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CHAYANDINSKOYE FIELD IS THE PROJECT OF NEW TECHNOLOGIES IMPLEMENTATION IN EAST SIBERIA

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ЧАЯНДИНСКОЕ МЕСТОРОЖДЕНИЕ – ПРОЕКТ ВНЕДРЕНИЯ НОВЫХ ТЕХНОЛОГИЙ В ВОСТОЧНОЙ СИБИРИ

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Modern level of study of structure of Chayandinskoye oil and gas condensate field is characterized by implementation of 3D seismic survey, carried out using a rich azimuth seismic survey system with a fold of 240. Complex seismic and geological conditions within this part of Eastern Siberia dictate high requirements to quality of field 3D seismic operations. A geological section of an area of operations is characterized by Lower Proterozoic formations of crystalline basement and Vendian, Cambrian, Jurassic, Quaternary deposits of the sedimentary cover. The main role in structure of the sedimentary cover is played by clastic and carbonate deposits of Vendian and halogen-carbonate formations of Cambrian Period. Productive part of a section refers to Botuobinsk, Khamakin and Talakh suits and is characterized by a very complex structure of natural reservoirs. Study of productive section structure is caused by need to prepare a field for production drilling and its subsequent development. In order to reveal features of structure of productive part of a section in a region with complex seismic and geological conditions, migration is used up to the summation in the deep region. Wide-azimuth observation system is aimed to study the most important challenges of medium structure such as direction and nature of change in fracture, study of azimuthal anisotropy of velocity characteristics of section and identification of characteristics of elastic properties change. Base technologies to study anisotropy of geological section properties are adapted and introduced into seismic exploration technique. They are as follows: 1) a method based on study of geometric attributes; 2) azimuthal analysis of velocities; 3) azimuth AVO-analysis (AVAZ); 4) anisotropic inversion. Based on results of processing and complex interpretation of seismic data of MOGT-3D works at the Chayandinskoye oil and gas condensate field the most important information about geological structure of sedimentary cover deposits and productive section was obtained. That allowed to significantly clarifying concept of structure of productive formations and geological development of this area. It also allowed determining distribution of reservoirs and evaluating reserves with considered new built structural and tectonic model.

Современный уровень изучения строения Чаяндинского нефтегазоконденсатного месторождения характеризуется внедрением сейсморазведки 3D, выполненной по технологии полноазимутальной системы наблюдений с кратностью 240. Сложные сейсмогеологические условия в пределах данной части Восточной Сибири диктуют повышенные требования к качеству проведения полевых сейсморазведочных работ 3D. Геологический разрез района работ характеризуют нижнепротерозойские образования кристаллического фундамента и вендские, кембрийские, юрские, четвертичные отложения осадочного чехла. Основную роль в строении осадочного чехла играют терригенно-карбонатные отложения венда и галогенно-карбонатные образования кембрия. Продуктивная часть разреза относится к ботуобинскому, хамакинскому и талахскому горизонтам и характеризуется очень сложным строением природных резервуаров. Изучение строения продуктивной части разреза необходимостью подготовки месторождения к эксплуатационному бурению и последующей его разработки. С целью выявления особенностей строения продуктивной части разреза в регионе со сложными сейсмогеологическими условиями используется миграция до суммирования в глубинной области. Выполняемая широкоазимутальная система наблюдения направлена на изучение важнейших вопросов строения среды: направление и характер изменения трещиноватости, изучение азимутальной анизотропии скоростных характеристик разреза, выявление характеристик изменения упругих свойств. Адаптированы и внедрены в практику сейсморазведочных работ основные технологии изучения анизотропии свойств геологического разреза: 1) метод, основанный на изучении геометрических атрибутов; 2) азимутальный анализ скоростей; 3) азимутальный AVO-анализ (AVAZ); 4) анизотропная инверсия. По результатам обработки и комплексной интерпретации сейсморазведочных материалов работ МОГТ-3Д на Чаяндинском нефтегазоконденсатном месторождении получена важнейшая информация о геологическом строении отложений осадочного чехла и продуктивной части разреза, что позволило значительно уточнить представление о строении продуктивных горизонтов и геологическом развитии данной территории, более адекватно определить пространственное распространение коллекторов и оценить запасы с учетом вновь построенной структурно-тектонической модели.

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Introduction

The group of companies of Gazprom PJSC owns following license areas on the territory of the Republic of Sakha (Yakutia) such as Chayandinskoye, Verkhne-Vilyuchanskoye, Tas-Yuryakhskoye, Sobolokh-Nedzhelinskoye, Srednetungskoye and Tympuchikanskoye. The most significant is Chayandinskoye giant field of hydrocarbon reserves. Chayandinskoye oil and gas condensate field is located in the southwestern part of the Republic of Sakha (Yakutia) and belongs to Leno-Tunguska oil and gas province, Nepsko-Botuobinsk oil and gas region, Botuobinsk oil and gas bearing area. The field was discovered in 1980. Vendian deposits such as Botuobinsk, Khamaki and Talakh reservoirs are productive. The State Register of Mineral Reserves of Russian Federation mineral deposits contain reserves of oil, gas, condensate and helium. Since 2009 Gazprom PJSC has been conducting work on additional exploration of the field. Gazprom Geologorazvedka LLC is an operator of geological exploration [1]. Scientific, technical, geological and geophysical works are preformed by specialists from such companies as Gazprom Geologorazvedka engineering and technical center, CNIP GIS LLC, Gazprom VNIIGAZ LLC and INGEOSERVICE LLC.

Today, the field is covered by a 2D seismic survey network (1500 km), 6,300 km^2 of 3D seismic survey is performed with a subsurface area of 6,980 km^2. From 2013 a modern level 3D survey is implemented on the field. It is performed using a technology of a rich azimuth observation system with a multiplicity of 240 (Fig. 1).

Processing of field seismic material was carried out in INGEOSERVICE LLC in Geocluster processing system version 5000 of CGG Veritas company.

Goal statement

It was stated that 3D seismic had to study in details geological structure and a structural and tectonic model of pay section of reservoir of Chayandinskoye field, clarify geometry of tectonic blocks, zone and determine zones of rock fracturing, predict rock lithotypes and reservoir properties of a section. Solution of such a range of tasks is impossible without use of modern methodical and technological means from supervision of fieldwork to processing and interpretation.
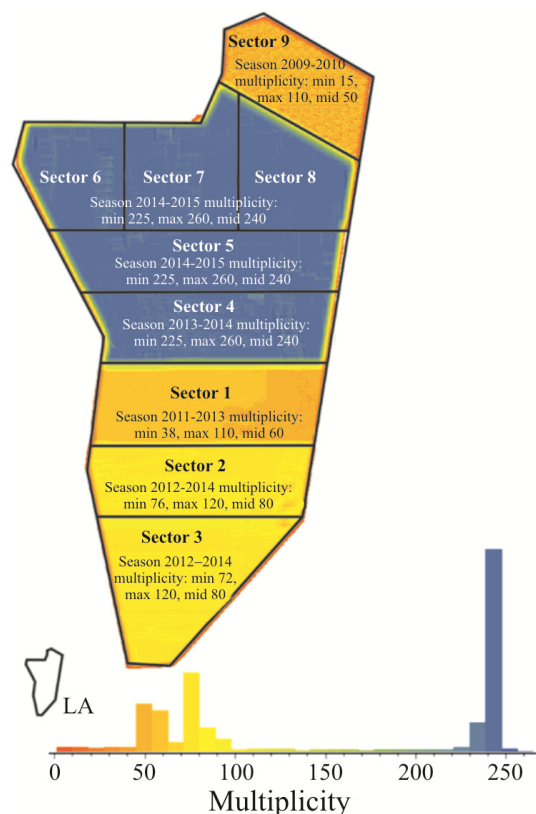

Fig. 1. Map of multiplicity of seismic works

A big number of works of specialists have been devoted to studying features of structural and tectonic structure and conditions of formation of hydrocarbon traps in clastic Vendian deposits [2–11].

The main seismic and geological features of oil and gas potential layers in Eastern Siberia are age of deposits and, as a consequence, high degree of secondary rock trasformations. Age of rocks of a plateau Vendian-Cambrian stage of the sedimentary cover is 500-680 Ma, sediments of the pre-Riphean stage of the sedimentary cover are 950-1500 Ma. This explains high interval velocity

of propagation of reflected seismic waves in a given interval.

Complex spatial arrangement of predominantly clastic oil and gas complexes and features of their correlation with overlapping higher-velocity saliferous deposits cause an objective difficulty in studying their structure from seismic data. A section of the sedimentary cover is divided into following contrasting velocity zones:

1. Halogen-carbonate Cambrian part and carbonate deposits of Vendian where the average velocity is 4700–5700 m/s.

2. The Vendian clastic deposits where the average velocity is 3700–4500 m/s.

3. Riphean deposits with medium speed 5700–6000 m/s.

The upper part of a section in the northern part of Chayandinskaya area is represented by low-speed clastic deposits of the Bordon suite where reservoir velocities are in the range of 1500-3500 m/s. Thickness of sediments within the area is not constant. Paleodepression in the north is filled with a thickness of clastic sediments of up to 295 m (wells 321-60), in the southern part wells have small pay thickness 2-70 m (wells 321-72 and 321-72 m respectively). In conditions of inclined multispeed rocks a lateral velocity gradient is observed in the upper part of the section, which is reflected in functions of $V_{av}(H)$ versus $H(T_0)$.

Halogen-carbonate stratum of rocks occupy the upper part of the sedimentary cover and is composed by alternating layers of salts and dolomites. These deposits differ sharply in terms of acoustic characteristics both from above clastic rocks and from below productive thickness of clastic Vendian deposits. They are well maintained over a large area. As a consequence, maintained reflecting horizons form both single and multiple and partially multiple waves.

Productive Vendian clastic complex, to which most of oil and gas fields of the Siberian platform is related, is located in the lower part of the plate stage of the sedimentary cover. The complex is composed of finely interbedded rock associations and is characterized by a substantial facies

variability in the same age structures. There are almost no regionally constant reflecting boundaries in its volume.

Anisotropic pre-stack depth migration

The application of pre-stack migration in a deep region has proved itself as an efficient technique in various regions with complex seismic and geological conditions. Thanks to large computation power it became possible to implement algorithms for deep migration, both isotropic and anisotropic. Anisotropic migration makes it possible to obtain an image in depth scale, which corresponds to actual depths. This is achieved by introducing the anisotropy parameters δ and ε into the algorithm. A refinement of a depth-velocity model and anisotropy parameters was carried out using tomographic inversion. Migrated seismograms on a deep scale were used to obtain a stackcube on a deep scale, as well as a stack cube that was recalculated into a time scale for comparison with result of time pre-stack migration.

A comparison of results of time migration and anisotropic depth migration in the time domain is presented in Fig. 2 and shows an improvement in traceability of seismic horizons and, most importantly, at an interval of the foundation roof.
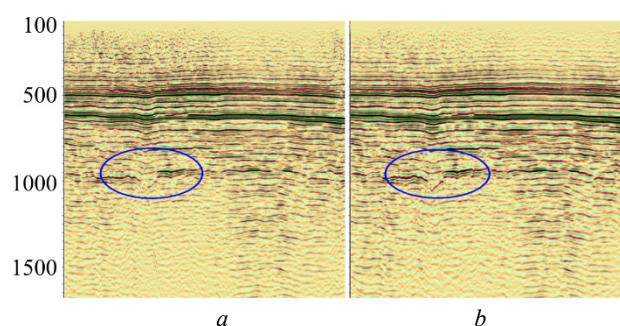

Fig. 2. Comparison of results: *a* – after time migration; *b* – after anisotropic depth migration

All this reflect robustness and stability of executed migration reforms.

The main result of processing is production of migrated cubes and seismograms of high quality while maintaining true ratio of amplitudes and

speed characteristics. As a result, qualitatively new information was obtained due to the following technological and methodical methods:

– application of interference cancellation procedures made it possible to achieve a high signal-to-interference ratio both in seismograms and in the cube;

– application of procedures of correction of static corrections allowed to compensate their influence on a seismic image and to increase quality of summation;

– application of time (PSTM) and pre-stack depth migration (PSDM) provided a correct display of inclined reflecting boundaries in a wave field and transformation of diffracted waves; as a result elements of geological structure became more clear;

– results of migration allow to reveal features of geological structure on a deep scale.

Received seismic materials allowed to solve a large range of scientific and applied issues such as clarifying the structural-tectonic model of the field, detailing the geological structure of the productive part of the section in space between wells, justifying the establishment of new wells and dividing the fracture.

Specification of a structural-tectonic model of the field

Chayandinskoye oil and gas condensate field is characterized by a complex geological structure. According to an officially accepted geological model it is divided into tectonic blocks such as Northern, Southern I and II, Samanchak. Fundamental differences in understanding of tectonic structure of the field are seen in Fig. 3.

A previously accepted tectonic model included a system of faults of submeridional, north-western and north-eastern strike, dividing the territory into blocks [11] such as Northern, Southern and Samanchak. A newly obtained fault-block model differs greatly from the previously adopted one.

Mapping of tectonic disturbances was carried out on the basis of following set of methodical techniques such as detection of the vertical

displacement of in-phase axes on time seismic sections and presence of local anomalies of intensity of reflected waves of the linear strike, control of attenuation and disturbance of dynamics of intensity of reflected waves, analysis of seismic attributes such as cubes of coherence, angles of inclination of surfaces of seismic horizons.
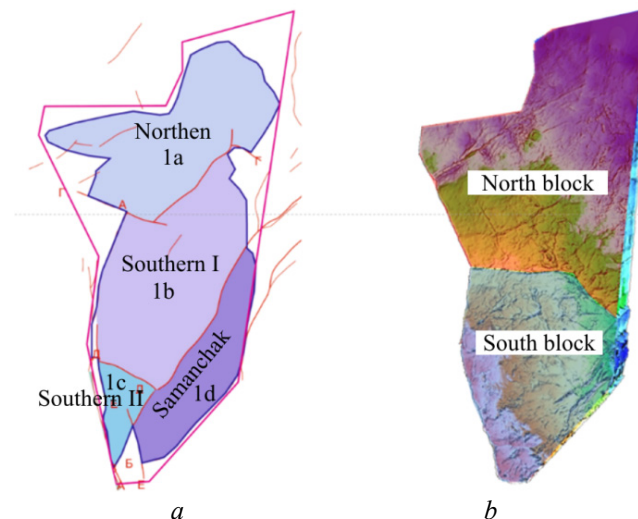

Fig. 3. Comparison of tectonic models, newly obtained (*b*) and previously assumed (*a*)

Analysis of a wave pattern showed that all structural floors of the sedimentary cover are subject to tectonic dislocations. On the background of graben-like narrow directional fault zones that limit tectonic blocks, many elements of local low-amplitude tectonics are traced. Probably, multiple and multidirectional tectonic rearrangements contributed to the wide development of macro- and micro-complexity.

Analyzis of the seismic cube in the interval of 1.5-3.5 s there are bodies of irregular shape with steep slope are found in foundation body. According to our assumption, those bodies belong to batholiths, which took root in the early stages of formation and evolution of the Siberian platform. It is clear that bodies similar to batholiths are centers of gravitational and magnetoactive masses.

Another important conclusion concerns causal relationship between the origin of deep faults, their roots and extent. A demonstration of the results of interpretation of a wave pattern and reconstruction of the deep structure of a basement are shown in Fig. 4.
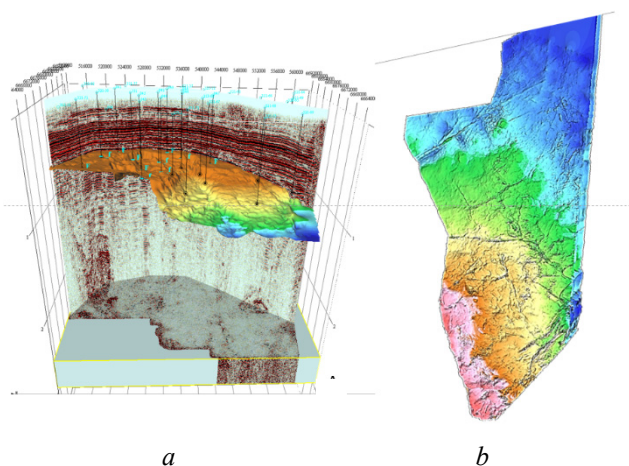
Fig. 4. Established link of fault tectonics with deep structure of the basement: a – 3D cube section; b – axonometry of the surface of Botuobinsk horizon

We believe that a block tectonics mechanism is inseparably linked with geological bodies of deep occurrence, which on the background of time-varying tectonic stresses influenced and possibly determined the mechanism of nucleation, configuration, morphology, system of tectonic discontinuities displacements and shifts.

We propose the following possible mechanism of formation of the fault-block model of the Chayandinskoye field.

Fig. 5 shows a diagram of the interpretation of tectonic stresses, a diagonal system of cracks, which gives good explanation of geometry and configuration of tectonic disturbances by comparing the fracture pattern shown on the map of surface dip angle attribute (DIP).
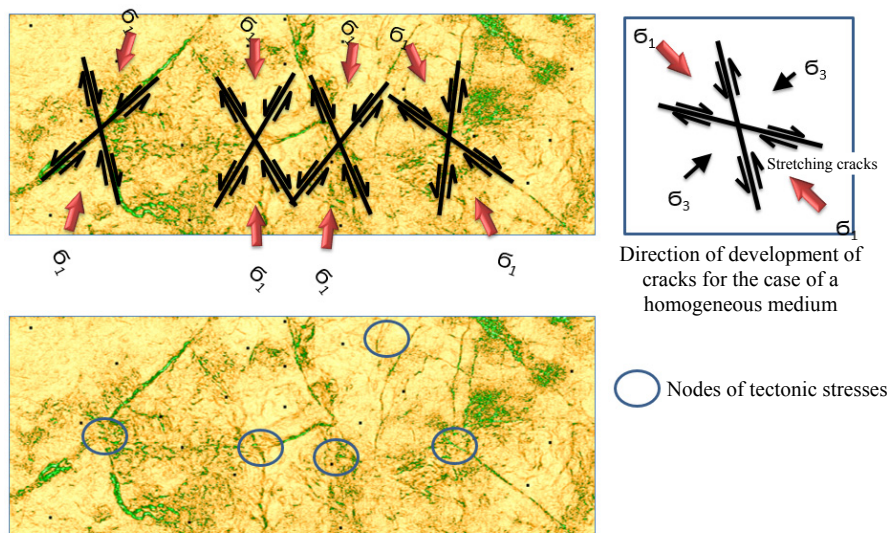

Direction of development of cracks for the case of a homogeneous medium

Nodes of tectonic stresses

Fig. 5. Application of the theory of formation of cracks to the fault-block model of the field:
σ_1 – maximum horizontal stresses; σ_3 – minimum horizontal stresses

To our mind, the scheme of stress location given above proves that the most important directions of compression vectors are from the north and south with formation of characteristic diagonally located planes of disturbances.

Mechanism of fault tectonics formation at the interval of productive horizons

Many researchers have suggested the formation of hydrocarbon deposits in the Nepsko-Peleduysky arch of the Nepa-Botuoba anteclise under the influence of vertical fluid migration and that

activated fault systems of the north-north-east and north-north-west generations played significant role in that [4, 6, 7, 9, 10, 12, 13].

Such systems were activated in the Late Permian and post-Cretaceous epochs, respectively [12]. In the opinion of the authors, activation processes contributed both to formation of deposits in a botanobin horizon of the Vendian, reorganization and partial destruction of zones of oil and gas accumulation of earlier generations in the underlying terrigenous deposits of the Vendian. Stretch cracks are potentially capable of being

conductors for vertical migration of hydrocarbons. It is possible to say that there were generated zones of decompression and unloading within the Chayandinskoye field which led to hydrodynamic fluid communication between each other and flow of hydrocarbons in a direction down upwards along the fractures of tension and failure.

Another important observation for understanding of the tectonic model of the field is a well-distinguishable crater-like shape along the basement roof (Fig. 6).
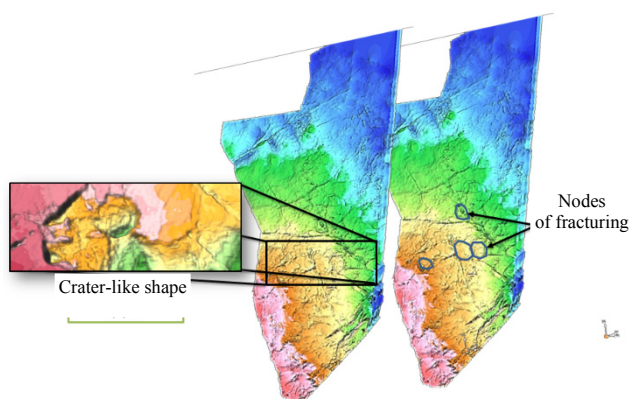

Fig. 6. Nodes and zones of generation of faults and cracks in the roof of the foundation

Such a shape similar to oval does not fit into geometry of the appearence of cracks, ruptures and chips of a low-elastic medium. Attention to this structural form is caused by strong influence on all overlying structural surfaces of different ages. Today, there are three hypotheses that allow to explain the origin of such a rare crater-like shape on the basement surface: 1) an explosion tube; 2) an astroblem; 3) an annular crack – a cylindrical crack of detachment.

We assumed that this round shape is comparable to an explosion tube, which is developed in the territory of Yakutia.

The fact that an explosion tube is formed (or accompanies) and is located in a depocenter zone of a block-fault system proves it. For today, the tectonophysical aspects of formation have been well studied due to their accessibility for full-scale measurements and can serve as an analogue of such artifacts. The second hypothesis of the

formation of such structural forms is an astrobleme, which was formed as a result of fall of a cosmic body.

Specification of a geological model of reservoir pay section

Results and materials of 3D seismic data allow to clarify a geological model of the structure of productive reservoirs in space between wells.

Botuobinsk productive interval is the main object of preparation of hydrocarbon reserves in Nepsko-Botuobinskoye oil and gas area, therefore its distribution, lithological composition, reservoir properties and oil and gas content have been thoroughly studied [1, 11, 14].

The Botuobinsk productive interval is stratigraphically confined to predominantly sandy lower subcrop of Buka suite of the Iktekh Vendian series. The Buka suite is divided into two sub-components such as the lower clastic and the upper carbonate.

Lower subsuite (Vbk1) is composed predominantly by sandstones of light gray, to white, quartz, less often feldspar-quartz, and is heterogeneous. Thickness of the subordinate is up to 40 m. Botuobinsk pay interval is distinguished in the volume of the Lower Buka subsuite. Inflows of gas and oil were received from it at the Chayandinskoye field. *Upper subsuite* (Vbk2) is composed of dolomites, anhydrite-dolomites, interbeds of dolomite marls and mudstones, less often siltstones and sandstones. Thickness of the subsuite is 17-107 m. Total thickness of Buka suite is 28-150 m. Thickness of Botuoba pay interval on the Chayandinskaya area varies from the first meters to 26.6 m.

Distribution of effective thicknesses of the Botuobinsk productive formation is similar to the distribution of total power in particular they reach their maximum values in the center of a propagation band more than 20 m in the Chayandinskoye (wells 321-07, 321-14) and 39 m in the Besyuryakhskaya (wells 340-2) areas. They regularly decrease to zero at the boundaries of wedging.

Botuobinsk horizon is represented by sandstones with subordinate interbeds of siltstones. Sandstones of Botuobinsk productive interval are predominantly quartz, more rare – feldspar and quartz composition, well-sorted fine-grained, medium-grained, rarely coarse-grained differences predominate. In the plantar part of the interval there are interlayers of argillites and aleuros, have thickness mostly from the first millimeters to several centimeters. Only in separate wells the sandstones of the lower part of the Botuoba interval are replaced by intercalation of mudstones, sandstones and siltstones (wells 321-19, 321-2, 847, 849).

Sandstones have very good reservoir properties in the central part of the strip. Their open porosity varies within the limits of 12-26 %, permeability – 55-4650 mD. Reservoir properties of sandstones deteriorate in the central part of the strip (open porosity – up to 3-10 %, permeability – up to 1-5 mD). Reservoirs of the III class prevail at the Chayandinskoye field. The maximum oil rate of 55 m^3/day was obtained at wells 321-07, gas rate of 574 thousand m^3/day was obtained at wells 321-5.

The Botuobinsk productive interval is covered by a thick (about 40 m) dolomite of the upper subordinate of the Buka suite, which is substantially anhydrited in the lowest part (10-15 m). Anhydrite dolomites are the upper regional cap rock.

At the moment, there are two main points of view on the conditions of formation of the Botuobinsk interval. The first point of view is that the sandstones of the Botuobinsk interval were formed as a result of early transgression, accompanied by erosion of dolt formations and accumulation of more sorted material in zones of temporary stabilization of coastlines. This hypothesis is supported by A.N. Dmitrievsky and others. Researchers got to such conclusion due to results of an analysis of the facial substitution of the Botuobinsk interval into facial analogues. Authors of the second point of view [15] believe that the Botuobinsk interval is a large system of bar bodies. This view is based on a detailed core study, detailed cross-well correlation and lithofacies interpretation of sediments studied. For example, in the opinion of O.V. Ivchenko [14] the system of sedimentation of the Botuobinsk interval allows to pick facies of silt and sandy-silt sediments that switch into pre-beach and transitional zones. The author fairly concludes that potential productivity of the wells depends on their facial affiliation. The most productive sediments are located within sediments of the upper part of a coastal slope and deposits of the lower beach and the upper pre-beach zone (facies of silt and silt-sand deposits and facies of coastal slope). According to the author, the best reservoir properties are found on a shore slope.

According to L.D. Kolotushchenko [13], the deposits of the Botuobinsk interval are formed in the subaqua zone of low or normal salinity under conditions of relative stabilization of sea level. Land areas such as Mirninsky, Nizhnechonsky, Peleduisky paleo domes were the source of transportation. In the coastal part of the ancient sea, systems of accumulative bar bodies were formed. In our opinion, the last of the above described points of view (according to L.D. Kolotushchenko [13]) most fully explains the conditions of formation of Botuobinsk interval deposits.

Khamakin productive interval stratigraphically confined to a predominantly sandy pack of the upper part of the Parsh suite. It is studied by deep drilling within the Nepa-Botuoba oil and gas area only [1, 10, 11].

The regional zone of development of the interval is stretched towards the south-west–north-east. Length of the zone is more than 200 km, width is 85 km. The maximum effective thickness of reservoirs (up to 34 m) is found in the Chayandinskoye field. Maximal total thickness of the interval (from 25 to 100 m and more) can be traced in the zone of conjunction of the Nepa-Peleduy dome with the Predpatom depression.

The deposits of the Khamakin productive interval are represented by uneven alternation of sandstone layers, gravelites, siltstones with argillite

interlayers. Sandstones are very diverse in terms of lithological properties. For example, in some sections feldspar-quartz slightly sorted coarse-grained differences predominate, where large sand and gravelite fractions dominate. There are feldspath-quartz and quartz well-sorted medium and fine-grained sandstones in others. The rocks are cemented mainly by clay cement with chlorite-hydromicaceous composition, carbonatized in various degrees, salty, fractured.

The drilling data show that the Khamakin productive interval combines a series of formations differing in both thickness and area of distribution and in terms of their reservoir properties. An interval was formed in various alluvial and coastal-marine environments. This led to the presence in its composition of both poorly sorted gravelite sandstones and well-sorted, "tongue" shapes of sand bodies, appearance of kaolinite cement in sandstones. Lithological-facies heterogeneity and complexity of composition of rocks composing this interval increase near the zone of pinching out of the Khamakin productive interval. A clear tendency of deterioration of reservoir parameters of interval rocks is observed with an increase in their carbonate content.

The porosity of rocks of the Hamakin interval varies from 1.0 to 21 %, permeability varies in the range of 1-6000 mD. The reservoirs of IV class prevail.

Upper clay pack of the Upper-Parsh subsuite is a cap rock for the Khamakin productive interval. Its thickness in the northern and north-western parts of the interval of spreading region is 13-30 m and increases more than 80 m in the southeast direction. It is composed of argillites, silty mudstones of the hydrosilicate composition. There are siltstones passing into sandstones (from fiber type 2-10 cm), fine-grained clayish, with inclusions and cracks of anhydrite. Inclusions of pyrite are noted.

Gas deposits have been discovered at the Chayandinskoye and Talakanskoye fields within the regional zone. The maximum gas rates from rocks of the Khamakin interval were obtained in wells 321-63 and 321-48 – 770.6 and 642.6 thousand m^3/day, respectively.

Formation of the Khamakin interval of the Upper-Parsh suite is associated with the conditions for existence of a strongly dissected paleorelief. A feature of paleorelief is presence of steep slopes of a complex configuration in plan with a trend of falling from west to east and southeast. The direction of removal of clastic material determines features of the paleorelief structure.

According to modern ideas, deposits formed in a coastal zone partly in conditions of temporary flows, partly in conditions of beach.

A.B. Tarasenko [16] proposed a model of structure of layers of the sedimentary system of isolated shallow water for Khamakin time. The author believes that during Khamakin time on the territory of the Nepa-Botuoba anteclise sedimentation occured in the zone of isolated shallow water with a bar complex of deposits of the northeast direction. A decrease in sea level led to displacement of bar bodies towards the sea. Increase in removal of detrital material from land contributed to formation of a sandy beach. The beach gradually through the inner inactive lagoon area, in which clay deposits accumulated, passed into the moving part where alternating layers of clays, sands and siltstones formed. There were "patchwork sands" accumulated in the conditions of forebar variable wave hydrodynamics. The researcher made such conclusions on the basis of an optical microscopic study of rocks in thin sections, cores description materials and well logging data.

In the opinion of M.V. Lebedev [17, 18], the Khamakin facies series were accumulated on the southern slope of extensive paleoanteclise in sub-continental and coastal-marine sedimentation environments. The main factors that caused heterogeneity of the reservoir were transgressive pitching out of deposits at the slope of the paleoanteclise, lateral replacement of sandstones of the delta complexes by clay sediments of the coastal plains and shallow bays. We believe that

the theory of conditions of sedimentation of the Khamakin interval, proposed by M.V. Lebedev [17, 18], is the most correct. That well describes revealed lithologic, facies and sedimentological features of these clastic deposits.

The Khamakin productive interval is lithologically represented by sandstones gray, medium and coarse grained, feldspar-quartz, cross-bedded, with clay-anhydrite and clay-carbonate cement, which contains thin interlayers of green to gray and red to brown silty mudstones, gravelites. Total thickness of clastic deposits of the Khamakin interval within the research area changes from 20 to 100 m and more, increasing to the southeast. Gas inflow was obtained from the deposits of the Khamakin interval at the Chayandinskoye field.

Correlation and tracing of clastic rocks of the Khamakin interval revealed that the reservoirs of the Khamakin horizon are not traced in the section and in some places are split into two sub-horizons two productive layers of Khm-1 and Khm-2. Picking of two reservoirs is necessary in order to trace spatial distribution of the reservoirs in details, reveal regularities of quality of reserves and construct a structural framework for three-dimensional geological modeling correctly. Cycles of layers Khm-1 and Khm-2 are different. Khm-1 corresponds to regressive cycle. Khm-2 corresponds to transgressive cycle.

We believe that conditions where Khm-1 deposits were formed are associated with wandering channels and embedded valleys for Khm-2 deposits. Fig. 7 shows delineated channel-like embedding in well 2, which is clearly seen in the sections of the cube of pseudo impedances.
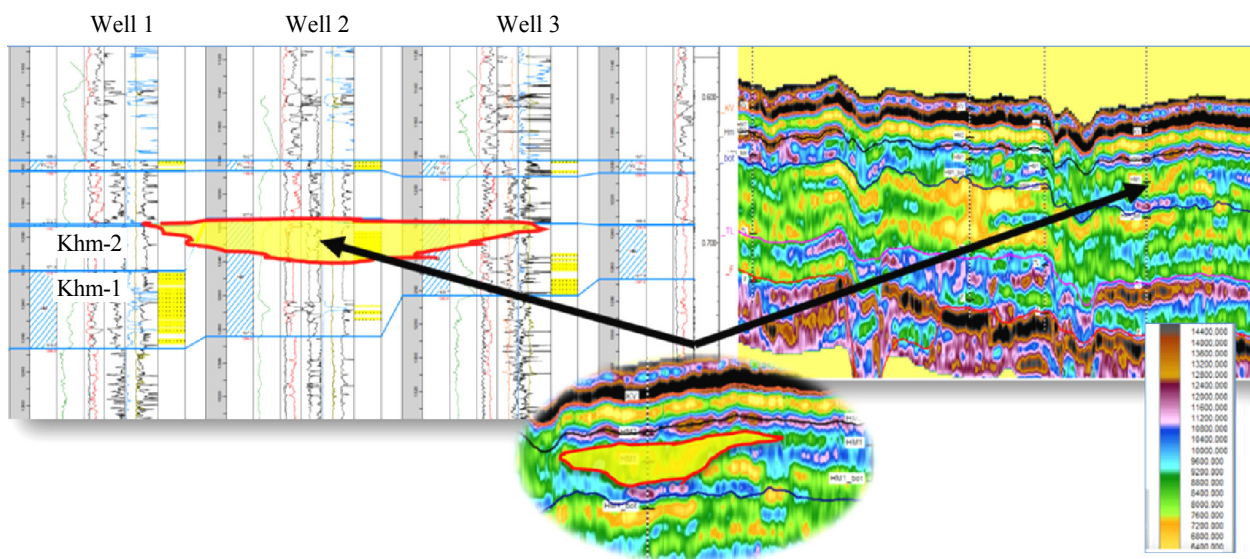

Fig. 7. An example of the allocation of erosion embedded valleys in the Late Khamakin period

FMI method was used in wells. That allowed based on the analysis of textural features by presence of sandstone with an admixture of gravelite material in the lower part of clastic cycles, presence of frequently appearing oblique layering and a double erosion surface to diagnose deposits as precipitations that were deposited in the conditions of wandering rivers.

Such conclusion was made based on sedimentological criteria of E.Yu. Baraboshkin [19].

Use of AVO-analysis to study features of structure of productive deposits

Function of amplitude (reflection) versus deletion (AVO (AVA)) is a technique used to obtain information about properties of host rocks and presence of hydrocarbon saturation in the reservoir [20-24]. During processing of seismic data, "angular samples" were obtained. Each trace is a sequence of signals with the same

range of angles of incidence, summation of which gives a volume called the "angular sum". From the set of angular sums AVO attributes were calculated as

$$\text{cubes} - \text{AVO} - \text{intercept } (A), \qquad (1)$$

where A is a value, proportional to the coefficient of reflection Rp in case of normal incidence;

$$\text{cube of gradients} - \text{AVO} - \text{gradient } (B), \qquad (2)$$

where B is a value, proportional to the tangent of slope angle, that averages dependancy of $R(\sin^2\theta)$, in set range of incident angles θ;
cube "fluid-factor":

$$\Delta F = \Delta V_p/V_p - 1{,}16 V_s/V_p \cdot \Delta V_s/V_s, \qquad (3)$$

where the coefficient of 1.16 of sandy-argillaceous rocks with reservoir water saturation leads to a value of ΔF to zero, which allows to predict gas saturation by increase in "fluid factor";

$$\text{cube } (N_{far} - N_{near})N_{far}. \qquad (4)$$

If a sandstone saturated with water is characterized by an acoustic impedance smaller than that of surrounding medium, and the impedance of a clastic reservoir saturated with hydrocarbons is even smaller, then sections of that attribute will contain anomalies with more contrast that previous attributes if thickness of differentiated by impedance layers is enough. When different angular sums are compared, the nature of dependence of energy of a reflected wave on an angle of incidence for individual seismic horizons is determined. Significant changes in amplitudes as a function of an angle of incidence represent a good indication of the possible presence of hydrocarbons.
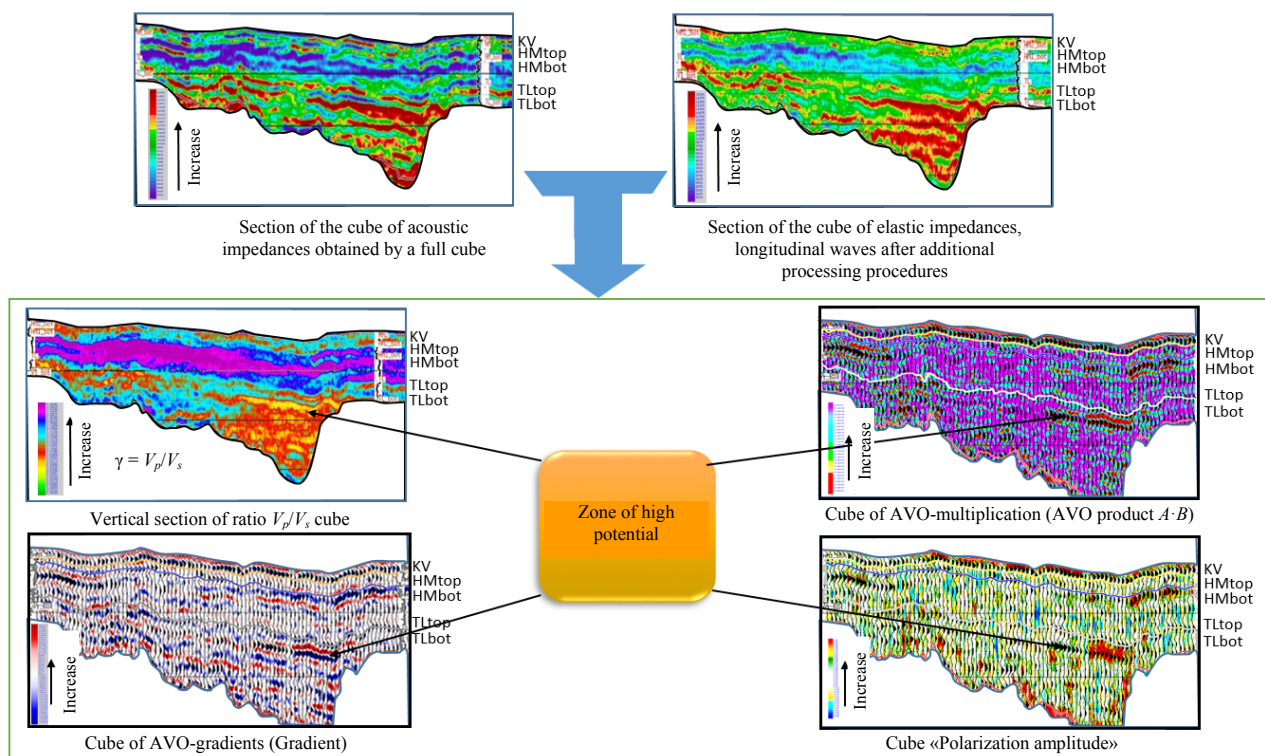

Fig. 8. Attribute characteristic of the productive part of the section: KV – Roof of the Botuobinsk formation; HMtop – roof of the Khamakin formation; HMbot – bottom of of the Khamakin formation; TLtop – roof of the Talakh formation; TLbot – bottom of of the Talakh formation

In classical formulation of the issue AVO-technology is used to predict gas saturation of target objects. To assess reliability of information about attributes obtained by AVO-technology, gradient maps, productivity in the interval of occurrence of the Botuobinsk, Khamakin and Talakh horizons are calculated (Fig. 8).

Experience shows that after careful selection of attributes obtained and compilation with each other it is possible to localize potential zones and recommend to drill exploration wells.

Azimuth processing of seismic data to overcome geological challenges

Note that the standard 3D seismic survey is able to solve a limited range of applied challenges. Therefore, the attention paid by specialists to technologies that are aimed to study anisotropy of properties of the section becomes understandable [20, 25-31].

Today, all four basic methods for studying anisotropy of properties of the geological section are used in practice of seismic exploration such as:

– a method based on the study of geometric attributes;

– azimuth velocity analysis;

– azimuth AVO-analysis (AVAZ);

– azimuth inversion.

The main purpose of azimuth processing is to obtain data characterizing direction of the "fast" and "slow" velocity vectors in the layer, and in the case of a successful analysis they allow forecasting prevailing direction of fracturing of rocks. To carry out such an analysis special processing is applied, which is used for wide-azimuth data. In order to preserve information on azimuths, special regularization is carried out with preservation of data on azimuths of removal. The data were divided into eight azimuth sectors of 45 degrees, time migration of Kirchhoff pre-stacking is performed on four sets of data into which opposing azimuth sectors were put together (0-45 and 180-225 degrees, 45-90 degrees and 225-270 degrees etc.). According to migrated seismograms, a high-resolution specification of migration velocities was carried out. Cubes of migration velocities are recalculated into interval velocities through the analytic transformation. Next, the interval velocity calculation along the target horizons in a narrow interval of 25 ms is performed. Obtained maps of interval velocities were used to calculate directions of "fast" and "slow" velocity at each common

depth point using the "ellipse fitting" algorithm. As a result, maps of the direction of "fast" speed, interpreted as fracturing of rocks, were obtained for three horizons.

An example of a map of probable distribution of the direction of crack propagation, constructed on the basis of azimuth-velocity analysis of data, with the data of bedding measurements using FMI is presented next. Measurements of elements of the occurrence of cracks in one of wells showed that azimuth of bedding of cracks has a preferential direction of 140-150 degrees (south-east), and in the interval of the foundation of rocks the trend of cracks bedding varies by 80-100 degrees. The analysis showed that good convergence was obtained between measurements of direction of crack propagation according to data of a downhole scanner and according to azimuth-velocity analysis performed (Fig. 9).

It should be noted that good convergence comparing bedding of fracturing in the interval of the productive part of the Vendian section is not the only result. Preliminary conclusion has been made according to which it is possible to evaluate big faults located near the well by a downhole scanner (see Fig. 9).

The main result of establishing convergence of well and seismic data is that we are able to identify features of development of fracture fields in space between wells.
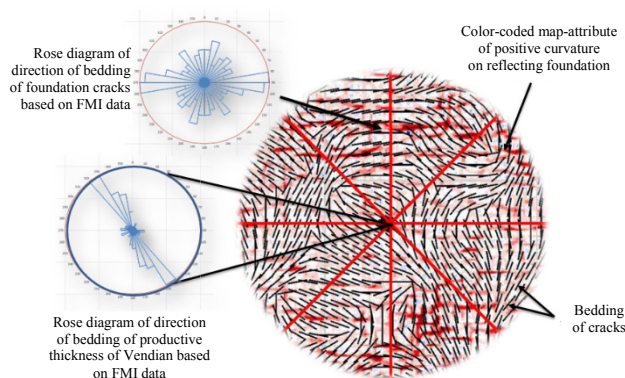

Fig. 9. Fragment of the map of probable distribution of the direction of the bedding of cracks, built on the basis of azimuth-velocity data analysis
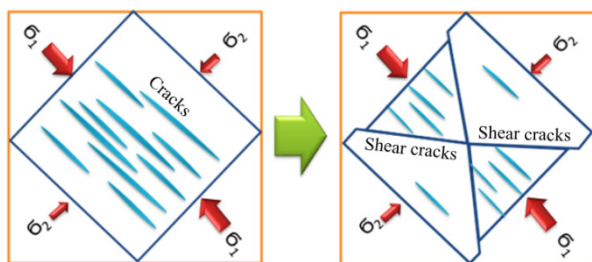
Fig. 10. Shear and tear cracks formed during
the isotropic medium compression

The analysis and comparison of directions of crack propagation in a well and in space between them were performed. That was the basis for forecast of the main stresses directions. The main stresses have strike azimuths of 140-150 degrees (south-east) - 320-330 degrees (north-west), which allows planning to drill horizontal or inclined wells across the established bedding of the fracture system. In this case the direction is 240 degrees to south-west or 60 degrees to north-east. Shear cracks accompany tearing cracks, which occur during compression when the shear strength of the rock is exceeded.

Conclusion

It should be noted that during the seismic survey at the Chayadinskoye field it was possible to draw very important conclusions.

Based on results of processing and complex interpretation of seismic data of MOGT-3D works at the Chayandinskoye oil and gas condensate field, the most important information was obtained on the geological structure of deposits of the sedimentary cover and the productive part of the section. That allowed to significantly clarify the concept of structure of productive horizons and geological development of the given territory and make more accurate estimation of spatial distribution of reservoirs and reserves taking into account the new built structural and tectonic model. Data cubes that are as following were obtained: pseudo-acoustic impedances from a full multiplicity data cube, pseudo-gamma ray logging, elastic and shear impedances, densities and V_p/V_s, on AVO-technology (intercept, gradient, fluid factor, $\lambda\rho$, $\mu\rho$, Z_p, Z_s, R_p, R_s).

Note that used wide azimuthal observation system will correctly perform an analysis of azimuthal anisotropy of velocity characteristics of the section. Therefore, the conclusions are:

1. Results of treatment prove expediency of applying the technique in complex seismic and geological conditions of Eastern Siberia. It becomes real to use fracture prediction in oil exploration works.

2. We consider that important to continue the work on improving the field methodology aimed to increase geological information content of 3D seismic studies (including the refusal to group etc.).

That works are carried out in accordance with the program of experimental and methodological fieldwork of 2013, developed by specialists of INGEOSERVICE LLC and coordinated with Gazprom Geologorazvedka LLC.

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