SOUTH-ORENBURG BAR – NEW EXPLORATION TARGET OF SOL-ILETSK DOME

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Abstract: The relevance of the study is explained by the need to maintain and consolidate the hydrocarbon raw materials base of Orenburg natural gas chemical complex due to depletion of reserves of the main source of raw materials – Orenburg oil-gas condensate field and search for the new lines of hydrocarbon exploration. Lithological features of the section, sedimentary environment, rock dating by faunal remains, reservoir properties, oil-and-gas content indicators, bitumen survey results were considered. Sandstone strata (reservoirs) and loamy-argillous series were identified as caps (impermeable layers). Porous, fractured-porous reservoirs with prevailing poor-porous reservoirs with low matrix permeability. Poor deep-hole prospecting study of a thick deposit section was demonstrated (core definition of the penetrated section is 2%). Drilling and seismic survey results were used to specify the structure of the Ordovician series within Orenburg bar and adjacent territories. Exploration HC deposit targets were identified and their predicted resources were estimated. A new large exploration target with a range of 1,200 m and more than 100 km long was identified as an East-West direction strip to the south of Orenburg bar. The existence of South-Orenburg bar along deposits from Ordovician through to Lower Permian subsalt deposits is assumed. This object with major predicted resources is a new potentially promising line of prospecting in the area of operations of Gazprom Dobycha Orenburg LLC.

Keywords: Ordovician, Sol-Iletsk dome, geological structure, oil-and-gas content, HC resources.

1. INTRODUCTION

Ordovician system deposits are oil-and-gas-bearing in many regions of the world (Vysotskiy, 1981). However, these deposits are poorly studied in Orenburg region and all of Volga-Ural Province and no HC deposits have been found in them so far. The paper is aimed at assessing oil-and-gas potential of Ordovician deposits in Orenburg region.

Formation of Ordovician deposits in Orenburg region was preceded by a continental perturbation as no Cambrian deposits were found in the region. A new wave of marine transgression in the Ordovician period brought clastic deposits to the area of Sol-Iletsk dome that was the most submerged back then and adjacent western part of Pre-Urals basin. Shallow marine predominantly argillaceous-silt rocks with sparse interlayers of limestone, dolomites, sandstone prevail in the most of the territory. High concentration of sandstone – (35-50%) is observed in southern (well 80 Dimitrovskaya, 85 Berdyanskaya), north-eastern (well 106 Oktyabrskaya, 630 Belozerskaya) areas and in well 1 Ordovician. Ordovician deposits are overlaid with trans-Volga horizon rocks of the Famennian, Lower Devonian or Silurian period. In Orenburg region, the Ordovician terrigene series is developed within Sol-Iletsk dome, southern part of East-Orenburg elevation and adjacent areas of Pre-Urals basin (Lukinykh and Belyaev, 1998) (Figure 1).

2. MATERIALS AND METHODS

The main study method is integral analysis of results of prospecting conducted in the territory of Sol-Iletsk dome and adjacent lands: deep-hole prospecting (core examination, well testing), regional, exploratory and detailed seismic CMP surveys. More than 60 fields are known in Ordovician deposits in the North-American platform. Gas fields, including some large ones prevail here.

In the Permian petroleum basin of North America, more than half of booked proven free gas reserves of as much as 2.3 trn m^3 is contained in Ordovician deposits. Booked mineable condensate reserves were 0.5 bln t. The main gas accumulation zones are confined to Delaware depression and Val Verde and Fort-Worth sweep. Caps are represented by dense carbonate and halogen rocks. Three large gas fields were established in Ordovician dolomites: Gomez 5,790-6,800 m deep, booked reserves of 283 bln m^3; Pakket (3,048-4,572 m), 184 bln; Lockridge (5,600-6,000 m), 103 bln. Regionally, Lower Ordovician Ellen siliceous dolomites that enclose deposits at great depths are oil-and-gas-bearing. Porosity of Ellen dolomitic limestone is conditioned by fracturing. Vertical fractures are typical. Reservoirs are of porous and fractured type; at Gomez field, average porosity of limestone is 1.5%, permeability – 420 mD.

Apko, Arbuckel and Kansas fields in the west of Texas are also confined to Elen dolomites. Albion-Scipio field in Trenton Ordovician limestone was found in Michigan. Porous dolomites build up the top of Trenton formation. Lima-Indiana field in Indiana and Ohio is also confined to Trenton limestone. Oklahoma City was found in Simpson Ordovician sandstone. In the Western Internal PB in the Central Kansas oil-and-gas accumulation area, the most common traps rich in oil and gas are dome-erosion or erosion scarps with Cambrian-Ordovician carbonate reservoirs. In Abilene oil-and-gas accumulation zone and Nimeha area, the richest pay horizons are Ordovician sandstone.

In the Michigan basin, few gas deposits that are minor in terms of reserves are present in Ordovician limestone and dolomites. The same basin has a peculiar oil-and-gas accumulation zone, Albion-Scipio. It comprises three mutually isolated parts characterized by low porosity and permeability that gas and oil fields of near-break fractured sections are confined to – Albion, Scipio, Pulaski. Deposits are enclosed in dolomites and limestone of the Middle Ordovician Trenton suite in tectonic fracturing lenses. In terms of oil reserves, Albion and Scipio fields are of medium size. In the Willistone basin, Ordovician sandstone is oil-and-gas-bearing.

In Ordovician-Sinian series of the North-China basin, more than 40 oil fields were discovered (Guodu et al., 1998). Inmai 1 and Inmai 2 oil fields were discovered in Ordovician deposits within the largest Tarim basin in North-Tarim elevation. Oil-bearing deposits occur at the 5,340-5,378 m depth. Oil pool in Lower Ordovician carbonates of Nanke-Inmaliy elevation is largely preserved thanks to the presence of Middle–Upper Ordovician thick loamy impermeable layer. Initial oil yield is 100-211 m/day.

Taichung 1 field was discovered in 1989 in fractured and vesicular Lower Ordovician dolomites in Central-Tarim elevation. Its depth is 3,566-3,737 m, oil yield – 576 m^3/s, gas yield – 360 th. m^3/day. At Jenchiyu field (North-China PB) confined to the subsurface high of Sinian carbonates, oil inflow with a yield of 600 m^3/day (Lee, 1992) was obtained via a 15 mm connecting pipe at well Gu-2 from Ordovician carbonate rocks.

In Australia, oil-and-gas content of Ordovician rocks was established in Amadeus petroleum basin (Ancient Australian Platform). On the Australian platform in Amadeus downfold, Ordovician deposits (2.4 km) are built up by shallow marine sandstone, silty rocks, mudstone with dolomite and limestone streaks. Mereenie gas condensate field and Palm Valley gas field were discovered in the north of the central region. At both fields, deposits are enclosed in dome traps in Lower-Medium Ordovician sandstone. Mereenie field reserves are some 40 mln t of oil, Palm Valley – up to 280 bln m^3 of gas.

In the Sahara-Libyian petroleum basin within Central-Algerian syneclise, a huge oil field named Hassi Messaoud was found with oil productive capacity of 1.2 bln t. The field size is 40 km x 45 km, Paleozoic roof range is 280 m. Ordovician and Cambrian sandstone and quartzose sandstone are productive at the 3,200-3,400 m depth. Sandstone porosity is 5-10%, permeability – up to 10 mD. The rock is capped by a Triassic loamy-salt-bearing section up to 600 m thick.

Ordovician deposits within Algerian-Lybian syneclise (Illizi depression) are also productive. In West-Algerian syneclise, pay gas horizons were identified in Ordovician – Bahar-Al-Amar field; reservoirs are represented by sandstone. In Algeria, at a huge oil-gas condensate field named Rhourde Nouss (850 bln m^3 of gas), the main pay horizon is sandy-clayey Triassic series. Commercial gas inflows were also obtained from underlying Devonian, Silurian and Ordovician sandstone from a depth of up to 3,000 m. In Timan-Pechora province, Ordovician deposits are comprised in two hydrocarbon plays: Terrigene Lower-Medium Ordovician and carbonate Upper Ordovician-Lower Devonian. Reservoir beds are confined to Lower Ordovician sandstone and Upper Ordovician dolomites. Reservoir bed distribution areas are fixed to domes and banks of large paleo-elevations.

Cap reservoirs are identified in loamy-sulphate-carbonate and salt-bearing benches of Upper Ordovician deposits. Within the province, Srednemakarikhinskoye oil field was discovered in Upper Ordovician Baganskaya suite in Khoreyverskaya depression. Dolomitic limestone and secondary dolomites are oil-bearing. They build up biostromes 10-30 m thick. Porosity of fractured-porous reservoirs reaches 11% (Prishchepa, 2005). Anhydrite-dolomite series of Malotavrinsky horizon up to 160-300 m thick acts as a cap. A blanket deposit was also identified at Masterylskoye field. Yield varies from 3 to 42 m^3/day, oil is light (0.833-0.856 g/cm^3).

Medium and Upper Ordovician deposits contain moss-stromatopore biostromes 2 to 10 m thick. They are confined to the top of Malomakarikhinskaya and Baganskaya suites. They are built up by low-porosity dolomites (0.5-4%). Matrix permeability rarely exceeds 1 mD, fracture permeability reaches 4 mD. Complex reservoirs are porous-fissured, fractured-porous, fractured-vuggy. Oil inflow at Verkhnevozeyskaya and gas inflow at Kochmesskaya sites were obtained.

Ordovician deposits in the south-west of the Russian platform were established by acritarchs found in wells drilled in the territory of Orenburg bar (Chibrikova and Olli, 2001). Wells Ordovician 2, Krasnokholmskaya 28, Krasnoyarskaya 16 exposed thick Ordovician deposits (more than 2 km thick). The deposits are represented by light-gray fine well-graded quartzose sandstone and silty rocks with mudstone streaks. Wells 102 Zapadno-Orenburgskaya and 108 Novotatischevskaya exposed the top of terrigene Ordovician deposits more than 130 m thick. In addition to Ordovician acritarchs, samples contain derived Sinian-Vendian forms. Remains are also represented by scolecodonts and Chitinozoa. According to R.R. Yakupov (Yakupov and Kondratenko, 2012), the age of Chitinozoa matches Medium-Late Ordovician, while the foundation matches Medium Darrivillian of Medium Ordovician – Volkhovsky and Kundasky horizons. E.V. Chibrikova also identified Chitinozoa of Medium-Late Ordovician in this well. The rocks are represented by gray band silty sandstone with burrow traces. Silty sandstone has feldsparic-quartzose composition with mica and glauconite grain inclusions. The presence of derived forms of Late Cambrian acritarchs is indicative of bottom deposit formation as a result of washout of Sinian-Vendian deposits. Bottom deposits developed in discrete shallow rift-valley type basins. Sinian-Vendian rocks of downthrown blocks were the sources of debris (Gorozhanina, 2012a, 2012b).

[Figure 1 here]

Their presence was identified by deep-hole prospecting (appendix 1. table 1). Wells 1 Krasnoyarskaya, 1 and 2 Ordovician located on Orenburg bar exposed it to a depth of more than 2,000 m. Most wells (Politykina et al., 2001) are located in the northern part of Sol-Iletsk dome, 10 of them were drilled within Orenburg bar. Two wells (106 Oktyabrskaya and 630 Belozerskaya) exposed Ordovician deposits in East-Orenburg bending fold and 4 in Pre-Urals basin.

After wells No. 28, 17, 66, 100, 302, 310, 324, 501, 1 Krasny Yar were drilled, it became evident that Orenburg bar is the same elevation along the Ordovician surface as along overlying marker horizons. The structure size at minus 3100 m elevation is 85x15 km, the range is 500 m. The Ordovician series was for the first time exposed by appraisal well 28 Krasnokholmskaya drilled in 1968 in the crest of reservoir of Orenburg bar. Ordovician loamy-silty rocks were found below Tournaisian limestone at the 2,935 (minus 2,836) m depth instead of expected Devonian deposits. The well penetrated 677 m of Ordovician series. It is mainly represented by greenish-gray, gray and dark-gray thinly bedded slabby mudstone with thin interlayers of silty rocks and sandstone. Upper Ordovician mass, more than 1.5 km thick, in well 1 Krasny Yar is built up of the same deposits.

Prospecting well 1 Krasny Yar is situated at the southern limb of Orenburg bar. Penetrated thickness of Ordovician system deposits is 2,026 m. 181.1 m, i.e. 7.8% of the penetrated thickness was penetrated with core sampling. Mudstone was recovered with the core of well 1 Krasny Yar from a depth of 4,123.5-4,131.0 m, in which palaeontologist E.S. Levitsky identified Pseudobasilicunae trilobite typical of the Medium Ordovician division of East European Platform. This is why the exposed Ordovician series was conventionally classified as the medium division. There is no paleontologic data for the stratigraphic breakdown of Ordovician deposits. The log of well 1 Krasny Yar is broken down into 8 benches (three enlarged) bottom-up (Figure 2) in terms of lithological features and logging data:

1. Lower bench. Sandstone, silty rocks and mudstone. Coarse-grained sandstone and gravelite. The core features oil staining, smell of gasoline. The thickness is 390 m (4,920-5,310 m).

2. Homogenous sandstone bench. Sandstone is gray, poorly sorted, mainly quartzose with dark-gray mudstone and silty rock streaks. The thickness is 266 m (4,654-4,920 m).

3. Lower interbedded bench. Sandstone is poorly sorted, light-gray and black. The bench is quite distinct when microdevices are used. The thickness is 240 m (4,414-4,654 m).

4. Mudstone and silty rock bench. It is different from the underlying bench with its higher clay content. The bench top features faint smell of gasoline. The thickness is 341 m (4,073-4,414 m).

5. Argillaceous sandstone bench. Microdevices show relatively flat curves of low resistance due to large flaws. An oil film appeared in the solution when this bench was drilled at a bottomhole of 3,890 m. The thickness is 263 m (3,810-4,073 m).

6. Mudstone bench. Features hole enlargement. The thickness is 217 m (3,593-3,810 m).

7. Loamy silty rock bench. Features well narrowing in reference to overlying and underlying rocks. The thickness is 80 m (3,513-3,593 m).

8. Upper interbedded bench. Dark-gray loams with a greenish cast, silty rocks of the same color with thin sandstone and limestone streaks. The thickness is 209 m (3,304-3,513 m).

For the summary of drilling of Ordovician wells, tie and correlation of sections, lithologic and facies maps, see reports by I.A. Shpilman (1986a, 1986b, 1986c, 1986d), V.S. Dubinin (Dubinin, 1993; Dubinin et al., 1994), S.P. Makarova (1975, 2002), S.V. Bagmanova et al. (2001).

[Figure 2 here]

According to data of all wells in the area of Orenburg bar, Ordovician deposits are represented by a relatively homogenous terrigene mass mostly built up of sandstone interbedded with silty rocks and mudstone. The section exposed by the wells is divided into three parts: bottom, middle and top. The bottom and middle parts are exposed only by well 1 Ordovician sunk in the structurally highest part of the bar (Figure 3). Due to a high position of Ordovician deposits, the well exposed 1,600 m of unexplored more ancient layers. Accordingly, the cumulative penetrated thickness of Ordovician deposits is at least 3,447 m.

The bottom part (4,070-4,804 m) is built up of fine sugary grained quartzose sandstone. Billies of hydrothermal-metasomatic genesis were identified. Gradual transition from sandstone to quartzite via quartzose sandstone, which preserved relics of the primary arenaceous texture, is observed. The middle part (3,461–4,070 m) is represented by interbedded sandstone, silty rocks, mudstone and singular interlayers of limestone and dolomites. Gray, fine- and short-grained, feldspathic little fractured sandstone prevails. Mudstone is dark-gray, kaolinite-hydromicaceous with thin-slabby structure.

The top part (2,640-3,461 m) in well 1 Ordovician is 821 m thick and it is built up of interbedded feldsparic-quartzose sandstone, silty rocks and mudstone up to dozens of meters thick. With regard to the data of other wells, the cumulative thickness of the top part is no less than 1,500 m. It should be taken into account that the top part may be heavily eroded. The bottom section of the top part is only exposed by well 1 Ordovician. Feldsparic-quartzose fine sandstone prevails here; however, silty rocks and mudstone dominate in the higher2 section. In well 1 Krasny Yar, 16 Krasnoyarskaya, narrow bands of limestone and dolomites were also found. In the log of well 1 Ordovician, sandstone porosity generally ranges from 0.6 to 4.5%. Only one sample (silty rocks) has porosity of 5.7% (2,828-2,832 m). According to logging data, subvertical (60-900) fractures are very well developed in the 2,700-4,400 interval. Figure 4 shows the fracturing pattern according to logging conducted by Schlumberger in well 1 Ordovician (1990), where prevalence of north-north-east north-north-west and north-west oriented fractures is visible.

[Figure 3 here]

In the core, these fractures are represented by even chips. Fracture orientation persistence is indicative of fracture tectonic nature, which plays a very important role in permeability increase and change in rock storage capacity.

[Figure 4 here]

The log of well 2 Ordovician may be conventionally divided into three parts by lithological features (Figure 5). The top part (2,810–3,350 m) is represented by interbedded mudstone with silty rock streaks. Mudstone is dark-gray, almost black, flaglike, kaolinite-hydromicaceous, irregularly silty with a horizontal thin-slabby cleavage. Massive texture is with microstratified slabby texture streaks.

[Figure 5 here]

In massive mudstone, small fractures are caused by anhydrite. Rare inclusions of plant fragments and oil-carbon sludge are present. Silty rocks are gray, dark-gray, quartzose, poorly sorted, low sand content, isolated glauconite grains and dissociated plagioclases are present. Cement is kaolinite-hydromicaceous of basal film type. The middle part (3,350–4,475 m) is represented by interbedded mudstone, silty rocks and sandstone.

Sandstone is light-gray, greenish-gray, light-bluish-gray, quartzose, silt, poorly porous. Cement is quartz-regenerating and argillaceous, of basal, film-pore filling type. A porous reservoir sample with porosity of 9.5% is observed along the core (4,105-4,108 m interval). Heavy (6.5 m^3 in 15 minutes) entry of fluid with low content of combustion gas was obtained from the middle part during a test in the 3,763-3,792 interval column represented by fractured sandstone. The average yield at a depression of 15.8 MPa was 621.6 m^3/day. According to logging data, formation thickness is 25 m, reservoir porosity by RL ranges from 7.5 to 9%.

The bottom part (4,475–5,174 m) is represented by sandstone interbedded by subordinate mudstone. Sandstone is light-gray, light-greenish-gray, light-bluish-gray, hard, dense, quartzose, irregular aleurolite content, from poorly porous to homogenous. Cement is quartz-regenerating and argillaceous, of film-pore filling type, rarely – of basal type. Clay matter content varies from 3-5 to 20-30%. Small fractures are oblique and vertical. Black mudstone is seen along the fractures. Cement is quartz-regenerating and argillaceous, film-pore filling type. Sandstone is mostly dense and poorly porous.

Dark-gray kaolinite-hydromicaceous mudstone with horizontal thin-slabby cleavage. Starting at the 4,309 m depth, the rock features low fracturing. Light-gray, hard, polymictic sandstone with active fracturing was retrieved from the 4,360.8-4,862.1 interval, including mudstone streaks with pronounced polish faults. This rock was extracted up to 4,470 m. Mudstone interbedding becomes much less expressed gradually with depth, but all intervals feature evident fracturing, polish faults and heavy folding of mudstone and mudstone-like rocks.

According to S.P. Makarova (2002), well 28 of Kranokholmskaya top of Ordovician deposits are divided into four benches. The first bottom bench 204 m thick is represented by interbedded silty rocks and mudstone; the second (128 m) – by interbedded mudstone and silty rocks of micaceous-feldsparic-quartzose composition on carbonaceous cement; the third (163 m) – by interbedded mudstone and silty rocks, but with sandstone streaks of micaceous-feldsparic-quartzose composition on glauconite-micaceous or carbonaceous basal cement; the fourth bench 194 m thick – by silty rocks and sandstone with rare mudstone streaks. Sandstone of the fourth bench is built up of feldspars and quartz on regenerating quartzose or feldspathic cement. To the west of the well, the section is thickened by the fifth bench represented by mudstone. Well logs were matched by logging data with appearance of quartzose sandstone in well logs used as the correlation basis; thus, in well 1 Krasny Yar – at the 4,700 m depth; 1 Ordovician – at the

2,695 m depth; 2 Ordovician – at the 3,110 m depth. Quartzose sandstone is characterized by high NGL curve readings and low natural gamma-ray activity.

Strata with identical gamma characteristic were identified in the following intervals: well 1 Krasny Yar – 4,700-5,104 m; well 1 Ordovician – 2,695-2,954 m; well 2 Ordovician – 3,110-3,541 m, which was the basis for log correlation (Figure 6). The log of well 2 Ordovician poorly matches the log of well 1 Ordovician. The log of well 1 Ordovician is assumed to lack the top part 551 m thick, which is present in the log of well 2 Ordovician in the 2,810-3,361 m interval. This part is mainly represented by mudstone and narrow layers of silty rocks or argillaceous sandstone. Streaks of argillaceous (clean) sandstone appear in 3,050-3,152 and 3,180-3,266 m intervals. The 3,361 m depth in well 2 presumedly matches the Ordovician roof in well 1 (2,640 m).

In well 1 Krasny Yar, the Ordovician roof is exposed at the 3,304 m depth. Here, the top part absent from well 1 Ordovician, according to logging data, gets much thicker compared to well 2 Ordovician (Figure 6). In the log of well 1 Krasny Yar, it is established in the 3,304-4,654 m interval; it is mostly built up of mudstone and silty rocks. Thin sandstone strata occur at times. Quartzose sandstone, sandstone with carbonaceous cement were found in the section below 4,654 m. Interbedding of dense sandstone clogged up to varying degree and mudstone is often observed. Cumulative thickness of sandstone is about 50% of bench thickness (5,328 m – bottomhole). The log of well 1 below the 3,007 m depth is built up of thick benches of dense sandstone that dominates mudstone series in terms of thickness. Mudstone is in between sandstone occurs as 40-50 m series (with sandstone inclusions) and as narrow bands.

[Figure 6 here]

No thick mudstone was found below the 3,850 m level in the log of well 1. In the log of well 2 Ordovician, below the 3,704 m depth, no thick benches of dense homogenous sandstone similar in thickness to the log of well 1 Ordovician are observed. Dense sandstone (5-10 m thick) occurs intermittently with thin streaks of mudstone. Sandstone apparently contains carbonaceous cement and little fractures (3,704-3,967 m). Sandstone in the 3,976-4,120 m interval differs vastly from the above: less dense (Кп=4-6%) with low natural radioactivity, less thick (1-5 m) interbed with thin streaks of mudstone. Below, to the 4,730 m depth, the log has identical characteristics. Exceptions are 4,480-4,510, 4,607-4,638 and 4,702-4,704 m intervals where sandstone is dense (Кп=1-2%), presumedly with carbonaceous cement.

Well 1 Krasny Yar was drilled in 1979 in the southern limb of Orenburg bar in the eastern periclinal zone. The Ordovician roof is exposed at the 3,302 m depth, 2,026 m of Ordovician deposits is penetrated, 181.1 m of core is extracted. Core recovery was 8.9% or 0.089 m per 1 m of headway. The whole log bottom (153 m) mainly represented by sandstone was penetrated without core sampling. Slight shows of oil and gas occurrence were identified, but no testing and sampling of Lower Paleozoic deposits was done because of an accident. The well was abandoned for technical reasons without having exposed the target horizon (foundation) and without having reached the target depth (5,500 m).

The top of Ordovician deposits (700 m) in well 1 Krasny Yar is represented by mudstone with thin streaks of silty rocks; the middle part (1,000 m) – by mudstone, sandstone with mudstone streaks; the bottom (326 m) – by silty rocks, sandstone with mudstone streaks. Oil and gas shows were observed in the middle and bottom Ordovician parts of well 1 Krasny Yar (Figure 2). Formation logging cable testing was conducted in two intervals, but no inflow was obtained. Prospecting well 1 Ordovician was drilled in the center of Orenburg field. The well was taken off on 30/10/87 and drilled out on 24/02/93; the bottomhole was at the 4,804 m depth (Figure 3). Ordovician deposits are exposed at the 2,638 m depth with 2,164 m penetrated. 44.35 m of core (with the total length of core taken of 89 m) was recovered from this interval. Thus, the cored percentage of the exposed log is 2%. Quartzose sandstone has low porosity (maximum – 3.5-3.7%), mudstone porosity ranges from 9.6 to 2.2%. Permeability was determined in three samples – 0.01-0.018 mD.

Four intervals were tested with a wireline tester and seven intervals were tested with a drill stem tester during drilling of well 1 Ordovician. 10 objects were tested in the column, but no producing layers were revealed. Based on testing results, the geotechnical meeting decided to redesign the well as a pressure observation well of Mississippian period. Well 2 Ordovician was sunk in the crest position of the western dome of Orenburg bar 25 km west of well 1 Ordovician. The target well depth is 5,500 m, actual depth is 5,174 m. The well was taken off on 01/02/93 and drilled out on 01/09/97. Ordovician system deposits were exposed at the 2,810 m depth. A total of 2,364 m were penetrated and core sampling amounted to a total of 16.93 m out of 95.6 m drilled (17.8%). Thus, the cored percentage of the exposed log was 0.74%.

It is 39 core samples of well 2 Ordovician were used to determine permeability and porosity of silty rocks and sandstone: porosity – 0.4-5.2% (only in one sample, Fp=13.9%), permeability from 0.001 to 0.080x10-3 ηm^2 (in fractured varieties). VSP seismic logging operations were conducted at the bottomhole of 5,174 m. Ordovician deposits were not tested due to the lack of hydrocarbon indications according to drilling and logging data. FTS-146 formation testing was conducted in the well in the 3,763-3,792 m interval during drilling at the bottomhole of 3,827 m. Reservoir water inflow with a small amount of gas with a density of 1.18 g/cm^3, estimated flow of 621.6 m^3/day at a depression of 158 atm, Erp – 451.8 atm was obtained. At the end of fluid outwash from the annular space, weak gas flashes were observed in the flow above the flare. According to the logging report, Ordovician deposits have no formations recommended for HC inflow testing.

Extremely low definition of the exposed Ordovician section should be mentioned: core recovery in well 2 Ordovician is 0.74%, in well 1 – 2%, in well Krasny Yar – 8.9%. It is no wonder that no porous and permeable rock variations were recovered. Sandstone fracturing is typical of the log of wells 1 and 2 Ordovician. According to Schlumberger study in well 1, fractures feature north-eastern direction (Figure 4). Unlike the central and western domes of Orenburg bar, in its eastern part, well 1 Krasny Yar exposed a younger fine section of Lower-Middle Ordovician deposits mostly represented by mudstone and silty rocks with subordinate sandstone streaks. A trilobite of Middle Ordovician was found in this well. In the eastern bank of Sol-Iletsk dome, Ordovician deposits are similar to Orenburg bar rocks. For example, in well 110 Preduralskaya (penetrated thickness –

276 m), Ordovician deposits are represented by alternating benches of dark-gray and greenish-gray mudstone, silty rocks, more rare sandstone and benches mainly built up of sandstone. To the north, in well 640, Sludnogorskoy section (77 m) has similar composition.

The age of terrigenous deposits accepted as Ordovician in the logs of well 1 Mayorskaya, 40 Uchkhozovskaya, 4 and 5 Shuvalovskaya 1 and 2 Ordovician, 85 Berdynskaya, 89 Dimitrovskaya was conventionally accepted based on lithologic similarity with faunistically justified sections. Besides, in well 80 Dimitrovskaya, profile shooting data was used to identify the Ordovician system – reflecting horizon R correlating with the Ordovician surface was recorded above the bottomhole. The Ordovician age was justified by trilobites found in well 1 Krasny Yar, brachiopods found in well 17 Orenburgskaya, Chitinozoa found in well Zapadno-Orenburgskaya, conodonts found in well 102 Orenburgskaya, vegetative microfossils, spore-pollen complexes and acritarchs found in well 28 Krasnokholmskaya. Acritarchs date the age of enclosing rocks as High Middle – Low Late Ordovician. The same arenigian-llarnviksky age was confirmed by graptolites found in well 110 Preduralskaya.

In well 1 Ordovician, bitumen testing of 106 samples was conducted in order to study regularities of distribution of the organic substance (OS) in Ordovician rocks. According to I.N. Lyapustina (2001), these studies ascertained prevalence of bitumen microinclusions throughout the Ordovician deposit section. The content of chloroform bitumens (CEB) ranges from 0.0025 to 0.1%, organic substance content – from 0.07 to 0.4%. The bitumen content is indicative of the presence of syngenetic and epigenetic bitumens in Ordovician deposits. Epigenetic (migrating) bitumen inclusions are commonly found in sandstone, and syngenetic bituminous components are observed in silty rocks and mudstone. Epigenetic bitumens were found to contain many light mobile components. This indicates that HC was enclosed in the terrigenous rock mass, through which HC migrated. Thus, HC may be preserved in the Ordovician rock mass as deposits.

Prevalence of light mobile bitumen microinclusions of migration and mixed genesis was observed in the 3,717-4,157 m interval in the sandstone mass more than 400 m thick. The content of light ends is high, the bitumen concentration in the petroleum-ether extract is equal to or exceeds that of chloroform bitumen, which is indicative of high bitumen mobility. The migration bitumen concentration in a number of interlayers reaches 0.06-0.08%, which implies probable accumulation of hydrocarbon fluids in underlying deposits (deposit “ballooning” effect). According to Lyapustina, bulk earth content of organic substance and presence of recovered syngenetic bitumoids gives ground for classifying mudstone and silty rocks of Ordovician deposits as oil-and-gas-producing series.

Sand formations and sandstone mass were found in the bottom of the Ordovician section; these formations may be classified as oil and gas reservoirs. Sandstone, mostly quartzose, well rounded and poorly sorted, with silty rock and gravelite streaks, sometimes with dolomite streaks (Politykina et al., 2001; Politykina and Tyurin, 2002). Petrophysical studies ascertained that prevailing porosity of sandstone is 0.4-5.2%; some samples had porosity above 7%. One sample had porosity of 13.9%. The presence of reservoirs in Ordovician sandstone was confirmed during well 2 Ordovician testing where an inflow of salt water with low combustion gas content with a flow rate of more than

621.6 m^3/day was obtained from the 3,763-3,792 m interval. Sandstone permeability and porosity values are conditioned by the presence of intergranular pores, fractures and associated cavities. This sandstone together with the underlying clay bed may form adequate natural reservoirs.

Formation water inflow with overflow of 6-8 l/min and high gas ratio was obtained from Ordovician deposits in well 85 Berdyanskaya. The section has clay rock benches that could be used as caps. Elevated gas indications, decreased density of drilling mud and oil films were observed when drilling in Ordovician deposits. The core had smell of gasoline and oil staining. In well 1 Krasny Yar located in the southern limb of Orenburg bar, below the Ordovician roof, sandstone and mudstone had smell of gasoline (4,070-4,072 m interval), smell of gas (4,110.7-4,115.3 m interval), oil lines and trickles (4,578-4,588 m interval), oil staining and smell of gasoline (5,037-5,038 m interval). 19 out of 59 samples point at reservoirs with porosity of more than 7% (Shpilman, 1990).

Besides, oil films were observed in the drilling fluid; gas logging revealed elevated total gas indications in the drilling fluid. Oil film was observed in the solution at the 3,890 m bottomhole. Logging identified three thin sandstone layers. Reservoirs were identified in 4,300-4,334 m, 4,538-4,541 m, 4,658-4,683 m intervals. High gas indications are confined to the last two intervals. An oil film was observed when drilling. Deeper horizons have sandstone reservoir beds, sandstone prevails starting from the depth of 4,900-5,000 m to 5,328 m. The well was not tested in the production casing and no drill stem tester was run.

Elevated gas indications were observed throughout Ordovician deposits when drilling well 2 Ordovician; they are often confined to excessive fissuring zones. Componential analysis identified elevated content of heavy HC; methane content of up to 11% was observed in the 4,087-4,088 m interval. Besides, total gas indications in excess of background values were observed during cleanout following long circulation breaks. They reached 12.5% in the 3,992-4,052 m interval. Oil and gas shows were also observed in core recovered starting from the roof part and at large depths. However, the total length of core taken is 96 m, which is extremely little considering large penetrated thickness of deposits, i.e. 16.93 m of core extracted from 2,274 m of the penetrated section, which is negligible. As to the bottom of the well, it was not at all core-defined.

Direct oil and gas shows of Ordovician deposits are observed in well 1 Ordovician. According to gas logging data, background values of total gas indications are 0.1-1.0%. The most considerable total gas indications were identified in the following intervals: 3,670-3,704 (up to 6.5%), 4,651-4,652 (up to 4% with methane content of up to 47-68%), 4,691-4,734 (up to 40%), 4,783-4,784 m (up to 80% with methane content of up to 68%). Heavy hydrocarbons (C4-C6) were observed in all intervals. During drilling using the drilling mud, grooves showed an oil film probably associated with 2,663-2,685, 3,304, 3,681-3,690, 3,695, 3,698-3,709, 3,989-3,990 m depths. Starting from 4,144, 4,402 m depths, "slugs" of the lightened drilling mud with an oil film were observed during well cleanout after long (5 days) standby. According to the oil and gas laboratory of the South-Ural branch of the All-Russian Geological Research and Development Oil Institute, oil from the 4,144 m depth has a density of 0.8905 g/m^3 and molecular weight of 216.5 g/mol; from the 4,402 m depth – 0.8770 g/cm^3 and 202.1 g/mol, accordingly. The smell of gasoline and hydrocarbons was present in the core recovered from 3,191-3,194, 3,944-3,945, 4,008-4,009, 4,157-4,158 m intervals.

The core recovered also featured oil and gas shows starting from the roof part and at large depths. However, definition by core is negligible and the bottom of the well is not at all defined by core. Numerous lost returns that were observed when making well 1 Ordovician point at the presence of reservoirs in the penetrated section: at the bottomhole of 2,744 m, 2,753 m, 3,015 m (no returns). From the 3,052 m depth – partial loss, at the 3,055 m depth – complete loss was observed. This loss was eliminated only after a cement plug was installed. At the bottomhole of 3,207 m – complete loss, during drilling to the 3,211 m depth – partial loss was observed. Another complete loss was observed at the bottomhole of 3,211 m. Effluent was loaded. Loss decreased to 15 m^3/hour, at the 3,235 m depth – 30 m^3/hour. Effluent was loaded. To the 3,240 m depth, drilling was conducted with loss; effluent was loaded again. Complete loss was observed at the bottomhole of 3,242 m. Effluent loading (2 times) had no effect. 5 t of cement was poured in the bottomhole. Loss was eliminated.

Further penetration during well cleanouts resulted in the appearance of a degassed clay mud slug. The 2,660-2,740 m, 2,930-3,030 m reservoir was filled with mud. Cement was drilled out in the 3,180-3,242 m interval. Deepening resulted in partial loss (20 m^3/hour). Effluent was loaded, loss was eliminated. From the 3,260 m depth, partial loss was observed (10 m^3/hour). At the bottomhole of 3,306 m, partial loss at 50 m^3/hour was observed. Numerous loss returns were observed during drilling at the bottomhole of 3,408 m (partial), 3,420 m (5 m^3/hour), 3,483-3,487 m (4 m^3/hour), 3,705 m (complete). Losses were eliminated by effluent loading and well shut-ins. Drilling fluid losses, elevated gas indications up to 4-5% in certain intervals were observed during drilling from 4,400 m to 4,820 m.

3. RESULTS

Despite numerous direct and indirect oil and gas shows, the results of drilling and testing of wells in Orenburg region that had exposed Ordovician deposits did not provide credible evidence of commercial oil-and-gas content of these deposits. However, extremely low definition of deposits by core and a very small number of tests of Ordovician deposits should be mentioned. Besides, the presence of low-porous reservoirs with low matrix permeability in the section was not taken into account during testing. The lack of stimulation techniques when testing the section should also was mentioned.

V.M. Chervakov et al. (2001) explain the absence of HC deposits in Ordovician deposits of Orenburg bar by heavy vertical fracturing of Ordovician rocks identified during core analysis in wells 1 Krasnoyarskaya, 1 and 2 Ordovician. Apparently, fractured zones resulted from formation of a high-amplitude structure – Orenburg bar and acted as conductive zones for HC migration. Beyond the bar where Ordovician deposits are less fractured they may be assessed as oil and gas prospective (Karnaukhov et al., 1999) in Orenburg region.

Eroded and buried Ordovician layers with a major angular displacement are bridged over by Upper Devonian and carboniferous carbonate deposits. Ordovician deposits may have large stratigraphic and tectonic traps. The range of the latter may reach hundreds of meters. Mudstone, clay interbedded with silty rock streaks prevail in the top of the Ordovician section. Loamy-mudstone benches may be used as caps.

Analysis of formation conditions of Ordovician deposits evidences site prevalence of both top impermeable Ordovician mass used as a local impermeable layer (cap) and underlying reservoir beds of the Ordovician bottom.

According to drilling and seismic survey results, Ordovician deposits in Orenburg region are common within Sol-Iletsk dome and adjacent parts of East-Orenburg bending fold and Pre-Urals basin. The presumed fringe zone of Ordovician deposits in the eastern bank of East-Orenburg bending fold was recorded during CMP-2D regional scale surveys – at 43/5/2004-05, PC 116.5 and 37/05/05, PC 210-215 profiles.

The contour surface of Ordovician deposits in Sol-Iletsk elevation based on reflecting horizon R identified with the roof of Ordovician deposits was made of contour maps (Figure 7) based on the data of CMP 2D/3D seismic survey in individual areas.

[Figure 7 here]

Structural imaging of Ordovician deposits is mainly based on geophysical surveys, verified by isolated wells and is schematic. Structural imaging fragments may not be combined due to the lack of data. High hypsometric position in the Orenburg bar area, southward and eastward plunge and stepwise plunge via a system of break fractures throughout the territory from north to south are peculiarities of the surface of Ordovician deposits (Figure 7). According to drilling data, the surface of Ordovician deposits within Sol-Iletsk dome forms a stretched structural high. It is Orenburg bar that represents the same elevation along the Ordovician roof as along overlying marker horizons. The high size at minus 3,100 m elevation is 85x15 km, the range is 500 m.

In the contour of Orenburg bar, the Ordovician surface plunges from east to west changing from minus 2,540 m (1 Ordovician) to minus 2,793 m (302 Orenburgskaya) and minus 2,847 m (102 Orenburgskaya). Ordovician deposits plunge northward to the mark of minus 3,869 in well 106 Oktyabrskaya, southward – to minus 3,934 in well 85 Kopanskaya. In Pre-Urals basin, the roof elevation of Ordovician deposits in well 640 Sludnogorskaya is minus 4,419; to the east, according to shooting data, the occurrence depth of Ordovician deposits reaches minus 6,410 m (PC 1,060.0-1,070.0 reg. profile 43/5/2004-05).

According to geophysical data (Nazhmetdinov, 1990), the maximum thickness of Ordovician deposits is confined to the west of Orenburg block (up to 5,000 m) and it gradually decreases towards Caspian basin (up to 1,500 m) and Pre-Urals basin (up to 2,600 m). At the site of well Orenburgskaya 1-4 (Vyugovat, 1971), Orenburg fault with a range of up to 500 m complicated by a series of subparallel unconformities is traced on the contour map over the surface of terrigenous deposits of Ordovician-Lower Devonian age (reflecting horizon (RH) R) along the northern edge of the site. To the south, a system of sublatitudinal faults is identified; they split the surface into elongated horst-like and adjacent keystone structures. This heavy deformation is probably caused by vertical tectonic movements.

Apart from sublatitudinal faults, there is a net of linear zones of submeridional strike that may be identified with excessive fissuring zones. A submeridional downfold is identified between the central and eastern domes of Orenburg bar; the central dome is also separated from the western part by a block controlled from two sides with linear downfold zones of tectonic nature. The formation of these blocks and zones may also be associated with horizontal orogenic displacements. The surface of Ordovician deposits features a lot of break fractures and distinct block nature. Blocks vary in size, height and slope. Elevated blocks are eroded. Dimitrovsky, Kardailovsky, Limanny highs of Ordovician deposits stand out most clearly against the general plunge to the south-west of Orenburg bar (Figure 7).

Dimitrovsky high is complicated by Dimitrovskoye elevation. Wells 80, 81, 82, 83 Dimitrovskaya were drilled within the elevation and a same-name oil-gas condensate field was discovered in Lower Permian deposits. In the Dimitrovskoye elevation area, Ordovician roof levels are about minus 3,700 m, and they reach minus 3,800 m at the bank of Orenburg bar to the north of wells 80, 81.

Limanny high is divided into the southern and northern parts. In the south, the high is confined by Ileksko-Yaysansky fault. Limannaya structure stands out on the elevated block of Limanny high; this structure is a fault-line anticlinal fold of latitudinal strike. The Limannaya structure was identified along the roof of Ordovician deposits by Orenburg GE. Along the closed isohypse of minus 4,850 m, its size was 5.5x14 km, range – 250 m, area – 49 km^2. In 2000, experts of Orenburggeofizika LLC reprocessed and interpreted CMP seismic data, as a result of which the structure was specified and made ready for deep-hole prospecting. Prospective resources of C3 grade oil were as follows: balance – 70 mln t, mineable – 28 mln t. The structure was confirmed by subsequent reprocessing of seismic data (Ofman, 2012); its size along the isohypse of minus 4,480 m was 7.5x3.5 km, range – 110 m.

Sukhorechensly high stands out to the south-west of Limanny high; it is confined by break fractures. Within the high boundaries, the Ordovician roof level is from minus 6,000 to minus 6,300 m. Within the Peschanaya site, the Ordovician surface occurs at depths ranging from minus 5,200 m to minus 6,200 m. Two anticlinal folds traced by the isohypse of minus 5500 m are mapped here. One of them (north-eastern) isolated by three isolines is close in its shape to isometric. The other one (southern) is an arched asymmetric (the southern limb is steeper than the northern one) elongated fold that tapers away westward. A large fault runs through the axis of the southern fold; the maximum range of the fold (500-550 m) is observed in its in-line center. This is where one can also observe an increased range of the upfold (300 m) and fault-adjacent elevation – Peschanaya structure outlined by the isohypse of minus 5,350 m with the dome occurrence depth of minus 5,200 m and size of 7.5×1.0 km.

The largest closed high at Peschanaya site is the southern brachy-anticline if one assumes that it closes at minus 5,500 or minus 5,550 m. Its eastern part has sublatitudinal strike and it has less expressed relief (range of 100 m) compared to the western one (range of 200 m) spreading north-north-westward. The size of structure along the isohypse of minus 5,550 m is 6.85×2.55 km. The structural plan of reflecting horizon R within Vostochno-Peschanaya site is represented by two elevation zones of sublatitudinal strike associated to the depression that divides them. This depression is outlined by the isohypse of minus 5,400 m and it extends across the entire site occupying its central part.

The northern elevated zone stands out as a monocline with an uplift of Ordovician deposits in the north to more than minus 5,100 m. In the southern zone, a large anticlinal fold clipped in the south by a fault with a range of up to 200 m is mapped along the isohypse of minus 5350 m. A closed high 7.3×1.4 km in size with a range of 150 m is outlined within this fold with the isohypse of minus 5,300 m. The western periclinal of the high is disturbed by a low-relief (up to 50 m) fault stretching north-westward that extends away from the master fault.

A lowered limb of a structural fault is a narrow fault-line downfold that opens up (in the eastward strike) into the central basin and that is complicated by two small feathering faults of the south-eastern orientation. A steady gradient RH is observed to the south of the downfall; its range exceeds 200 m. To the south, in the near edge zone of Caspian basin, Troitsky, Novoivanovsky, Novodonskoy blocks divided by narrow rift valleys with a range of up to 200-430 m were singled out from north to south along Ordovician deposits in 070997-98 profile based on the data of regional seismic surveys and DNEM and EP electrical exploration. The surface of the first two plunges southward with gradients of 44 to 120 m per km. The surface of the southernmost Novodosnkoy block plunges northward with the gradient of 130 m per km (Albert and Brusyanin, 2000).

In the junction zone of Sol-Iletsk dome with Pre-Urals basin and Caspian basin on the contour map of Chiliksaysko-Nagumanovskaya zone, a marginal ledge of Caspian basin is traced along a break fracture and the western edge of Pre-Urals basin is traced by the depth contrast and fragmentarily traced break fracture. A high-amplitude elevation that has a genetic link with the north-eastern strike fault (Synkova et al., 2005) is mapped in this zone.

To the south, at Vershinovskaya site, an elevated zone is singled out that comprises a series of local elevations and that is confined by flexural-like horizon plunges in the south-west and south towards Caspian basin and in the north-east, east – towards Pre-Urals basin (Boldenkov, 2002). Vershinovskaya structure irregular in shape, outlined by the isohypse of minus 7,350 m, with a range of 400 m and 11×3.5 km in size is the most representative of local elevations. The structure is made up of two domes divided by minor faults. At the southern end of the northern dome, well 501 Vershinovskaya was drilled; it exposed Lower Devonian deposits in the reef fades at the mark of minus 6,438.8 m and one did not reach Ordovician deposits at the bottomhole of 7,005 m. Vershinovskaya structure periclinals are complicated by tectonic faults.

To the east of Orenburg bar, a number of small structures is identified against plunge in Pre-Urals basin along the Ordovician surface (Figure 7): Novokrasnoyarskaya of submeridional strike along a closed isohypse of minus 3,200 m, structure size is 5.3x1.4 km, range is 80 m, area is 7 km^2; Komarovskaya comprising two domes. The domes are enveloped by isohypse of minus 3,500 m and are arranged through a downfold with a mark of minus 3,600 m. The size of the western dome is 2.8x2.0 km, range is 50 m, area is 5 km^2, of the eastern – 3.5x2.0 km, range is 20 m, area is 5 km^2.

Various authors ascertained discrepancy in the morphology of inner Ordovician and overlying deposits (including the eroded Ordovician surface) during exploratory seismic operations at Orenburg bar and adjacent regions.

In late 1990s, specialists of OGE JSC found a large structure – Ordovician (Figures 8 and 9) in the mass of Ordovician deposits within the southern plunge of Orenburg bar based on CMP seismic survey data. This structure of East-West direction was mapped by benchmark O1. Limbs of the structure are complicated by tectonic faults. Along the isohypse of minus 4,650 m, its size was 8.5x14.5 km, range – 270 m.

[Figure 8 here]
[Figure 9 here]

Formation of the Ordovician structure is, perhaps, similar to that of Orenburg bar: presence of rift in fundamental rock, accumulation of a thick series of Ordovician and, perhaps, earlier deposits followed by contraction of the earth surface and formation of the Ordovician structure as a result of inversion. In the Devon – Mississippian period, uplift resulted in erosion of most deposits. According to magnetic exploration data (Pakhtel, 1990), a ring anomaly of radioactive elements compared to sedimentary cover tectogenic structures matches the Ordovician structure and its foundation matches a rift valley. V-shaped convergence of Ordovician reflecting horizons is observed in the Ordovician dome and they overlie reflecting horizon R1? The Ordovician structure is complicated by tectonic faults.

The presence of the Ordovician structure is confirmed by CMP regional scale surveys. Results of operations at the 252501-02 profile tested by OGE JSC in 2002 are of particular interest. The profile has submeridional arrangement and it crosses Vershinovskaya, Nagumanovskaya and Kopanskaya structures from south to north as well as the southern part of the eastern dome of Orenburg bar. A fragment of a CDP seismic section along the northern part of the profile is shown in Figure 10.

[Figure 10]

Morphology of the Pre-Devonian complex of the southern part of Orenburg bar is most clearly shown in 252501 and 031793-95 regional seismic WP profiles (Figures 11, 12). It is seen in the northern part of 252501 profile that rock masses from Lower Permian subsalt deposits through to the top of the Ordovician series rise northward forming the southern limb of Orenburg bar; underlying Ordovician and, perhaps, older deposits, by contrast, plunge northward. This northward plunge against common southward plunge of subsalt deposits towards Caspian basin predetermined a huge bend in ancient series, the range of which reaches 1,200 m and the occurrence depth of the crest of reservoir is 5,100 m.

[Figure 11]
[Figure 12]

4. DISCUSSION OF RESULTS

An assumption of existence of South-Orenburg bar to the south of the Orenburg bar in the Ordovician structure zone and to the west of it was for the first time put forward by the experts of OGE JSC (Albert and Brusyanin, 2003). To the south of Orenburg bar, they observed temporary bends with a range of northward plunge of up to 0.1 s at 6 (PC

660-816), 8 (PC 664-800) regional profiles along the horizons from Ordovician to Lower Permian. Similar bends were also earlier observed at 7a0997-98 regional profile and extended Dimitrovsko-Chernigovskaya zone was identified here by inner-Ordovician deposits. Considering the length and range of anticlinal bends, the existence of South-Orenburg bar of sublatitudinal strike along deposits from Ordovician through to Lower Permian subsalt deposits may be assumed (Figure 12).

This assumption was confirmed by the experts of Naftacom RPA LLC (Lurye, 2005) as a result of analysis of seismic section of regional profiles supported by drilling data and reports of seismic crews 6/88-90 and 5/94-96. Inner-Ordovician reflecting horizons were used to identify a chain of elevations along the southern bank of Palaeozoic Orenburg bar (Komarovskoye, Chernigovskoye, Dimitrovskoye) combined by I.P. Ofman (2012) into single South-Ordovician bar.

[Figure 13]

The Ordovician structure is localized in the east within its boundaries. South-Ordovician bar lies 20 km to the south of Orenburg bar. The elevation axis goes through Komarovskoye elevation in the east through Chernigovskoye, Dimitrovskoye to Yuzhno-Kardailovskoye elevation at the western periclinal of Orenburg bar (Figure 14). South-Orenburg and Orenburg elevations belong to a single tectonic block. They are divided at eastern periclinals by isohypses of minus 3,500 m, at the western end – by the marks of minus 3,900 m.

[Figure 14]

According to the experts of Naftacom RPA LLC (Ofman, 2012), South-Orenburg bar only shows itself by reflecting horizons in Ordovician deposits. The bar was named South-Ordovician and delimited. Anticipated HC resources in Ordovician deposits are assessed at 116/114 mln TOE (geological/mineable).

5. CONCLUSION

According to the estimate of VolgoUralNIPIgaz LLC, in 2016, HC resources in the Ordovician structure were 199/195 mln TOE (geol./extr.). Considering the length and range of anticlinal bends, the existence of South-Orenburg bar of sublatitudinal strike along deposits from Ordovician through to Lower Permian subsalt deposits is predicted. It was assumed that at least two local objects with characteristics similar to those of the Ordovician structure could be additionally singled out. In this case, South-Ordovician bar resources only along Ordovician deposits will amount to at least 585 mln TOE.

Today, there exist different HC estimates of the Ordovician structure and ambiguous views of the structure of South-Orenburg bar. Reinterpretation of regional seismic profiles with regard to 3D seismic survey is needed in the first place to localize South-Orenburg bar and identify exploration targets with a view to arrange oil and gas reconnaissance. Traversing of six submeridional seismic profiles in WP modification and one tie sublatitudinal profile is deemed feasible for the specification of the South-Orenburg bar morphology. In addition to those available, these profiles will help identify undulations of South-Orenburg bar in the east-west direction associated with local exploration targets similar to the Ordovician structure. South-Orenburg bar along Ordovician deposits and local exploration targets in Devonian-Lower Permian deposits controlled by it should be viewed as a new potentially promising line of prospecting in the area of operations of Gazprom Dobycha Orenburg LLC.

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Table and Figure captions:
Appendix 1. Table 1. Wells that exposed Ordovician deposits in Orenburg region

Figure 1. Northern part of Sol-Iletsk dome and adjacent regions. Ordovician deposit development scheme (Lukinykh and Belyaev, 1998).
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Well No.	Purpose	Drilling start Drilling end	Bottom-hole depth	Ordovician roof top	Penetrated thickness of Ordovician deposits, m
28 Krasnokholmskaya	appraisal	01/01/67	3,609	2,934 (-2,843)	675
16 Krasnoyarskaya	appraisal	01/01/62 30/12/68	3,928	3,440 (-3,290)	488
66 Orenburgskaya	prospecting	01/01/68 31/12/70	2,801	2,770 (-2,650)	31
17 Orenburgskaya	prospecting	01/01/69 31/12/71	3,104	3,035 (-2,905)	69
310 Orenburgskaya	prospecting	01/01/70 31/12/71	3,211	3,211 (-3,110)	
302 Orenburgskaya	prospecting	01/01/72 31/12/72	2,912	2,879 (-2,793)	33
501 Likhtinskaya	exploration	01/01/1972 31/12/1974	2,745	2,676 (-2,562)	69
324 Orenburgskaya	prospecting	01/01/73 31/12/74	3,080	3,049 (-2,878)	31
3 Shuvalovskaya	prospecting	11/06/1973 21/10/1974	4,041	3,932 (-3,737)	109
5 Shuvalovskaya	prospecting	01/01/74 28/04/75	3,814	3,805 (-3,712.9)	9
4 Shuvalovskaya	prospecting	01/12/1974 14/07/1977	3,910	3,901 (-3,748)	9
85 Berdyanskaya	prospecting	19/11/77 31/12/80	4,282	4,205 (-3,934)	77
1 Krasnoyarskaya	appraisal	1979	5,328	3,302 (-3,125)	2026
110 Preduralskaya	appraisal	01/01/80 31/12/82	4,501	4,162(-3,989)	339
106 Oktyabrskaya	prospecting	20/11/82 17/09/83	4,105	4,041 (-3,869.36)	64
40 Uchkhozovskaya	appraisal	29/04/84 30/06/85	3,697	3,654 (-3,557)	43
80 Dimitrovskaya	appraisal	20/12/88 01/09/89	4,200	3,988 (-3,798)	212
630 Belozerskaya	appraisal	16/12/1988 28/01/1990	4,232	3,720 (-3,580)	512
120 Burtinskaya	appraisal	18/05/89 14/11/90	4,800	4,765 (-4,516)	35

640 Sludnogorskaya	appraisal	16/09/90 01/01/91	4,705	4,629 (-4,419)	76
81 Dimitrovskaya	prospecting	18/05/90 10/03/91	3,847	3,815 (-3,611.9)	32
121 Staroklyuchevskaya	prospecting	29/17/91 17/04/92	4,776	4,744 (-4,582)	32
1 Ordovician	prospecting	01/01/87 01/01/94	4,804	2,640 (-2,540)	2,164
2 Ordovician	prospecting	01/01/93 01/01/97	5,174	2,810 (-2713,9)	2,364
102 Zapadno-Orenburgskaya	prospecting	29/11/04 13/08/05	3,080	3,019.2 (-2,847.9)	60.8
1 Mayorskaya	prospecting	2003	4,062	3,890.4	171.6

Figure 1. Northern part of Sol-Iletsk dome and adjacent regions. Ordovician deposit development scheme (Lukinykh and Belyaev, 1998).

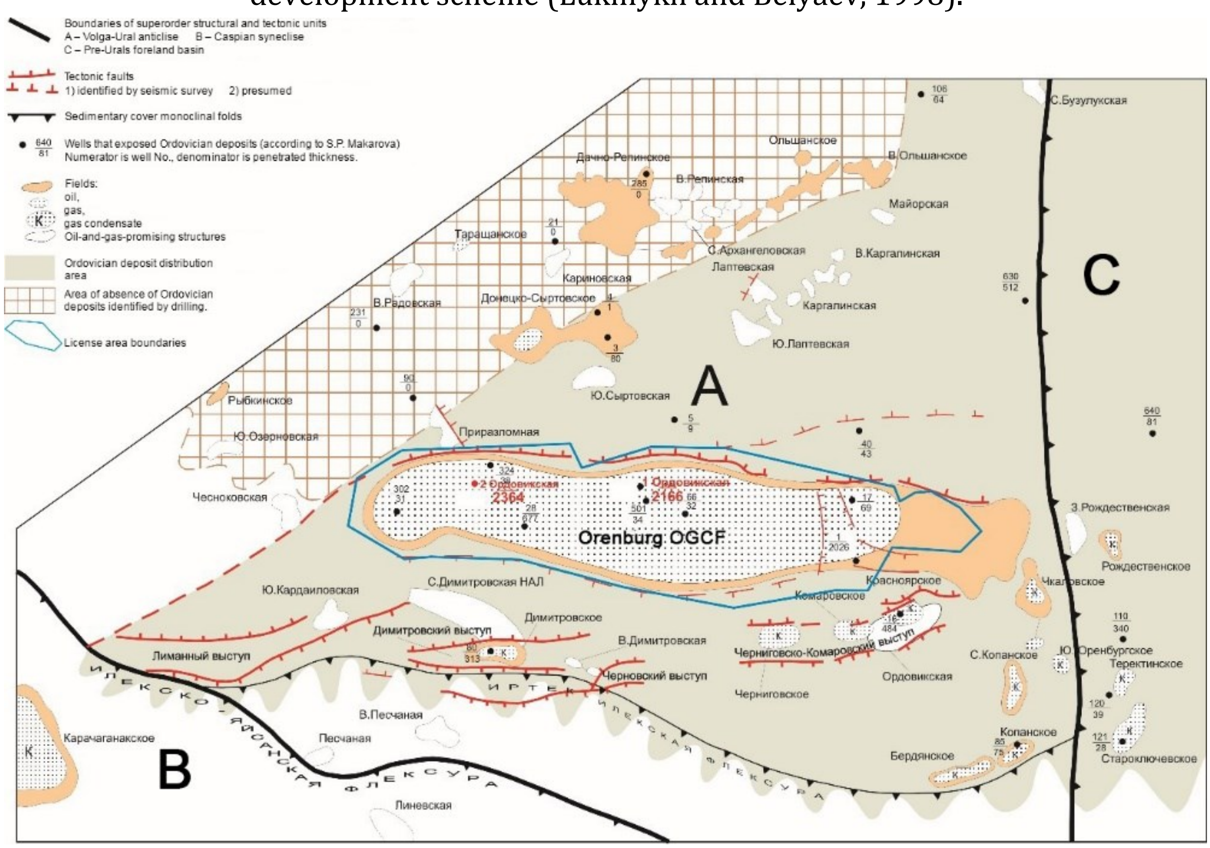


Figure 2. Section of Ordovician deposits in well 1 Ordovician (according to logging and core).

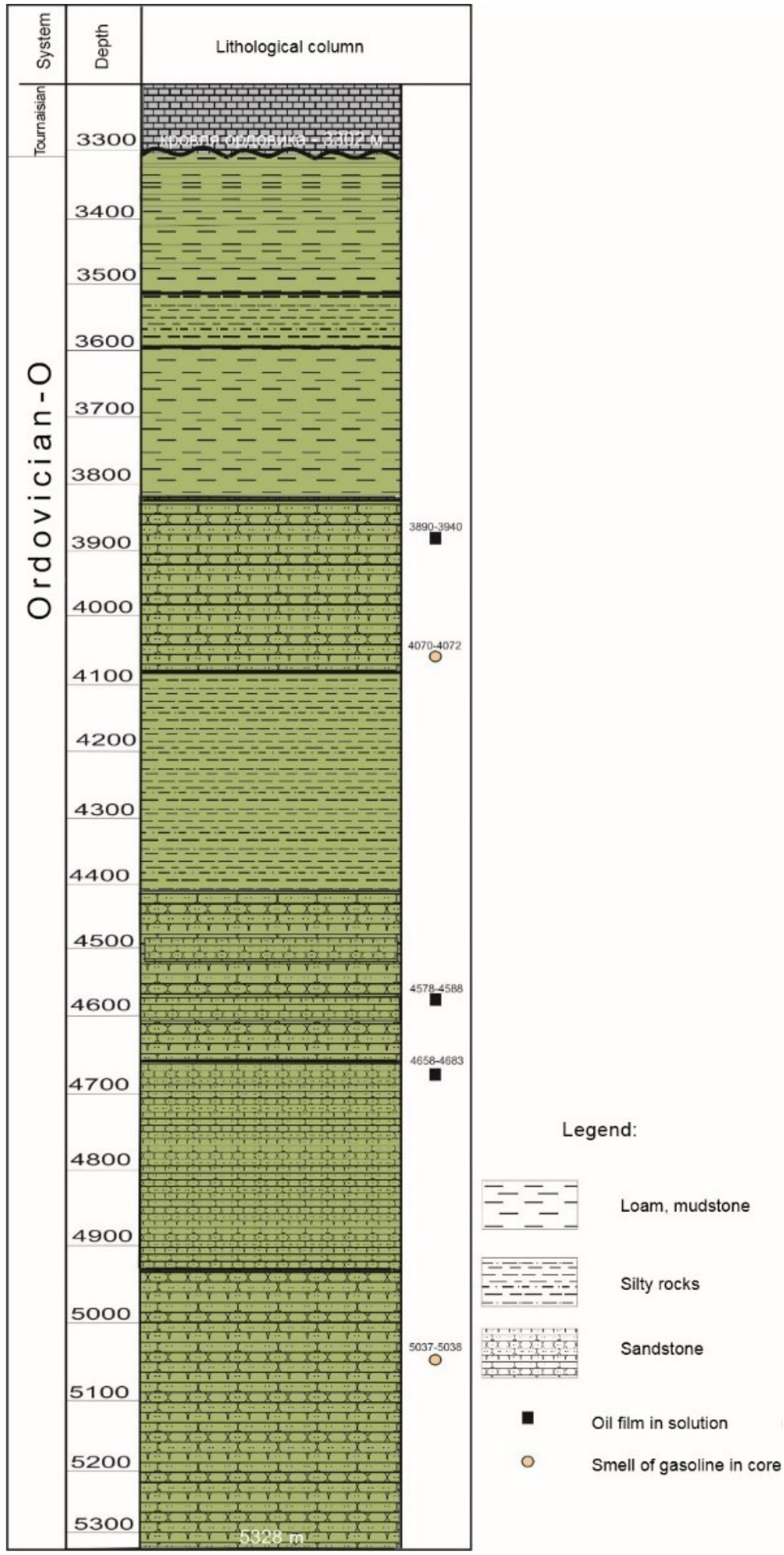


Figure 3. Section of Ordovician deposits in well 1 Ordovician (according to logging and core).

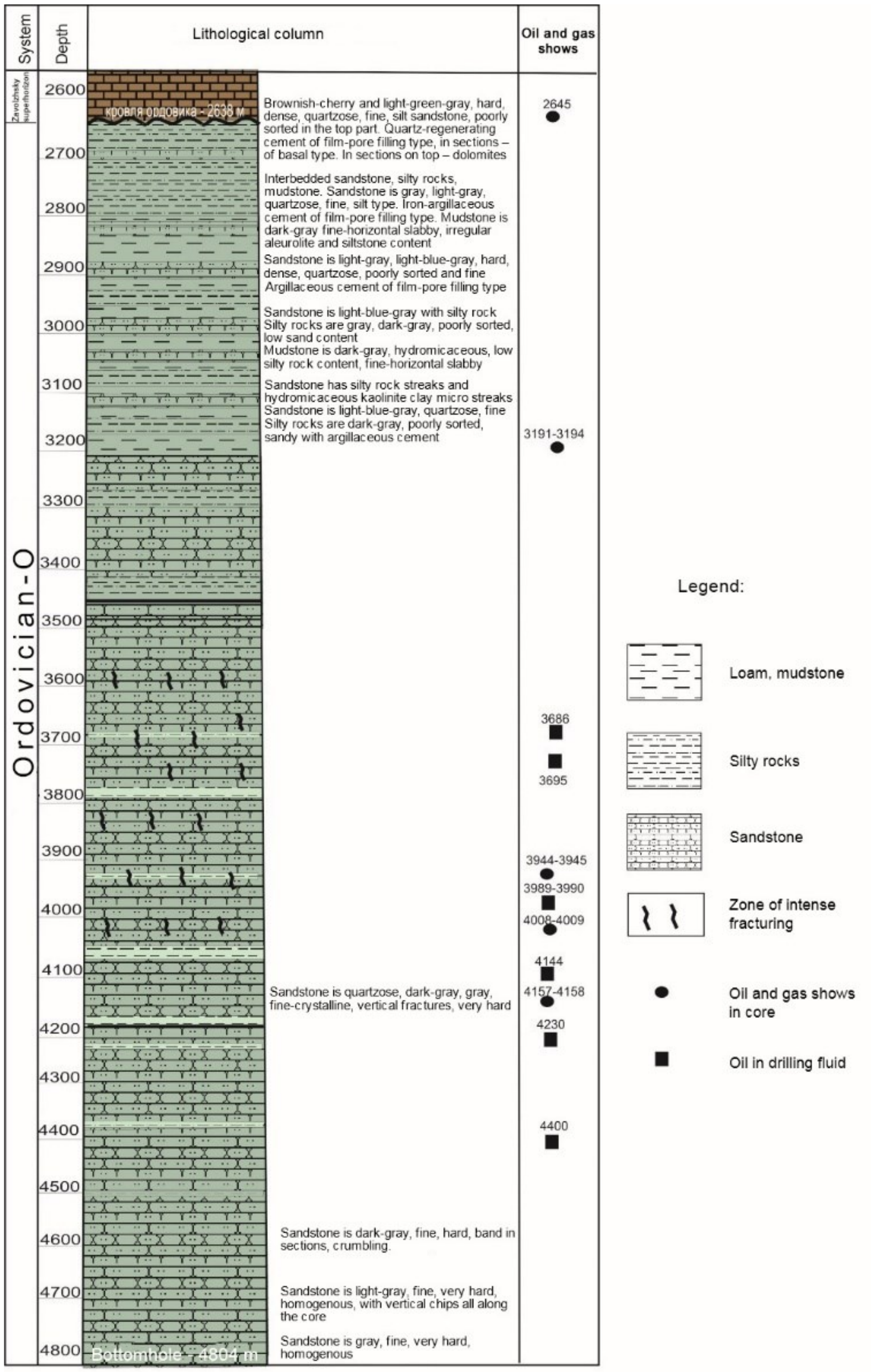


Figure 4. Fracture pattern in well 1 Ordovician (Bagmanova et al., 2001).

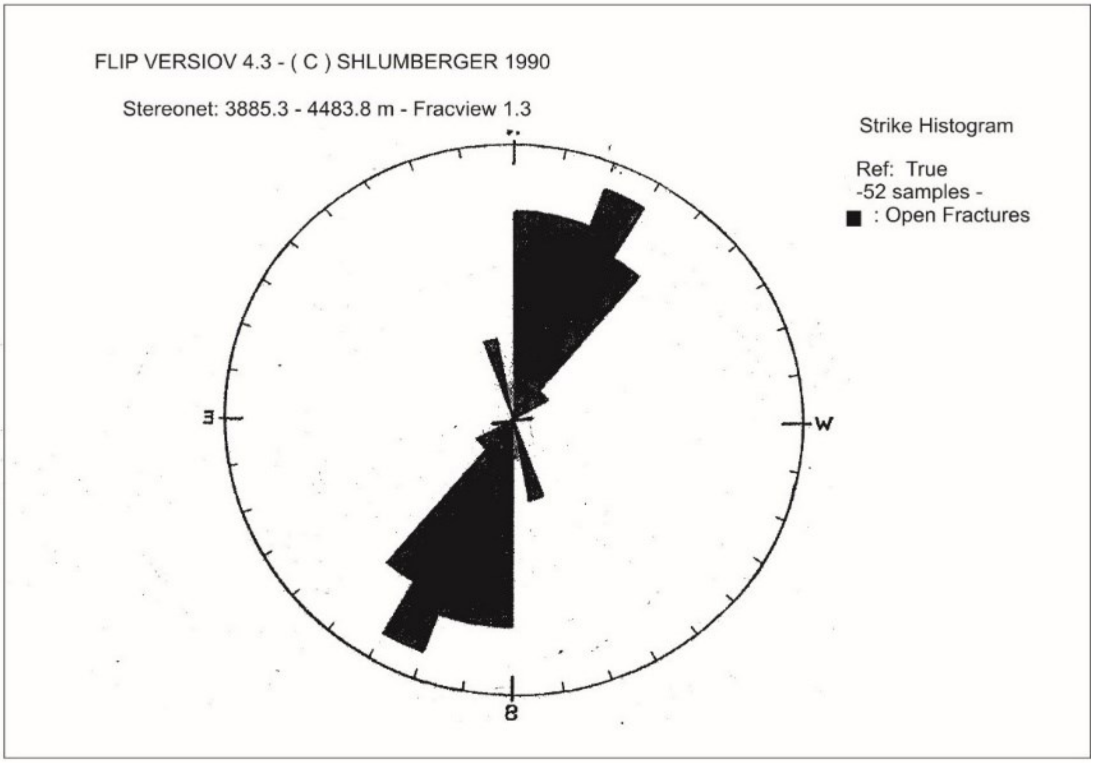


Figure 5. Section of Ordovician deposits in well 2 Ordovician (according to logging and core).

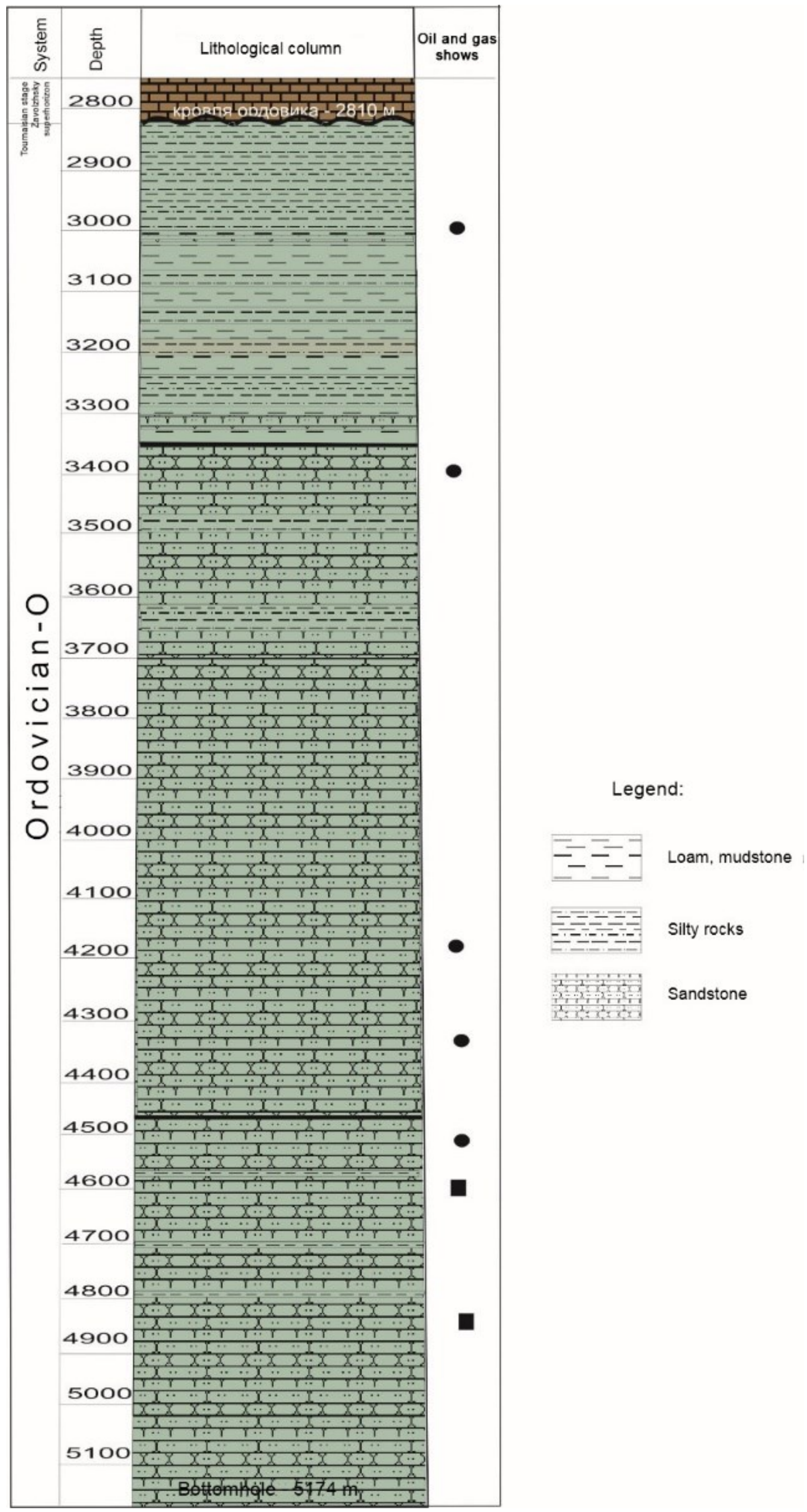


Figure 6. Principal correlation scheme of Ordovician deposits for wells 1, 2 Ordovician and 1 Krasnoyarskaya (Bagmanova et al., 2001).

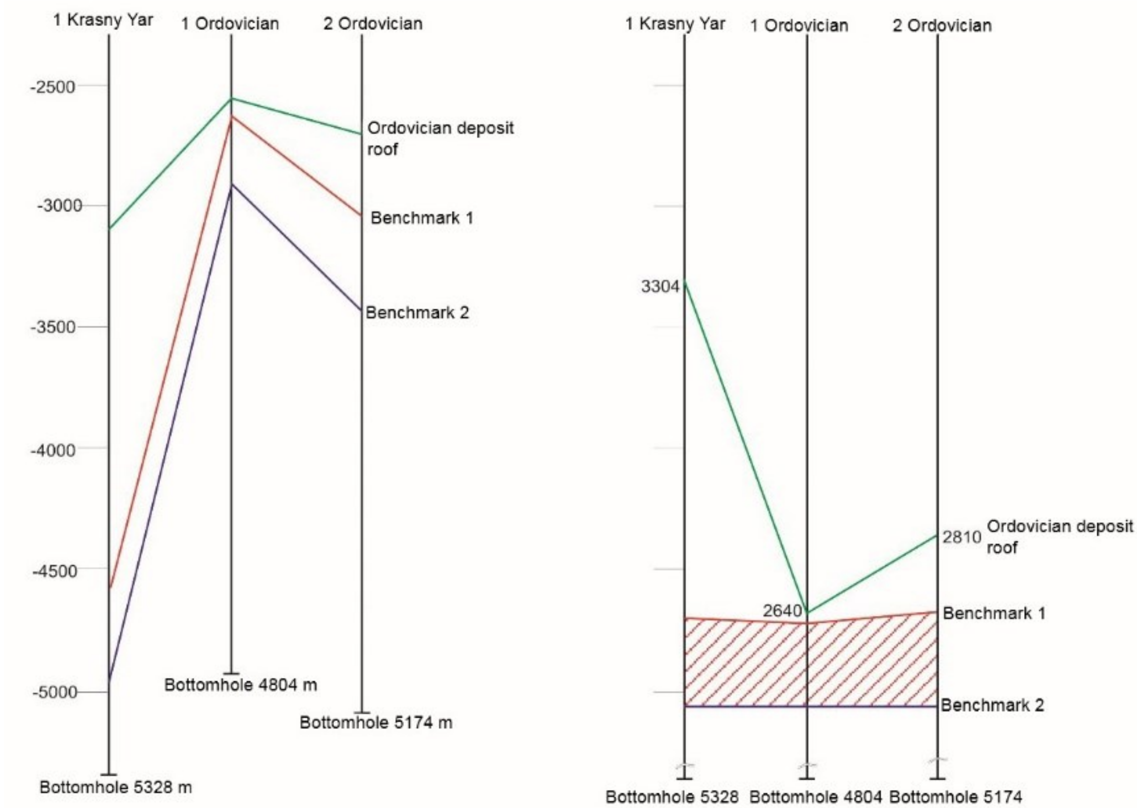


Figure 7. Contour surface map of Ordovician deposits in Orenburg region.

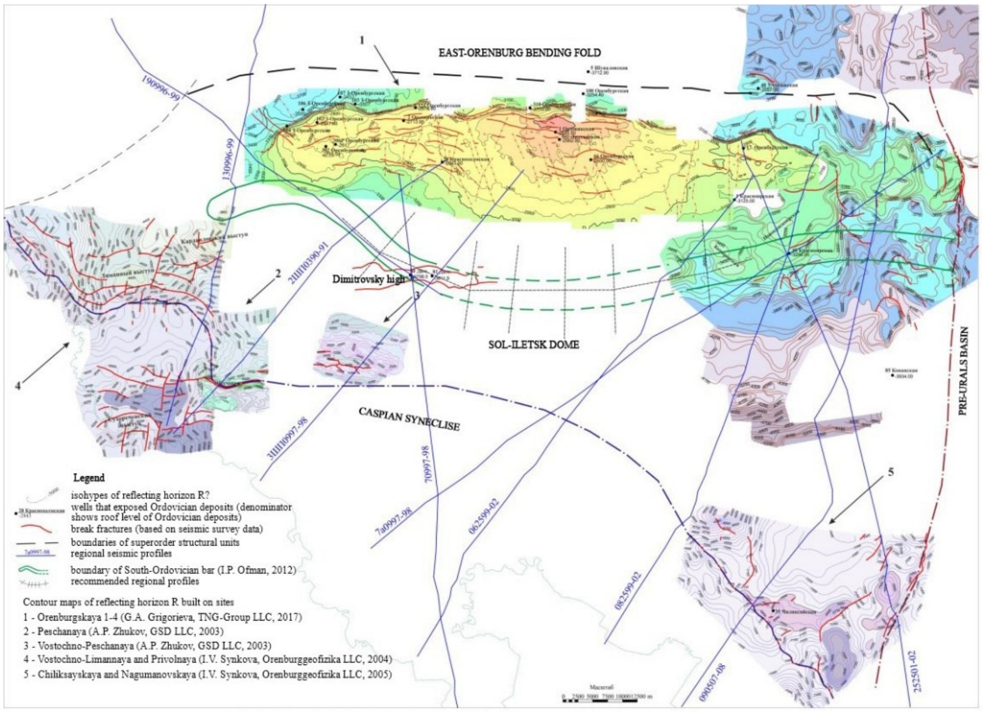
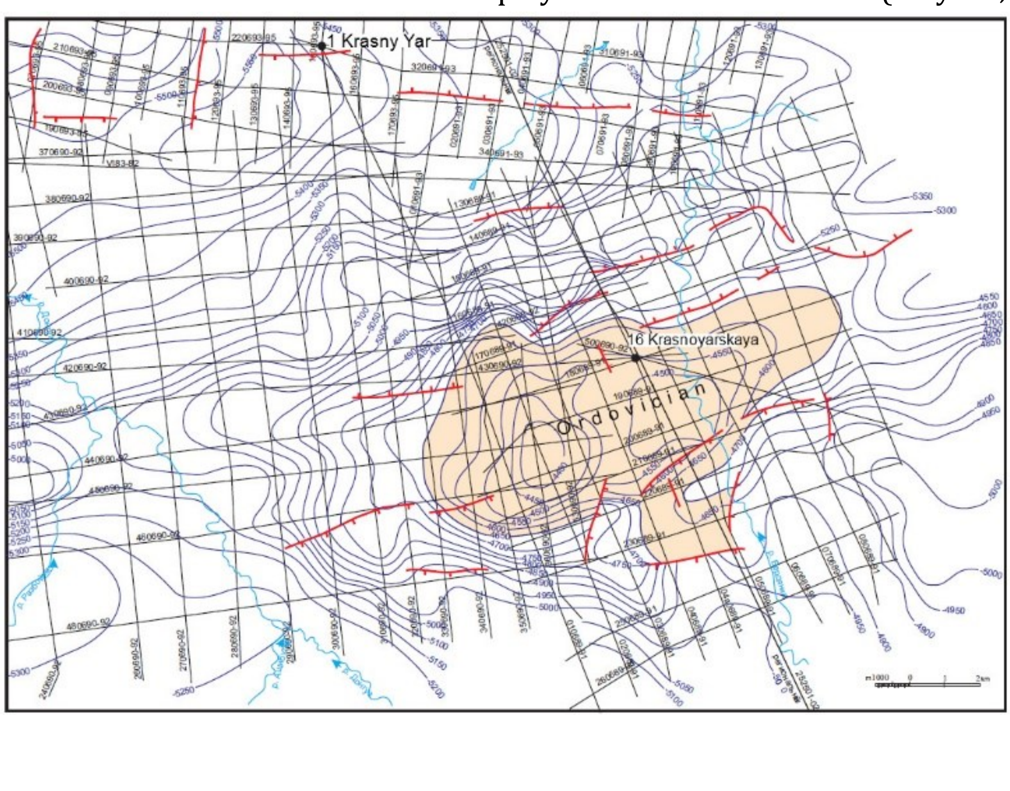


Figure 8. Ordovician structure. Contour map by seismic benchmark O1 (Belyaev, 1995).



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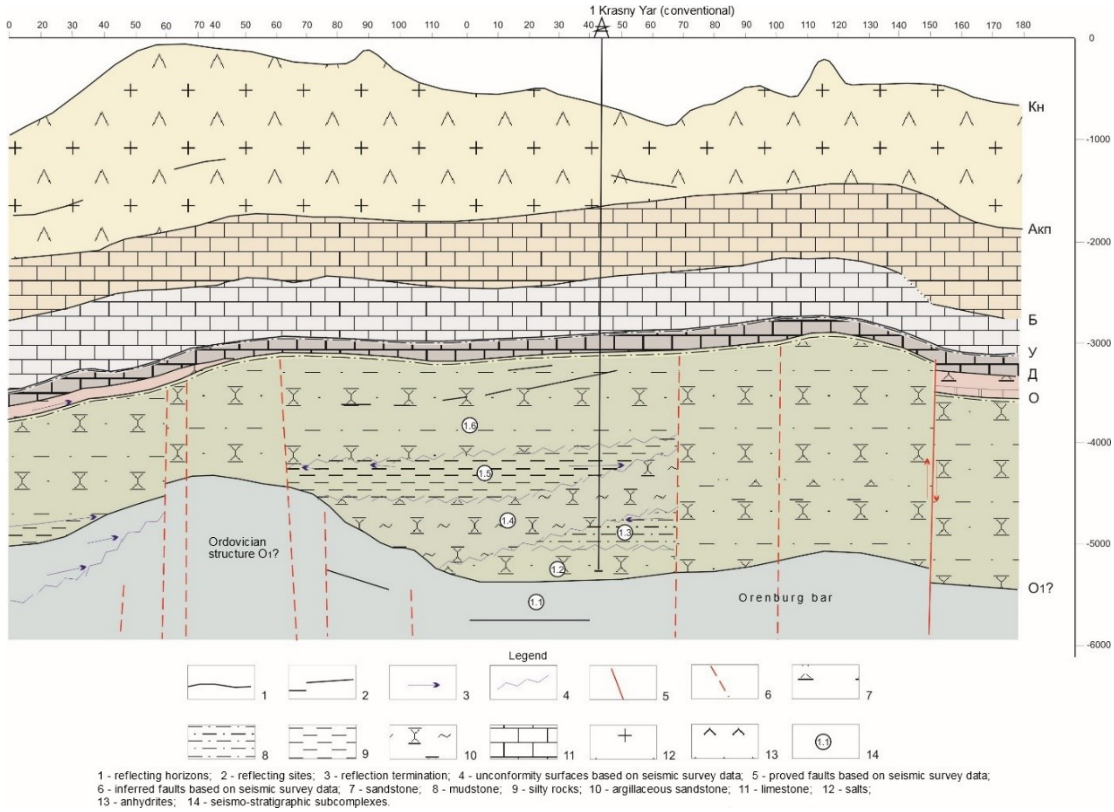

Figure 10. Ordovician structure. Fragment of a CDP seismic section along 252501-02 regional seismic profile (Votintseva, 2002).

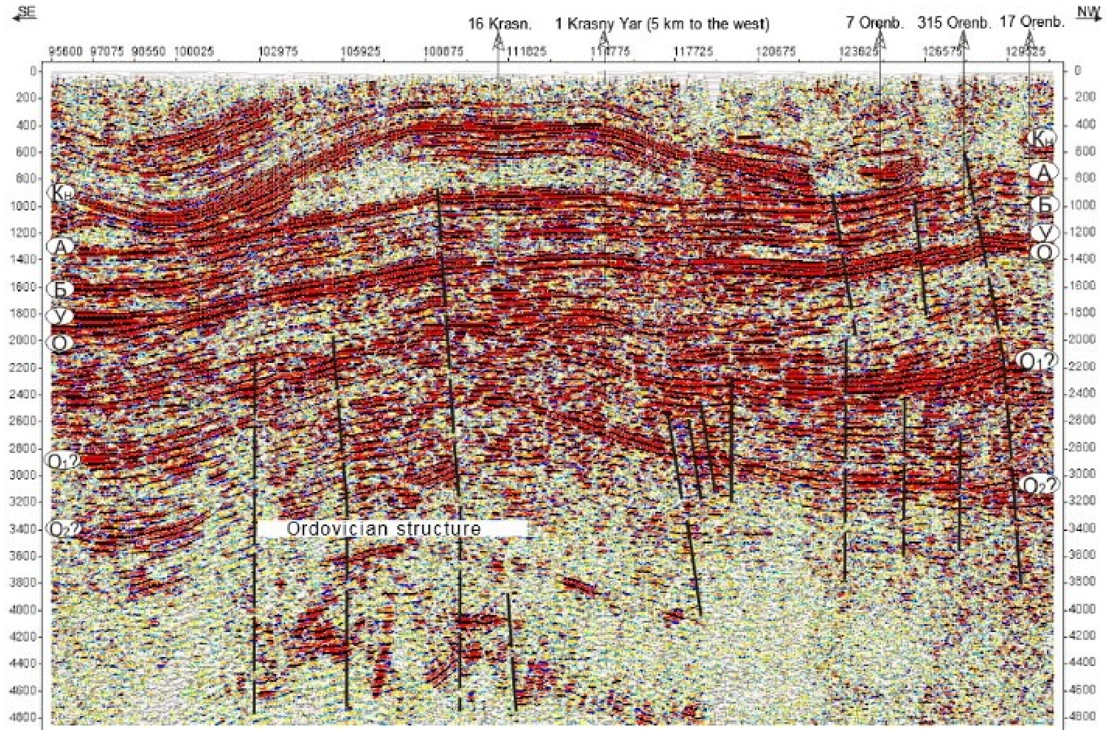

Figure 11. Morphology of Pre-Devonian complex of the southern part of Orenburg bar in the seismic section along 252501 profile.

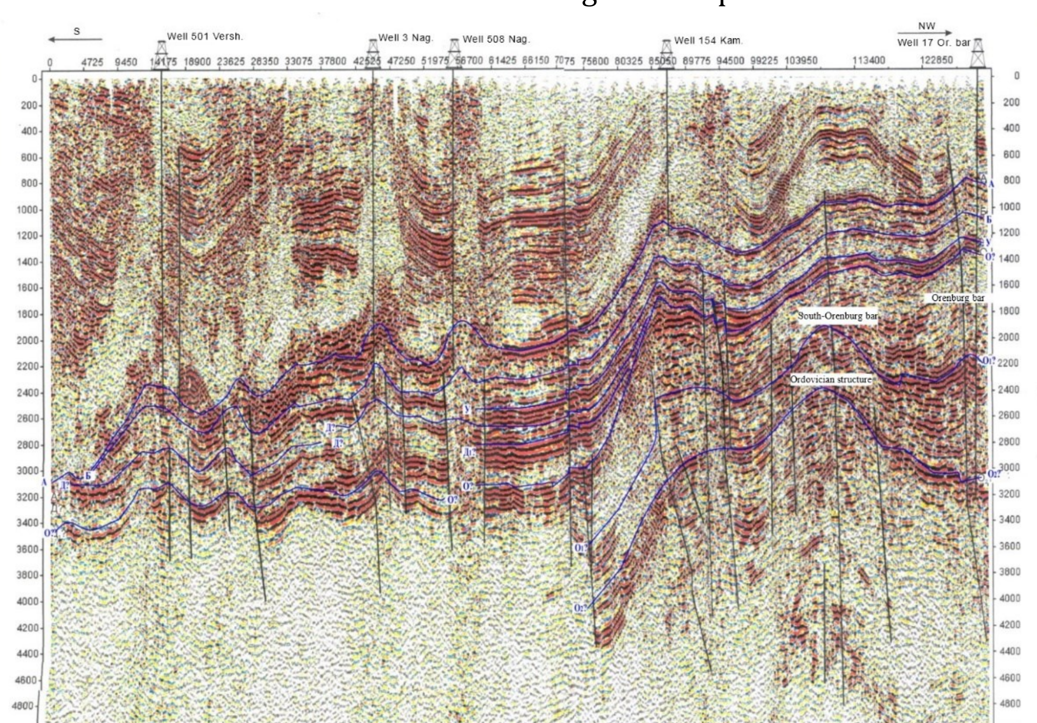

Figure 12. Fragment of a seismic section along 031793-95 WP regional seismic profile.

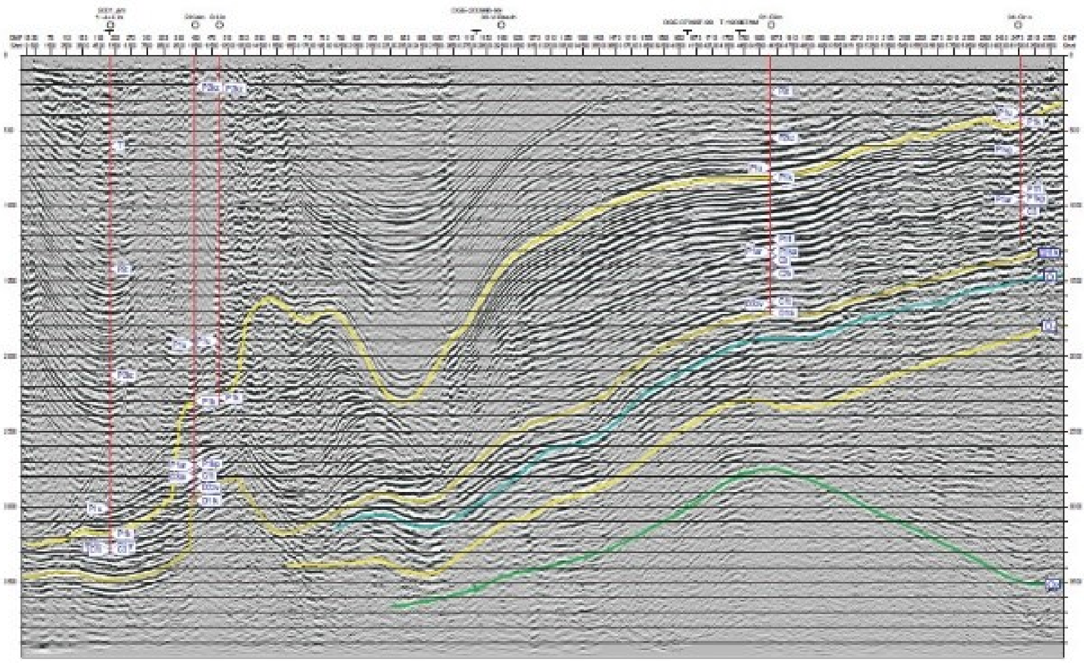

Figure 13. Mapping of South-Orenburg bar at 082599-02 profile (seismic section) (Albert and Brusyanin, 2003).

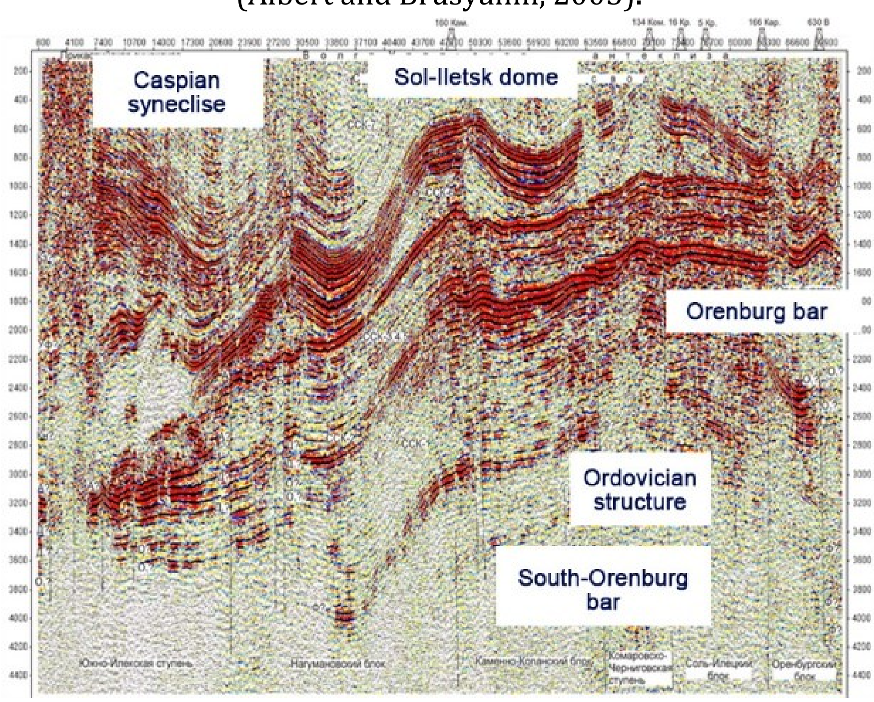

Figure 14. Mapping of South-Ordovician bar in a structural and tectonic diagram. Identification of an anticlinal bend in sedimentary cover deposits of Dimitrovskaya-Chernigovskaya elevation zone by 070997-99 (a), 062599-02 (b), 082599-02 (c) regional profiles –I.P. Ofman (2012).