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Variations of reservoir properties of Middle Cambrian rocks in Gargždai Elevations Zone of West Lithuania

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The composition and reservoir properties of Middle Cambrian rocks of newly drilled core samples were examined. The data are given in tables and differentiated maps compiled for West Lithuania and in more detail for the Gargždai Elevations Zone. The structure of the top of the Cambrian as well as maps of the thickness and sandstone porosity of the Middle Cambrian in West Lithuania are presented. The grain size composition and variation of reservoir properties of Middle Cambrian sandstones of Gargždai Elevations Zone are shown in sketch maps. The alternation of reservoir properties in the local structures of the Gargždai Elevations Zone is also presented.

Key words: reservoir, local structure, quartz sandstone, Middle Cambrian, West Lithuania

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INTRODUCTION

The quality of reservoir properties of rocks is one of the main oil exploration criteria and also the major index predetermining the amount of petroleum extraction. Therefore, the main goal of the present study was to analyse the variations of reservoir properties of Middle Cambrian rocks in the area of West Lithuania and to determine the reasons for these variations. For this purpose, the grain size composition and porosity patterns of sandstones from the Giruliai and Ablinga Formations in the local structures of the Gargždai Elevations Zone were examined and the Middle Cambrian structural, thickness and rock porosity maps (scale 1:200 000) were compiled for West Lithuania.

Most of the studied Caledonian local structures of West Lithuania were formed at the end of Caledonian or Hercynian tectonic cycles. They are mainly asymmetrical brachianticlinal fault structures. Their evolution includes one or two tectonic growth intensities: from the Late Silurian until the beginning of Early Devonian Cimmerian time (Pietų Šiūpariai, Kužiai and other structures) in the first case and from the Late Silurian until the beginning of Early Devonian Cimmerian time and from the Early Carboniferous until the Early Permian or even alpine time (Vėžaičiai, Šiūpariai, Vilkyčiai and Degliai structures) in the second (Sakalauskas, 1996).

Many scientists have investigated reservoir properties of Cambrian rocks: L. Laškova (1979, 1993, 1994), G. Vosylius (1998, 2000), L. Kilda (2002), D. Michelevičius (2003) and others.

DATA AND METHODS

The data of analytical and geological–geophysical investigations of all core samples from West Lithuania were employed in the present work for analysis of the composition of Middle Cambrian rocks. The reservoir properties of new core samples were examined at the laboratory of the Institute of Geology and Geography using special equipment for measuring rock permeability (ULTRAPERM-400) and equipment for porosity examination. The data were generalized in tables and maps compiled for West Lithuania. More detailed maps were compiled for the Gargždai Elevations Zone.

RESULTS AND DISCUSSION

The present structure of the top of the Cambrian in West Lithuania is shown in a sketch map (Fig. 1). The lowest subsidence of the Cambrian surface occurred in the southwestern part of the Baltic Sea area (territory of well D5-1) where it lies at a depth of 2,300 m and is even deeper further southwest. The deepest part of the Syneclise embracing the Lithuanian offshore and the territory west of the -1850 contour line of the Cambrian top is the most promising for oil exploration in Cambrian oil-bearing complexes of Lithuania. The area east of the -1000 – -1100 m contour line of the Cambrian top is not so well prospected and attributed to unpromising areas.

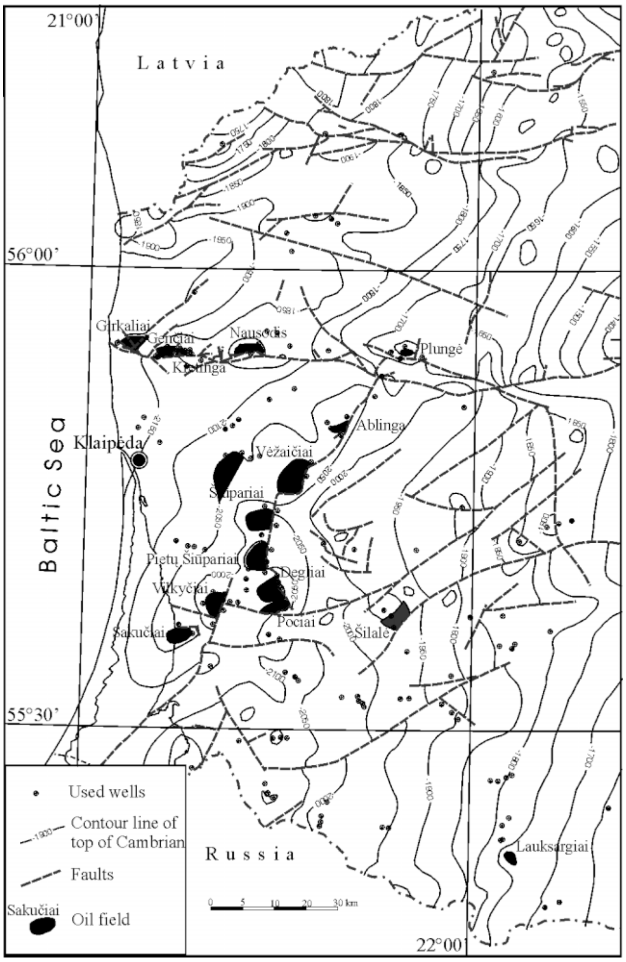

Fig. 1. The sketch map of the top of the Cambrian in West Lithuania, modified after K. Sakalauskas, 2003)

1 pav. Kambro kraigo struktūrinis Vakarų Lietuvos scheminis žemėlapis (modifikuota pagal K. Sakalauską, 2003)

A map of the thickness of Middle Cambrian rocks was compiled for the area of West Lithuania (Fig. 2). It also shows an increase of rock thickness from 40–50 m to 70–80 m in the direction from east to west. The areas with a more prominent variation of Middle Cambrian rock thickness (from zero to a few tens of metres) stand out on the general background (Plungė–Mamiai – 0–70 m, Veiviržėnai–Pociai – 0–71 m, Šilalė–Baubliai – 0–46 m, Šilutė–Naumiestis–Laukuva – 28–72 m). These territories are separated by areas with a bigger thickness of Middle Cambrian rocks (Kuliai–Stumbrė – 59–67 m, Žalgiris–Šilalė-2 – 62–76 m, Usėnai–Gorainiai – 61–69 m). Two areas of low capacity of Middle Cambrian rocks stand out to south of the Telšiai fault (Gribžėnai–Laugaliai–Macuičiai – 65–68 m and Žutautai–Kuliai – 66–67 m). The thickness of the Middle Cambrian succession in the surrounding areas reaches 77 m.

The palaeorelief of the crystalline basement predetermined the distribution pattern of the Middle Cambrian rocks. The variation of the Early Cambrian rock thickness predetermined by palaeorelief is even more prominent. The thickness of rocks on the elevations of relief is smaller but more variable, and it is greater in the sags of relief. The increase of rock thickness is gradual. The

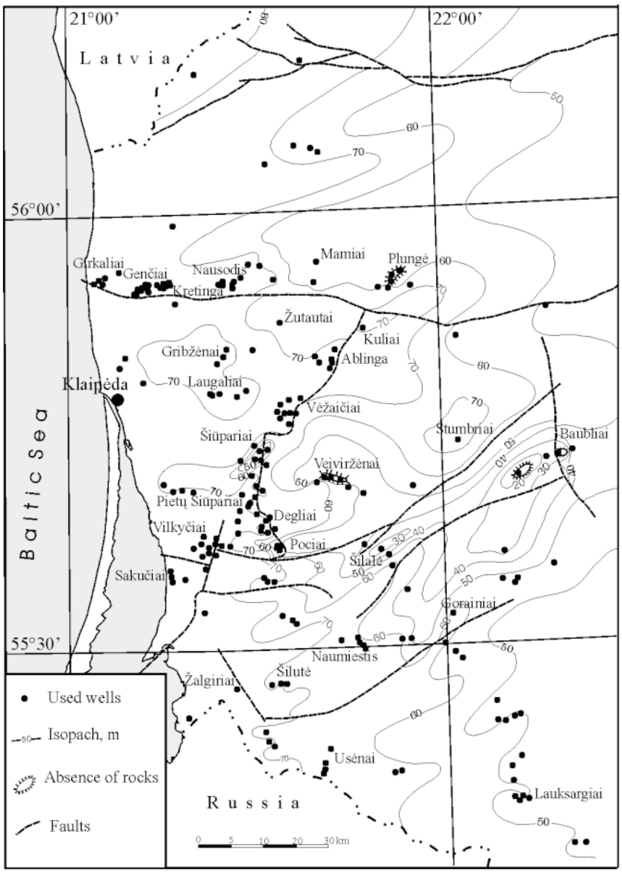

Fig. 2. The map of thickness of the Middle Cambrian deposits in West Lithuania

2 pav. Vidurinio kambro uolienų storio Vakarų Lietuvoje žemėlapis

Table 1. **Content of sandstones in the Middle Cambrian section of some structures**
1 lentelė. **Smiltainio kiekis pavienių struktūrų vidurinio kambro pjūvyje**

Name of structure Struktūros pavadinimas	Amount of sandstone, % Smėlio kiekis %	Sandshale ratio Smėlio ir molio santykis
Vilkyčiai	68–81	2.2–4.3
Vabalai	74	2.8
Degliai	73–84	2.7–5.3
Lašai	75–84	3.1–5.4
Pociai	73–80	2.8–5.0
Sakučiai	75–78	3.0–3.5
Traubai	76–81	3.2–4.4
Šiūpariai	73–89	2.7–7.8
P. Šiūpariai	70–83	2.9–4.0

variation of thickness is more pronounced in the local structures of the Gargždai Elevations Zone with protrusions of the crystalline basement: 32–70 m in the Šiūpariai structure and 38–71 m in the Pociai structure. In the other structures, the differences of the Early Cambrian rock thickness are 2–4 m (Sakučiai area) and sometimes reach 11 m (Vilkyčiai area). No substantial variations in the Middle Cambrian section composition of local structures have been observed. In the domes of the Pociai and Šiūpariai local structures there exists only the upper part of the Middle Cambrian succession. It is usually in good correlation with the analogous parts of sections in the structure slopes and bottom.

Sandstones compose a greater part of Middle Cambrian sections (68–89%) (Table 1).

The median diameter and the sorting index do not provide a full picture of the variation of grain size composition of rocks. The content of different fractions in sandstones is a more important index. For this reason, distribution maps of different sandstone fractions of Gi-

Table 2. **Total and effective thickness of Middle Cambrian sandstones**
2 lentelė. **Vidurinio kambro smiltainių bendras ir efektyvus storis**

Well Gręžinys	Thickness of Middle Cambrian sandstone, m Vidurinio kambro smiltainio storis m		Well Gręžinys	Thickness of Middle Cambrian sandstone, m Vidurinio kambro smiltainio storis m	
	Total Bendras	Effective Efektyvus		Total Bendras	Effective Efektyvus
Vabalai-1	54	22.8	Gargždai-16	51	17.2
Vilkyčiai-1	61	20.3	Gargždai-17	61	21.0
Vilkyčiai-2	53	6.8	Gargždai-18	55	14.2
Vilkyčiai-3	59	18.2	Degliai-1	51	23.8
Vilkyčiai-4	60	9.4	Degliai-2	53	21.8
Vilkyčiai-5	59	17.5	Degliai-3	51	24.2
Vilkyčiai-6	51	10.8	Degliai-4	53	22.8
Vilkyčiai-7	52	11.8	Degliai-5	55	16.8
Vilkyčiai-8	59	8.4	Degliai-6	58	n.d.
Vilkyčiai-9	64	29.0	Degliai-7	58	14.2
Vilkyčiai-10	55	19.2	Lašai-1	52	16.8
Vilkyčiai-11	58	19.2	Lašai-2	59	18.0
Vilkyčiai-12	62	15.6	Lašai-3	55	24.4
Vilkyčiai-14	60	11.4	Pociai-1	35	6.2
Gargždai-2	62	18.8	Pociai-2	39	12.4
Gargždai-4	62	16.8	Pociai-3	53	10.8
Gargždai-5	58	31.9	Pociai-4	28	9.6
Gargždai-6	56	n.d.	Pociai-5	45	24.8
Gargždai-8	57	10.0	Sakučiai-1	58	29.2
Gargždai-9	24	18.0	Sakučiai-2	57	21.2
Gargždai-10	28	5.8	Sakučiai-3	56	20.9
Gargždai-11	11	9.9	Sakučiai-4	54	5.0
Gargždai-12	49	23.0	Traubai-1	57	14.4
Gargždai-13	58	12.4	Traubai-2	56	31.0
Gargždai-14	53	7.4	Traubai-3	57	30.8
Gargždai-15	24	9.0	Traubai-4	55	23.4

ruliai and Ablinga formations were compiled for the Gargždai Elevations Zone, based on the data of grain size measurements (Figs 3a and 3b).

The distribution pattern of fractions 0.25–0.1 mm and >0.25 mm is plotted in the map of Giruliai Formation (Fig. 3a). Fine-grained sandstones are dominant in most of the northwest part of the territory. Its quantity reaches 50–60%. The sandstone fraction larger than >0.25 mm is spread in the southeast where hetero–granular sandstones prevail. They are more abounding in the enshrouding structures (Pociai and Lašai). The sandstones of Giruliai Formation are abundant in intermixtures of silt fractions. Their amount makes up to 27–32% of the total thickness in the Sakučiai area, 10–23% in Vilkyčiai, 8–16% in Degliai, 13–24% in Pietų Šiūpariai, 7–11% in Šiūpariai, 19–24% in Lašai and 10–24% in Pociai local structures.

The grain size composition of sandstones of the Ablinga Formation is variable (Fig. 3b). Fine-grained sandstones are dominant in the elongated territory stretching from south–west to north-east. Hetero-granular sandstones are spread south-east and north-west from this area. We have not determined any regular pattern of the distribution of clastic material. An increase of sandstone fraction >0.25 mm (two or three times) can be observed only in the dome of the Lašai structure. The sandstone fraction >0.25 mm composed 29–53% of the total thickness in the Sakučiai structure and its maximal content was determined in the well 4.

The description of reservoirs based only on the data of laboratory analysis is incomplete and reveals the general variation patterns of rock properties. This is related with the low yield of cores (from the old boreholes in particular) sometimes reaching only 30% of the section. As a rule, only strongly cemented rocks would be lifted up on the surface. Weakly cemented and fractured sandstones would be crushed and lifted up only with

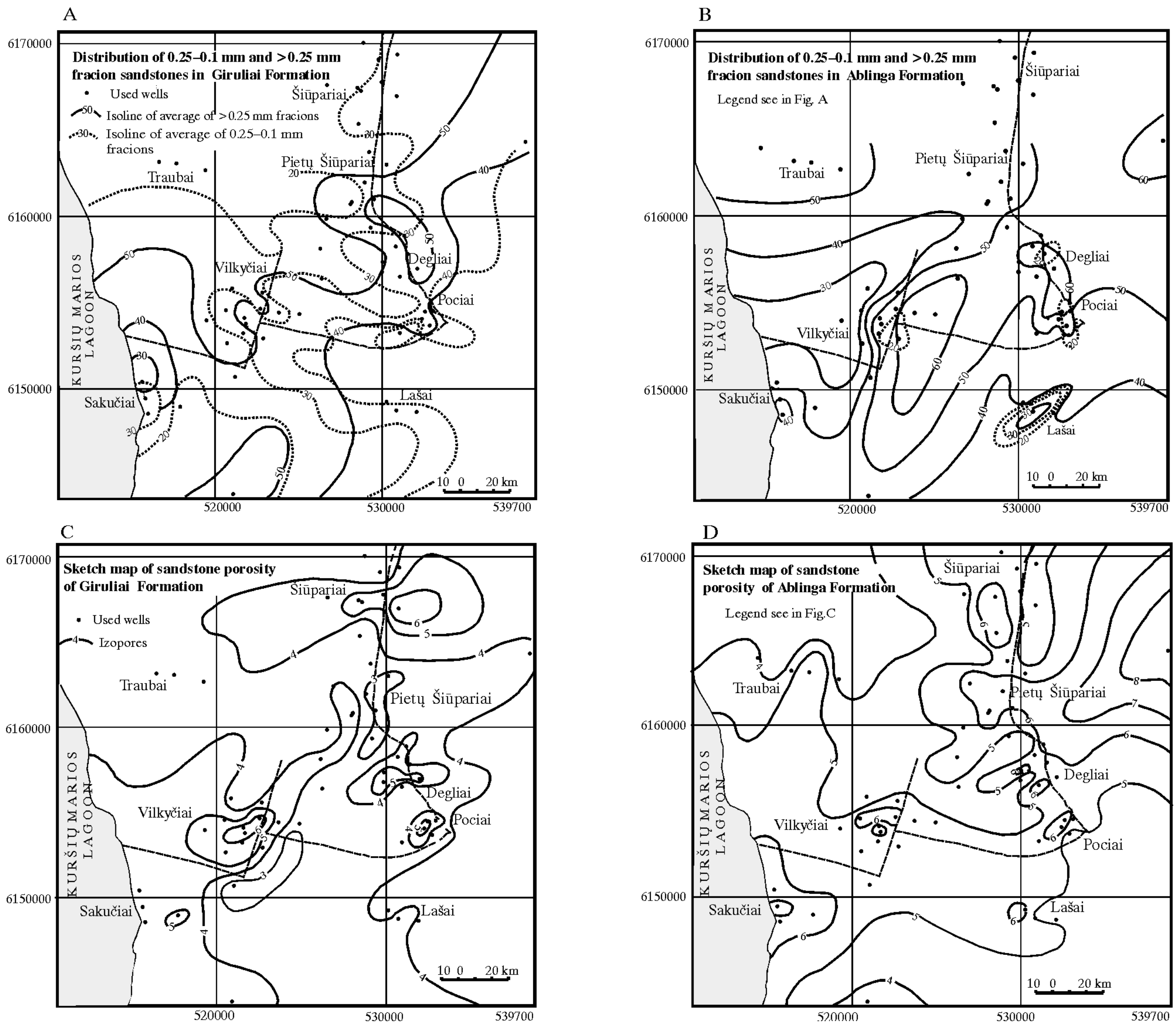

Fig. 3. Distribution of 0.25–0.1 mm and >0.25 mm sandstone fractions in Giruliai (A) and Ablinga (B) Formations and of average porosity of sandstones in Giruliai (C) and Ablinga (D) Formations. The system of Lithuanian coordinates

3 pav. 0,25–0,1 mm ir >0,25 mm smiltainio frakcijų paplitimo Girulių (A) ir Ablingos (B) svitose, taip pat Girulių (C) ir Ablingos (D) svitų smiltainių vidurkinio poringumo žemėlapiai. Lietuvos koordinačių sistema cuttings. Moreover, only cores from the sections of productive parts of Deimena Formation were selected. Currently the hundred-percent yields of cores from the new boreholes (unfortunately they are few) would always be secure.

The total thickness of reservoirs in the Middle Cambrian section varies from 24 to 62 m in the Gargždai Elevations Zone (Table 2).

The lowest thickness was determined in the Šiūpariai area and a slightly higher one in Vilkyčiai. In this territory, the quality of Middle Cambrian reservoirs mainly depends on the content of quartz cement. As in the whole Baltic Syneclise, the quartz cementation of Cambrian sandstones in the study area was related with regional and local factors. Regional factors are primarily the composition of rocks, section structure, maturity processes, palaeotemperature, etc. The total amount of quartz-cemented sandstones ranges from 54 to 87%. The maximal amount of quartz cement reaches 26%. A well-expressed variation of the level of quartz-cemented sandstone is observed in oil fields. This is related with the dynamics of filling the local structures by oil and variations of rock composition in the oil-water palaeointerfaces (palaeo OWC). The content of regenerated quartz cement in the dome of the oil field constitutes 10–12% in Vilkyčiai, 12–14% in Pociai, 6–9% in Šiūpariai, and 9–10% in Pietų Šiūpariai areas. Meanwhile, in the peripheral parts of the oil fields the content of quartz cement reaches 24–26%.

The reservoir properties of the Middle Cambrian sandstones depend on the level of quartz cementation and dissolution of quartz cement. The average of open porosity of the Giruliai Formation ranges from 2.4 to 8.7% (Fig. 3b); the maximal values (more than 5–6%) were determined in the domes of the oil field. Outside the boundaries of the structures, porosity is only 3–4%. Gas permeability of rocks follows a similar distribution pattern. It is highest in the domes of oil fields: borehole Šiūpariai-10 – 29 mD, P. Šiūpariai-12 – 3 mD, Vilkyčiai-9 – 281 mD, Pociai-1 – 81 mD, Degliai-1 – 79 mD, D5-1 – 9.2 mD, and it does not exceed 1 mD outside the boundary of the oil field.

According to G. Vosylius data (1996), most of fractures in the Middle Cambrian sandstones are open and situated within quartz-cemented layers. The gas permeability of most highly quartz-cemented layers through fractures exceeds the matrix permeability more than twice. Therefore, fractured-porous reservoirs are widespread in these layers.

The reservoir properties of sandstones of Ablinga Formation in the Gargždai Elevations Zone are considerably better (Fig. 3c). The average porosity reaches 0.2–3.4% and the gas permeability does not exceed 33 mD. The clay fraction in the sandstones of Ablinga Formation takes 1.2–24.7% and in the sandstones of Giruliai Formation 1.7–9.2%. The clayey cement mantles the grains or fills the pores. Sandstones with clayey cement and with caolinite in particular are characterised by good porosity but low gas permeability. The enlarged open porosity (over 6%) is characteristic of the domes of oil fields. The deposits of Ablinga Formation have many open fractures. Sometimes fracture permeability reaches 142.5 mD (well Pociai-5). Fractures occur in highly quartz-cemented sandstones.

The lowest values (12–26%) of silt fraction were determined in the Giruliai Formation and higher values in the Ablinga Formation (10–62%) of Vilkyčiai area (Fig. 4). The markedly higher value of

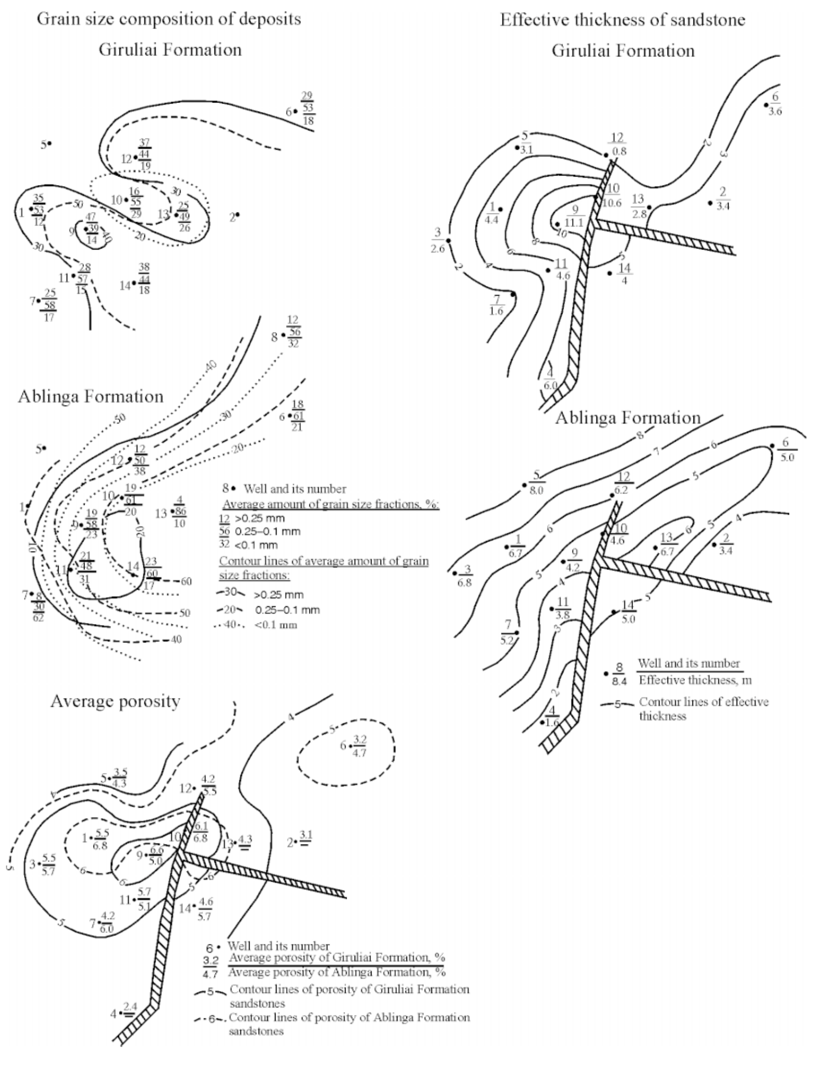

Fig. 4. Sketch maps of grain size composition, effective thickness and average porosity of Giruliai and Ablinga sandstones of Vilkyčiai oil field

4 pav. Vilkyčių naftos telkinio Girulių (A) ir Ablingos (B) svitų uolienų granuliometrinės sudėties, smiltainio efektyvių storių ir vidurkinio poringumo scheminiai žemėlapiai

0.1–0.01 mm fraction and a lower content of >0.25 fraction in the Ablinga Formation could worsen the reservoir properties of sandstone. However, this is not the case. Improved reservoir properties of sandstone are observed in the structure domes of both formations (wells Vilkyčiai-1, 9 and 10). This is another proof that the level of silicification related with the stages of the palaeo oil field formation is decisive for the quality of reservoirs. The average value of open porosity of sandstone in the dome of oil field exceeds 6% (wells Vilkyčiai-9 and 10), whereas in the peripheral parts it is only 3–4%. The fractures in the Middle Cambrian identified by G. Vosylius (1996) are empty or filled with oil, quartz or carbonates. Fracture permeability reaches 1.4 mD. Fractured–porous reservoirs are dominant.

Data on the grain size composition of sandstones from the Šiūpariai area are scanty. Fine-grained sandstones are dominant in the upper part of Giruliai Formation. They include 30–35% of >0.25 mm fraction and up to 2.5% of clayey fraction. The Middle Cambrian section in the oil field is composed of alternating quartz-cemented and uncemented 1–5 m thick layers of sandstone. In the interval 2–4 m of the structure dome (wells 8 and 9) sandstones are uncemented. Their open porosity is 3.1–9% and gas permeability 23.3–45.1 mD. Fracture permeability equals to 0.02 mD. The open porosity of underlying quartz-cemented sandstones is 1.7–4.5% and impermeable to gas. Fracture gas permeability is 2.7 mD. A similar variation of reservoir properties is characteristic of the lower part of the section. The thickness of the quartz-cemented succession of the Šiūpariai structure is 12–30 m, the total thickness of sandstone layer in it is 12–24 m and the effective thickness is 5.8–16 m.

The >0.25 mm fraction of hetero-granular sandstones of Giruliai, Ablinga and Pajūris formations (Pietų Šiūpariai area; well 12) amounts to 10–20%, silt fraction to 18–24% and clayey fraction to 9–16%. The thickness of weakly and strongly quartz-cemented sandstone beds ranges from 1 to 6 m. The open porosity of uncemented sandstones reaches 13.1%. Gas permeability is 11.6 mD. The quartz-cemented part of the Middle Cambrian section is 26–39 m thick. The total thickness of sandstone beds in it is 21–34 m and the total effective thickness is 6.8–11.9 m.

According to grain size data, fine-grained sandstones are dominant in boreholes 1, 2, 3, 6, and 7 of the Degliai area. Fraction 0.25–0.1 mm in them constitutes 33–46%, >0.25 mm – 25–55%, <0.1 – 12–30%. Hetero-granular silt-bearing sandstones are spread in the wells Degliai-4 and Degliai-5. The 0.25–0.1 mm fraction amounts to 44–49%, >0.25 mm – 13–20%, <0.1 – 15–17%. The thickness of weakly and strongly quartz-cemented sandstone beds ranges from 1 to 4 m. The thickness of quartz-cemented zone is 18–29 m, and the effective thickness being 4.8–10.4 m. The open porosity of quartz-cemented sandstones ranges from 1 to 12.9%, gas permeability reaches 79.1 mD and fracture permeability is 239.5 mD (well Degliai-2).

In the Pociai area, hetero-granular silt-bearing and silty sandstones and coarse- and medium-grained sandstones represent reservoirs. The 0.25–0.1 mm fraction amount is 33–46%, >0.25 mm – 25–55%, <0.1 – 12–30%. The quartz-cemented and uncemented beds are 4–8 m thick. The quartz-cemented part of the Middle Cambrian section is 21–26 m thick. The total thickness of sandstone beds is 16–21 m and the total effective thickness is 3.6–11.6 m. The best reservoir properties are characteristic of the interval of quartz-cemented sandstone in the well 1. The open porosity of sandstones is 1.8–13.6% (average value 7.8%), gas permeability 80 mD and fracture permeability 0.3 mD. The worst reservoirs are characteristic of the well 2. Almost the whole of its section is quartz–cemented. The content of regenerated quartz cement reaches 20–22%. Somewhat better reservoir properties are related with the melting zone of the palaeo OWC at the interval of 2002–2008 m, where open porosity is 2.2–7.5% and gas permeability 3.5 mD. Intensive quartz-cementation of sandstones in the well 2 is responsible for the partial lithological screening of the oil field.

The reservoir rocks in the Middle Cambrian in the Gargždai area are unevenly distributed: 0.2–3 m thick (sometimes thicker) layers of different types of reservoirs alternate in the section. The composition of the Middle Cambrian section in the Sakučiai area is different from the previously described one of the well Sakučiai-1. The rocks are composed of three beds separated by palaeo OWC levels. The upper bed is 12–13 m, the middle 18–19 m and the lower 20 m thick.

The sandstones of the upper bed are strongly quartz–cemented (the content of regenerated quartz cement is 16%) and marked by poor reservoir properties. Open porosity ranges from 1.8 to 8.5 (average value 7.2%), gas permeability reaches 0.3 mD and fracture permeability 3.3 mD. The reservoir properties of the middle bed are better. The open porosity reaches 2.7–10.7% (average value 7.2%), gas permeability is 19 mD, and content of quartz cement reduces to 5–9%. The sandstones of the lower bed are almost uncemented (the content of quartz cement is up to 2–3%). The content of clayey cement is low (up to 4%). This layer is distinguished for good reservoir properties. The open porosity is 2.3–13.9% (average value 11.8%) and gas permeability is up to 214 mD. The beds are well-defined by the reservoir properties and the level of quartz-cementation. In the base of each layer palaeo OWC was determined. Such constitution can be explained by formation conditions of palaeo oil field, which were different from the other oil fields formations in the Gargždai Elevations Zone. The latter were replenished by petroleum many times; up to 5–8 levels of palaeo OWC were identified. The Sakučiai oil field was filled with petroleum only thrice. We may assume that rocks of the well Sakučiai-1 had been quartz–cemented before the oil migration into the trap. Its upper part was filled up with petroleum in a comparatively short time, because quartz-cementation dissolution zone is weakly expressed. The second input of petroleum enlarged the oil field to 30 m. The filling of the deposit presumably was slower and the process of dissolution intensified. Therefore, the reservoir properties of sandstones in the middle bed improved. During the third petroleum filling, the oil field enlarged to the height of 50 m, but the growth was rather slow. The dissolution of regenerated membranes and quartz grains was more intensive. Sandstones attained better reservoir properties. The formation pattern of the Sakučiai oil field is comparable with that of the structure D6 or of Kaliningrad Region oil fields. Two or three palaeo OWC levels and well-expressed dissolution zones are identified there.

The open porosity in the well D5-1 in the Baltic Sea ranges from 3.1 to 11.7% (average 6.8%). Gas permeability reaches 9 mD. The content of regenerative quartz cement sometimes reaches 20–25%. The processes of dissolution are poorly expressed.

Middle Cambrian reservoir rocks on the Lašai area are represented by silt-bearing sandstones in which 0.25–0.1 mm fraction comprises 32–39%, >0.25 mm – 33–35% and <0.1 mm – 19–24%. In comparison with the other local structures of the Gargždai Elevations Zone, the reservoir properties of Lašai Middle Cambrian sandstones are considerably worse. The open porosity ranges from 0.7 to 13.1% (average 4.4–4.7%), gas permeability is up to 0.8 mD and fracture permeability reaches 14.5 mD. The degree of sandstone quartz-cementation is high. The total content of regenerative quartz and silicate cement in the well Lašai-1 is 9–18%, Lašai-2 7–19%, and Lašai-3 it reaches 3–13%. Their greatest amounts are concentrated in the upper part of the section. A palaeo OWC was identified 4 m below the Cambrian top in the borehole Lašai-1. Judging from the thickness of Salantai Formation, the height of the palaeo oil field reached 5–6 m. The traces of palaeo OWC were identified in the sandstone of Salantai Formation (well Lašai-2). The history of geological evolution between the wells Lašai-1 and Lašai-2 shows that the maximal difference between the altitudes of the Cambrian top in them reached 9 m. The content of regenerated quartz cement above the identified palaeo OWC is 15–17% and below it 17–19%. The zone of dissolution is poorly expressed. The traced bitumen is crystallized. All these evidences prove a short-lasting existence of the oil field. It is possible that wells in Lašai area were drilled in the peripheral part of the structure.

The Middle Cambrian sandstones in the sections of the new wells Šiūpariai-2 and Šiūpariai-3 are unevenly silicified. Strongly and weakly cemented 0.6–7.5 m thick beds of sandstones are alternating in the area. The open porosity of weakly quartz-cemented sandstones is 3.8–14.6% and gas permeability reaches 300 mD and of strongly quartz-cemented sandstones 1.4–9.8% and 2.6 mD, respectively.

As the Middle Cambrian section is composed of alternating sandstone and mudstone (clayey siltstone or argillite) layers, the quality of reservoirs is predetermined by the thickness (from a few to 20–30 m) and number (from 1 to 6) of sandstone beds. The total thickness of sandstone beds is 15–70 m on the average. The greatest total thickness of sandstone beds (50–70 m) occurs in West Lithuania and the Baltic Sea area where the total thickness of sandstone and argillite layers either is equal or the amount of sandstone exceeds the amount of argillite 1.5–2 times. The sandstone beds are three times as thick as argillite beds in the Kuršių Marios lagoon bordering on the Kaliningrad Region and in the adjacent sea area (structure D6). The maximal total thickness of sandstone layers exceeding the total thickness of argillite layers 4–12 times was determined around the local elevations of the crystalline basement relief in the Plungė, Šilalė, Naumiestis and Ablinga areas, in well the Mamiai-1 and elsewhere. In the Middle Cambrian sections of Middle Lithuania, the total thickness of sandstone beds reduces to 15–20 m but the content of sandstone is 3–4 times as high as the content of argillite. This is related with the changes of facies closer to the shoreline, a lower capacity of rocks and a smaller stratigraphic volume.

Sandstone layers are composed of grey and white fine-, medium-grained and hetero-granular quartz sandstone sometimes containing silt. Thin beds (up to 1–3 cm) and lenses of grey and dark grey argillite and argillite with inclusions of silt are unevenly distributed within the thicker layers.

Quartz (up to 99%) represents the clastic material in sandstones: feldspar, quartzite fragments, zircon, tourmaline, epidote, rutile, monazite, sphen, glauconite, etc. Sometimes quartz grains are incorporated or conformed. Microstilolites and macrostilolites occur somewhere with sutures 2–2.5 cm in height. Medium- and coarse-grained sandstones are found in the upper part of the section. Fine-grained silt-bearing sandstone is more frequent in the lower part of the section. The portion of cement in sandstones ranges from 1 to 30%. It is mainly represented by regenerated quartz, clayey material and dolomite or, in rarer cases, calcite (Лашкова, 1979). Quartz cement forms regenerative membranes on quartz grains or fills the pores. Clayey cement is characteristic of quartz siltstone and is composed of kaolinite, ilite and, in rarer cases, chlorite and mixed minerals of the montmorillonite-ilite group. Carbonate cement occurs sporadically in the form of patches of different size. It is dolomite composed of large crystals. Its cementation is of basic, porous or mixed type.

The quality of reservoir rocks mainly depends on the quantity of secondary quartz in them. Quartz-cementation is unevenly distributed laterally and vertically. Most highly quartz-cemented is the upper part of the section in West Lithuania and the Baltic Sea area, where the thickness of the quartz-cemented part of the section (down-ward from the Middle Cambrian roof) reaches 46 m or is up to 25–30 m in oil deposits. Eastwards and southwards, the thickness of quartz-cemented sections reduces to 10–7 m (Laukuva, Žvyliai, etc.).

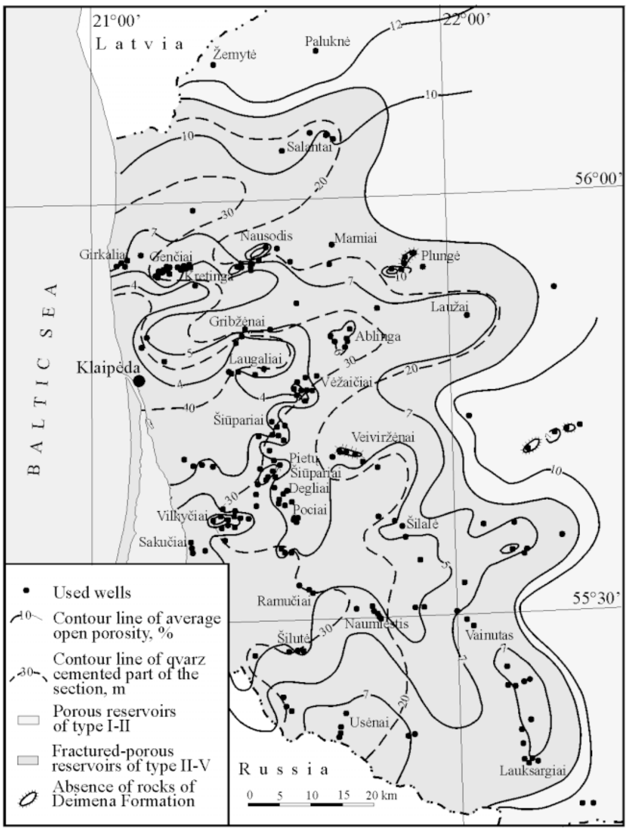

Fig. 5. Distribution of reservoir properties of Middle Cambrian rocks in West Lithuania

5 pav. Vidurinio kambro uolienų kolektorinių savybių kaitos Vakarų Lietuvoje žemėlapis

The zone of porous reservoirs of classes I and II includes the territories of West and North Lithuania (Fig. 5). We used A.A. Khanin's classification of the reservoirs (Ханин, 1969). Sandstone reservoirs in it comprise 41–88% of the section. The total thickness of sandstone beds ranges within the limits of 10–40 m and reaches 62 m in the northern part of the zone (well Paluknė-1). The sandstone is cemented by dolomite and regenerated quartz. Yet the content of cement does not exceed 2–3%, i.e. the sandstone is weakly cemented rather than powdery. The average value of open porosity of the reservoirs reaches 13.5% and of gas permeability 2105 mD.

The zone of porous and porous-fractured reservoirs of classes II–V is situated in West Lithuania and in the adjacent offshore. The total thickness of the sandy layers changes from 32 to 69 m. The average value of open porosity ranges from 2.8 to 12.9%. The gas permeability reaches 912.8 mD. In the lower bed 62 m thick, sandstone is not quartz-cemented. The total thickness of sandstones is 7–46 m. Open porosity ranges from 1.4 to 21.3% and gas permeability is 2153 mD.

In the southeastern part of the zone, the reservoir properties of Middle Cambrian sandstones are considerably better. The average value of open porosity is 6.6–12.9% and gas permeability reaches 778 mD. The quartz-cemented part of the section ranges from 5–6 m (Lauksargiai) to 5–13 m (Aukštupiai) in thickness.

CONCLUSIONS

The porosity of Middle Cambrian rocks mostly depends on their compaction and content of secondary (regenerated) quartz cement. The primary (mechanical) and secondary (chemical) compaction directly depends on the bedding depth of rocks. Among the primary conditions, the frequent alternation of thin (from 0.2–0.3 m to a few meters) sand and clay layers and the content of organic matter in clays produced a negative effect on the reservoir properties of Cambrian rocks. Oxidation of organic matter predetermined the formation of acid medium and SiO_2 precipitation in the interface zones of clayey and sandy layers. Authigenous quartz formed at a greater depth and higher temperatures due to dissolution of quartz grains in the contact zones. It filled the pores of thinner layers. The role of temperature was important but not the main. The temperature of the layer in the Meškinė–Šilutė environs reaches 96°C and the portion of authogenous quartz cement makes 8–15%. In the Gargždai Elevations zone the temperature does not exceed 86°C, whereas the content of quartz cement reaches 26%. The degree of silicification in different localities of the region depends on the influence of different factors: pressure, temperature, structure of the section, content of organic matter, tectonic regime, etc.

The reservoir properties of sandy members of Giruliai and Ablinga formations in the Gargždai Elevations Zone are better within the local petroliferous structures. Conspicuous transformations of Middle Cambrian sandstones also took place in the palaeo OWC zones of the oil fields. Dissolution of quartz cement and quartz grains and formation of bitumens and pyrite took place in the upper part of the zone whereas sedimentation of quartz and quartz-cementation of rocks took place in the lower (cementation). Due to stratification the deposits became irregular, layered and have different reservoir properties in the section of the zone of cementation and dissolution. In cases when the traps are filled with oil till bottom, cementation zones are not formed or not well expressed, because melted SiO_2 is washed out of the structure.

According to the influence of palaeo OWC on the transformation of reservoir properties of rocks two types of oil fields were classified. The first type includes the Vilkyčiai oil field. Its multiple transformations (up to 8 palaeo OWC) were related to the variations of filling with oil of the structure in the geological history. Quartz-cemented and uncemented beds up to a few metres in thickness can be followed up in the section. The Sakučiai deposit belongs to the second type. It has two palaeo OWC levels and a dissolution layer 20 m thick. Therefore, the reservoir properties of its sandstones are better. The more quartized sandstones are spread in the western and eastern parts of the Gargždai Elevations Zone (Šiūpariai, Pietų Šiūpariai, Vilkyčiai, Sakučiai areas). The total thickness of the quartz-cemented sandstones reaches 40–50 m, it consists 78–87% of the total thickness of the sandstones.

Not only structural but also non-structural (lithologic–stratigraphic and combination types) oil traps have been and presumably will be detected in the Cambrian oil–bearing complex. All local structures without or with reduced beds of Cambrian rocks in the domes (Šiūpariai, Veiviržėnai, Šilalė, Lauksargiai, Pociai, Pajūris, Baubliai, Plungė, and Mamiai structures) are related with the jags distributed on the crests of a crystalline basement detected also in the Middle Cambrian palaeorelief. Non-structural oil traps are possibly related with this type of structures. Non-structural oil traps formed under the influence of preserved porous reservoirs in the structure domes (Šilalė and Pociai oil fields) are also presumptive in the intensive quartz-cementation zone of Middle Cambrian sandstones.

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VIDURINIO KAMBRO UOLIENŲ KOLEKTORINIŲ SAVYBIŲ KAITA GARGŽDŲ PAKILUMŲ ZONOS LOKALIOSE STRUKTŪROSE (VAKARŲ LIETUVA)

Santrauka

Vidurinio kambro uolienų storis didėja iš rytų ir šiaurės rytų į vakarus ir pietvakarius nuo 30 iki 80 m sausumoje, o Baltijos jūros teritorijoje siekia 90 m. Mažiausias vidurinio kambro uolienų storis yra Šiūparių (30–40 m) ir Pocių (38–50 m) struktūrose, o ant kristalinio pamato kyšulių jų nėra (Plungės, Baublių, Veiviržėnų plotai). Vidurinio kambro pjūvį sudaro kvarcinio smiltainio, molingo aleurolito ir argilito persisluoksniavimas. Vyrauja smulkiagrūdžiai smiltainiai (0,25–0,1 mm frakcija, iki 86%) su stambios (>0,25 mm, iki 39%, gręž. Pocių-3) ir aleuritinės (0,1–0,01 mm, iki 38%, gręž. Vilkyčių-7) frakcijų priemaiša. Įvairiagrūdžiai smiltainiai labiau paplitę Pocių, Lašų ir Sakučių struktūrose. Labiau sukvarcėję smiltainiai yra vakarinėje ir pietvakarinėje Gargždų pakilumų dalyje (Šiūparių, P. Šiūparių, Vilkyčių, Sakučių plotai). Čia bendras sukvarcėjusio smiltainio sluoksnių storis siekia 40–50 m, ir tai sudaro 78–87% viso smiltainių storio. Atviras poringumas kinta nuo 0,7 iki 8,4% (vidurkis 2,9–4,1%), laidumas dujoms – iki 1,5 mD ir pasiskirsto netolygiai.

Vidurinio kambro uolienų poringumas daugiausiai priklauso nuo jų sutankėjimo ir antrinio (regeneracinio) kvarcinio cemento kiekio. Pirminis (mechaninis) ir antrinis (cheminis) sutankėjimas tiesiogiai priklauso nuo uolienų slūgsojimo gylio. Tačiau kvarco tirpimo ir nusėdimo procesai priklauso ir nuo temperatūros, todėl minimalaus poringumo zonos sutampa su uolienų slūgsojimo maksimalaus gylio teritorija, išsidėsčiusia prie TT zonos Lenkijoje ir geoterminės anomalijos centrinės dalies Lietuvoje. Nustatytas katalitinis molingos medžiagos, ypač plonų jos plėvelių, vaidmuo tirpstant ir regeneruojant kvarcui. Netolygus smiltainių sukvarcėjimas gali būti sietinas ir su kalcitiniu cementu.

Iš pirminių sąlygų neigiamą įtaką kambro uolienų kolektorinėms savybėms turėjo dažna plonų (nuo 0,2–0,3 m iki kelių metru) smėlio ir molio sluoksnių kaita ir organinės medžiagos kiekis moliuose. Organinės medžiagos oksidacija lėmė rūgščios terpės susidarymą ir SiO_2 iškritimą molingų ir smėlingų sluoksnių kontaktuose. Autigeninis kvarcas taip pat formavosi didėjant uolienų slūgsojimo gyliui ir temperatūrai, kvarco grūdelių tirpinimo ribose. Jis užpildė storesnių sluoksnių porų ertmes. Temperatūros poveikis buvo svarbus, bet ne pagrindinis veiksnys, turintis įtakos uolienų kolektorinėms savybėms. Meškinės–Šilutės rajone sluoksnio temperatūra siekia 96°C, autigeninio kvarcinio cemento kiekis sudaro 8–15%. Gargždų pakilumų zonoje temperatūra neviršija 86°C, o kvarcinio cemento kiekis siekia net 26%. Uolienų sukvarcėjimo dydis kiekviename regiono taške priklauso nuo skirtingų veiksnių įtakos: slėgio, temperatūros, pjūvio sandaros, organinės medžiagos kiekio, tektoninio režimo ir kt.

Ženklūs vidurinio kambro smiltainių pokyčiai vyko taip pat naftos telkinių senosiose VNK zonose. Viršutinėje, tirpinimo, zonoje vyko kvarcinio cemento ir grūdelių tirpinimas, bitumų ir pirito susidarymas, apatinėje, cementacijos, zonoje – kvarco nusėdimas ir uolienų sukvarcėjimas. Nustatyti du naftos telkinių tipai pagal poveikį senųjų VNK uolienų kolektorinių savybių kaitai. Pirmam tipui priklauso Vilkyčių naftos telkinys, kuriam būdinga daugkartinė senųjų VNK (iki 8) lygio kaita, susijusi su struktūros užpildymo nafta kaita geologiniame laike. Pjūvyje stebimi iki kelių metrų storio sukvarcėję ir nesukvarcėję sluoksniai. Antram tipui priklauso Sakučių telkinys. Jam būdingi tik du senieji VNK lygiai, tarp kurių tirpinimo zonos storis siekia 20 metrų. Joje smiltainių kolektorinės savybės geresnės.

Girulių ir Ablingos svitų smėlingų pluoštų kolektorinės savybės Gargždų pakilumų teritorijoje geresnės lokalių naftingų struktūrų ribose. Už struktūrų ribų uolienų poringumas retai kada viršija 5%, o skvarbumas nesiekia 1 mD, tuo tarpu struktūrų ribose poringumas siekia 6–8%, o skvarbumas kinta nuo keleto iki keliasdešimt mD.

Kambro naftingame komplekse yra aptiktos ir ateityje gali būti surastos ne tik antiklininės, bet ir nestruktūrinio tipo naftos kaupvietės. Visos lokalios struktūros, kurių kraige nėra kambro uolienų arba jų storiai redukuoti (Šiūparių, Veiviržėnų, Šilalės, Lauksargių, Pocių, Pajūrio, Baublių, Plungės, Mamių), susijusios su kyšuliais, išsidėsčiusiais ant kristalinio pamato keterų, aptinkamų ir vidurinio kambro paleoreljefe. Su tokio tipo struktūromis gali būti susijusios neantiklininio tipo naftos kaupvietės. Kambro smiltainių intensyvaus sukvarcėjimo zonoje taip pat galimos neantiklininio arba mišraus tipo naftos kaupvietės, kurių susidarymą lėmė naftingų struktūrų kraige išlikę (užsikonservavę) porinio tipo kolektoriai (Šilalės, Pocių naftos telkiniai).

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ИЗМЕНЕНИЯ КОЛЛЕКТОРСКИХ СВОЙСТВ ОТЛОЖЕНИЙ СРЕДНЕГО КЕМБРИЯ В ЛОКАЛЬНЫХ СТРУКТУРАХ ГАРГЖДАЙСКИХ ПОДНЯТИЙ ЗАПАДНОЙ ЛИТВЫ

Резюме

Мощность среднекембрийских отложений на исследуемой территории возрастает с востока и северо-востока в западном и юго-западном направлениях от 30 до 80 м на суше и достигает 90 м на территории Балтийского моря. Наименьшая мощность отложений среднего кембрия установлена на Шюпаряйской (30–40 м) и Поцяйской (38–50 м) структурах; эти отложения отсутствуют на выступах фундамента (Плунгеская, Бaубляйская, Вейвирженская площади). Разрез среднего кембрия представлен переслаиванием кварцевого песчаника, глинистого алевролита и аргиллита. Преобладают мелкозернистые песчаники (с содержанием до 86% фракции 0,25–0,1 мм) с примесью крупных (>0,25 мм до 39%, скв. Поцяй-3) и алевролитовых (0,1–0,01 мм до 38%, скв. Вилькичяй-7) фракций. В разрезах Поцяйской, Лашайской и Сакучяйской структур наиболее распространены разнозернистые песчаники. В западной и юго-западной части зоны Гаргждайских поднятий (Шюпаряйская, Южно-Шюпаряйская, Вилькичяйская и Сакучяйская площади) присутствуют наиболее окварцованные песчаники. Суммарная мощность слоев окварцованного песчаника здесь достигает 40–50 м, что составляет 78–87% общей мощности песчаников. Открытая пористость изменяется с 0,7 до 8,4% (в среднем 2,9–4,1%), газовая проницаемость отложений распределена неравномерно и достигает 1,5 mD.

Вторичные изменения отложений среднего кембрия обусловлены погружением песчаников (первичного сыпучего песка) и глин в течение длительного геологического времени. В процессе катагенеза глинистых пород выделены три этапа: до глубины 1500 м, 1500–2700 м и более 2700 м. Они характеризуются изменением состава глинистых минералов от смешанослойных иллит-монтмориллонитов до иллита, а также увеличением плотности отложений с 2,1–2,4 г/см^3 до 2,4–2,6 г/см^3. Из первичных условий на коллекторские свойства кембрийских отложений отрицательно повлияло частое чередование тонких (с 0,2–0,3 м до нескольких метров) слоев песка и глины, а также содержание органического вещества в глинах. Оксидация органического вещества обусловила создание кислой среды и оседание SiO_2 на контактах глинистых и песчаных слоев. С увеличением глубины, температуры и вследствие растворения зерен кварца на их контактах формировался автогенный кварц. Он заполнил поровое пространство наименее мощных слоев. Влияние температуры являлось важным, но не основным. В районе Мяшкине–Шилуте, где температура достигает 96°C, количество автогенного кварцевого цемента составляет 8–15%. В зоне Гаргждайских поднятий температура не превышает 86°C, а количество кварцевого цемента достигает 26%. В каждой точке района степень окварцевания зависит от влияния различных факторов: давления, температуры, геологического строения разреза, количества органического вещества, тектонического режима и т. д.

Заметные изменения среднекембрийских песчаников происходили также в зонах палео-водонефтяных контактов (палео-ВНК) нефтяных месторождений. В верхней зоне происходили растворение зерен и кварцевого цемента и отложение битума и пирита, в нижней зоне – оседание кварца и окварцевание отложений. По влиянию палео-ВНК на изменения коллекторских свойств песчаников установлены два типа нефтяных месторождений. К первому типу относится Вилькичяйское нефтяное месторождение, для которого характерны многократные изменения (до 8 палео-ВНК), связанные с постепенным порционным заполнением структуры нефтью в течение геологического времени. В разрезе прослеживаются окварцованные и неокварцованные песчаники мощностью до нескольких метров. Ко второму типу относится Сакучяйское месторождение. Для него характерны два уровня палео-ВНК, между которыми мощность зоны растворения достигает 20 м. Поэтому коллекторские свойства песчаников

в ней лучше. Коллекторские свойства песчаных толщ Аблингской и Гируляйской свит на территории зоны Гаргждайских поднятий лучше в пределах локальных нефтяных структур. Пористость отложений за пределами структур редко превышает 5%, а проницаемость не достигает 1 mD, в то же время в пределах структур пористость составляет 6–8%, а проницаемость изменяется от нескольких до десятков mD.

В кембрийском нефтяном комплексе выявлены ловушки нефти не только антиклинального, но и неструктурного типа. Все локальные структуры, в кровле которых нет кембрийских отложений или же их мощности редуцированы (Шюпаряйская, Вейвирженская, Шилальская, Лауксаргяйская, Поцяйская, Паюрская, Баубляйская, Плунгеская, Мамяйская структуры), связаны с выступами, расположенными на гребнях кристаллического фундамента, и прослеживаются в палеорельефе среднего кембрия. Со структурами такого типа могут быть связаны нефтяные ловушки неантиклинального, в том числе и кольцевого, типа. Месторождение такого типа в Балтийской синеклизе уже известно. В Калининградской области открыто Семеновское месторождение кольцевого типа (Десятков, Барсукова, 2002). В зоне интенсивного окварцевания кембрийских песчаников возможны ловушки неантиклинального или смешанного типа, на появление которых влияли сохранившиеся (законсервированные) в кровле нефтяных структур коллекторы пористого типа (Шилальское и Поцяйское нефтяные месторождения).