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Hydrocarbon deposits in non-anticlinal traps of the Yamal Peninsula of Western Siberia

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Abstract. The article considers various types of non-anticlinal traps of the Yamal Peninsula of Western Siberia. The task is to establish the features of their formation and structure. Gas and gas condensate deposits were allocated in the Akhskian stratum of the Neocomian section, associated with wedge-shaped traps (Bovanenkovsky, Kharasaveysky fields). This type of lithologically-shielded traps was formed due to clastic material entering the territory of the Yamal Peninsula from the East Siberian Platform, the Yenisei Ridge (from the east) and the Ural Mountains (from the west). Sand and clay material accumulated along the path of underwater hills, where wedging zones formed. Traps of various types are developed in the Jurassic deposits of the region. Traps of tectonically shielded type are formed in areas of the active influence of discontinuous disturbances on the structure of the section (for example, on the Nurminsky Swell). Lithologically-shielded traps are formed on the slopes of the erosive remnants of the paleorelief in zones of terrigenous horizons wedging. Such traps are also formed in zones of their screening by the surface of the pre-Cretaceous erosion. The considered examples made it possible to establish the confinement of various types of traps to the sediment section and their distribution over the area of the Yamal region.

Keywords: gas, oil, clinoforms, non-anticline trap, criterion, hydrocarbon deposit, Western Siberia, Yamal Peninsula

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Introduction

In Western Siberia, in its northern part (including the Yamal Peninsula), most of the anticlinal traps have been identified. Large and medium fields of oil and gas have been discovered in the upper (up to 4-5 km) section. The stock of anticlinal structures is almost exhausted. There is a need to study and identify complex non-anticline, combined traps.

As the depth of the search objects increases, the geological structure of the deposits becomes more complicated, the lithological composition of the rocks changes significantly, the influence of the tectonic activity on the subsoil structure increases, the type of void space changes, the reservoir properties of the rocks decrease and, due to these factors, the depth the structure of traps becomes more complicated, which varies from anticlinal to non-anticlinal combined type (Aleksin et al., 1992; Brekhuntsov, Bochkarev et al., 2001; Shuster, Punanova, 2019).

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In the world giants and large fields have been identified in non-anticlinal traps, along with a significant number of open hydrocarbon deposits with small reserves: Bolivar Coast (Venezuela) – 4.1 billion tons of oil, East Texas (USA) – 0.8 billion tons of oil, Hugoton (Mexico) – 1.1 trillion m^3 of gas and others (Aleksin et al., 1992).

According to the forecast estimate, the share of oil resources in non-anticlinal traps of Western Siberia is more than 50 % of their total volume. There is reason to believe that a significant amount of hydrocarbon resources and reserves are confined to non-anticlinal traps and on the Yamal Peninsula (Brekhuntsov, Kislukhin, 2001; Shuster, Dziublo, 2012; Shuster, Punanova, 2016).

Many classifications of non-anticlinal traps based on various principles (genetic, morphological, screen structure, etc.) have been developed (Brod, 1951; Aleksin et al., 1992). There are mainly three types of traps: lithologically-shielded, tectonically-shielded and stratigraphically-shielded. As well as traps of a combined type. A number of authors (Oknova, 2012; Polyakov et al., 2015; Zhemchugova, Berbenev, 2015) additionally distinguish subtypes and classes of traps.

It is necessary to determine the complex of geological and geophysical criteria for their prediction and searchin order to successfully identify and map non-anticlinal traps. The development of criteria requires the accumulation of significant factual material and special scientific research on various sedimentary basins of the world and Russia, which in recent years have been actively conducted in a number of countries (Russia, the USA, China, etc.).

In this article, we consider the features of formation, structure of traps, their areal distribution and confinement to the section in the Yamal oil and gas region in order to accumulate the necessary information on the genesis and structure of non-anticlinal traps to develop criteria for their prediction and searches.

Materials and methods

The northern part of Western Siberia, including the Yamal Peninsula, is one of the world centers of gas accumulation where large and giant gas, gas condensate and oil and gas condensate fields are discovered in the Jurassic-Cretaceous deposits. Formations of the pre-Jurassic complex of deposits and basements are also promising (Brekhuntsov, Bochkarev et al., 2001; Skorobogatov et al., 2003; Shuster, Dziublo, 2012; Shuster, Punanova, 2016). A number of open hydrocarbon deposits are confined to non-anticlinal traps of various types.

The authors of the article examined the structural features of the identified deposits and traps, to which these deposits are confined, for the fields of the Yamal Peninsula and the adjacent territory and water area (Fig. 1, 2) based on the accumulated geological and geophysical material and published works.

The authors had at their disposal factual materials of processing and interpretation of seismic materials of the CDP 3D with a volume of 400 km^2 in the Bovanenkovsky and Kharasaveysky areas, as well as the results of drilling deep wells. In 2005, with the participation of one of the authors (A.D. Dziublo), a structural-tectonic model of the Bovanenkovo-Kharasaveysky area was created, illuminating the structure of Jurassic, Cretaceous and younger deposits. A basin analysis has been carried out. The model was constantly updated. These materials form the basis of ongoing research.

Results and discussion

The geological structure and oil and gas potential of the Yamal Peninsula and the adjacent waters of the Kara Sea, especially in the upper (Cretaceous and, to a lesser extent, Jurassic) part of the section, have been studied quite fully and are reflected in a number of published works, including the authors of the article (Dziublo et al., 2019; Shuster, Dziublo, 2012; Shuster, Punanova, 2019). Therefore, we outline briefly the main features of the geological structure of the Yamal Peninsula and the adjacent waters of the Kara Sea.

In the section of the Yamal Peninsula, three structural-tectonic floors are distinguished:

- the lower floor (basement) is represented by rocks of the Paleozoic and Upper Precambrian – these are tuff-siltstones, porphyritic gabbro-diabases, schists (discovered at the Novoportovsky and Bovanenkovsky fields);
- the intermediate floor (Triassic-Upper Permian) is composed of clay, siliceous, carbonate and volcanic-sedimentary rocks. The thickness of the Triassic stands out in the hollows of the Paleozoic relief;
- the upper structural floor with stratigraphic disagreement lies on the deposits of the intermediate complex, represented by sandy clay rocks of marine and continental origin (Fig. 3).

The entire section of the Yamal oil and gas region, from the Paleozoic to the Cenomanian, has mostly gas saturated, gas condensate and oil and gas condensate fields (oil rims on Bovanenkovsky, Novoportovsky, etc.). HC deposits are discovered in the Lower Middle Jurassic, Upper Jurassic, Neocomian, Barrem-Aptian, Alb-Cenomanian oil and gas complexes. Hydrocarbon deposits are predicted and individual industrial tributaries in the Paleozoic, Triassic oil and gas condensate and in basement formations have already been obtained.

For exploration and development of already discovered hydrocarbon deposits, it is important to study the structural features and forecast capabilities of non-anticlinal, combined type traps.

Having analyzed the available data (including the published material (Brekhuntsov et al., 2001; Brekhuntsov, Kislukhin, 2001; Zhemchugova, Berbenev, 2015; Oknova, 2012; Skorobogatov et al., 2003)) on the structure of a number of Yamal hydrocarbon deposits, the authors studied these trap deposits.

In the northern part of Western Siberia and on the Yamal Peninsula, one of the most promising and, to a large extent, explored oil and gas objects in complex traps is the Lower Cretaceous wedge-shaped complex, confined to the Achimov stratum and its analogues, at the bottom of the Neocomian. These are wedge-shaped reservoirs of the Urengoy, Yambur, Novoportovsk and other giant fields.

The Achimov stratum is represented by interbedded sandstone, siltstone and mudstone strata with a thickness of 0.1-0.5 m, less often up to several meters, reaching 28 m in some cases. Sandstones are characterized by low reservoir properties, increased density, and fine-grained composition. The facies diversity of the stratum associated with the conditions of their formation is noted in different parts of the basin.

At the Novoportovsk oil and gas condensate field, the NovoportovskianLower Cretaceous is an analogue of the

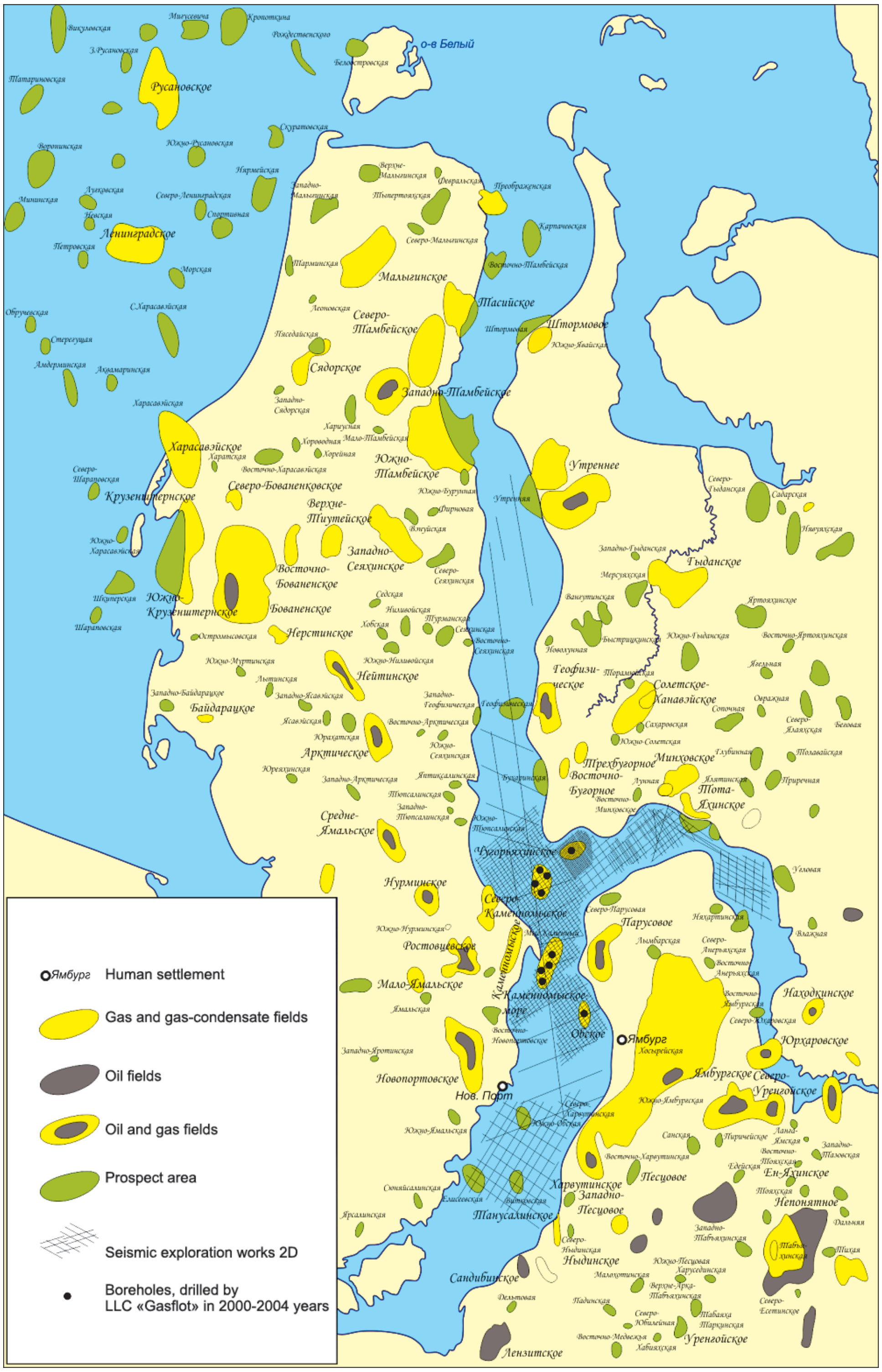

Fig. 1. Overview map of the Yamal Peninsula and the adjacent Kara Sea

Achimovstratum. The section of Cretaceous sediments begins with the Akhskian stratum, consisting of the Novoportovskian, Seyakhinskian, Znmuyakhinskian and Arctic strata (Skorobogatov et al., 2003).

The Novoportovskianstratum is represented by alternating wedge-shaped sand-aleurite and clay packs such as drift cones or underwater landslides. Horizontal sections of the section alternate with slanting. Facies of delta and drift cones are developed in the section of the sequence. From south to north, the thickness of the stratum decreases due to pinching of individual packs and lithological substitution of formations with good reservoir properties of clay horizons. In these areas, the formation of lithologically shielded traps is possible.

The Seyakhskian stratum is represented by dense clays.

The Nulmuyakhinskian stratum is composed of alternating sand-silt strata with clay strata.

The Arctic stratum is formed by clays.

To the north of the Novoportovsky field, the thickness

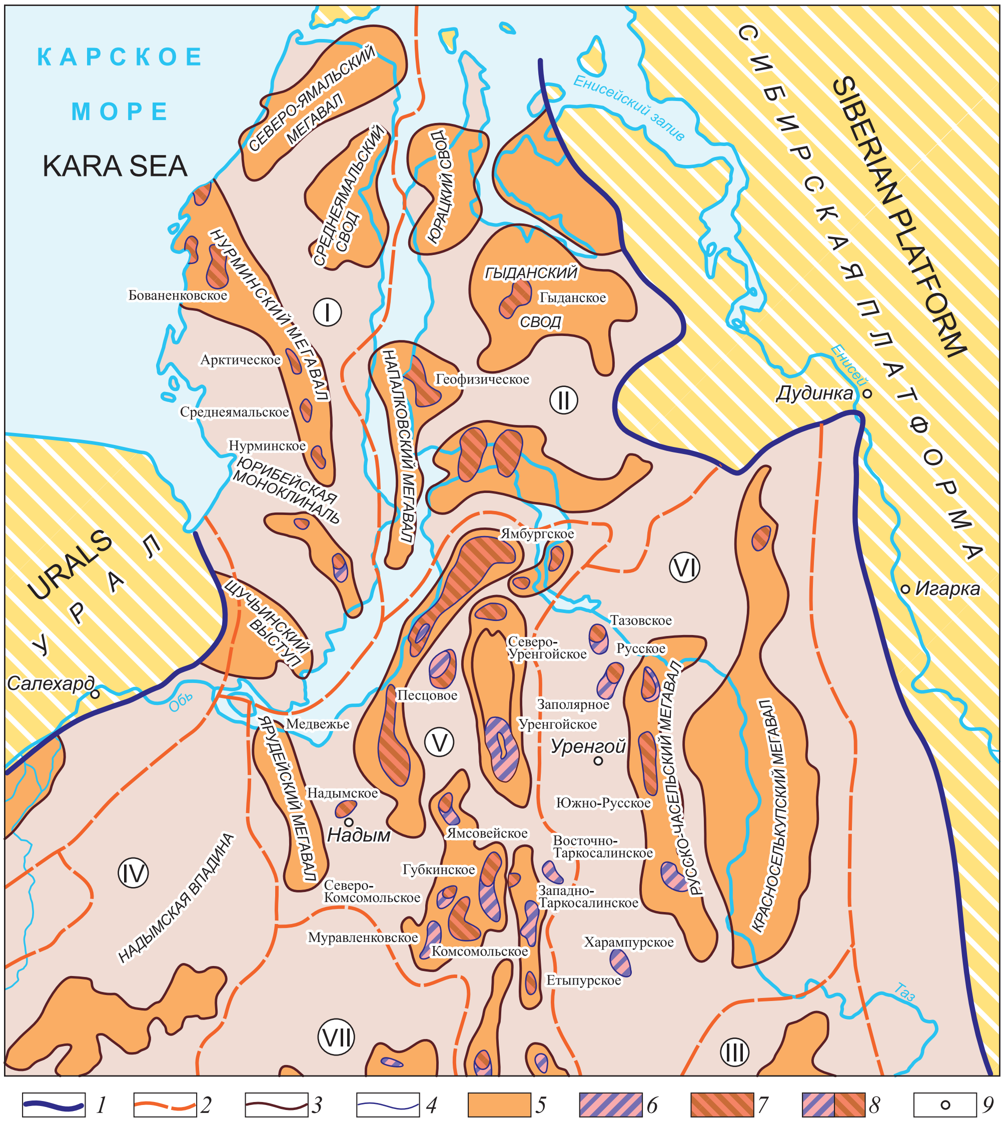

Fig. 2. Map of oil and gas geological zoning of the northern part of the West Siberian oil and gas basin (Oil and gas provinces ..., 1983, with additions and changes): 1-4 – borders: 1 – West Siberian oil and gas basin, 2 – oil and gas regions (I– Yamal, II – Gydansk, III – Payduginsky, IV – Frolovsky, V – Nadym-Pursky, VI – Pur-Tazovsky, VII – Sredneobsky), 3 – first-order structures (megaswells and vaults), 4 – field contours; 5 – megaswells and arches; 6-8 – fields: 6 – oil, 7 – gas and gas condensate, 8 – oil and gas condensate; 9 – settlements (Zhemchugova, Berbenev, 2015).

of the Akhskian stratum increases and the clay content of the section increases. The Novoportovskian sequence here is extremely complex, with frequent substitutions by other rocks with a lenticular structure. Sandstones are replaced laterally with mudstones and clays.

Within the Bovanenkovo-Kharasaveysky zone of the Yamal Peninsula, the sand-mudstone stratum in the Akhskian stratum of the Lower Cretaceous is an analogue of the Achimov sequence. Directly on the deposits of the Upper Jurassic, clinoforms are distinguished, plunging from west to east. Higher in the section, in the lower Tanopchinskian stratum, paleo-river basins are projected (based on seismic data). Deposits of gas and gas condensate were discovered in the Akhskian and Tanopchinskian stratums, in combined traps at the Kharasaveysky and Bovanenkovsky fields. Oil rims were encountered at the Bovanenkovsky field.

There is an idea (Brekhuntsov, Kislukhin, 2001) about the formation of clinoform strata due to clastic material coming from the east (East Siberian Platform, Yenisei Ridge) and to a lesser extent from the west (from the Urals), confirmed by seismic and drilling data. This explains the asymmetric structure of the neocomclinoforms.

The accumulation of sandy clay material occurred at the base of the underwater hills that impeded their advancement, which created wedging zones. Moreover, wedging zones are formed in the area of each new barrier. This is a favorable factor for the formation of lithologically-shielded type traps. This model is confirmed by modern well drilling materials.

There is also the point of view of TyumenNIIGiprogaz employees expressed at a scientific and practical conference in Tyumen (2010) about the deep-sea

Возраст		Литология	Мощн. м	Свита, описание		Газ на шельфе
ПАЛЕОГЕН-ЧЕТВ.			299-435	Глины и алевриты, пески, гравий		
ВЕРХНИЙ МЕЛ	Маастрихт		140	Ганькинская - глины, алевр.		
ВЕРХНИЙ МЕЛ	Коньяк - сантон - компан		470-567	Березовская. Верх - глины с просл. алевр. и песчаников. Низ - опоки, опоковидные глины, силициты		
ВЕРХНИЙ МЕЛ	Турон		63-79	Кузнецовская - глины		
ВЕРХНИЙ МЕЛ	Поздний альб - сеноман		490,8-700	Марресалинская - чередование песчаных, песчано-алевролитовых аркозовых и алевро-пелитовых пород. Углистые прослои		
НИЖНИЙ МЕЛ	Нижний - средний альб		115-186,8	Яронгская - аргиллиты с прослоями песчаников		
НИЖНИЙ МЕЛ	Верхняя часть готерива - баррем - апт		500-950	Танопчинская - неравномерное переслаивание аркозовых песчаников, алевролитов и аргиллитов		
НИЖНИЙ МЕЛ	Барриас - валанжин - начало готерива		460-1200	Ахская - клиноформные песчано-глинистые образования. Верх - аргиллиты часто битуминозные; низ - терригенные и глинистые породы с прослоями глинистых известняков		
ЮРА	Титон		8-10	Баженовская - аргиллиты		
ЮРА	Кел. - оксф. - кимер.		65-82	Абалакская - аргиллиты		
ЮРА	Бат		70-220	Большехетская серия	Малышевская - песчаники	
ЮРА	Байосс		110	Большехетская серия	Леонтьевская - аргиллиты	
ЮРА	Верхи аалена		90-120	Большехетская серия	Вымская - песч., алевр.	
ЮРА	Верхи тоара - аален		20-120	Большехетская серия	Лайдинская - аргил., песч.	
ЮРА	Плинсбах - тоар		278-350	Большехетская серия	Джангодская - песчаники и аргиллиты	
ЮРА	Плинсбах - низы		100-150	Большехетская серия	Левинская - арглиллиты	
ЮРА	Геттанг - синемюр		0-200	Большехетская серия	Зимняя - песчаники и аргиллиты	
ТРИАС			0-115	Мергели, карбонатно-глинистые,глинисто-кремнистые породы, долерито-базальты		
PCm - PZ3			>300	Слабо метаморфизированные сланцы, песчаники; мраморизован. известняки, габбро-диабазы		

Fig. 3. Summary lithological-stratigraphic section of the Yamal oil and gas region

underwater-landslide origin of these deposits, according to which the Novoportskian stratum has a macrolens structure and is represented by a series of sand-aleurite material cones.

Based on seismic data based on seismic facies analysis, wedge-shaped traps in the Novoportovsky sequence are predicted and discovered both at the Novoportovsky field and in adjacent territories in the Cretaceous and Jurassic deposits.

The conditions for the formation of terrigenous bodies of the Achimov stratum of the Neocomian and its analogues were fairly close in all parts of the territory, despite differences in the depth and distance from the drift sources. The best reservoirs were formed in front of the barriers to the "grain" material, i.e. on the slopes of the uplifts.

On the Yamal Peninsula, tectonically shielded traps are widespread, limited by discontinuous faults of the northwestern "Pai-Khoi" strike (Fig. 5).

Parusovsky field (east of the Novoportovsky field) is located in the zone of active fault tectonics. According to seismic data (Yamalgeofizika OJSC), about 30 tectonic faults have been identified here. Faults are usually represented by downthrows. The displacement of the layers along the faults reaches 100 m or more in some

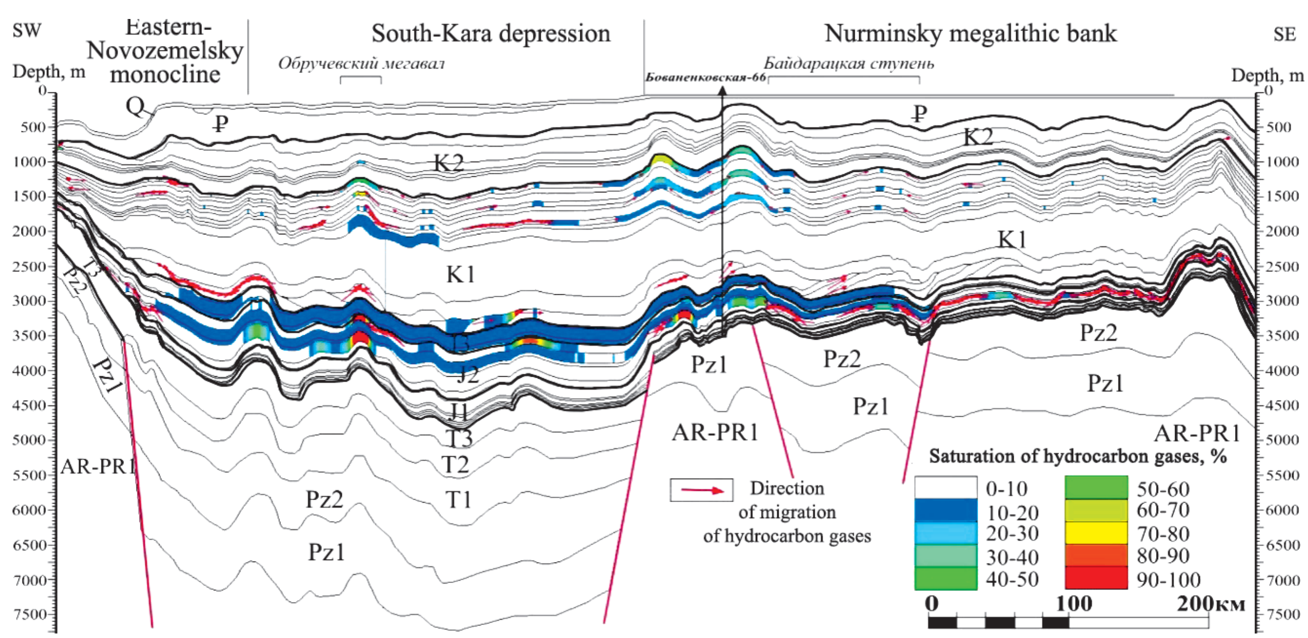

Fig. 4. Deep seismological section along the NW-SE profile

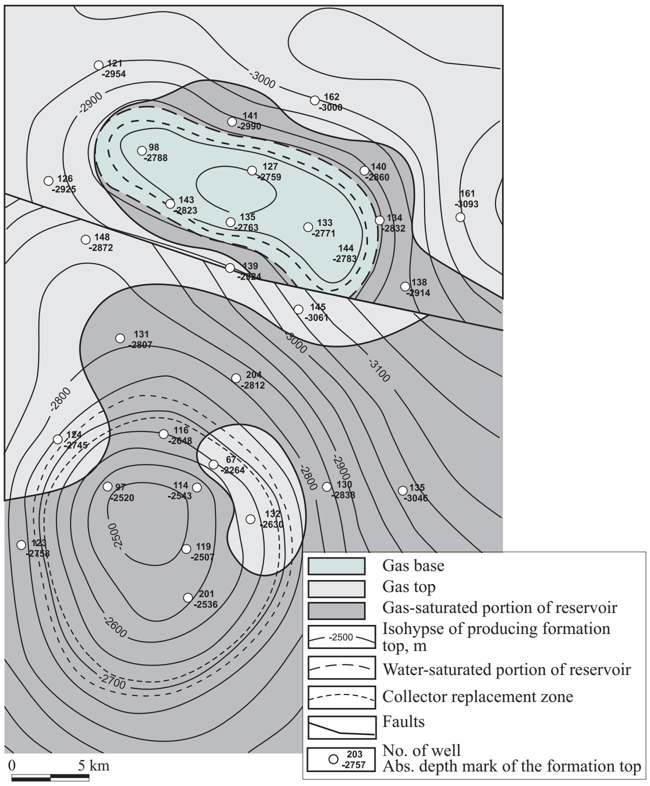

Fig. 5. Bovanenkovskyoil and gas condensate field. Structural map for the top of the Yu$_3$ formation (Skorobogatov et al., 2003).

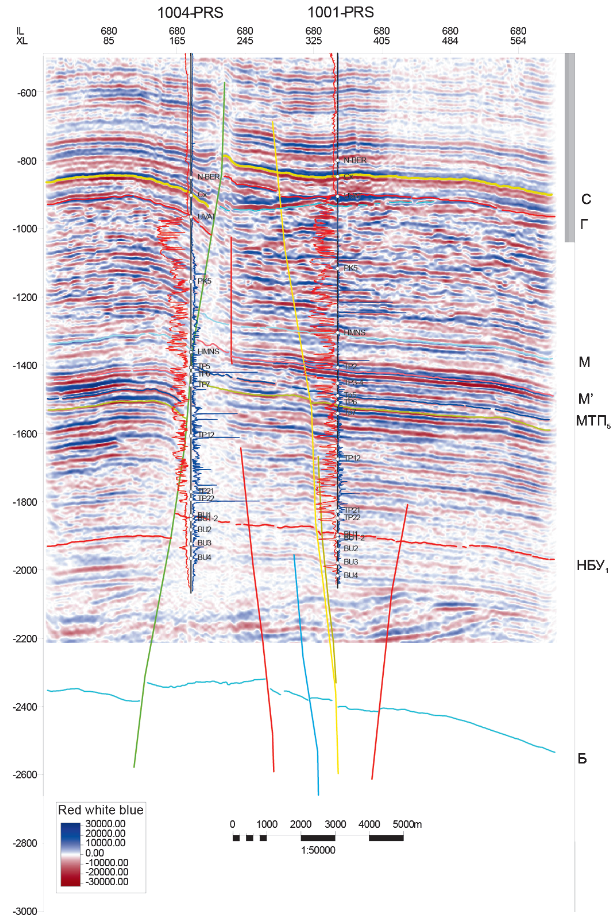

Fig. 6. Temporary seismic section along line 680 of the Parusovsky field (A.A. Doroshenko, Gazprom Geologo-razvedka LLC, 2014)

intervals of the sedimentary cover. Violations are recorded not only on seismic data, but also in exploratory wells (Fig. 6). The system of explosive disturbances can be traced in the interval of the Jurassic and Cretaceous. Promising objects are associated with lithologically-shielded traps in the Achimov formations; tectonically-shielded traps in the Yu$_2$ – Tyumen Formation complex are predicted.

At the Bovanenkovsky field, a fault separating the north and south domes acts as a screen in a tectonically shielded trap in Jurassic deposits. Such traps are formed in the zones of tectonic disturbances of Jurassic and more ancient deposits, as well as in the basement formations.

Three fields have been discovered in the Kara Sea adjacent to the Yamal Peninsula: two gas condensate fields in the Cretaceous Alb-Cenomanian deposits and the Pobeda oil and gas field on Universitetsky area in the Jurassic deposits.

According to the Rosneft press center, recoverable gas reserves (499.2 billion m^3) in the Cretaceous deposits of the Cenomanian and Apt-Alb and oil (130 million tons) in Jurassic deposits have been registered. Judging by the seismic data presented (Fig. 7) there are traps in the Cretaceous and Jurassic sediments of the non-anticlinal combined type.

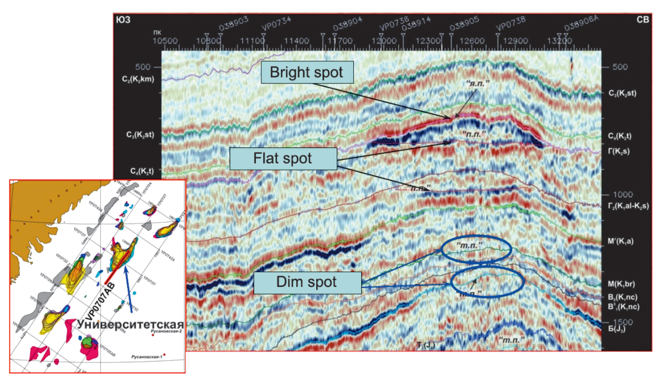

Fig. 7. Universitetsky structure. Anomalies of seismic recording in Cretaceous and Jurassic sediments (profile VP0707AB) (K.A. Dolgunov, Sevmorneftegeofizika OJSC, 2012)

Conclusion

In the Yamal oil and gas region, the identified hydrocarbon deposits are confined to a wide range of non-anticlinal traps in the Jurassic-Cretaceous part of the section.

Clinoforms formed by clastic material coming from the East Siberian Platform, the Yenisei Ridge (from the east) and the Ural Mountains (from the west) are one of the widespread types of traps detected in the Achimov stratum at the bottom of the Neocomian sand-clay material accumulated along the path of movement underwater hills, where wedging zones formed.

The thickness has a macrolensed structure in the form of cones for the removal of sand-silt material. The formation of wedge-shaped bodies of the Achimov stratum and its analogues in the Yamal oil and gas region is fairly close throughout the territory. This provides a basis for predicting such traps in new areas of the region.

In the Jurassic deposits of the Yamal oil and gas region, traps of a tectonically shielded type are developed in areas of the active discontinuous faults of the northwestern strike influencing on the structure of local uplifts, as well as of a lithologically shielded type in the zones of wedging of terrigenous horizons on the slopes of erosive remnants of the paleorelief. Traps of a similar type are also formed in the zones of their screening by the surface of the pre-Cretaceous erosion.

The considered examples of the trap types common in the Yamal oil and gas regions, their genesis and structure, confinement to the sediment section and spread over the area allow expanding the capabilities of forecasting, searching and exploring non-anticlinal traps, as well as increasing the efficiency of oil and gas production at the field development stage.

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