INTEGRATION OF PETROPHYSICAL AND PETROGRAPHIC DATA FOR THE PREDICTION OF RESERVOIR AND FILTRATION PARAMETERS IN DEEP-LYING LAYERS IN POLISH ROTLIEGEND BASIN

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ABSTRACT
The Rotliegend basin in the Polish Lowlands area is still one of the most perspective gas provinces for both conventional and tight gas reservoirs [1, 2]. Furthermore, there exists a high probability of the presence of mixed types of reservoirs. To this day, only the upper part of the Rotliegend basin—the top 120m—has been recognized. The Zechstein evaporites were the main problem in attempts to penetrate the deeper part of the sediments. Hydrocarbons generation are associated with the Carboniferous organic matter. Hydrocarbon migration in the Triassic and Jurassic period was generally vertical. This suggests a high probability of finding new accumulations in these structures.
The main goal of this investigation was to define the position of reservoir beds in the basin, particularly for deep-laid sediments. This is essential because the thickness of the Rotliegend sediment is greater than 4000m and non-zero values of permeability are observed deeper than 5000m. This study has attempted to synthesize all of the gathered data from various analyses that were performed on samples obtained from the exploration wells, which were drilled though the full profile of the Rotliegend sediments. Porosity and permeability measurements were carried out, and special attention was paid to detailed investigations of pore space through mercury porosimetry and computer analysis of microscopic images. The second analytical block consisted of petrographic analyses, determination of diagenesis processes and their influence on pore space, to define the processes influencing variations in pore space volume. Cementation and compaction models were verified and changes of porosity with depth were estimated. To establish the correlation between porosity and permeability values, with detritic grain distribution, granulometric analyses were also performed.
The cut-off parameters of porosity and permeability in correlation analysis were defined for conventional, unconventional and mixed-type reservoirs. The results obtained enable the formation of cementation and compaction models, and to facilitate the prediction of reservoir and filtration parameters in deep-deposited layers.

INTRODUCTION
This paper presents a synthesis of petrophysical**,** petrographical, sedimentological and facies analyses focussed on describing processes in the Polish area of the Rotliegend basin. Good reservoir properties were found at depths greater than 4700m. It was found that diagenetic processes steered the reservoir properties of the Rotliegend sandstones.

AREA OF INTEREST
The Rotliegend sediments in Poland are in the eastern part of the European Rotliegend basin. The exploration of hydrocarbons has been performed over the last 50 years, and many gas reservoirs were found during this period. These reservoirs are mainly connected with aeolian and fluvial sandstones [3, 4, 5]. The majority of discovered reservoirs occupied the top 120 m of the Rotliegend deposits. This is a result of the relatively poor quality of under salt seismic.

However, several deep wells bored to the base of this complex allow us to analyse the reservoir's properties for its whole profile.
The base gas province in Poland occurs at a bed thickness of 4000m. Sedimentological and facies investigations allow us to divide the upper Rotliegend sediments into four deposition systems, connected mainly by a desert sedimentation environment: aeolian, fluvial, playa and so called "white Rotliegend" washing effect of sea water. A sketch of the basin is shown in Fig. 1.

The upper Rotliegend sandstones are sealed by the Zechstein salts, with the base composed of folded Carboniferous sediments and volcanic rocks of the lower Rotliegend [3, 4, 5, 6, 7]. The source is Carboniferous (Westfal) rock. Space distributions of gas reservoirs were determinate by two factors: anisotropy of reservoir properties between the south and north part of the basin—with the southern part showing better reservoir properties and the fact that there are no Westfal-source rocks under the south part of the Rotliegend basin. This shows that horizontal long-distance migration plays the main role in the formation of reservoir sands. Space distribution of the reservoirs was also affected by burial of the Rotliegend sediments in the central part of the basin to a depth equal to 7000-8000m, with tectonic rebuilding and Laramian inversion.
In fact, at this stage of our understanding of the Rotliegend basin, the main aim is to research unconventional tight gas reservoir-types (TGR) and basin-centred gas systems (BCGS).

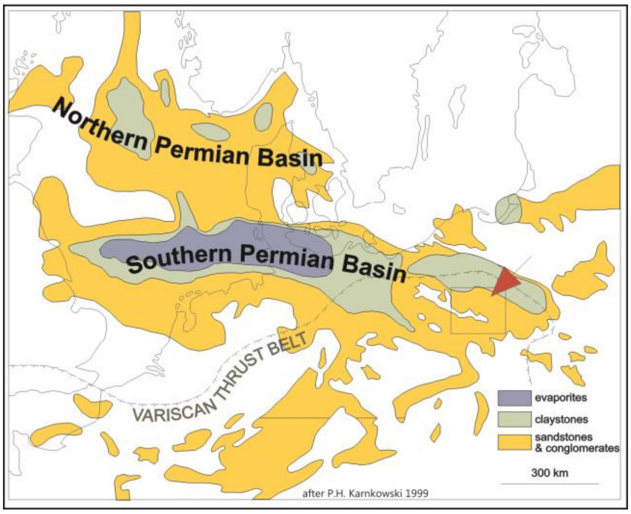

Fig 1. The Polish part of the Rotliegend basin [7]. Red arrow shows the area of interest.

DIAGENESIS

Heterogeneity of the reservoir properties of sandstone lithofacies is influenced by diagenetic processes. Mechanical and chemical compaction, crystallization, dissolution and substitution diagenesis processes were described by several Authors[1, 2, 8, 9].

Compaction and cementation negatively affected the pore space of reservoir sandstone. A high volume of the cements was precipitated during late diagenesis, after compaction. There are no early diagenetic cements that could neutralize compaction in the samples studied.
A significant proportion of results are placed in the field of compaction in the Lunegard triangle (Fig. 2.), showing compaction porosity loss (COPL) and cementation porosity loss (CEPL). Cementation dominates in samples with a matrix content above ten percent, in samples connected with the Zechstein water invasion order stagnation of dune. Special attention must be paid to the fact that compaction, as well as cementation, preserves relatively high porosity.
The confirmation of compaction domination is shown as a cross-plot ICOMPACT [COPL/(COPL + CEPL)] versus depth (Fig. 4.). The analysis of microscopic images confirms the domination of compaction. Fig. 5 presents the correlation between depth and elongation. Increasing values of elongation in the function of depth also confirms the domination of compaction. There are two lines of correlation in Fig. 5; the green one is prepared from the

whole database, while the blue is calculated with the use of data from one dune in one well. The general diagenetic sequence in the upper Rotliegend basin is presented in Fig. 3.

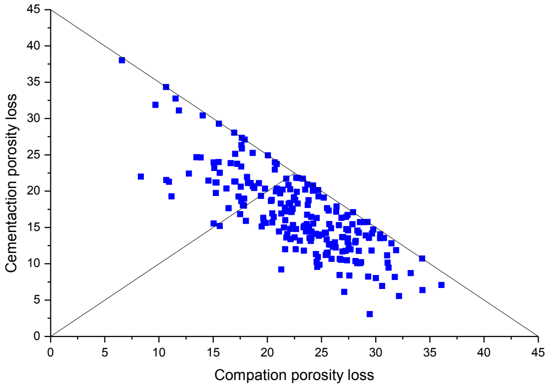

Fig. 2. Porosity loss by compaction and cementation (after Lunegard, 1992)

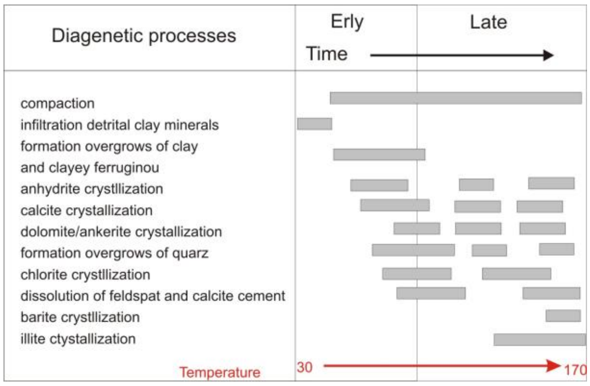

Fig. 3. Sketch of diagenetic sequence in the upper Rotliegend deposits

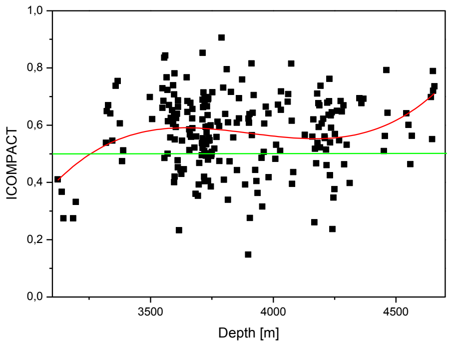

Fig. 4. Cross-plot ICOMPACT – depth; green line – ICOMPACT=0.5; red line – trend line

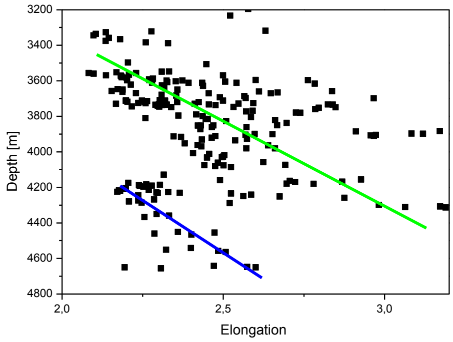

Fig. 5. Values of elongation pore in the function of depth; green line – trend line for the whole data base; blue line – trend line for chosen dune

Cementation processes in the top part of the Rotliegend deposits can be explained by infiltration of the Zechstein waters. On the other hand, relatively weak cementation in the bottom of the basin is a result of low levels of infiltration by the Carboniferous waters. Higher levels of cementation in the middle area of the investigated profiles can be connected with rising levels of groundwater and halted dune development. Generally, there are early diagenetic cements that may later be dissolved in the next stages of diagenesis [1, 8, 9].

Granulometric analyses were performed for all the samples. The results obtained correlate with petrophysical parameters. Fig. 6 presents a cross-plot of permeability and porosity revealing sorting of grains (colored lines). The resulting trends show that a higher level of sorting is correlated with lower values of permeability.

Fig. 7 presents all the results in the database. The trends of permeability values, shown in Fig. 7, reached asymptotic values near 1mD. The obtained trend is confirmed by the results of permeability measurements carried out for samples from a depth of 4800m (values from 1 to 5mD) [10, 11].

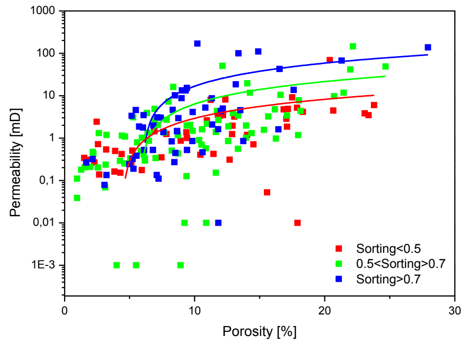

Fig. 6. Cross plot porosity – permeability with sorting as a parameter: red – sorting<0.5, green – 0.5<sorting<0.7, blue – sorting>0.7

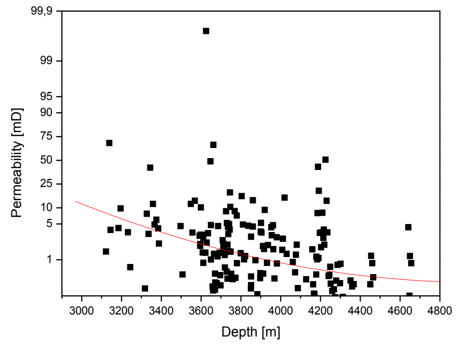

Fig. 7. Permeability in a function of depth (red line – depth trend of permeability)

This raises the possibility of finding permeable sandstone deposits even at greater burial depths.

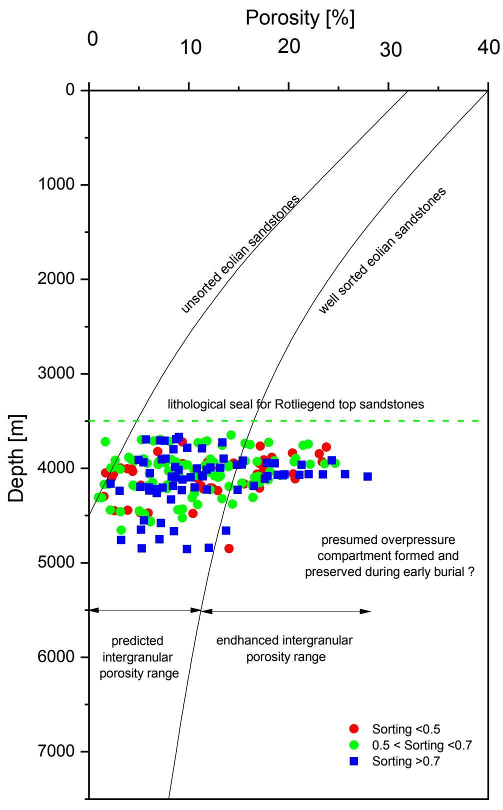

Fig. 8. Porosity and sorting as a function of depth coupled with depth porosity model [2]

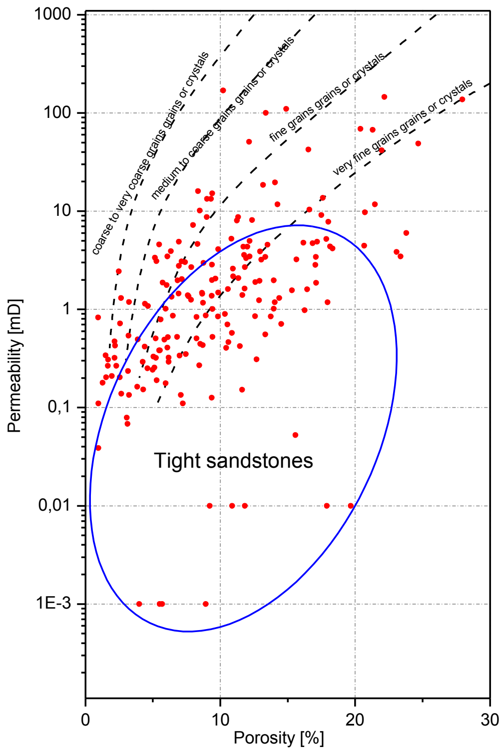

Fig. 9. Porosity to permeability cross plot in function of type of clastic rocks [12]

Discussion

The Rotliegend sandstones generally show strong space heterogeneity, along with several unique features:

- Reservoir sandstones from the top part of the basin form two types of reservoir rocks: moderate and very good. The first shows permeability to be numerically equal to porosity, whilst the second type shows a value of permeability numerically more than ten times higher than porosity. For this second type porosity could reach 40 percent and permeability values could be greater than 3mD.
- In the deeper part of the basin a strong decrease in reservoir properties is observed from one side. From the other side there is porous and permeable sandstone at depths below 5000m. In general, diagenesis processes have steered reservoir properties in this part of the basin.

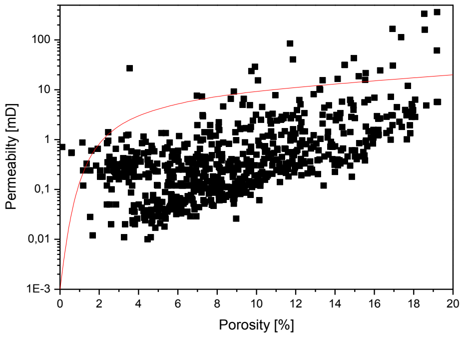

Fig.10. Cross plot porosity – permeability; the red line - numerically porosity equal to permeability

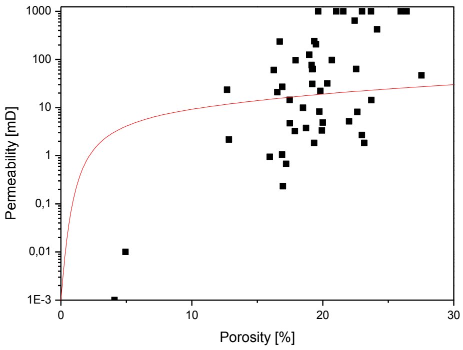

Fig. 11. Cross plot of porosity - permeability for one conventional reservoir; red line - numerically porosity equal to permeability

The values of permeability for conventional reservoirs are higher than the values of porosity, expressed numerically. For tight gas reservoirs, the values of permeability are obviously lower than porosity, but practically these rocks are dominating in the aeolian and fluvial complexes in the Rotliegend deposits (Fig. 10). Tight gas rock is also present in a large part of the conventional reservoir. Fig. 11 presents a cross-plot of porosity and permeability for one conventional reservoir.

CONCLUSIONS

The performed analyses allow us to come to several conclusions:

- Reservoir properties of the investigated profiles can be described as good or very good. Periodicity is observed in investigated profiles.
- Porosity correlates with pore space parameters.
- No critical depth for reservoir parameters was observed. Investigated sediments show porosity higher than 15 percent at depths below 4700m.
- Non-zero filtration properties are connected with three processes:
    - Regular flow of fluids for samples with threshold diameters greater than 3µm.
    - Flow-through microfractures on the grain borders showing permeabilities up to 3mD: this effect was observed in all the facies.
    - Flow-through fracture or pseudofracture systems showing permeabilities higher than 10mD: this effect was observed only in the aeolian dune core, giving strong values of permeability.
- Correlation between granulometry and petrophysical parameters show that permeability decreases for sandstones showing higher degree of sorting.

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