Litho-geophysical structure of Paleozoic-Mesozoic contact zones in North-Ostaninsk oil field (Tomsk Oblast)

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Abstract A multidiscipline seismic and gravimagnetic survey, as well as paleomagnetic and lithologic-stratigraphic analysis of pre-Jurassic formations were conducted in North-Ostaninsk oil field within south-east Western Siberian petroleum province. A multidirectional tectonic deformation network merging into the destruction zones of Paleozoic basement was identified. The material composition and age of pre-Jurassic formations within each tectonic block were determined. Fundamentally new geological structure model of the Paleozoic suite was proposed: North-Ostaninsk erosion-tectonic protrusion - a reversed and structurally-complex fracture - deformed tectonic syncline fold where the oil reservoir is confined to the dipping limb. Reversed morphostructures in the erosion-tectonic protrusions could be a prospecting indicator in evaluating the hydrocarbon potential of Paleozoic sediments.
1. Geological setting
North-Ostaninsk oil field is located in the south-east Western Siberian petroleum province and is confined to similar structural high north-west strike. According to seismic survey data (i.e. correlation refraction method- CRM and CDP-method), which has been applied since the 80's of the last century and even nowadays, the structural geometry of the reflection horizon \( F_2 \) (Paleozoic surface) is characterized by a significant degree of compartmentalization and structural element contrasts [1, 2, 6]. This feature of the basement surface is governed by the extensive development of tectonic deformation systems of two generations (figure 1). The basic one of which is the NW-trending geological strike formed after Hercynian folding, while the latter (Triassic) one – being the NE-trending geological strike. As a result of subduction rocks of different age and composition were isolated on the Jurassic surface.

Figure 1. Structural map of the reflection horizon \( F_2 \) in North-Ostaninsk oil field based on seismic survey data by CDP-method (according to T.V. Zabug, V.P.Mel'nikov, 2011)
2. Background information
North-Ostaninsk oil field is confined to NW-strike tectonic elevation in the north-eastern Nurolsk sedimentation basin. The structure base includes eroded basement protusion which is laterally restricted and split into separate fault blocks, detected by seismic survey and drilling activities. Heterogeneous Paleozoic formation is composed of complex sequences of limestones, dolomites, magmatic and terrigeneous rocks, embracing depositional processes, whereas, the lithological members could not be traced in correlated well logging.

Research objective- investigation of Paleozoic sediments and rocks in Paleozoic-Mesozoic contact zones within North-Ostaninsk oil field to identify the following factors: void formation, detection of high-productive reservoir zones and bedding orientation by applying the paleomagnetic method for further exploration well distribution pattern.

3. Research data
Geologic-geophysical survey and rock composition study of Paleozoic-Mesozoic contact zones within North-Ostaninsk oil field have been conducted during the 1980's – 1990's [1, 2, 8]. The updated material and data provides practical overviewing of previous survey results in order to define more precisely the tectonic structure of North-Ostaninsk area. Based on core and section description, analytical investigation, age determination and well log interpretation, a lithological characteristic of 19 wells was compiled. According to paleomagnetic investigation results of core samples the bedding elements were determined. Specific features of weathering crust rocks were also studied.

High-precision gravimagnetic survey (scale 1:50 000) was conducted within the North-Ostaninsk area, the data results of which refined such aspects as unit structure, major setting of tectonic elements and material composition of Paleozoic deposits [7].

Correlation of gravimagnetic field anomaly obtained after regional background processing, averaging and subtraction which is depicted in figure 2.

Regional magnetic field within North-Ostaninsk area is characterized by relatively insignificant field density variation intervals, from +47 nT to -36nT. The analysis of magnetic field isodynam direction revealed primarily positive and negative NW-trending strike anomalies.

Gravity field anomalies showed a distinct wavy structure, displaying positive and negative anomaly sequences lying from North-east to South-west. Striking isodynams of gravity high and / or low closely matches the behavior of magnetic anomalies.

The analysis of the gravimagnetic field element layout showed that these elements form a characteristic block system with NE and NW-trending strikes, where the predominate one is the NW strike. Such an anomaly localization is associated with the fact that basement tectonics is involved in the formation of the field structure itself as invading fractured zones into the sediment mantle. Most
probable existing location of hydrocarbon accumulations is associated with the tectonic structure features and material composition of pre-Jurassic formations. Based on surface magnetic and gravimetric survey data typical micromagnetic anomaly zones and in-situ gravity low develop above these formations within the North-Ostaninsk field, which, in its turn, are considered to be geophysical prospecting indicator.

Application of the paleomagnetic method involving the study of multiple collected samples is based on the rock property which determines individual geomagnetic field direction as a remanence vector [8].

Primary remanent magnetic induction, developing simultaneously with rock formation, has an orientation behavior. Existing magnetic field generates viscous magnetization coinciding with the field direction. Viscous and primary magnetization comprise the vector sum, and, in a first approximation, generates natural remanent magnetic induction, which, in its turn, can be measured in individual collected samples. Paleomagnetic survey results [7, 8] showed that the difference between viscous and primary magnetization is based on their stability level to heating: the more stable the primary magnetization is, the faster the viscous magnetization degrades. The experimental procedure included the following: first, temporary magnetic cleaning was conducted with 2-week duration samples in the “along field” position, and then within the same time interval-in the “reversed” field to compensate “laboratory” remanent magnetic induction. Further, thermal demagnetization was conducted in V. Aparin thermal oven to compensate the external magnetic field by means of multi-layered permalloy shield, where thermal demagnetization step is 25°C and final heating temperature - 125°C. Natural viscous remanent magnetic induction component significantly degrades within this temperature range.

Based on experimental data results vector differences were calculated to determine the viscous magnetization direction, governed by the existing geomagnetic field effect and its corresponding orientation. This data was applied for spatial core orientation. The verification of the obtained directions is the correlation of the dipping viscous magnetization to the existing dipping geomagnetic field in the point of the sampling location, as well as the comparison of the bedding elements to the bedding itself in oriented samples. Orientation angular error of viscous magnetization is $3^\circ - 8^\circ$.

Paleomagnetic survey, involving core samples from wells 3E, 5E, 13R and 15R, was conducted by V. Merkulov in the North-Ostaninsk field. Based on this survey the following bedding elements were revealed: SW layer dip azimuth angle of $60^\circ$ и $68^\circ$ (wells 3E and 5E), $34^\circ$ (well 13R), while in the western area (well 15R)- NE layer dip azimuth angle of $45^\circ$ (well location ref. to figure1).

Analytical survey was conducted to investigate the material composition of pre-Jurassic formations, involving the following: core and thin section description, chemical and XRD analysis data, determination of reservoir properties and age and log suite interpretation. Based on this data the lithological characteristic of the upper Paleozoic formation was described for exploratory and production wells with defined lithologic member sequences [3, 5].

Due to the lack of core samples, lithological log suite interpretation was conducted, where carbonates showed high-value resistance, gamma-ray intensity (according to neutron logging), low-level radio-activity; silica rocks- low-value resistivity curve, average / low gamma-ray intensity (according to neutron logging); and effusives (volcanic rocks)- induction logging revealing high-value and high-level radio-activity.

According to faunal remain identification, the deposit age in the upper Paleozoic formation was determined: in the east- late Devonian D$_{3fr}$ (well 16R), Silurian-Lower Devonian S-D$_1$ (well 2R), Devonian D$_{1,2}$ and D$_{2gv-D_3}$ (well 9R); in the south- Lower Carboniferous C$_{1v}$ (well 6R) and C$_1$ (well 8R) in the central section.

Permo-Triassic weathering crust rocks underlie Paleozoic- Mesozoic formation contact. Weathering crust products are divided into two large groups: residual and sediment [4]. Residual weathering crust products are structural eluvium, which, in its turn, can be subdivided into three groups depending on the specific weathering crust rock composition: orthoeluvium accumulated as a
result of intrusions; para-eluvium accumulated as a result of lithified sedimentary rocks and neo-
eluvium accumulated as a result of the decomposition of loose sediments.

Sediment weathering crust products are those rocks formed as a result of sedimentation of suspension and coarse clastics, as well as transported colloids during the formation of structural eluvium. Both groups of weathering crust products have been observed in the investigated sections. In the elevated sections argillaceous-siliceous sideritized deposits, i.e. para-eluvium accumulated from silica rocks (spongolites), while breccia, as well as shales with enclosed brown iron-ore, siderite and bauxite are confined to declined paleo-relief. Weathering crust rocks revealed high-value electrical conductivity and radio-activity on well loggings, as well as positive anomalies on SP-curves.

4. Results and discussion
To correlate well log in the North-Ostaninsk field, depth formation of Jurassic coal layer was determined. Coal layer U10 was considered as a reference horizon to correlate Paleozoic- Mesozoic contact rock zones. Coal layer U10 has an unambiguous geophysical characteristic and can be traced throughout the whole territory. To describe Paleozoic- Mesozoic contact zones structural correlations and cross-sections in both sub-meridional (near NS) and sub-latereal (near EW) directions were plotted (figure 3- legend identifying geological sections).

Plotted well lines 11R-12R-3R-7R-5R in the geological cross-section revealed the fact that exposed pre-Jurassic formations in the wells 11R, 3R, 7R and 5R are almost on a level with one another, whereas weathering crust (3.0-4.0 m) embraces siliceous-argillaceous iron-rich rocks, while the upper Paleozoic formation section is formed by dolomites. (figure 4).

At the same time, well 12R cross-section showed quite a different structure. Jurassic sediment thickness from U10 top to weathering crust top increases up to 46m. in comparison to 19-23m. in the above-described wells, while weathering crust includes permeable sandy breccia. Palaeozoic formation encloses varied altered effusives (volcanic rocks) with sparse marlstone interlayers. These rocks can be found in the down-dip block. In view of above-mentioned description, both previously mapped fault between wells 3R and 12R and inferred fault between wells 12R and 11R should be considered.
Plotted well line 15R-6R-5R-14R in the geological cross-section (figure 5) revealed that the Upper Palaeozoic section is comprised of different rock composition: limestone in well 15R, breccia and fractured spongolites in well 6R, replacement dolomite in well 5R and organogenic (algae) limestone in well 14R.

High-hysdometric horizon position (coal layer U10) was observed in the geological cross-section, and, respectively, pre-Jurassic top sediments in well 6R, which was drilled within the block limited by tectonic faults. In well 6R the rock age was determined as Lower Carboniferous (C1v), while in 5R - by analogy with well 3R data- Middle-Upper Devonian (D2gv-D3).

Palaeozoic formation exposed in wells 5R and 14R is different in age and composition: Middle-Upper Devonian replacement dolomites and Sirulian-Lower Devonian organogenic limestone) which, in its turn, confirms the presence of tectonic faults between these wells.

Plotted well line 4R-6R-7R-3R-9R in the geological cross-section (figure 6) revealed that the Upper Paleozoic section in the wells 4R and 6R is composed of silica rocks- spongolites, although in accordance to their thickness (14m. in well 4R and 41m. in 6R) are incomparably. Besides, silica rocks in well 6R are of high porosity and permeability, due to intensive fracturing and leaching which is not observed in well 4R cross-section.

Figure 5. Geological cross-section through plotted well lines 15R-6R-5R-14R depicting Palaeozoic- Mesozoic contact zones in North-Ostaninsk field. Horizontal scale 1:75 000; vertical scale 1:500 (Legend- figure 3)

Figure 6. Geological cross-section through plotted well lines 4R-6R-7R-3R-9R depicting Palaeozoic- Mesozoic contact zones in North-Ostaninsk field. Horizontal scale 1:75 000; vertical scale 1:500 (Legend- figure 3)
Weathering crust products in both wells are of siliceous-argillaceous sideritized rocks-paraeluvium[4]. High-hysdrometric horizon position of pre-Jurassic top sediments in well 6R. Thus, based on the above-described characteristic cross-section feature possible tectonic faulting exists between wells 4R and 6R.

In the block where wells 7R and 3R have been drilled pre-Jurassic sediment sections have identical structure: Middle Devonian replacement dolomites (D2gv-D3) and siliceous-argillaceous iron-rich rocks, and in the weathering crust-breccia with agrillo-ferruginous cement.

In the block, NW to the above-described one, in well 9R Lower-Middle Devonian replacement dolomite top is located a bit lower than that in well 3R; while the weathering crust includes red breccias with agrillo-ferruginous cement (16m.). It is assumed that possible tectonic faulting exists between wells 3R and 9R.

A geological model of Paleozoic-Mesozoic sediment contact zones was plotted on the basis of an integrated litho-geophysical study of the pre-Jurassic formation. Erosion-tectonic basement protusion underlying the North-Ostaninsk structure is split into separate tectonic fracture blocks. The structural map of plotted reflection horizon F2 (refer. to figure 1) illustrates not only the block boundaries according to CRM and gravimagnetic data but also numerous random tectonic faults based on seismic survey by CDP-method. Integrated geophysical survey conducted in this studied area provided the contouring of these tectonic faults and their further merging into Paleozoic basement degradation zones (figure 7).

To study the outcropping rock cluster distribution on the Palaeozoic basement surface the following components were plotted: schematic lithological columns, based on litho-geophysical well logging (upper 30m.); formation age – fauna identification; and strike and dip of rock layers – paleomagnetic investigation of oriented cores.

Summarizing performed litho-geophysical survey the distribution of corresponding rock types within isolated blocks, the boundaries of which correlate with previously identified boundaries has been proposed (figure 7).

According to lithological data, limestones, dolomites, silica rocks and effusives (volcanic rocks) outcrop onto the basement surface.

Limestones found in drilled wells 10R, 16R, 17R, 15R and 14R are in the western, south-western and south-eastern blocks of the North-Ostaninsk structure. They contain fauna remains which are indicators of Late Devonian D3 fr being intensively fractured and brecciated.

Dolomites are widely distributed in the eastern flank, as well as within the well 11R area. They are comprised of limestone interlayers with fauna, being of Silurian- Early Devonian (S-D1) and Middle-Late Devonian (D2gv-D3) age. Dolomites formed as a result of metasomatism during catagenesis under the influence of enriched magnesium water on limestones, i.e. calcite replacement dolomite. The abundance of magnesium ions in the formation waters is the result of the alteration of mafic effusives (volcanic rocks). Generally, dolomites are porous and vesicular. Dolomite replacement is restricted to the oil reservoir of the North-Ostaninsk field.

Silica rocks found in drilled wells 4R, 6R, 8R and 13R are distributed in the south-western, central and north-eastern blocks of the North-Ostaninsk structure. They are basically spongolites,
spicula sponges, as well as the remains of crinoids, foraminifera and other fauna which are indicators of Early Carboniferous (C1v) rocks. These rocks have pores and vugs as a result of leached fauna remains during post-deposition. During well testing of the upper Paleozoic formation section oil bleeding was detected in well 6R.

Effusives (volcanic rocks) include basalt porpyrites, diabase, spilites, i.e. mafic rocks. According to chemical analysis results these post-depositional altered rocks contain a significant amount of magnesium and ferrum oxides. Effusives can be practically found in all the studied cross-sections as isolated layers or members, but in well 12R these rocks are found in maximum thicknesses. It is assumed that these rocks are distributed throughout the well 12R area and NW to the fault.

5. Conclusion
Thus, in view of lithological data, fauna identification and paleomagnetic survey results, it was defined that the eroded tectonic protusion of the North-Ostaninsk field exhibits distinct inverted morphostructure features, i.e. elevated basement block reflecting structurally complex and fractured tectonic faults within syncline folded block in Paleozoic formations. North-Ostaninsk oil deposit is confined to the steep dipping NE flank of the field itself. Similar correlatives as plicative basement structure elements, horizon F2 erosion surface structures and oil field layout were defined in the following Solonovsk, Kalinov and Severo-Kalino oil fields [8]. It should be noted that above-mentioned oil fields are rather closely-spaced and concentrated in one structural element of the NE Nurolsk depression flange. The evidence of such inverted morphostructures in eroded tectonic protusions could be considered as an exploratory criterion and/or parameter in evaluating potential oil-bearing Paleozoic formations.

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