Oil and Gas in Poland: future prospecting and critical points

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Abstract. Shale gas revolution in Poland is over. But several years of shale gas investigations gave a method for prospecting and exploitation of various types of unconventional reservoirs. Tight gas reservoir rocks show 10 to 100 times greater permeability than shale reservoir rocks. It is the base to profitable exploitation these reservoirs. The paper relieved and ranked the polish sedimentary basins in context of possibilities of discovery unconventional and low permeable conventional reservoirs. The Miocene sediments of The Carpathian Foredeep, the polish part of the Rotliegend basin, the Carpathians and the Upper Silesian Coal Basin were taken into considerations. Advantages and critical points was discussed.

1. Introduction
Shale gas revolution in Poland failed but several years of investigations and proof of exploitation gave us tools for prospecting and exploitation other types of unconventional reservoirs. It also changed mentality of oilers. Today it is clear that our possibilities of profitable exploitation of unconventional reservoirs except shale gas reservoirs were underestimated. This paper in a review of our sedimentary basins. Probability of discovery and profitable exploitation is discuss (advantages and critical points). Advantages will be connected with modern methods of investigations, interpretation of data, modern fracturing and precision modelling. Critical points will be high prices for single well (great depths of potentially reservoir layers), complicated geological structures and some troubles with seismic interpretation. Number one are the Miocene sediments of the Carpathian Foredeep. For these sediments prospecting and exploitation started and now we have the first positive results. The second group covers two huge sedimentary basins. There are the polish part of the Rotliegend basin and the Carpathians. The third are generally connected with coal and covers methane from coal seams (CBM, CMM, AMM) and new look on perspectives of the Upper Silesian Coal Basin.

2. The base of a new perspectives
The works performed by Javadpour [1] and Javadpour at al. [2] shows that pore channel radius equal to100 nm is a border between two mechanism of flow of fluids through porous media. For greater pores or pore channel it is Darcy low. Below this value dominates Knudsen diffusion. The flow under the Darcy low is two order more efficient than diffusion. In (figure 1) typical pore size distribution cumulative curves for the Polish shale gas reservoir rocks (blue line) and the same typical curve for tight gas rocks (black line) are shown [3]. Only a few part (about 30%) of shale rock pore space is connected with pore channels greater than 100 nm. Additionally big heterogeneity of shale pore space caused that these biggest pores and pore channels forms only small cluster not connected one with another. Black line in (figure 1) shows also typical cumulative curve but for tight gas reservoirs. More than 80% of pore space is connected with the pore channels greater than 100 nm.
For such pore space permeability is 10 times greater than permeability for shale gas pore space. Generally permeabilities of tight gas rocks are 10 – 100 times greater than shale rocks. Because of total gas flux is proportional to permeability, exploitation of these types of unconventional reservoirs could be profitable. Additionally several year of shale gas experiments gave technology of prospecting, modeling, fracturing and exploitation not only for shale gas reservoirs [4]. They can be widely applied to other types of unconventional reservoirs.

![Figure 1](image)

Figure 1. Comparison of typical cumulative curves of pore size distribution for shale reservoir rocks (blue line) and tight gas reservoir rocks (black line).

3. The Miocene sediments of the Carpathian Foredeep
The Miocene sediments lays relatively shallow. The depths cover the range 2000 – 2500 m. They show generally multilayer types of structures. Gas in these reservoirs are mainly biogenic [5]. It means that source rocks are also the Miocene sediments. Such gas can be generated and accumulated on small depths. The only requirement for accumulation is a presence of seal rocks.

Layer type of reservoirs give as a result various type of reservoirs. There are all multilayer reservoirs. A part of horizons shows conventional type of reservoir rocks, the rest is tight gas type [6]. Conventional horizons forms layers 3-20 m thick, sunken in mudstone and claystone sediments. Conventional reservoir rocks are characterize by very good reservoir and filtration properties. Porosity up to 35% permeability 200 – 500 mD.

The second type of reservoir are thin bedded reservoirs. Thickness of sandstone layers cover the range 1 – 20 cm. Porosity of such type of reservoirs are also high up ty 25% but because of very small total thickness of sandstone rocks total flux is rather restricted.

The third type are unconventional tight gas reservoirs. Grain distribution of these rocks is similar to mudstones. Porosity reaches 24%. Their filtration properties are updated by pseudofractures build by coarse grained sandstones. Pseudofracture in the Miocene sediments [6] is presented in (figure2).
Additional factor which increased filtration properties are existed systems of fractures. In investigated boreholes for some layers fracture permeability reaches value 400 mD.

The part of unconventional layers in mixed with conventional horizons in exploited reservoirs. Analyses of well logs allow us to characterize these layers and prepare the exploitation model. Now drilling and exploitation is on. The first results show that exploitation could be profitable. Now, also new unconventional accumulations are recognized. Its exploitation is prepared. Actually, the Miocene basin became the most perspective one with relatively simple prospecting. Additionally, moderate depths give low prices for well drilling. The part of layers is recognized and there are well logs and cores. Pseudo fractures and fractures systems improved permeability of these sediments [6,7]. Critical point are connected with low mechanical resistance. It could create problems with multistage fracturing, additionally fracturing can destroy relatively thin seal beds. Reservoir waters as well as water based frac fluids could damage pore space. Conducted investigations shows that residual water saturation raises average 14% for these rocks [7].

4. The Rotliegend basin
The sediments of the Polish part of huge the Rotliegend basin reaches thickness up to 3000m. There are intensively exploited but only in upper part of basin. All discovered reservoirs occupied space of 120 m from the top. From 50 years investigation are performed. Several deep well were drilled. Results? It was found that; generation of gas has the origin in the Carboniferous source rocks so migrations was mainly vertical. It means that traps in all part of basin could be fulfilled. Generation was huge and is a big chance for discovering next reservoirs. The Rotliegend basin was formed by the Aeolian, fluvial and playa sediments [7]. Playa sediments could form a sealing rocks in several parts of basin.

Investigation of cores from the deep wells shows unique reservoir and filtration parameters the Aeolian sandstones [8,9]. Three types of reservoir sandstones could be shared. Their parameters are shown in table 1. Permeability of these sandstones are steering by content of matrix and dimension of grains [10].
Table 1. Main types of the Rotliegend reservoir sandstones.

| Type | Reservoir characterization                                      | Porosity (%) | Permeability (mD) | Threshold diameter (µm) |
|------|----------------------------------------------------------------|--------------|-------------------|------------------------|
| 1    | Very good reservoir and filtration properties                  | >15          | >100              | >20                    |
| 2    | Very good reservoir and poor filtration properties             | >10          | 10-30             | 1-10                   |
| 3    | Tight gas reservoir sandstones                                 | >5           | <0.01             | <3                     |

Figure 3. Porosity as a function of depth for the Rotliegend sandstones.

A part of tight gas sandstones show good filtration parameters. Even on the depth equal to 5000 m porosity could be greater than 10% (figure 3). Additionally, permeability for the third type of rocks with the threshold diameter lower than 3 µm is greater than expected (figure 4). Two phenomena are responsible for these results. There are fractures originated big grains and pseudofractures connected with various grain size (figure 5). These two phenomena are described in the work [10].

Summarize, there were huge generation from the Carboniferous rocks coupled with the mainly vertical migration. Additionally reservoir rocks are present in the whole basin even on depth 5000m. Additionally reservoir properties are improved by systems of fractures and pseudofractures. Sealing rocks could be formed by playa sediments. Such rocks could create structural and lithological types of reservoirs. Critical point is connected with under salt seismic. The Rotliegend sediments lays below
thick salt beds. Salt give strong signal attenuation and practically drowned other signals. It creates the risk of prospecting. A part of reservoirs could be not structural but lithological type. It also increases risk of prospecting. Practically seismic investigations ought to be coupled with recognizing wells. It is very expensive. In such situation eventually profitable exploitation will be connected firstly with volume of recoverable reserves of reservoir not with petrophysical properties of pore space.

The Rotliegend basin gives an unique opportunity for a big gas but it is really risky basin.

![Figure 4. The Rotliegend sandstones permeability versus depth.](image)

**Figure 4.** The Rotliegend sandstones permeability versus depth.

![Figure 5. A-SEM photomicrograph of fracture between grains, B-photomicrograph of pseudofracture (by Leśniak G).](image)

**Figure 5.** A-SEM photomicrograph of fracture between grains, B-photomicrograph of pseudofracture (by Leśniak G).

5. **The Carpathians**

Historically, it is the first oil province in Poland. Performed through last year’s investigations gave new perspectives for hydrocarbons prospecting. There are two directions established: deep laying reservoirs (2000 – 5000m) and tight type reservoirs in places not intensively investigated up today.

Investigations have concentrated on:

- seismic – reinterpretation of the Carpathian profiles (figure 6) with the use of all new interpretation methods [11, 12];
- geology – surface investigations (analyses of natural outflows of oil, outcrops, faults, correlations between cartography and geology), geological history of basin with taking into account extension episode, tectonics (faults, mélange zones) [13,14];
• geochemistry – methods of evaluation of geochemical parameters of rocks on the base of surface samples analyses, finding the second origin of hydrocarbons generation [15,16];
• petrophysics – application of shale reservoir methods of analyses to tight gas reservoirs, fractures analyses, regional investigations. (rocks which were fulfilled with hydrocarbons before orogenesis preserved good reservoir properties [13,15].

![Figure 6](image-url)

**Figure 6.** Results of applying new interpretation methods (A – old interpretation, B – new interpretation) [17].

Additionally trans border cooperation in the Carpathians gave:
• there are oil and gas reservoir in the Carpathian on the depth greater than 5000m;
• fracture systems are present in all types of potentially reservoir rock.

Actually, big scientific program INGA starts. In the frame of this program two teams (from Warsaw University and Oil and Gas Institute – PIB) will carry out two prospecting projects in the Carpathian. Final results will consist in sharing and ranking perspective zones in the Carpathian.

Advantage depends on great progress in seismic methods of prospecting reservoirs in such complicated geological conditions as in the Carpathians. It is possible to find conventional and unconventional reservoirs (not only gas but also oil)

Critical points:
• there are very complicated geological structures in the Carpathian and great depths of potentially discovered reservoirs;
• high prices for well drilling caused by their depth.
6. The Upper Silesian Coal Basin

The first direction of activity is methane exploitation from coal. There are coal bed methane (CBM), coal mine methane (CMM) and abandoned mines methane (AMM). Coal bed methane project is under realization. Coal mine methane is successfully applied by several mines and abandoned mine methane should start in several years. The key to methane exploitation from coal is specific structure of polish coal pore space.

Polish coal is practically non permeable in coal beds. Open porosity of polish coals lays below 2 % while the total one reaching 17%. Why? Polish coals are built with the closed nano packets. During exploitation coal is depressurized, nano packets are destroy, arriving fractures [18] and methane migrate into mines (figure 7). Profitability of production will be the main problem in such situation (main factor is permeability of depressurized coal bed [19]).

There are several advantages in potentially coal bed methane exploitation. It is known where coal beds are placed. Depth are very shallow (500 – 1000m).

But there is one big critical point – nano packets. The main question is: is possible with the use of modern fracturing destroy so many nano packets to give appropriate volume of gas. Project (PGNiG “Gilowice”) now is conducted and we will see. Some experiments with intensification of CBM production with the use of CO₂ were also conducted [20].

Coal mine methane exploitation is needed and profitable. The most important factor is miners safety. The only problem is minimization the time of removing methane from mine [21, 22]. Experiments with abandoned mines are depressurized so there are a big chance for profitable exploitation. There were done several test and experimental exploitation in abandoned mines [23,24].

Very interesting work was realized by scientist team from INiG – PIB [25]. They made and discuss model of gas system in the Upper Silesian Coal Basin on the area about 25% of the whole basin. Results showed giant methane generation. Most of accumulated methane is absorber in coal seams but many billion cubic meters of methane are probably accumulated in tight type reservoirs built by mudstones and mudstone – sandstone rocks. It is also a chance for methane exploitation.

Recapitulation: CMM and CBM works are actually perform. New AMM scientific project could started in several years. An opportunity for tight gas prospecting occurs after drilling several relatively deep wells in analyzed area of the Upper Silesian Coal Basin.

7. Discussion

Short review of the polish sedimentary basins permit to rank them. The first is of course the Miocene of the Carpathian Foredeep basin in which actually some prospecting and exploitation projects are
realized. Low depths and unconventional beds mixed with conventional ones reduces risk of prospecting. The Rotliegend and the Carpathian basins presents big risk of prospecting. Depths of potentially reservoirs cover the range 3-5 km. Additionally undersalt seismic (the Rotliegend) and very complicate geological structures (the Carpathian) increases risk of gas prospecting. On the other hand, these basins give a chance for really big gas. They give also a chance for discovery conventional reservoirs (gas – the Rotliegend and the Carpathian, oil – the Carpathian). This year scientific projects devoted to the Carpathian will start, in 2-3 years also in the Rotliegend sediments.

Individual position occupy the Upper Silesian basin in which CBM, CMM, AMM projects are performed. Maybe also prospecting of tight gas reservoirs will start.

8. Conclusion
We enter the second stage of prospecting hydrocarbons in Poland. Potentially volume of gas in various types of unconventional reservoirs are huge. Additionally, in contrast with shale gas other types of unconventional reservoirs give a big chance for profitable exploitation but it requires application of complex, modern methods of investigations and very carefully calculation of all prices connected with facilities of such types of reservoirs.

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