INTRODUCTION

After a long interruption, oil inflow was extracted at U okai-1 and Antkoptis-1 wells in 2004. Furthermore, several structures prospective for oil-bearing were found. All these facts encourage examining the problem of oil-bearing in Western Lithuania again. While developing scientific research in oil geology and applying the obtained results in production, attention has been focused on forecasts of the most prospective regions and areas, estimation of geological reserves, recommendations as to the directions of oil exploration at the Institute of Geology (the Institute of Geology and Geography at present). The research has been developing in these directions: tectonics of regional and local structures; sedimentology of oil-bearing horizons and caprocks; detection of facies and reservoir properties of rocks; analysis of the geochemical composition of oil and bitumoids as well the origin of oil; forecast assessment of oil fields as well estimation of geological reserves of oil; methodical studies of data application of well logs; gravimetric and magnetometric exploration of the geological structure of Lithuanian territory. The summary of derived data is presented in many reports, monographs and scientific papers, which are most widely listed in the book “Lithuanian Institute of Geology 1941–2001” (ed. Grigelis A., 2001).

Collaboration with scientists from the neighbouring countries (Latvia, Poland, and Russia) and with Scandinavian geochemical laboratories in recent years enabled not only to use modern facilities and to ana-
lyse the composition and properties of oil, organic matter and reservoir rocks in more detail, but also to take advantage of databases compiled in different countries. Data from mentioned research are also presented in special reports and a few publications. In 2001–2002, 3-D modelling software SEMI (applied to modelling of micro-oil emigration from source rocks, secondary migration through oil reservoirs and accumulation in traps) with permission of the Norwegian SINTEF Petroleum Research Institute was employed to determine formation and survival conditions of oil fields in the Baltic Synclise.

TECHNIQUES APPLIED

All available geological, geochemical and geophysical information has been used in this paper. The zoning of Western Lithuania was carried out by summing up the occurrence of oil source rocks, reservoirs and caprocks, the closeness of Earth’s interior, estimated geological reserves of hydrocarbons, and correcting the zones prospective for oil accumulation distinguished earlier (Figure). The original map is compiled in the LKL coordinate system to a scale 1:200,000.

DISCUSSION

The estimation of the amount of hydrocarbons generated by oil source rocks underlies researches of such processes as hydrocarbon emigration, migration and accumulation and also the territorial assessment of perspectives for oil exploration. Volumetric techniques applied to estimate the amount of hydrocarbons are very variable, though some parameters used are derivative and have large calculation errors. However, has been proven that recoverable reserves of oil comprise 10% of the estimated resources only in few cases; as a rule, they reach only few percent of the amount of generated hydrocarbons (McDowell, 1975).

The total amount of 987.94 million t of hydrocarbons were generated from Cambrian oil source rocks in the Lithuanian onshore and offshore (Zdanavičiūtė et al., 2004, calculated by means of J. W. Schmoker's technique). Assuming the accumulation coefficient as 0.05, the primary reserves of oil in the Cambrian rocks aggregated 69 million t. In the Lithuanian onshore, 189.2 million t of liquid hydrocarbons emigrated from the Ordovician oil source rocks and 4.7 billion t from the Silurian. Therefore, the amount of generated hydrocarbons calculated by means of two techniques is very similar.

Modelling data have shown that the largest intensity of oil migration flows was in the deepest part of the Baltic Synclise. Traps are the most fully filled up with hydrocarbons in that territory. The situation for oil generation and migration was optimal by Late Silurian-Lower Devonian, when the spread of Silurian oil source rocks in the central part of the Baltic Synclise was submerged at a depth of more than 1600 m. Generated hydrocarbons could accumulate in the isolated structures that existed by the end of the Early Silurian, but the majority of oil fields is screened by faults formed during the Early Devonian, accordingly the beginning of oil field formation should be related to the Middle Devonian. The very general modelling results allowed to deduce that not only the Middle Cambrian oil source rocks were involved in oil generation of the Middle Cambrian oil fields in Western Lithuania; there should be additional sources, i.e. micro-oil generated from the Ordovician and Silurian oil source rocks (Zdanaviciute, Lazauskiene, 2004).

Let us remind an interesting idea given by J. Calikowski (Calikowski, 1984) about oil migration during the Early Paleozoic. This author attributes the part of hydrocarbons located in the Cambrian reservoir rocks to epigenetic, generated from the Silurian oil source rocks. A. Witkowski (Witkowski, 1989), W. Gorecki et al. (Gorecki et al. 1992) ventilated some reasons against this idea. However, migration of the Silurian hydrocarbons to the Cambrian reservoir rocks could be take place in the south-western part of the territory along the TTZ, where, according to R. Dadlez (1994), Cambrian deposits were contacting with younger rocks by faults of the Caledonian origin.

By the end of the Hercynian tectogenetic stage, tectonic structures in the central part of the Baltic Synclise and in Gargždai Elevation Zone (Western Lithuania) were elevated, but good caps preserved fields from their dissolution. Solid asphaltenes found in arches of some structures suggest stages of the oil field formation. In Kaliningrad Region, local structures were in a more favourable situation, since oil migration into them could take place from west and north-west at that time.

By the end of the Alpinian tectogenetic stage, when the western part of Kaliningrad Region and Lithuania was significantly sunk, the focus of oil generation expanded, new oil portions replenished the
existing oil fields and influenced formation of new ones. This fact, also suggested by water/oil palaeo-
contacts, was determined by L. Lashkova et al. (Lashkova and dr., 1979; Lashkova, 1994) in oil fields. Au-
thors deduced that the intensive increase of struc-
ture amplitudes was related to the Middle Cambri-
ian, Upper Permian - Lower Triassic. The ampli-
tudes of the oil fields decreased, sometimes very size-
ably, in the Middle Jurassic. The further growth of the structures is related to the Cretaceous.

Summing up the tectonic evolution of the territo-
ry, the occurrence of oil source rocks, the amount and degree of organic matter catagenesis, occur-
rence of reservoirs, and closeness of Earth’s interior as well other available geological, geochemical and ge-
ophysical data, the prospective, less prospective and non-prospective zones for oil accumulation in We-
stern Lithuania are distinguished (Figure). The zone prospective for oil search occupies the whole western part of Lithuania, from North-east bounded by the “vitrinite” isoline Ro = 0.7% and from the south-
east by the 1650 m isoline of the key reflecting ho-

rizon (Upper Ordovician – Lower Llandovery), ap-
proximately corresponding with the isoline of –1750 m of the Cambrian top. In the indicated territory, all discovered oil fields and 13 structures prepared for drilling (Viekšniai, Plėnakių, Dvntoji, ḟyga, jūo-
deišiai (drilled one well in this structure gave nega-
tive results), ḟlibinai, Svirpliai, U rulių, Mąjąliai, ḟvaginiai, Rambynas and one without name) and qui-
te a great number of structures revealed by seismic data are located. In this territory the Cambrian top oc-
curs at a depth of ~1750 – ~2000 m. The maturity of oil source rocks (according to the “vitrinite” re-
flexion, Ro) is more than 0.7%. Here the porosity of

rocks of the upper part of Deimena Group ranges
from <3% in the Toliai–Laugalai tract up to 14.9% in the Paluknė well. The average porosity of Deime-
na Group sandstones here is less than 7.0%. The coefficient of silicification ranges from 0 to 0.7. Wa-
ter salinity is 140-150 g/l and more, the coefficient of sulphatization (SO4/Cl) being 0.1-1.4. In the territory of the wells Ramužai-1, 2 and 3 a zone non-prospective for oil search is distinguished. In fact it could be larger, but the drillcore from adjacent wells was not stu-

died. In this zone, organic matter studied is charac-
terized by a very high degree of catagenesis reaching Ro = 1.5%. It corresponds to the postmaturity stage of
catagenesis, i.e. the Earth’s interior is burned out. To carry out oil exploration in this region, it is ne-
necessary to accomplish modelling and determine the limits beyond which it is possible to expect the dis-
covery of oil fields.

Let us overview the possibility of discovering oil
traps of non-anticlinal and combined type in the Mid-
dle Cambrian and the Salantai Formation, Lower Or-

Figure. Prospective exploration of oil fields in the Cambrian deposits of Western Lithuania.

1 - major tectonic faults; 2 - isohypses of the main reflection horizon of Upper Ordovician-Lower Landover top
(according to the map of the Lithuanian area compiled by V. Markaitienė, 1996 and the maps for the Kaliningrad
district compiled by N. Lisovskaja et al., 1984); 3 - total water mineralisation of the Middle Cambrian, g/l; 4 - isolines
of organic matter maturity of Cambrian oil source rocks (under “vitrinite”); 5 - isopores; 6 - isolines of the rate of
quartz cementation of rocks; 7 - new petroliferous wells; 8 - oil fields. Local structures: 9 - developed for drilling; 10
- drilled; 11 - prospective structures. Area: 12 - prospective; 13 - less prospective.


Oil fields discovered in the area of Kaliningrad district shown in the map: 16. Slavskaja; 17. Zapadno Rakitinskoye; 18.


Pav. Naftos telkiniai Vakarų Lietuvos vidurinio kambro uolienose prognozės ėmėlapis. 1 - pagrindinių tektoninių lūpų; 2 - atraminio apatinio horizonto viršutinio ordoviko–apatinio landoverio kraiga (pagal 1996 m. V. Markaitienės Lietuvos teritorijos ėmėlapą ir N. Lisovskajos ir kt. 1984 bei vėlesniø metø Kalining-
rado srities ėmėlapiø) izochipsø; 3 - vidurinio kambro sluoksnio vandens bendros mineralizacijos izoliniojø g/l; 4 - kambro naftos motininiø uolienø organinës medþiagos katagenezës izoliniojø (pagal „vitrinità”); 5 - izopores; 6 - ap-
kvarcëjimo koeficientø izoliniojø; 7 - naui naftà dave græþiniai; 8 - naftø telkiniai; vietinës struktûros: 9 - paruoðtø græþimui; 10 - kuriose vykdyti græþimø darbai; 11 - numatomos struktûros; plotai: 12 - perspektyvûs; 13 - maþiau perspektyvûs.


Ondrůvician oil-bearing complex in this zone. L. Laškova (Zdanaviūtė, 2003) has analysed data from more than 200 boreholes and deduced that the sedimentological-facial analysis of deposits from the Cambrian basin shows a paleogeographic environment unfavourable for the formation of non-anticlinal oil traps related with a regional thinning out of sandy and clayey beds, because claystone beds become more sandy to the east and northeast (towards the basin coast) and lose their caprock properties. Oil traps of lithological-structural type in the Cambrian rocks are related with anticlinal elevations, in which oil fields are partly covered by secondary silicification of the reservoir. Traps of this type are discovered in oil fields of Pociai, Girkalai and Bīlažė areas. The Pociai, Girkalai and Bīlažė oil fields of lithological-structural type are situated in the silicification zone of the Cambrian sandstone where the silicification coefficient is more than 0.5. They include 14% of oil search areas explored by drilling. Oil fields of such type are expected in the Baltic offshore, within the zone of intensive silicification.

Besides oil traps of lithological-structural type in the Cambrian rocks, oil traps of lithological-stratigraphic (ring) type can be forecasted. Their formation is related with thinning out of the Cambrian rocks in the elevation zones of Precambrian relict landscape. For this purpose, the thickness map of the Cambrian rocks occurring above the bottom of Ablinga Formation was compiled, applying techniques proposed by M. V. Pronicheva et al. (Проничева, Савинова, 1980). The map shows a buried landscape of the Cambrian surface before the Ordovician sediments settled. It is a monocline with inclination to the west and the south-west, complicated with elevations and depressions differing in height from a few up to 30 meters. In the northern part of the territory, the landscape is shaped in south-western and northern direction; in the southern part it is irregular. All local structures known at this moment and located in the landscape elevations are determined by seismic exploration and proved by drilling. Ring-shaped lithological-stratigraphic and structural-lithological-stratigraphic oil traps could be found near the so-called enveloping “naked” structures, in which the Ordovician carbonate succession covers rocks of relict landscape of the crystalline basement. In such cases, oil trap is determined by thinning out of reservoir rocks around the protrusion of the crystalline basement (Veivirėnai, Plungė, Baubliai area). From this point of view, some local structures determined by seismic exploration methods in the elevation zones of relict landscape could be prospective.

The less prospective zone envelopes the prospective one by a narrow bend. Its eastern boundary is approximately determined by the -1350 isoline of the key reflecting horizon (Upper Ordovician - Lower Llandovery). Organic matter of the source rocks has reached only the degree of “early oil” maturity in this territory, i.e. its oil production potential is very poor, though oil fields could be formed due to migration. The quality of the reservoirs is better because of a shallower setting of Cambrian rocks. In the southern part of this tract the upper part of Deimena Group rocks is denuded; in the northern part their porosity reaches more than 13% and in the lower part 9-17%. The mean porosity of Deimena Group sandstones is about 10% in this zone. Sandstone is not silicified. In this territory, parameters of water formation (water salinity, coefficients of sulphatization and metamorphization) show rather a good closeness of Earth's interior. The perspectives of this territory decrease because of remoteness of the territory from sources of oil generation and absence of “local hydrocarbon kitchens”.

The earlier forecasted two more zones, Akmenė and Mapeikiai, prospective for oil accumulation and located northwards from Telšiai oil accumulation zone (Laškovan et al., 1996), in our opinion, are less prospective for oil exploration in the Cambrian rocks (only a small western part of the mentioned scarps could attract attention), because they are remote from sources of oil generation. We take into consideration a short distance of migration, which is evaluated also by modelling of migration processes, and data of detailed studies of oil composition. It is proved by the chemical composition of oil found in Latvia and in Plungė area. The oil is oxidized, i.e. hypergenetically changed. The territory of Telšiai Scarp located eastwards from Plungė area is less prospective, too.

The rest territory of Lithuania located eastwards from the less prospective one, as well the territory including Ramušai-1-3 wells, are attributed to the territory non-prospective for oil exploration.

It should be noted that some petroleum geologists of Lithuania consider the search for oil traps in narrow belts of raised ramparts located near fractures (tracks, 3-5 km wide) to be most efficient, because the chains of local structures or even near-fault horomolines, where tectonic screened oil fields may be found, rest against the fractures. Meanwhile, geologists of the Kaliningrad Region are of slightly different opinion that oil fields may be discovered also in local structures uncomplicated by fractures, but usually oil fields found in near-fault local structures are larger. They have proved it by discovery of oil fields southwards from Kaliningrad Rampart as well in the eastern territory adjacent to Lithuania.

We shall try to call attention to the other disputable problem, i.e. to availability of so-called “local kitchens of hydrocarbons”. The conception that one of them exists in Salantai Trough is apparently misleading. The analysis of organic matter provided by geologists of the Institute of Geology and from...
Latvia rejects any serious probability of such kitchens in the Baltic region. True, the organic matter from Cambrian rocks in Salantai Trough is attributed to the degree of early maturity of oil, but its amount is not sufficient for formation of some large oil fields. Besides, the main portion of generated hydrocarbons migrated north-eastwards in a direction of the pressure decrease.

Differently from the previous report of such type (Laškovas et al., 1966), in this work the south-western part of Lithuania is attributed to prospective areas for oil exploration, though in the thinning out zone of Permian anhydrites, structures are found with difficulty, on analogy with the distribution of structures and oil fields in it in Kaliningrad Region it is possible to assert that in the territory of Lithuania they exist too. The complicated geological structure of the territory, for example, the distribution of Permian anhydrites, causes very much trouble, but the modern possibilities of seismic interpretation data may overcome this barrier too.

Over the recent years, the volume of works on oil search decreased very much. To preserve the rate of oil production, it is necessary to intensify search for oil in the south-western part of Lithuania and to start oil search in the Baltic Sea. The exploration degree of the territory is sufficiently high to start new works in the prospective territory; only a skilled evaluation of available geological-geochemical and geophysical information and supplementary seismic works of little volume could be necessary. In the Baltic Sea, the amplitudes of fractures increase, thus the amplitudes and size of near-fault structures increase too. Common geological regularities connect the land and sea territories, so the maximum efficiency of oil search in the sea could be reached already in the first stage of structure drilling.

The primary geological reserves of crude oil within the Cambrian rocks account for approx. 59.8 million t, the average resource density being 4.37 thous. t/km². Assuming the recovery coefficient as 0.35, recoverable crude oil reserves are approx. 20.9 million t, and gases 0.75 billion m³ (Vosylius, 2004).

The recoverable oil reserves explored and estimated till present aggregate only approx. 8 million t of oil, allowing temporarily increase oil production only up to 400–500 thous. t per year. The amount of about 4 million t of oil is already worked out. Maximum work efficiency in the development of oil resources in the regions with small resources of oil is reached as a rule when the amount of explored reserves is up to 10–20% (Medelevskis ir kt., 1977). The amount of explored and estimated Cambrian oil reserves already reached approx. 30% in the Lithuanian onshore. Therefore oil search efficiency will decrease in the onshore, since it has reached the maximum of main discoveries in Gargždai and Telšiai scarps. Discovery chances of larger oil fields with more than 1.5 million t of recoverable reserves of oil decrease in the onshore.

**CONCLUSIONS**

The available geological, geochemical, geophysical material and modelling data allow some conclusions.

1. In Western Lithuania, oil source rocks occurring at a depth of ~1750 m and more are within the main oil generation zone. The Cambrian oil source rocks generated 987.94 million t of hydrocarbons in the Lithuanian onshore and offshore. Assuming the accumulation coefficient to be 0.05, the primary geological reserves of hydrocarbons in the Cambrian rocks aggregate 49.4 million t. In the Lithuanian onshore and offshore, 1.7 billion t of hydrocarbons emigrated from Ordovician oil source rocks and 5.8 billion t from the Silurian; however, due to a specific lithology of the geological section, only very small amount of them could accumulate in the traps.

2. The formation stages of oil fields for different geological time have been restored according to modelling data of hydrocarbon migration and accumulation. In the Baltic Syncline, the beginning of oil generation is related to the late Silurian, while the main phase of oil generation is ascribed to the Devonian and Permian time. Slow sedimentation in the whole Baltic Syncline, ambiguous earth motions conditioned the slow formation of oil fields and in some cases dissolution of earlier formed oil fields. Oil fields during their existence were replenished with new oil portions. Therefore, traps in the Cambrian rocks could accumulate oil generated not only by Cambrian, but also by Ordovician and Silurian source rocks. The survival of oil fields was provided by a favourable hydrogeological regime, and the good cap was ensured by closeness of Earth’s interior in the region.

3. Oil traps of not only anticlinal, but also non-structural type have been discovered and can be discovered in future in the Cambrian oil-bearing complex. All local structures without Cambrian rocks on their top or with reduced thickness (Būpariai, Věivpěnai, Dīlalē, Luksargai, Pociai, Pajūris, Baubliai, Plungė, Mamiai local structures) are related with protrusions located on crests of the crystalline basement, traced also in the Middle Cambrian paleolandscape. The oil traps of non-anticlinal type can be related with structures of this type. Oil traps of non-anticlinal or combined type are also expected within the zone of intensive silicification of Cambrian sandstone. Their formation was influenced by reservoirs of a pore type, preserved in tops of oil-bearing structures (Dīlalē, Pociai oil fields).

4. The source rocks of Western Lithuania with the content of organic matter of one or more percent and buried deeper than 1500–1600 m, and in which the degree of catagenesis according to the index of
“vitrinite” reflection reaches more than 0.7%, generated oil. The territory is prospective for oil exploration. Here the porosity of rocks of the upper part of Deimena Formation ranges from <3% to 7%, the coefficient of silicification varying from 0 to 0.7. Water salinity, the coefficient of sulphatization (SO4/Cl × 100) as well the coefficient of metamorphization (Na/Cl) indicate a good closeness of Earth’s interior. The less prospective zone envelopes the prospective one by a narrow bend. Its eastern boundary is approximately determined by the isoline of ~1350 m of the key reflecting horizon (Upper Ordovician – Lower Llandovery). Organic matter in the source rocks has reasonably determined by the isoline of –1350 m of the key reflecting horizon (Upper Ordovician – Lower Llandovery). Organic matter in the source rocks has reached only the degree of “early oil” maturity in this territory, i.e. its oil production potential is very poor.

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Onyčė Zdanavičiūtė

NAFTOS TELKINIO PAIEDKÕ PERSPEKTIVOS VIDURINIO KAMBRO SMILTAINIŪSE VAKARŪ LIETUVOJE

Santrauka

Kambro naftos motininės uolienos Lietuvos sasauomoje ir akvatorijosje generavo 987,94 mln. t angliavandenilių. Pasiūlės 0,05 akumuliacijos koeficientą, pradiniai prognozinių angliavandenilių išteklių kambro naftingose uolienose sudaro ~30 mln. t. Pagal angliavandenilių migracijos ir akumuliacijos procesų modeliai vikos, paleozojaus angliavandenilių išteklių formavimasis ir susidaro sàlygas lëtam naftos telkiniø formavimui, o kartais ir jëm apigaliuojant. Naftos telkiniai per savo egzistencijà pasipildë ~30% naftos produkcijos. Naftos telkiniai per savo egzistencijà pasipildë ~30% naftos produkcijos. Naftos telkiniai per savo egzistencijà pasipildë ~30% naftos produkcijos. Naftos telkiniai per savo egzistencijà pasipildë ~30% naftos produkcijos.
tainei intensyvaus apkvarcėjimo zonoje taip pat galimos ne-
antiklininio arba mūdraus tipo naftos kaupvietės, kuria sudarymo žakos turėjo naftinė struktūra kraigai iržalavų (up-
sikonservavęs) porinio tipo kolektoriai (Dilašės, Pocių naftos telkiniai).

Avėrės teritorijos tektonica-rädai, motininis uolienos paplitimas, organinės medžiagos kiekis kategatės laipsnis sukalba kolektoriai, gėlmių uždarymas bei kitus turimus geologines, geocheminės ir geofizinio suamžiais, Vakarų Lietuvoje išskirta perspektyvi, mažai perspektyvi ir neper-
spektyvi zona naftai susikaupė. Naftos paieškos perspek-
tyvi zona apima visą vakarų Lietuvos dalį iš šiaurės ryto ir apribojoma Ro = 0,7% „vitrinito“ izoliniu, iš pietybės pradedama pagal atraminio aspinindės horizonto (viršutin-
is or doliskos-patatinės landoveris) 1650 m izochipsė maž-
daug atitinkančio kambro kraigo 1750 m izohipse Naurody-
jeje toje irjei vaizduoja Lietuvos dalį iš šiaurės ryto, jį sprog全文翻译如下。
 câ ôåóëèêàëüíîãî òèïà. Â çîíå ñòðóêòóðû), ñâÿçàíû ñ âûñòóïàìè, ðàñïîëîæåííûìè Îàõëåéñêàÿ, Ïëóíãåñêàÿ, Ìàìÿéñêàÿ èçìåíÿåòñÿ îò 0 äî 0,7. Ìèíåðàëèçàöèÿ âîäû Ñðåäíÿÿ ïîðèñòîñòü ïåñ÷àíèêîâ äåéìåíàñêîé ñåðèè ó÷àñòêå äî 14,5% â Ïàëóêíÿéñêîé ñêâàæèíå. Óìåëà íàõëåéñêàÿ, Ïëåíàêñêàÿ, Òåððèòîðèè íàõëåéñêàÿ, íà ñóøå ïîíèçèòñÿ, ïîñêîëüêó óæå äîñòèãíóò çàïàñîâ. Ïîýòîìó ýôôåêòèâíîñòü ïîèñêîâûõ ðàáîò ðàáîò â îñâîåííûõ ðàéîíàõ íåôòÿíûõ ñêâàæèí Ðàìó÷ÿé 1–3. Ýòî çàëåæåé íåôòè, òåððèòîðèè ìåëêîãî çàëåãàíèÿ êåìáðèéñêèõ èçîëèíèåé “âèòðèíèòà” Ro = 0,7%, íà þãî-âîñòîêå ÷àñòü Ëèòâû: ñ ñåâåðî-âîñòîêà îíà îãðàíè÷åí ãåîëîãè÷åñêèõ, ãåîõèìè÷åñêèõ è ãåîôèçè÷åñêèõ òàêæå íà îñíîâàíèè äðóãèõ ðåçóëüòàòîâ îðãàíè÷åñêîãî âåùåñòâà è ñòåïåíè êàòàãåíåçà. Ïåðñïåêòèâíàÿ çîíà îõâàòûâàåò âñþ çàïàäíóþ Rî) ïðåâûøàåò 0,7%. Ïîðèñòîñòü Òåíäýëåéñêèé áîëåå 1,5 ìëí. ò äîáûâàåìîé íåôòè.