whole. The results allow estimate look-ahead resources of regions.

In our opinion, the earliest hydrocarbon generation in the western Arctic shelf of Russia was associated with the organic matter accumulation within the depositional sequences over the passive continental margin in Middle Riphean-Vendian (1350-620 MMY), in the southeastern extremity of the Russian Plate (Fig. 1).

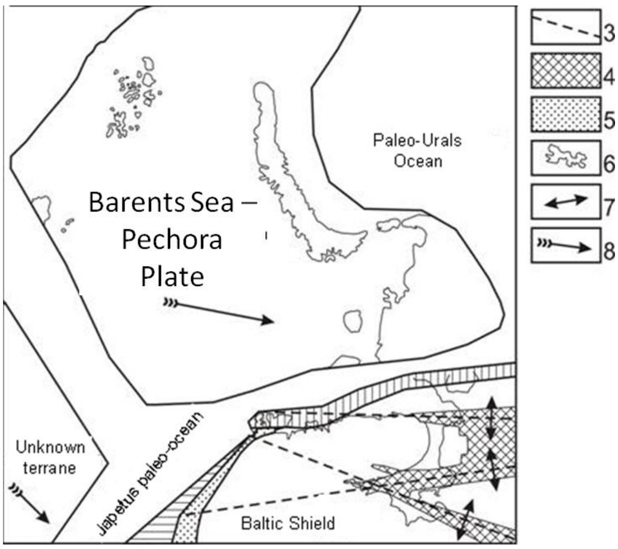

Fig. 1. Paleo-geodynamic reconstruction of the northern East-European Platform and the adjacent Arctic basin in Middle Riphean – Vendian (1,350-540 MMY ago): 1. folded Late-Middle Riphean formations of the Dalsland area (1,200-900 MMY), 2. Middle-Late Riphean and Vendian sedimentary complexes of the shelf and continental slope over the NE Baltic Shield and Russian Plate passive margin (1,350-620 MMY), 3. major lineaments of the Baltic Shield, 4. Late Riphean riftogenic formations, 5. Vendian continental clastics (650-570 MMY), 6. the present-day shoreline, 7. stress field vectors in the continental lithosphere, 8. the general direction of the lithospheric plate motions

This 730 MMY-long time interval must manifest the accumulation at the base of the continent of multi-kilometer thick and organic-rich sedimentary sequences. These sequences in the course of the evolution migrated together with the continent from the equatorial to the near-polar areas. *V. Khain* (2001) and *O. Sorokhtin* (2007) indicate that 1.0 BY ago the area was part of the Mesogea (Rodinia) supercontinent. At that time it was positioned at 10 to 30 degrees North and later moved northward, in the sheet glaciation zone.

This is supported by tillites and tilloids discovered in the continental Vendian (650-570 MMY) clastics on the northwestern Baltic Shield (*Chumakov*, 1978). Large oil and gas accumulations might have concentrated within them under the overburden pressure. These accumulations would be similar to the fields formed in Meso-Cenozoic over the continental slopes of the South American and African passive margins fringing the Atlantic Ocean.

Fragments of the continental margin and slope complexes represented by the uppermost part of the section are currently observed in the merger zone of the Russian Platform's Archaean basement and Late-Proterozoic Barents Sea – Pechora plates. At first sight, the lack of a convergent boundary and a great depth (over 20 km) of the potentially oil-bearing Riphean in that zone makes its economic potential minuscule. However, as we will show later, the superimposed Caledonian and Hercynian tectonic processes could have and possibly did mobilize hydrocarbon of that age and caused their transformation and secondary migration into the upper structural stages.

2. Discussion

The strongest increments in the region's oil and gas potential were associated with the Caledonian and Hercynian tectonic phases. On the one hand, they caused the formation of large and unique fields within the Svalbard, Pechora and South Kara Plates. And on the other hand, they exposed buried oil and gas complexes of the preceding (Riphean-Vendian) interval.

It is known that the largest hydrocarbon accumulations arise at the island arc or active continental margins obduction over the passive margins during the closing of their separating ocean. In the process, the primary-migration accumulations form because of mobilization of the organic matter dispersed in the deposits and due to the hydrocarbon supply form the subduction zone (*Sorokhtin et al.*, 2011).

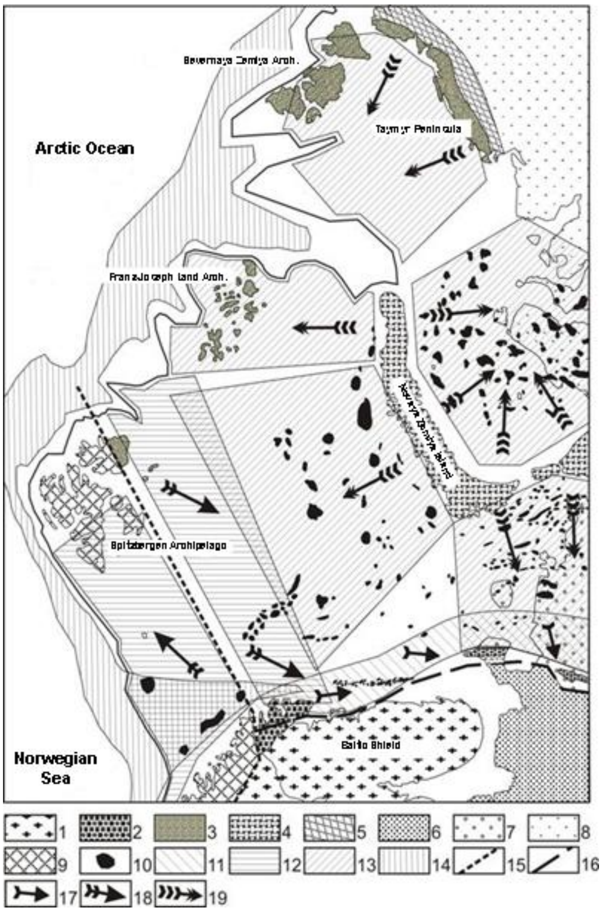

Fig. 2. Schematic map of the potential oil and gas occurrences on the Russian Barents Sea – Kara shelf. 1. Archaean basement of the Baltic Shield; 2. Riphean and Vendian sedimentary complexes; 3. basement of the Svalbard and North-Kara plates; 4. folded formations of the Urals and Novaya Zemlya (Urals-Mongolian belt); 5. Taymyr Peninsula folded formations; 6. sediment cover of the East-European Platform; 7. sediment cover of the Pechora Plate; 8. sediment cover of the West Siberian and Siberian platforms; 9. sediment cover of the North Atlantic belt Caledonides; 10. potential oil and gas structures (geophysical data) and discovered hydrocarbon accumulations; 11. potentially oil and gas-bearing Riphean-Vendian zone; 12. potentially oil and gas-bearing areas associated with the closing of the Japetus Ocean in Early Ordovician – Late Devonian (505-362 MMY); 13. potentially oil and gas-bearing areas associated with the closing of the Paleo-Urals Ocean in Early Permian – Early Triassic (290-241 MMY); 14. biogenic and gas-hydrate (abiogenic) hydrocarbon formation zone over passive continental margin in Mesozoic (55-0 MMY); 15. boundary of the North Atlantic Belt folded Caledonian formations on the Barents shelf; 16. edge suture of the continental margin-type Timan-Varanger system; 17. migration of hydrocarbons formed during Riphean-Vendian; 18. migration of hydrocarbons formed in Ordovician – Late Devonian; 19. migration of hydrocarbons formed in Early Permian – Early Triassic

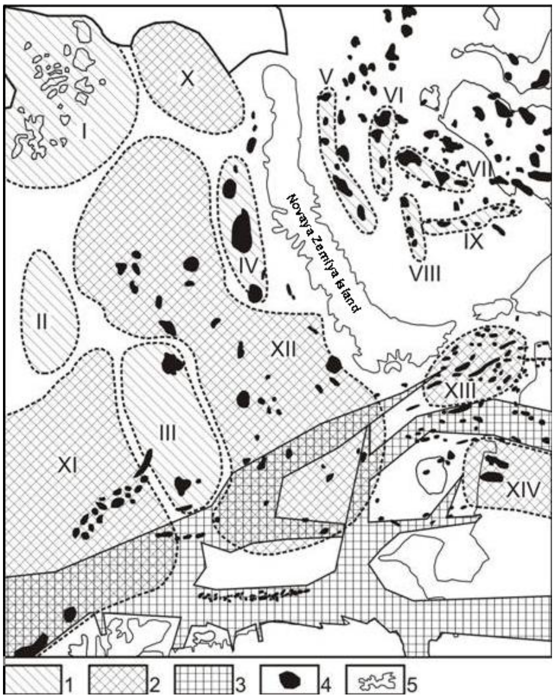

Fig. 3. Schematic map of oil- and gas-controlling structures in the Barents – Kara region: 1. highs and swells: I-IV. Svalbard Plate highs: I. Franz-Joseph Land, II. Perseus, III. Central Barents, IV. Admiralty; V-IX. South Kara Plate mega-swells: V. Vikulov, VI. Kropotkin, VII. Rusanov, VIII. Voronin, IX. Obruchev; 2. troughs, depressions and syneclises: X-XIV. Svalbard and Pechora Plates: X. St. Anna, XI. Nordkap, XII. East Barents Sea, XIII. Pechora, XIV. Izhma-Pechora; 3. Norway-Mezen rift system; 4. potentially oil- and gas structures and discovered hydrocarbon deposits; 5. shoreline

This was the scenario that could have existed at the closing of the Japetus Ocean (505-362 MMY ago). It resulted in the oil and gas migration from high-pressure zones (the Caledonian folded system) into the tectonic discharge areas. The migration vector in such cases is usually perpendicular to the folding axis, and the distance may reach 500-600 km (Fig. 2). Fig. 2 reflects vari-directional migration paths. This is a testimony of the two-stage nature of the ocean closing. In the process, the Greenland Plate was subducted under the Svalbard Plate, and then it began subsiding under the Archaean and Early-Proterozoic complexes of the Baltic Shield.

The activation and intense development of the Norway-Mezen rift system (Fig. 3) occurred at the same time. At that stage that may have led to the formation of large gas-hydrate accumulations within it. A wedge-like rift formation (Varanger graben) in the Caledonides' knee-like bend, its active hydrothermal regime and the magmatism over the shoulders indicate that gas-hydrates could have formed in the lower section (the gas-hydrates similar to those discovered on the present-day continental slope of the Barents Sea shelf) (*Dmitriyevsky et al*., 1997).

Besides, the Varanger-Kanin branch of the Norway-Mezen system exposes the section of the earlier buried passive continental margin. Affected by their intense heating, it allows the hydrocarbon migration up and sidewise along a system of axial and transform faults. These processes could have resulted in the formation of an extended potentially oil- and gas-bearing zone coinciding with the merger area of the different age lithospheric plates (Fig. 2).

The elevated oil and gas potential of the Varanger, Rybachy and Kildin Peninsulas (the northeastern extremity of the Baltic Shield) is associated in particular with this process (fault – strike-slip fault of the type discovered there typically act as hydrocarbon traps). Horizontal displacements along these faults reach 100-150 m, sometimes up to 1 km, and the vertical displacement is about 60 m. Salt diapirs abundant in the vicinity of the Kola Peninsula along the rift axis may also form potential traps.

Analysis of the hydrocarbon types, time intervals of their deposition and localization as well as the manifestation nature of the oil and gas-generating events shows that these parameters are drastically different in the North and Norway Seas from the same parameters in the adjacent territories of the East Barents, Kara and Pechora basins (Fig. 4).

Gas-condensate accumulations within the southwestern and western frameworks of the East European Platform are associated with the older sedimentary complexes, whereas the oil accumulations with the younger ones. The situation is inverse in the region's eastern areas.

The reasons for that may be as follows.

The Norwegian Caledonides (in particular, the North Sea oil and gas basin formed during the same time) underwent the repetition of a strong tectono-thermal activation at the Hercynian stage. The oil fields associated with the Caledonian evolution interval have not been discovered at the exploration stage. That created a seemingly inverse trend in the hydrocarbon accumulation types different from the adjacent oil and gas provinces.

The Hercynian stage of the tectono-thermal activation in the Barents Sea – Kara region was associated with the closing of the Paleo-Urals Ocean and the collision between the East European and West Siberian platforms about 290-241 MMY ago. These events formed the Timan-Pechora, East Barents Sea, North Kara and South Kara (West Siberian) oil and gas basins.

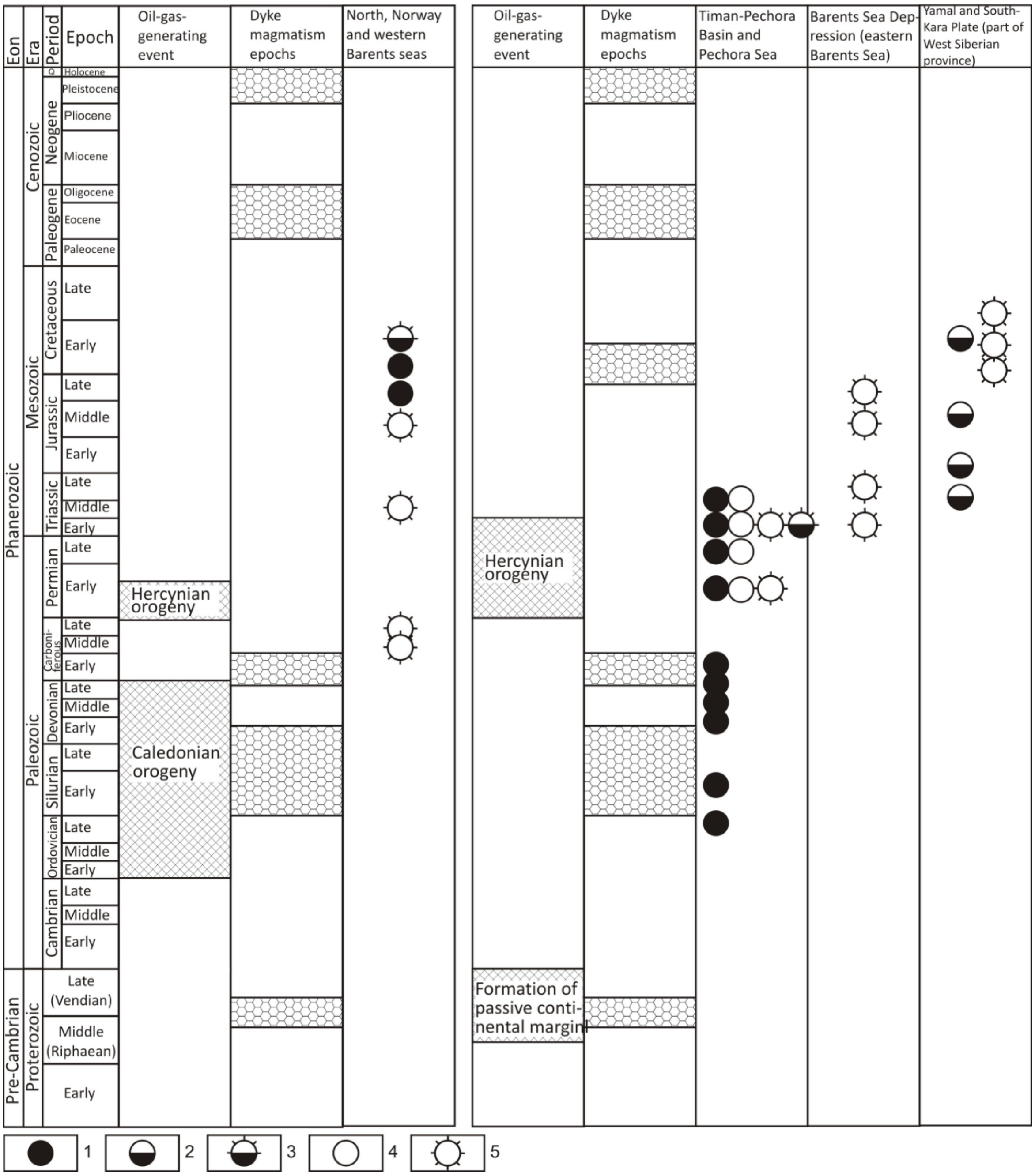

Fig. 4. Oil- and gas-generating events and stratigraphic distribution intervals of hydrocarbon types in the Barents – Kara and adjacent regions (modified after *Shipilov*, 1998; 2000):
1-5. hydrocarbon deposits: 1. oil; 2. oil – gas; 3. oil – gas – condensate; 4. gas; 5. gas – condensate

These processes of the formation of the structural ensemble in the subject region display a regular image of the collision zone at the merger of two lithospheric plates. On the other hand, they reflect their evolution in the pre-collision period (Fig. 3, 5). Clear distinctions are observed in the structural setup of the Svalbard, Pechora and South-Kara Plates. The structure was finally completed as a result of their non-uniform tectonic warping.

The East Barents Sea region displays a regular spatial distribution of broad anticlinal structures extending parallel to the Uralian Hercynides (Perseus and Central Barents hight). They are separated from it by the East Barents and St. Anna depressions (Fig. 3).

The Nordkap Trough was formed mostly due to the Caledonides evolution, and its southern portion is a typical foredeep. It is worth to remember that the high of the Franz-Joseph Land and also of Severnaya Zemlya and Spitzbergen are formed not so much due to these processes but rather as a result of the isostatic adjustment of the continent's margin at the opening of the Arctic Ocean in Cenozoic.

Subsidence of the Svalbard Plate's basement and the formation of the East Barents Sea depression were caused by the development of a fore deep of the autochthonous plate. On the other hand, it reflects the plate's non-uniformity and the presence of the oceanic-type crust. That apparently was the reason for the formation of such large basement subsidence as the fore deeps are usually narrow and elongated (Fig. 5).

A common occurrence in the sediment cover warping process is typical saddle-like formations separating it into segments. An example is the Ludlov Saddle separating the East Barents Depression into the northern and southern segments. Another example is the Vorkuta and Middle-Pechora cross-highs separating the Urals Foredeep into segments (Fig. 5). These cross-highs emerged most likely as a result in a change of the collision zone strike angles, and as a consequence, of the development of strike-slip deformations and warping structures. It is important that the aforementioned structures include a rift system which makes the basement sagging processes stronger.

A slightly different picture of structuring the oil- and gas-controlling complexes is observed in the Timan-Pechora region (Fig. 5). A number of factors led to the formation in the collision zone basement of the foredeep, the Pechora-Kolva aulacogen and a series of anticlinal and synclinal structures which later were deformed by numerous northwesterly narrow anticlinal swells and overthrusts. These factors are the asymmetric closing of the Paleo-Urals Ocean (when the intense anticlinal compression migrated in time from south to north) and an irregular shape of the collision zone.

These processes facilitated oil and gas migration from the subduction zone and their concentration at the boundaries of the structural complexes superposed over the pre-collision sedimentary formations (Figs. 4, 5). It is likely that these events resulted in the saturation of the upthrusted and intensely folded Ordovician-Silurian-Devonian sedimentary complexes by the primary-migrating oil in the Varandey-Adzva structural zone and in the Khoreyver depression. Besides, these processes facilitated the release and migration into the overlying structural stages of the buried hydrocarbons from the continental-margin formations of the Riphean stage in the Izhma-Pechora syneclise.

The South-Kara region is the autochthon of the West Siberian Plate thrust over the Barents Sea Plate. In effect, it is the northwestern extension of the West Siberian Plate. As a result, the echelon system of narrow and long anticlines (mega-swells) is formed at the rear of the collision zone. The strike of the swells reflects the zone's geometry (Fig. 3).

The hydrocarbon migration processes always reflect the stress field change vectors which coincide with the shortest hydrocarbon migration paths from the elevated-pressure zone into the tectonic relaxation areas. The length of the migration paths may reach 500-600 km.

Figs. 2 and 5 show the oil migration directions during the Riphean, Caledonian and Hercynian tectogeneses. The figures show the areas where the sediment cover may be to a various extent saturated by hydrocarbons (Fig. 2). The crossing of the migration vector axes should have resulted in maximum concentration of oil and gas accumulations in the sedimentary complexes, and their divergence should have led to a hydrocarbon impoverishment.

Geological and structural analysis of the study area indicated that the oil and gas potential in the sediment coves complexes of the South- and North-Kara plates should be much greater than that of the Barents Sea shelf. The northern and northeastern Timan-Pechora plate and especially the Pechora-Kolva aulacogen and the Khoreyver depression should be at least as rich (Fig. 5).

Usually narrow linear anticlines (mega-swells) serve as structural limitations of the oil migration that facilitated its concentration. The oil migrated along these structures and was discharged to form large accumulations (Figs. 2, 5).

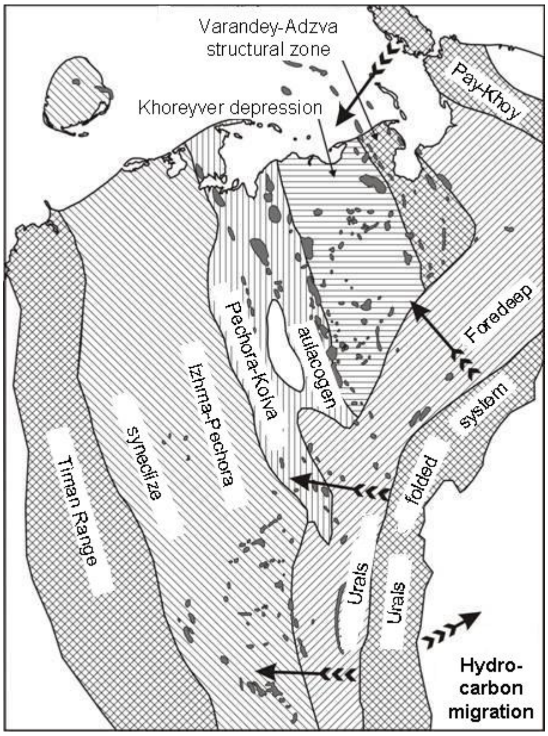

Fig. 5. Schematic tectonic map of the Timan-Pechora oil and gas province (modified after *Gromeka et al*., 1994; *Kalantar et al*., 1982)

A characteristic occurrence with respect to the Timan-Pechora Plate is a significant impoverishment of the northern Izhma-Pechora syneclise in oil and gas fields. It may have been a result of their migration paths being restricted by the Pechora-Kozhva and Shapkin-Yuryakhin mega-swells positioned at the boundary of the syneclise with the Pechora-Kolva aulacogen (Fig. 5). The spatial closeness of the Urals folded system and the Timan Range in the southern Izhma-Pechora syneclise may have resulted in the spatial superposition within the sediment cover of the Riphean and Hercynian hydrocarbon complexes.

The hydrocarbon concentration processes within the lithospheric plate sediment cover suggest their age correlation with the generating events. These are the processes of the deposition on the continental margin and the Caledonian and Hercynian tectonic phases (Fig. 4).

The geographic separation of the Caledonian and Hercynian orogenies in the subject area apparently resulted in the formation of independent oil and gas basins where the hydrocarbon accumulation processes were different.

As noted, the composition and age localization of oil and gas-condensate fields in the North and Norwegian Seas are different from the equivalent complexes in the Barents-Kara region and are not reviewed in this article. The source rocks of the primary and secondary oil and gas migration within the Timan-Pechora, East Barents and Yamal-South Kara basins are the sedimentary structural-lithological complexes contemporary with the tectonic activity as well as the older and younger structural-lithological complexes of the sediment cover (Fig. 4).

Hydrocarbon accumulations in the Timan-Pechora Basin are regularly distributed in space and time. The Ordovician, Silurian and Devonian sedimentary complexes contain oil accumulations. The Permian and Triassic ones include oil, gas and gas-condensate accumulations. No oil fields are discovered within the East Barents Sea depression, but the gas-condensate accumulations are found in the Upper Permian – Upper Jurassic sediments. In the Yamal – South Kara region oil-gas and gas-condensate accumulations are associated with even younger sediments (Middle Triassic – Lower Cretaceous complexes) (Fig. 4).

This clear spatially- and temporally-associated trend in hydrocarbon composition, type and localization zone variability may have the dual nature. On the one hand, its appearance was affected by the structure-forming geodynamic processes and, on the other hand, it was affected by the multi-stage magmatism manifestation both within and outside the collision zone caused by the same processes.

The spatial distribution of oil, gas and gas-condensate accumulations in the Timan-Pechora Basin shows that the latter are mostly associated with the Urals Foredeep and areas of synorogenic magmatism of the Hercynian stage. The most typical example is a large Vuktyl field.

It appears that the appearance of gas-condensate accumulations in the region was closely related to the syn-collision magmatism and may be attributed to the secondary formation. Large magmatic bodies intruded hydrocarbon-rich source rocks and caused secondary thermolysis and sublimation of oil and gas accumulations. The result was their separation into the mostly gas-condensate and bitumen components.

The natural bitumen accumulations are numerous and practically omnipresent over the main structures of the Timan-Pechora Basin. This is also supported by the data of the hydrocarbon localization geotectonic analysis. For instance, the major portion of the Ordovician-Early Devonian oil accumulations gravitates to the areas of active and moderate basement subsidence, and the accumulations associated with the Late-Devonian – Early Carboniferous sequences are mostly associated with the highs.

The opposite picture is observed in the oil and gas-condensate complexes (*Dmitriyevskaya et al*., 1999). It appears that during the pre-collision time the normal hydrocarbon differentiation occurred (separated by density and migrating properties), whereas in the collision process this trend reversed to the opposite one.

This kind of a change in hydrocarbon migration trend at the Devonian/Carboniferous time boundary indicates a start of the Hercynian tectonism processes. They resulted in the disruption in the normal sequence of differentiation, reworking of some of the primary-migrating hydrocarbons, the formation of secondary gas-condensate accumulations, and an increased complexity of the oil and gas-controlling structure (folding) in the sedimentary complexes of the Timan-Pechora Basin.

As a result, a regular picture was created in the time-distribution of hydrocarbons (Fig. 4): the oldest accumulations are oil and oil-gas, whereas the younger accumulations are gas and gas-condensate. The oil fields in the Khoreyver Depression's and Varandey-Adzva folded zone's Ordovician-Early Devonian sediments reflect maximum extent of the folding and metamorphism manifestation.

That was the reason why the oil encountered there is strongly degassed and has high density (*Gromeka et al*., 1994). From our viewpoint, Middle Devonian – Early Carboniferous sediments in the Izhma-Pechora syneclise include two age-different hydrocarbon complexes. In that area (especially in its southwestern part), the mixing of Riphean and Hercynian mostly oil-accumulations occurred with subsequent migration into the Devonian and Carboniferous sediments as a result of later processes. The best example of the oil and gas occurrences at the Riphean evolution stage is the Yarega Field currently positioned in the Devonian complexes.

The Early-Permian – Late Triassic interval in the studied area includes the greatest variety of hydrocarbon types. This undoubtedly reflects the nature and manifestation extent of the superimposed tectono-thermal processes in the Timan-Pechora Basin. It is important that the hydrocarbon migration there continued even later. That resulted in the formation there of oil source rocks up to the Late Triassic time, i.e., at least 20 MMY after the main tectono-magmatic activity of the orogen died out (Fig. 4). This is an indication of the inert nature of the processes that caused the formation of this type fields, as well as of the hydrocarbon mobility within certain conditions of the stress field parameters.

It is noteworthy that the structural complexes controlling the oil in the adjacent areas are even younger. In the East Barents Sea region they are restricted to the Late-Jurassic formations, and in the South Kara and northern West Siberian province they are associated with the Late-Permian complexes (Fig. 4). Thus, there is a substantial time and localization shift in the oil and gas-formation processes. This indicates, on the one hand, the belonging of these regions to different oil and gas basins (areas, provinces), and on the other hand, long duration of the post-collision tectono-thermal events and gradual relaxation of the state of stress in the geodynamic system formed.

Together with the effect of the structure-forming collision events and multi-stage magmatic manifestations caused by these events, the hydrocarbon deposit formation processes are strongly affected by the exponential function of the stress fields emerging within the lithospheric plate. In other words, if the studied region has higher stress field parameters than the adjacent areas, the migration processes in this area will last longer. The maximum manifestation of such processes may have resulted in the oilfield degassing, which is observed in the Timan-Pechora Basin whose basement was jammed between the Russian and West Siberian lithospheric plates.

On the whole, the spatial distribution of the stress fields is highly important in determining the oil and gas potential. Currently, however, there are practically no studies conducted in this direction. This prevents us from operating with the media's physical parameters. Instead, we have to limit ourselves to the assumptions and knowledge of the general physical patterns in the hydrocarbon migration processes.

A review of the formation of sedimentary-volcanic complexes in the Barents Sea – Kara region's sediment cover from this position suggests with a high degree of reliability that the stress field in the eastern portion of the East Barents Sea (Svalbard) Plate during the post-Hercynian time was weaker than in the North Kara and South Kara regions. The reason lies first of all in the geometric shape of the collision zone between the lithospheric plates.

As Figs. 2 and 3 show, the maximum structure-forming vectors intersect in the back portion of the Novaya Zemlya and Taymyr segments of the collision zone, whereas in the East Barents Sea region these vectors diverge. Therefore, based on the aforementioned regularities, the oil and gas potential of the fields in the North Kara, South Kara regions and on the Yamal Peninsula is much higher than in the East Barents Sea Basin, and the age of the fields is younger (Fig. 4).

The extent of the collision action on the sediment cover complexes in the South Kara region and on the Yamal Peninsula may not have resulted in a large-scale degassing of the primary-migrating oils so they are represented by the oil and gas aggregations as opposed to the similar fields in the Timan-Pechora basin. It also relates to the manifestation epochs of the syn- and post-collision magmatism with which secondary-migrating gas-condensate accumulations are often associated (Fig. 4) (*Shipilov*, 1998).

The potentially oil- and gas-bearing areas were not uniformly studied. The result is that we are forced to solve, using the math language, the equation system with many unknown variables. For instance, in evaluating the oil and gas potential of the East Barents Sea basin we had to utilize only limited geologo-geophysical data. Despite that, a number of large and unique gas and gas-condensate fields were discovered in the upper (Triassic-Cretaceous) structural stages of the sediment cover. The fields include the Shtokmanov and Ledovoye gas-condensate and Ludlov gas fields. The deepest well within the subject region has the TD of 4,524 m (*Borisov et al.*, 1995), but most of the wells are much shallower.

As it is shown above, the fields discovered in the East Barents Sea depression belong most likely to the secondary-migration events. They were probably formed as a result of invasion by base composition dykes and sills into the oil-saturated (primary-migration) sediments during the syn-collision and post-collision stage of the region's evolution. That should have unavoidably led to the processes of their thermal separation into the bitumen, gas, and gas-condensate components, which then invaded the overlying younger structural stages.

In our opinion, most likely oil source rock complexes for the primary-migrating hydrocarbons are the Upper Devonian – Lower Permian sediments. *B. Klubov* and *E. Korago* (1990) evaluated the potential of this age interval along the western shore of Novaya Zemlya. They discovered numerous shows of high-viscosity oil and solid bitumens. Our view is supported by *Yu. Fedorovsky's* (2007) data from Lower-Middle Devonian, Upper Frasnian – Famenian, Tournaisian and Visean sediments on the islands of Novaya Zemlya, Franz-Joseph Land and Spitzbergen.

Within the Admiralty High, the Early- to Middle-Paleozoic rocks are believed to include oil source rocks. In this connection, the liquid and solid bitumen data from the Franz-Joseph Land are very interesting. They are everywhere associated with the dolerite and dolerite-basalt dyke complex cutting through Triassic and Jurassic sediments (*Klubov, Vinokurov*, 1998; *Bezrukov,* 1997).

This kind of bitumen shows is an indication of oil and gas occurrences in the underlying section; in addition, there is evidence of secondary migration. However, three deep wells drilled in different parts of the archipelago did not discover potential oil-bearing complexes, and the bitumen and oil content was insignificant there (*Preobrazhenskaya et al.*, 1985).

The regular occurrence of hydrodynamic events led to an almost total degassing of the Triassic-Jurassic sedimentary complexes and to the degrading of their oil and gas potential in the continental margin areas.

The existing parametric wells[1] did not reach the potential Devonian – Early Permian oil-bearing sediments. Degrading of the hydrocarbon potential is associated first of all with the opening in Cenozoic of the Arctic Ocean. That resulted in isostatic uplift and exposure of the continental shelf's edge portions. The surface erosion resulted in the destruction of caprocks of oil-gas-bearing Triassic-Jurassic complexes' and subsequent degassing.

Thus, the massive indirect data indicate ubiquitous oil potential of the Devonian – Early Permian sedimentary interval of the east Barents Sea depression. Its hydrocarbon potential may turn out to be tremendous. If this is true then the hydrocarbon field type age distribution diagram of Fig. 3 would include a missing link represented by the shows of mostly oil composition. That would exhibit similarity to the trend discovered in the adjacent areas.

The lithospheric plate split within the Pangaea supercontinent and the opening of the northern segment of the Atlantic and Arctic Oceans in Cenozoic (about 55 MMY ago) resulted in the formation of one more hydrocarbon type region. It is represented by very peculiar and so far poorly studied gas with water compounds.

The gas-hydrate formation within the specified basins is still continuing. *A. Dmitriyevsky et al.* (1997) indicate that it encompasses almost entire offshore areas. The best potential for the formation of the economic gas-hydrate deposits belongs to the merger areas of the Arctic shelf and the continental slope. A large gas-hydrate accumulation of such type was discovered recently southwest of the Spitzbergen Archipelago, in the Bear Island area (*Dmitriyevsky et al*., 1997). Besides, the modern data show that stable gas-water compounds may form within the sediment cover of the internal areas of the shelf seas. An example is the discovery of gas-hydrates in the well drilled on the Admiralty High west of the Novaya Zemlya Island (*Semenovich, Nazaruk,* 1992).

Therefore, active tectonic zones (not only on the continents and in the oceans but also in the oceans' internal areas) may under certain conditions be prospective for major gas-hydrate accumulations. Such areas may include the northwestern part of the Norway-Mezen rift system and the merger zone of the suboceanic and continental crust within the Barents Sea Plate. All these zones have elevated heat-flows, which open a possibility for the water convection in the sediment sequence (*Levashkevich*, 2005). Also it is important that the oil and gas basin evolution within the near-shore zone and shelf areas of the northern Russia in the Late-Mesozoic and Cenozoic time occurred, as it does today, under high-latitude and Arctic conditions attributed to the cryozone.

In general, the oil and gas formation, saturation and migration within the sedimentary complexes of the continental water-saturated lowlands (as well as of the continental slope under the existing climatic environment) are poorly studied. It may be suggested, however, that the overcooling of the sediment cover near-surface layers, on the one hand, forms a fluid-seal for the organic hydrocarbon accumulations and, on the other hand, prevents their degassing. The result may be occurrence of stable compounds of water and abiogenic gas. It is known that the formation of abiogenic hydrocarbon accumulations on the Arctic basin's continental slope under certain conditions is accompanied by the migration of organic hydrocarbons from the oil and gas complexes in the continental slope's sediment cover.

For instance, the Franz-Victoria Trough north of the Franz-Joseph Land Archipelago is a rift formed in Late-Permian – Early Triassic. Within the trough's downthrown blocks, the accumulation processes of primary-migrating bitumens were observed in the lower portion of the seafloor deposits (*Shkatov et al*., 2001). It was shown that they contain methane, propane and other gases as well as bitumens (asphaltenes and maltenes) apparently associated with the hydrocarbon migration from the high-pressure zones (shelf depositional sequences) into the tectonic shadow area (continental slope). Most likely, these processes increase the oil and gas potential and may result in the formation of accumulations of commercial size.

The authors identified a number of particular features in the geologic structure and geodynamic evolution of different areas in the European Arctic shelf of Russia and of the adjacent countries. In line with findings of *Dmitriyevsky* and *Belonin* (2004), it enabled the authors to subdivide the area under study into

[1] In Russia, the category of wells drilled mostly for establishing the petrophysical parameters of the rocks.

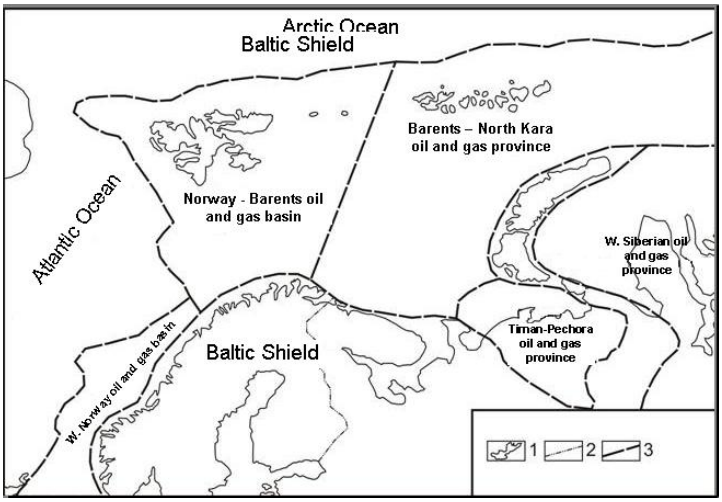

Fig. 6. Oil and gas basins and provinces in the western Russian Arctic (modified after *Dmitriyevsky, Belonin,* 2004):
1. shoreline; 2. international boundary; 3. median line between the Russian and Norwegian territories;
boundaries of oil and gas basins, areas and provinces

a number of regularly positioned oil and gas basins and provinces (Fig. 6). The space-time patterns in the hydrocarbon type locations as well as the geologo-geodynamic analysis of the crust-forming and modifying processes showed the following. The North Sea, Norwegian Sea and West Barents Sea basins (containing the West Norwegian and Norwegian-Barents oil and gas basins) are drastically different from the Barents-North Kara, Timan-Pechora and West Siberian provinces and, most likely, represent two large genetic types (Fig. 6).

The first type encompasses those that underwent in the oil and gas basin evolutionary process 1 (Caledonian) or 2 (Caledonian and Hercynian) stages of tectono-magmatic activation. The second type includes those that underwent only one (Hercynian) stage of tectono-magmatic activation. Besides, within the southern portion of the Barents-North Kara and Timan-Pechora provinces (bordering on the Archaean complexes of the Baltic Shield) there is a zone of potential Riphean oil and gas accumulation. This emphasizes the unique nature of these basins and a possibility of significant increment in the region's hydrocarbon potential.

It is important that the northern boundary of the identified oil and gas basins and provinces within the Atlantic and Arctic oceans continental slope and the oceanic lithosphere merger zone may be drawn at the continent's foot. This may substantially change their combined oil and gas potential. Due to severe climate conditions, the North Kara Basin is the least studied. The basin may be considered a natural extension of the Svalbard Plate separated by a transform fault from the South Kara fragment of the West Siberian petroleum province (Fig. 6).

3. Conclusions

Four oil and gas generation time intervals and the corresponding complexes may be identified in the evolution process of the Eurasian western Arctic shelf. They form a regular spatial pattern, which reflects the continental crust evolution specifics in the region. Riphean complexes within the merger zone of the Russian Plate with the Timan-Pechora and Barents Sea lithospheric plates are responsible for the formation of the earliest potential oil and gas-bearing deposits.

Later, potential oil and gas areas were associated with the Japetus Ocean closing in Early Ordovician – Late Devonian (505-362 MMY) time. They are localized within the western Barents Sea plate and also north of the Baltic Shield's Caledonides. Subsequently, as a result of the Paleo-Urals Ocean closing in Early Permian – Early Triassic (290-241 MMY), oil and gas areas west and east of the Urals folded system (along the line Polar Urals – Pay-Khoy – Novaya Zemlya – Taymyr Peninsula) were formed. The fourth and final region's oil and gas potential formation episode was associated with the accumulation zone of biogenic and abiogenic (gas-hydrate) type hydrocarbons in the continental slope base over the passive continental margin in Cenozoic (55-0 MMY).

All of the above stages of hydrocarbon generation and accumulation in the sediment cover of the European Russia continental crust's Arctic shelf resulted in the formation of a number of large and spatially regularly positioned oil and gas areas with a huge potential.

There are a number of already discovered and partially appraised large and unique oil and gas fields in the Barents – North Kara, Timan-Pechora and West Siberian Provinces. Beside those, it is possible to identify at least three more potential hydrocarbon-rich but insufficiently studied areas. Should commercial accumulations be discovered there, the oil and gas potential of the entire region would be substantially increased.

The first such area is situated northwards the Murmansk region on the Rybachy Peninsula. It is associated with the Riphean sediments of then passive continental margin. The area is located close to the infrastructure of the large industrial center of the Murmansk region, which may be a significant factor in lowering the costs of exploration and drilling.

The second potential area may be associated with the Franz-Joseph Land. It has deeply buried (5 to 6 km) rich oil source rocks in the Devonian-Early Permian sediment cover of the Barents Sea shelf. Despite their remoteness from the shore, the water-depth is not great and drilling would be conducted economically from specialized platforms.

The third area with the potential of discovering large and possibly unique oil and gas field is the North Kara shelf. Our geodynamic analysis indicates that this area may be comparable in terms of its hydrocarbon reserves with the South Kara and Yamal segments of the West Siberian oil and gas province. However, not only the region is very remote from the Northern Russia's industrial centers but it also has difficult ice conditions. Apparently, its development may only occur in a distant future when new underwater drilling and oil and gas production technologies directly on the sea-floor are implemented.

Acknowledgements. The authors are greatly indebted to Dr. Michael Gorfunkel for his invaluable help.

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