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THE CHARACTERISTICS OF PERSPECTIVE AREAS OF NON-CONVENTIONAL OIL ACCUMULATIONS IN POLAND

About 40% of hydrocarbons generated within a source rock are trapped in the pores and microfissures of native rock. The remaining part has migrated outside to reservoir formations. Nonetheless, in spite of the migration movement significant quantities of hydrocarbons remain in the source rocks. Hydrocarbons often change their chemical and physical properties, with no further migration to other rock units as a result. Hydrocarbons cannot be extracted with the use of the basic technology methods typical of conventional reservoirs. These types of deposits are called non-conventional oil deposits.

In Poland, only one type of non-conventional deposits, i.e. heavy crude oil deposit, has been identified so far. In recent years, a revolution has been observed on the Polish market of unconventional hydrocarbon deposits. It turned out that we have a significant amount of shale deposits, which may be rich in hydrocarbons, both gas and oil. The research and analyses performed so far were primarily focused on the perspective of shale gas occurrence, though unconventional oil reservoirs should be considered as well.

The most likely areas of unconventional oil occurrence in Poland are (Fig.1):

1. shale formations in the Baltic - Podlasie – Lublin basin (potential of the Silurian and Ordovician),
2. Prągowiec Ravine (southeast of Kielce) - Graptolitic Shales (Silurian)
3. Menilite Shales in the Outer Carpathians - especially south of Rzeszow in the municipalities of Błażowa, Boguchwala, Wojaszówka.
4. already discovered heavy oil deposit in Lubaczów

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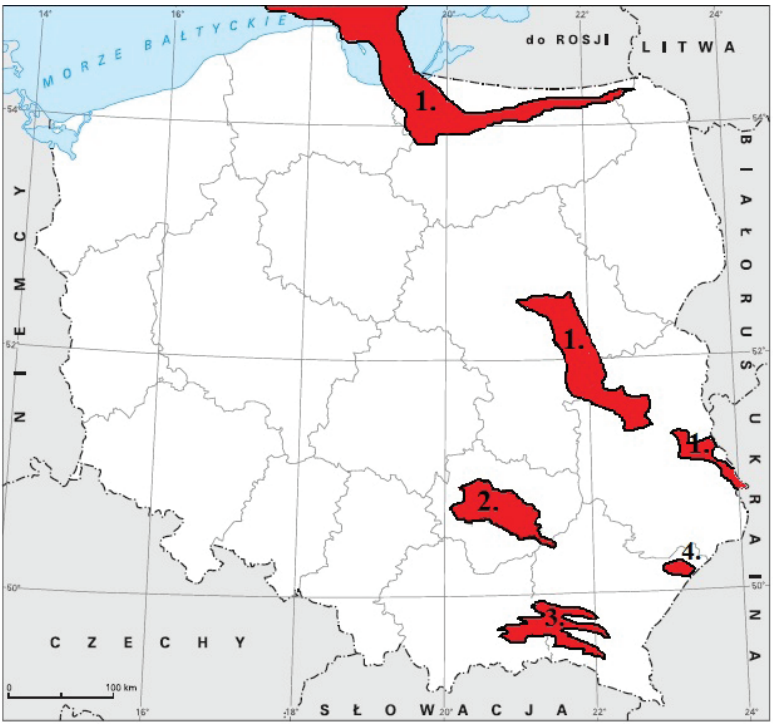

Fig.1. The occurrence of the perspective non-conventional oil areas in Poland [1]
1-formations of shale basin of the Baltic - Podlasie - Lublin, 2 - Graptolitic Shales - Prągowiec Ravine, 3 - Menilite Shales of Outer Carpathians, 4 – Lubaczów heavy oil deposit

1. BALTIC - PODLASIE – LUBLIN SHALE BASIN

Shales of this region are part of the Lower Palaeozoic sediment profile containing organic matter of Type-II kerogen [6]. The oil-bearing shales were generated mainly in the as a result of tectonic processes controlling the development of the basin. The oldest formations of the basin are bituminous shales of the Upper Cambrian or Lower Ordovician period. These shales can be found only in the northern onshore part of the Baltic Basin and its shelf parts [9]. It should be noted that they have a very small thickness in all regions of incidence. Typically all the wells are high in organic matter, on average 3-12% TOC [10]. Another formation of sediments enriched in organic matter is the Upper Ordovician shales, mainly Caradoc. They are found in the central and western part of the Baltic Basin and in the western part of the Podlasie Depression. The deposition of this sediment type expanded diachronically to the east and south-east [3,7]. The total organic carbon content in the Baltic - Podlasie - Lublin area varies from about 0.5 to almost 5%. The TOC values in the regions are shown in Tab. 1

Table 1

The total organic carbon content in shales in the Baltic - Podlasie – Lublin basin [6]

Baltic – Podlasie – Lublin area	Average TOC content in shales [wt%]
Western and central part of the Podlasie Depression	1-1.25
Basement of Płock – Warsaw trough	2.1-3.76
central part of the Baltic Basin	1-3
Lublin region	<1
Leba elevation	4.5

More information is show in Tab.2.

Table 2

Some parameters of shale oil in Poland /Advanced Resources International, 2013/

Basic Data	Basin/Gross Area		Baltic/Warsaw Trough (16,200 mi²)		Podlasie (6,600 mi²)	
	Shale Formation		Liandovery		Liandovery	
	Geologic Age		L Sil - Ord. - U. Cambrian		L Sil - Ord. - U. Cambrian	
	Depositional Environment		Marine		Marine	
Physical Extent	Prospective Area (mi²)		830	2,070	1,000	1,100
	Thickness (ft)	Organically Rich	820	820	540	540
		Net	451	451	297	297
	Depth (ft)	Interval	6,500–9,800	7,000–13,000	6,000–9,000	6,500–11,500
		Average	8,200	10,000	7,500	9,500
Reservoir Properties	Reservoir Pressure		Mod. Overpress.	Mod. Overpress.	Slightly Overpress.	Slightly Overpress.
	Average TOC (wt. %)		3.9%	3.9%	3.0%	3.0%
	Thermal Maturity (% Ro)		0.85%	1.15%	0.85%	1.15%
	Clay Content		Medium	Medium	Medium	Medium
Resource	Oil Phase		Oil	Condensate	Oil	Condensate
	OIP Concentration (MMbbl/mi²)		42.2	12.8	36.2	11.1
	Risked OIP (B bbl)		14.0	10.6	8.7	2.9
	Risked Recoverable (B bbl)		0.70	0.53	0.43	0,15

The study area was analyzed in the period 2010 to 2012. The first in Poland report on the estimation of reserves of natural gas and crude oil in these areas was developed in March 2012. The analyses were carried out by the Polish Geological Institute - National Research Institute and the U.S. Geological Survey [6]. This has been the only report on oil shale and their resources at the Baltic - Podlasie – Lublin basin yet, but more systematic reports with

new data from these areas are expected to be worked out every two years (the most recent in the current year). The estimates of technically recoverable oil resources are preliminary and are based on few historical data of 39 exploration wells drilled in the years 1950 to 1990. A number of data, i.e. shale porosity, permeability, reservoir pressure, etc. are not known. Therefore, the estimated shale oil reserves are far from exact and some compensation factor has to be accounted for. For the effect of obtaining the desired effect, the characteristic of the American deposits was assumed. This is another evidence that the evaluations in the report may be different from the actual data. The Polish deposits have different characteristics and mainly occur at greater depths. Reservoir zones are classified due to the thickness of a homogeneous shale layer (at least 15 m and at least 2 wt.% of the total organic carbon (TOC)). In addition, limitations were also imposed on the maximum allowable thermal maturity of 3.5% Ro and borders of Poland and Polish territorial waters. The shale gas deposits were separated from shale oil deposits by thermal maturity isolines of 1.1% Ro (Fig. 2).

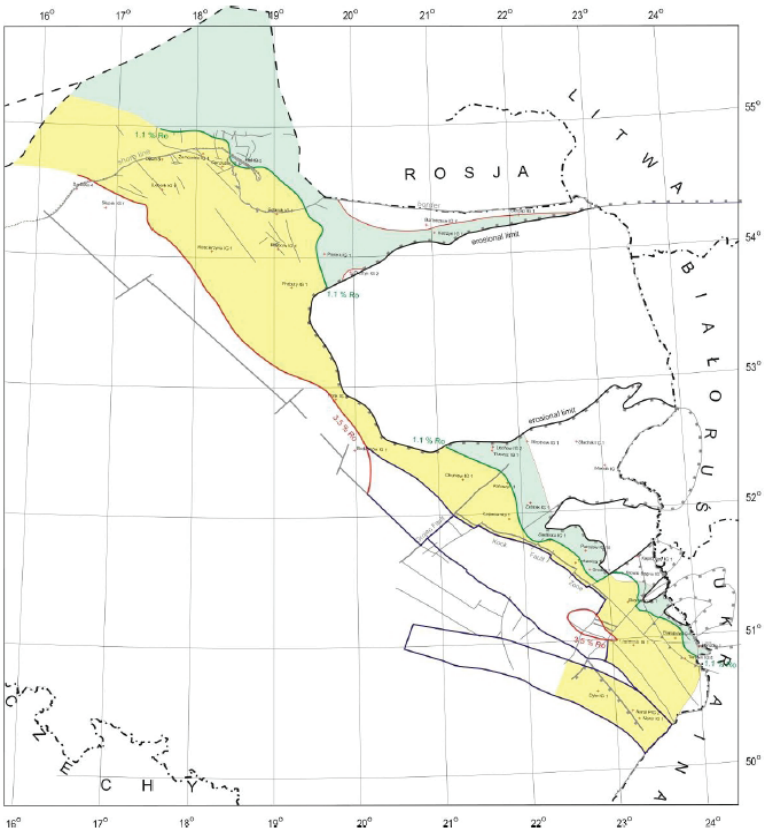

Fig. 2. The area selected for the calculation of shale gas (yellow) and shale oil resources (green) for maximum thickness of shale packages TOC> 2 wt.% determined based on the data from 39 wells in the years 1950 to 1990 [6]

The analyses revealed that total recoverable reserves of shale oil from the Baltic - Podlasie - Lublin basin may amount to 535 million Mg. Taking into account the estimated parameters, these resources are most likely to range between 215 and 268 million Mg. As compared with conventional resources these deposits are from 8.5 to 10.5 times higher (around 26 million tonnes) - tab. 3 [6].

Table 3

Recoverable resources of shale oil in the Lower Palaeozoic sediments.
The estimated total production /ETP/ from a well [6].

	ETP minimum 4.11 thousand Mg	ETP most likely 6.85 thousand Mg	ETP maximum 13.7 thousand Mg
Baltic shelf maximum surface 14 767 km^2	100.0 mln Mg	166.6 mln Mg	333.2 mln Mg
Baltic shelf minimum surface 14 767 km^2	100.0 mln Mg	166.6 mln Mg	333.2 mln Mg
on shore maximum surface 8 964.3 km^2	60.7 mln Mg	101.1 mln Mg	202.3 mln Mg
on shore minimum surface 4 323.3 km^2	29.3 mln Mg	48.8 mln Mg	97.6 mln Mg
Total maximum surface 23 731.3 km^2	160. 7 mln Mg	267.8 mln Mg	535.5 mln Mg
total minimum surface 19 090.3 km^2	58.5 mln Mg	215.4 mln Mg	430.8 mln Mg

2. GRAPTOLITE SHALES/ PRĄGOWIEC RAVINE SOUTHEAST OF KIELCE / – SILURIAN

Graptolite Shales include pelagic or hemipelagic sediments. They contain mostly thin interbeddings of quartzitic sandstones and silica shales. These are the Ordovician-Silurian rocks, which are rich in graptolite fossils (hence their name). In Poland, the prospective graptolite shale deposits are located in the Holy Cross Mountains and more specifically in the Prągowiec Ravine. The Holy Cross Mountains Paleozoic profile revealed the presence of several horizons with high organic matter content. In the Silurian, rocks rich in organic matter present in the Llandovery, where are represented by Bardo layers. Studies of organic matter in this area were carried out already in the 1960s and they

showed to a small quantity of bituminous shales located in the Ordovician which were represented by Graptolite Shales in Zbrza area. In addition it was shown that the lower Paleozoic strata belong to the richest Graptolite Shales - Lower Silurian (Llandovery). These shales, accidentally thrown into the fire began to burn which was indicative of hydrocarbons content. The highest bitumen concentrations were observed in the Upper Devonian carbonate formations in the Kielce region. Unfortunately little (if at all) research was carried out on the quantitative participation of organic matter. It was only later when geochemical analyses (Rock - Eval) were made, and an initial characterization of organic matter was set out. Thus, the organic matter content in the Lower Silurian (Llandovery) was assumed to be about 3 wt.%, which makes this rock highly prospective. A horizon of black shale and limestone marl clays can be found in the marl - limestone series of the Upper Devonian horizon. There are several oil shale layers 30 to 180 cm thick, and organic matter 10 to 22 wt.%, on average 1 to 1.5 wt.%. Such high values of above-mentioned parameters classify these rocks to a group of high hydrocarbon potential. However, little drilling operations are realized in this area, therefore the data may be not reliable for all the layers. This has been the least recognized area where the occurrence of unconventional oil was probable.

3. MENILITE SHALES – OUTER CARPATHIAN ARC (SKOLE UNIT)

The stratigraphy of the Skole unit in the Polish area is very diversified. The Menilite Shales occur in the Upper Eocene and Lowermost Oligocene. Based on the map of facies it can be established [6] that Menilite Shale deposits extend from the southwestern part of the Rzeszów to the north-east part of the Ustrzyki Dolne. The subsequent deposits are located near the Polish border beyond Bukowsko and below Dukla. It should be noted that these layers are of considerable thicknesses, and may contain significant amounts of oil. Numerous studies on the geological structure of the Skole Unit have been already carried out. Geochemical analyses performed on drill cores confirmed that the Menilite layers in this region are the best source rocks. They contain Type-II and Type-III kerogen. They are also high in organic carbon (TOC), exceeding even 20 wt.%. The largest volumes of Menilite Shales were found in Kuzmina 1, Paszowa 1 and Rozpucie 1 wells. The following conclusions can be drawn from the analysis of the available industrial materials from the the Outer Carpathians area:

- Menilite Shales in that area are not thermally mature. However, this does not exclude them as a possible source of unconventional shale oil.
- shale layers are located at great depths above 2,000 and sometimes 3,000 m. At present the technologies used in Poland do not suffice to produce these types of deposits on an industrial scale
- high degree of tectonic deformation is observed in these areas
- tight oil deposits are also possible in this area

4. LUBACZÓW HEAVY OIL DEPOSIT

The deposit of heavy oil in the region Lubaczów was discovered between 1960 and 1961. It is located in the eastern part of the Carpathian Foredeep. The deposit is located in the Subcarpathian Province in the vicinity of Uszkowce and Cetynia gas fields. The foredeep area (with deposits in it) is represented by the sediments of the upper Badenian and Sarmatian which are transgressively located on the sediments of the Lower Paleozoic (Cambrian, Ordovician), Mesozoic (Middle Jurassic) and Upper Jurassic period (fig.3)/.

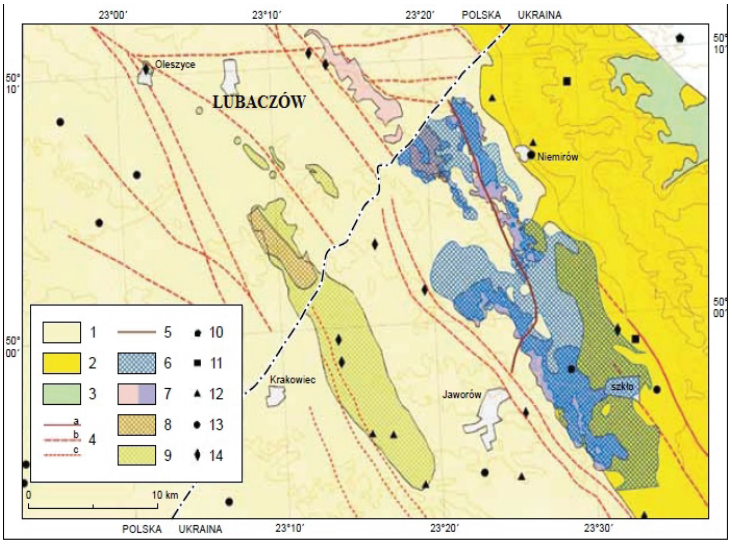

Fig. 3. Location of Lubaczów deposit on the Polish and Ukrainian border area
1,2-Miocene; 3 Upper Cretaceous; 4-faults (a-confirmed, b- likely, c-by seismic), 5-flexure; 6-gypsum and anhydrite range (Ukraine); 7-deposits of native sulfur, 8 -crude oil; 9-gas deposits; 10- lignite; 11-limestones and marl; 12-peats; 13-sands and gravels; 14 clays [1,8]

The accumulation of oil in the sub-Miocene deposits is associated with limestones. It is a type of layered deposit where heavy oil occurs in the oil asphalt. In such conditions, the classical methods of exploitation cannot be used. The typical asphalt black oil having specific gravity of 0.9934 g/cm^3 at 20°C and viscosity of 64 Pas at 27°C is the medium. It contains (Lubaczow 156) 20 % of hard bitumen, 17% of coke, 35% of asphaltenes, 2% of paraffins and about 9% of sulfur [2]. After degassing the oil has a low mobility. Test and proper oil production was undertaken in 1960-61 and abandoned for the reasons of lack of profitability, and small production of crude oil. The documented geological resources for the year 1985 amounted to 3 890 thousand tons of crude oil, of which only 116 thousand tons were estimated as recoverable. The exploitation has been discontinued for technical and economic problems. The main factor limiting the operation was the kind of reservoir rocks. Lubaczów deposit was built of fissured limestones. This fact limits the use of many exploitation methods.

In 2010 a project /Department of Petroleum Engineering – AGH-University of Science & Technology – Faculty of Drilling Oil and Gas AGH [8]/ on the possible exploitation of heavy oil from the Lubaczów deposit was prepared. The object of this work was to use a thermal technology for future exploitation of this deposit. Two most common technologies were selected for heavy oil deposits, i.e. cyclic steam injection and gravity drainage assisted steam (SAGD). With these methods high performance can be achieved, especially when using horizontal wells. The calculations were based on the Eclipse compositional model. The use of a cyclic steam injection method allows for relatively high efficiency, especially with the use of horizontal wells. The results show that in the first cycle of the "huff and puff" process [4,8] the results of exploitation are low and only after heating to well sites the flow of oil increased and the results were better. The maximum flow is takes place at the end of the first cycle and is followed by a gradual decline at the second cycle. It should also be noted that the production of oil in eight years has been maintained at a much higher level than that of the classical method of exploitation. Also SAGD method increases the productivity of wells. However, the continuous use of this method results in fast draining of the production well environment and flux of steam at a high pressure hindering the flow of oil from the further parts of the deposit. Assuming such a possibility, a modification of the method can be proposed, i.e. periodic suspension of steam injection with the production. Thanks to this modification the heated zone brings about a continuous oil flow improving the efficiency. The SAGD method is used for lowering the viscosity of oil. Reservoir water supports this effect and plays the function of a heat carrier. Another good idea for this deposit would be the use of injection of gases such as CO_2. This technology could be advantageous in the combination of carbon dioxide sequestration. In this case, the main goal was to store the gas. It could be used for this deposit to the increase in oil production. The use of the Miocene gas beds in the Lubaczów area would be related to considerable investments.

The decisive factor for the implementation of heavy oil extraction was the size of the deposit and cost-effectiveness. The economic analysis of the AGH-UST project did not produce positive results [5]. We have found that the total costs of steam production and other operations are too high as compared to oil prices at the hydrocarbon market.

However, given the current high oil prices and the continuous improvement of mining methods used in the operation of this type of deposit it may be worthwhile to come back to this project.

In conclusion, it should be noted that Poland has not only probable but also documented significant unconventional oil resources. The provision requires the introduction of new, advanced mining technologies in the place of the existing methods used in the operation of conventional oil deposits. It is necessary to gain experience, take more courageous decisions and accept the technical and geological risk.

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