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Correlation of the Rotliegend strata in Central Poland based on the interpretation of well logging data

Jadwiga JARZYNA[1], Maria BAŁA[1], Barbara CZOPEK[2], Natalia GÓRECKA[1]

[1] *Zakład Geofizyki, Akademia Górniczo-Hutnicza, 30-359 Kraków, al. A. Mickiewicza 30*

[2] *Zakład Surowców Energetycznych, Akademia Górniczo-Hutnicza, 30-359 Kraków, al. A. Mickiewicza 30*

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Comprehensive interpretation of well logging data, based on selected set of borehole geophysical measurements, enabled the determination of lithology and porosity of the Rotliegend strata. The detailed lithological subdivision and calculation of porosity values have been made on the basis of well logs with the use of the domestic GEO computer program. The subdivisions of the studied rock sequences into porous and sealing series will allow to determine the exact thicknesses of reservoir layers and their average porosity. The results of comprehensive interpretation of lithology on the basis of well logging data are more reliable in comparison to a qualitative appraisal, inferred from apparent values, recorded during measurements in wells. The generalized complexes ("series") have been correlated along selected profiles. Correlations along longitudinal profiles (concordant with the NW–SE axis of the basin) and transversal ones show the trends of changes in depths, thicknesses and relations of rock sequences in individual parts of the area in question. The lack of some "series" in vertical profiles suggests variations in conditions of sedimentation. Discontinuity of some correlation lines between the boreholes under study supports the assumption about changes caused by facies differentiation. The results of interpretation of well logging data may be applied in geological consideration aimed at evaluation of reservoir capacity of the Rotliegend rocks (generation, migration and storage of hydrocarbons). The comparison of results of geophysical interpretation with core analyses may bring about new data on the development of the Rotliegend strata.

INTRODUCTION

The Permian basin in Poland has been intensively explored for years due to its hydrocarbon prospects (J. Pokorski, 1989; P. Karnkowski, 1993; P. H. Karnkowski *et al.*, 1996; W. Burzewski *et al.*, 1993, 1996; T. Bachleda-Curuś, R. Semyrka, 1995). About 70 natural gas deposits have been found within the Fore-Sudetic Monocline and Wielkopolska area in Carboniferous, Rotliegend and Zechstein horizons, and also 12 oil deposits in the Zechstein strata (P. Karnkowski, 1993). The favourable reservoir properties of the Saxonian sandstones combined with the structural forms, which have inherited the relief of the sub-Permian basement and formed traps for migrating hydrocarbons make this formation an interesting prospective target.

Geological and geophysical studies, carried out during the exploration, have also resulted in detailed recognition of the geological structure of units, distinguished within the Fore-Sudetic Monocline, i.e. the Wolsztyn Range, the Poznań Basin, and the post-Variscan intramontane Zielona Góra–Rawicz Depression (P. Karnkowski, 1993). The reservoir rocks of the recognized gas deposits are represented by the sandstone strata of the Upper Rotliegend — Saxonian. The results of extended interpretation of well logs and geological investigations have brought about also the recognition of the Lower Rotliegend — Autunian. Geophysical measurements and their interpretation, carried out in the sections of Rotliegend in numerous boreholes localized in the whole area of the Fore-Sudetic Monocline, have allowed to outline a more detailed model of the geological structure of the Rotliegend. It has been possible to distinguish and correlate formations with the variable lithology and thickness, from the lowermost Dolsk Formation (P. H. Karnkowski *et al.*, 1996) to the Wyrzeka and Książ Formations, and to the Siekierki Sandstone Formation and Piła Claystone Formation (P. H. Karnkowski, 1987).

Well logging data provide information on changes in lithology and in petrophysical properties of rocks with depth.

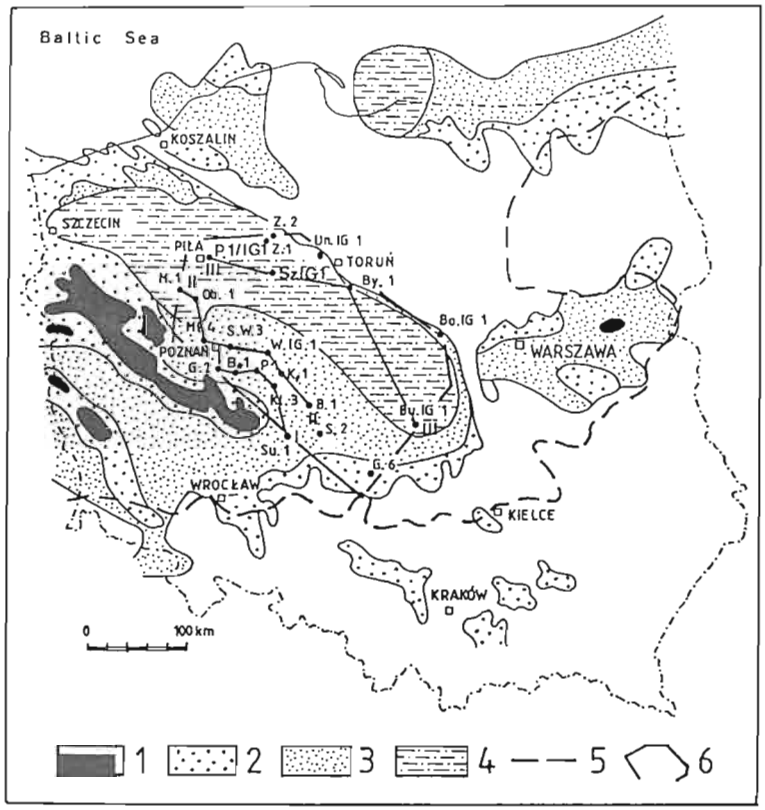


Fig. 1. Map of the Rotliegend extent in Poland (after P. H. Karnkowski, 1996)

1 — area of Rotliegend sediments apart from Wielkopolska Subgroup in Polish Basin, 2 — conglomerate, 3 — sandstone, 4 — mudstone and claystone, 5 — maximum range of chemical Werra deposits, 6 — study area; profile I–I — boreholes: G. 2 — Grodzisk 2, B. 1 — Brodnica 1, P. 1 — Polwica 1, Kl. 3 — Klęka 3 and Su. 1 — Sulmierzyce 1; profile II–II — boreholes: M. 1 — Mężyk 1, Ob. 1 — Obrzycko 1, Mł. 4 — Młodasko 4, S. W. 3 — Siekierki 3, W. IG 1 — Września IG 1, K. 1 — Komorze 1 and B. 1 — Brudzewek 1; profile III–III — boreholes: P. 1/IG 1 — Piła 1/IG 1, Sz. IG 1 — Szubin IG 1, By. 1 — Byczyna IG 1 and Bu. IG 1 — Budziszewice IG 1

Mapa zasięgu czerwonego spągowca w Polsce (według P. H. Karnkowskiego, 1996)

1 — obszary pozbawione osadów podgrupy wielkopolskiej w obrębie polskiego basenu czerwonego spągowca, 2 — zlepieńce, 3 — piaskowce, 4 — mułowce i iłowce, 5 — maksymalny zasięg osadów chemicznych cyklotemu werra, 6 — teren badań; I–I — III–III — profile geologiczne; objaśnienia symboli otworów patrz tekst angielski

A short radius of investigation with relevant devices makes impossible to extrapolate the logging results too far from a borehole. Well curves from numerous boreholes within a study area and an available geological information have always represented a basis for identification and correlation of specific horizons among the boreholes. The possibility of a comprehensive interpretation of geophysical data (seismic and well logging ones) in a given area which has existed since the introduction of interactive workstations gives the chance to recognize the geological structure even in more details. The interpretation of well logging data instead of analyses of only recording logs makes a resulting geological model more reliable.

Well logging data have been interpretated just in this way with the aim to identify lithology and to determine total porosity. Next, the distinguished lithological series have been correlated along specific cross-section. The quantitative interpretation has been done with the use of the GEO system (W. Gądek, J. Litwin, 1988). The changes of lithology have been continuously determined in the sections of selected boreholes where the Rotliegend strata occur.

The Rotliegend strata are developed in the study area as sandstone, claystone, mudstone and conglomerate strata but the mentioned lithological types are seldom homogeneous. The sandstones usually contain a significant admixture of a clay material. In some boreholes also volcanic rocks were observed.

On the basis of the detailed results of interpretation, supported by the diagrams representing the changes in porosity and lithology with depth, the Rotliegend strata have been divided into the sandstone, claystone, mudstone, conglomerate and volcanic lithological series. Also series with mixed lithology have been distinguished, such as sandstone-claystone, sandstone-mudstone, mudstone-claystone and claystone-sandstone ones. All the series in question have their thickness and porosity ranges determined; their average porosity has also been calculated.

DETERMINATION OF LITHOLOGY AND TOTAL POROSITY ON THE BASIS OF WELL LOGGING DATA

INTERPRETATION OF WELL LOGGING DATA

The lithology presented above (mainly clastic rocks) has been determined from the following set of logs: GR and neutron-gamma, caliper, sonic, and resistivity (at least two lateral devices: 1.05 and 8.5 m or laterologs were used). All the logs were digitized with the step 0.25 m (W. Burzewski *et al.*, 1996). Laboratory investigations provided also core data of rock samples from selected boreholes. The porosity determined in such a way was compared with results of geophysical interpretation. The lithology of individual profiles inferred from the results of geophysical interpretation

Table 1

Lithological series and porosity distinguished in Budziszewice IG 1 well as a result of quantitative interpretation

Number of horizon	Depth of bottom [m]	Lithology	Porosity Φ [%]	Average porosity Φ_{av} [%]	Additional information
1	4623.0	sandstone-claystone series	0.0–12.0	7.3	intercalations of porous sandstones
2	4813.0	sandstone series	0.0—4.7	2.5	intercalations of mudstones and claystones
3	4930.0	claystone- mudstone series	0	0	intercalations of sandstones
4	5050.0	conglomerate-claystone series	0	0	intercalations of sandstones (porosity up to 2%)

was confronted with the geological logging of a core if such a description was contained in well reports.

Geophysical measurements were carried out with Russia-made equipment in the 80 s and at the beginning of the 90 s. Therefore, the results of nuclear logs are expressed in relative units (impulses per minute) and cannot be directly compared. Gamma-gamma logs, carried out with older devices — not standardized and without calibration, has been neglected in interpretation because their results will not bring any additional, useful information.

Digitized logs, set in the LAS format, were then prepared for the correlation of the distinguished lithological series among boreholes using the LogX program of GMA company (GMA-Log X, 1992). The LAS files were next converted into the GEO system format in which further interpretation was carried out.

During the initial interpretation of nuclear logs, corrections for the influence of a borehole were introduced. If a variable diameter of a borehole is not considered, the content of a clay material derived from gamma curves may be miscalculated, as well as the porosity determined from neutron logs. The presence of washouts or mud cake in the borehole sections where porous and permeable horizons have been intersected decreases the intensity of gamma rays in GR and neutron-gamma logs. Minimum amplitudes on GR curves corresponded to pure sandstone strata, while maximum intensities to clay horizons. The porosity of clay strata determined from neutron logging was accepted as equal to 30–40% of the conventional porosity units of limestones. In the boreholes in which volcanic rocks had been described in well reports, the independent interpretation was carried out not only in the horizons of these rocks but also in remaining sections because of very high anomalies on GR logs.

A sandstone-claystone model has been selected for the quantitative interpretation. Shaliness was being calculated from GR logs only on the basis of a non-linear function, determined for the strata older than the Cainozoic ones. Lithology and porosity were determined from neutron-gamma and GR logs. Another set of logs, namely GR, neutron-gamma and resistivity ones, allowed to distinguish three lithological components: sandstone, claystone and mudstone. In the sections where also conglomerates occur, additional sonic log was used to delineate the fourth lithological component. Average total porosity of an identified horizon was determined together with lithology.

DISCUSSION OF RESULTS

The results of quantitative interpretation of data from 22 boreholes, localized in the Fore-Sudetic Monocline and in the central part of the Rotliegend basin (Fig. 1) (W. Burzewski *et al.*, 1996) have been presented as graphs showing the changes of shaliness, lithological composition and porosity with depth. Additionally, a table presenting lithological series has been prepared for each borehole. It also contains minimum and maximum total porosity values (Φ) for the distinguished rock series as well as average porosity values (Φ_{av}), estimated from the analyses of the computerized GEO interpretation. The results achieved have been presented as exemplary graphs (Figs. 2–5) and tables (Tabs. 1–4) for the selected boreholes: Budziszewice IG 1, Grodzisk 2, Obrzycko 1 and Piła 1/IG 1. There are characteristic lithological series in the profiles of these boreholes, while the range of total porosity and average porosity values for the distinguished horizons reflects the variability of reservoir properties.

Budziszewice IG 1. The Rotliegend strata occur at a depth 4559.0–5050.0 m (thickness = 490.5 m). There are sandstone, sandstone-mudstone and claystone series distinguishable in the profile. In the lower part of the Rotliegend (below 4935.0 m) there are conglomerate strata (Fig. 2).

Porosity values, calculated on the basis of the comprehensive interpretation of well logging data, are differentiated. In the upper part of sandstones they are higher (maximum up to 12%), decreasing downwards to 3–4%. The lower rock complex (claystones, mudstones and conglomerates) does not show any porosity (Tab. 1).

Grodzisk 2. The Rotliegend strata occur at a depth 2788.0 –3357.0 m (thickness = 569.0 m). They are developed as sandstones, conglomerates and claystones. Sandstones pre-

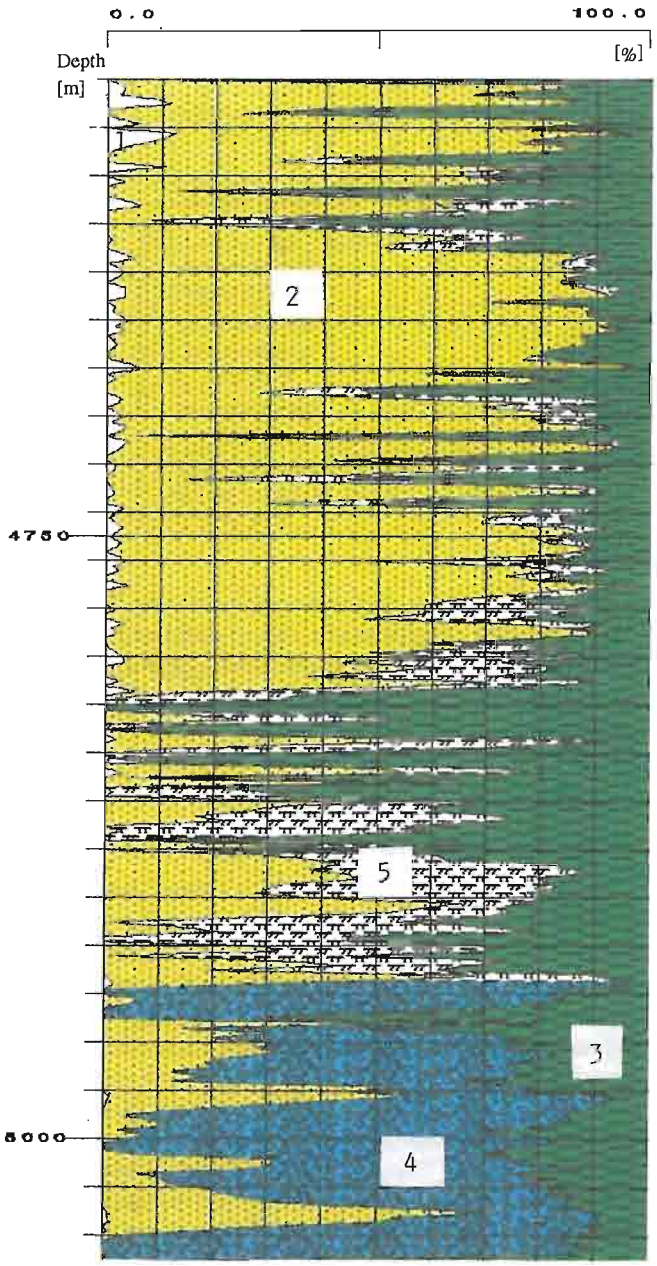


Fig. 2. Results of quantitative interpretation of well logging data in Budziszewice IG 1 well

1 — porosity, 2 — sandstone series, 3 — claystone series, 4 — conglomerate series, 5 — mudstone series

Ilościowa interpretacja profilowań geofizycznych w otworze Budziszewice IG 1

1 — porowatość, 2 — seria piaskowcowa, 3 — seria iłowcowa, 4 — seria zlepieńcowa, 5 — seria mułowcowa

vail in the upper part of the profile, to 3113 m. Going down, the content of conglomerates and conglomeratic sandstones with insets of claystones increases (Fig. 3).

Interpretation of well logs (GR, neutron-gamma, resistivity) has been based on a multicomponental model: sandstone-claystone-conglomerate. Calculated porosity values are much differentiated. The upper part of the sandstone series is characterized by high Φ values (up to 24%), while the average porosity in the section from 2788.0 to 2997.0 m is 10%. Going down the profile porosity decreases, and this trend has been supported by the results of laboratory research, present in the well reports (Tab. 2).

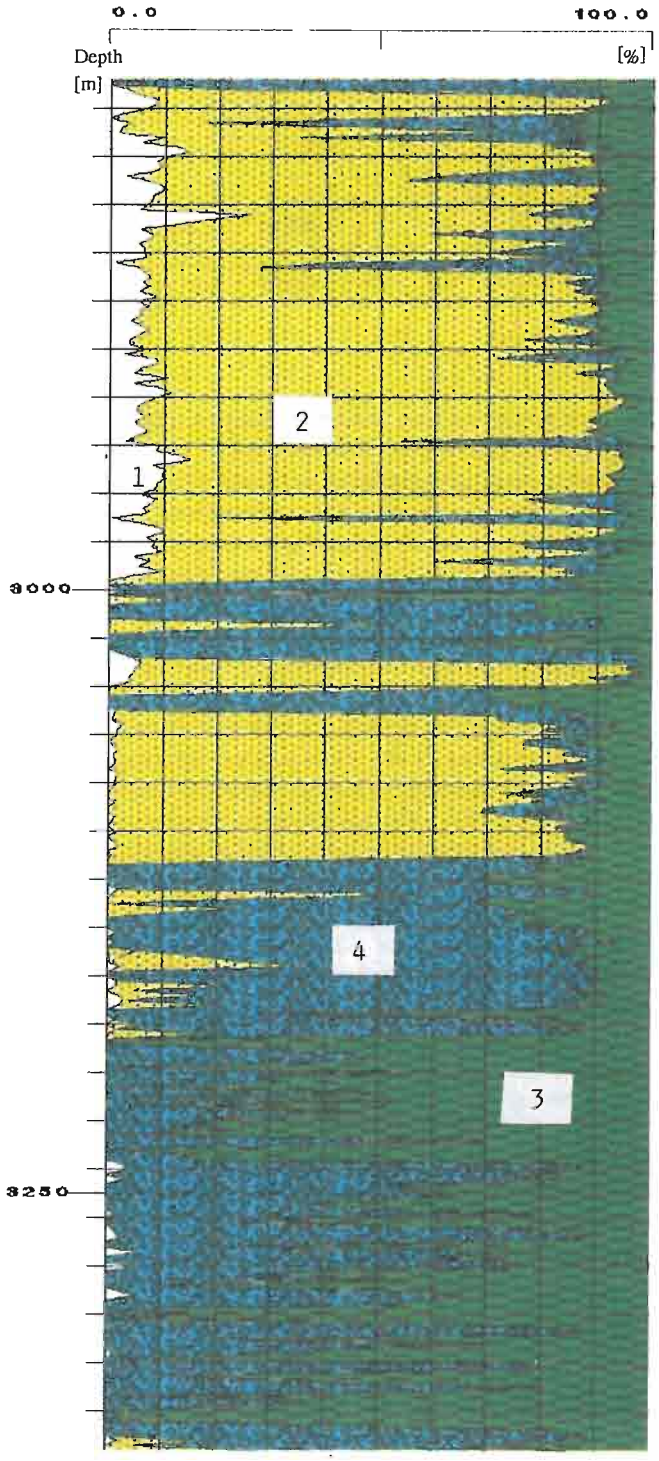


Fig. 3. Results of quantitative interpretation of well logging data in Grodzisk 2 well

Explanations as in Fig. 2

Ilościowa interpretacja profilowań geofizycznych w otworze Grodzisk 2

Objaśnienia jak na fig. 2

Table 2

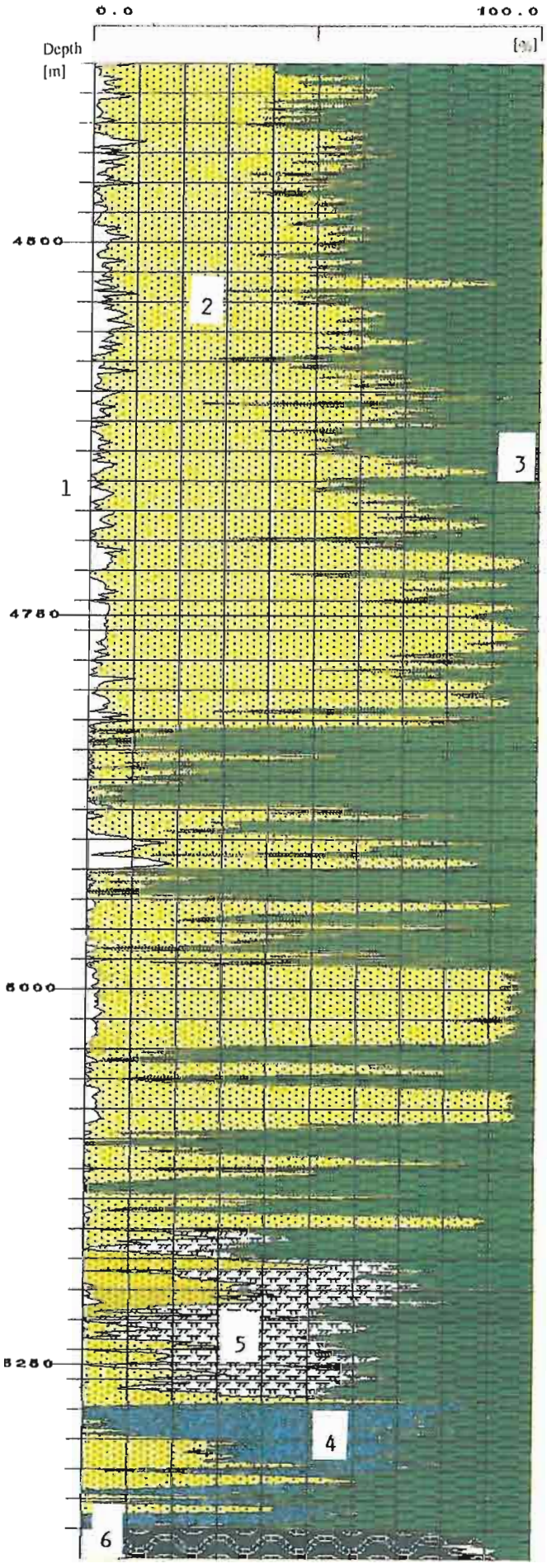
Lithological series and porosity distinguished in Grodzisk 2 well as a result of quantitative interpretation

Number of horizon	Depth of bottom [m]	Lithology	Porosity Φ [%]	Average porosity Φ_{av} [%]	Additional information
1	2997.0	sandstone series with conglomerate intercalations	2.4–24.0	10.0	
2	3028.0	conglomerate series	0	0	thin porous (4%) layer at the bottom
3	3041.0	sandstone	5.8	5.8	
4	3052.0	conglomerate series	0.0–4.8	0.2	porosity from core data: 4.3–7.4%
5	3113.0	sandstone series	1.0–2.5	1.5	
6	3187.0	conglomerate series with sandstone intercalations	0.0–4.0	2.0	porosity from core data: 1.0–5.1%
7	3237.0	claystone-conglomerate series	0	0	fragments of sandstone and conglomerates
8	3357.0	conglomerate-claystone series	0.0–6.5	4.5	porosity from core data: 0.4–3.1%

Table 3

Lithological series and porosity distinguished in Piła 1/IG 1 well as a result of quantitative interpretation

Number of horizon	Depth of bottom [m]	Lithology	Porosity Φ [%]	Average porosity Φ_{av} [%]	Additional information
1	4597.0	sandstone-claystone series	0.5–10.2	3.5	the same percentage of sandstone and claystone
2	4824.0	sandstone series	0.5–10.5	4.0	small percentage of claystone
3	4876.0	claystone series	0.0–1.5	0.2	thin intercalations of sandstone
4	4982.0	claystone-sandstone series	0.0–17.5	8.5	intercalations of porous sandstone
5	5039.0	sandstone series	4.0	4.0	no changes of porosity in whole horizon
6	5063.0	claystone series	0.0–2.0	0.2	thin sandstone bed
7	5090.0	sandstone series	4.0	4.0	homogeneous series
8	5160.0	claystone-sandstone series	0.0–2.0	0.2	pure sandstone intercalations
9	5180.0	claystone-mudstone series	0	0	
10	5272.0	claystone-mudstone-sandstone series	0	0	local values of porosity up to 4.5%
11	5358.5	conglomerate-claystone-sandstone series	0	0	sandstone intercalations, according to well report:at bottom rhyolite is present
12	5380.0	volcanic series diabases	0	0	



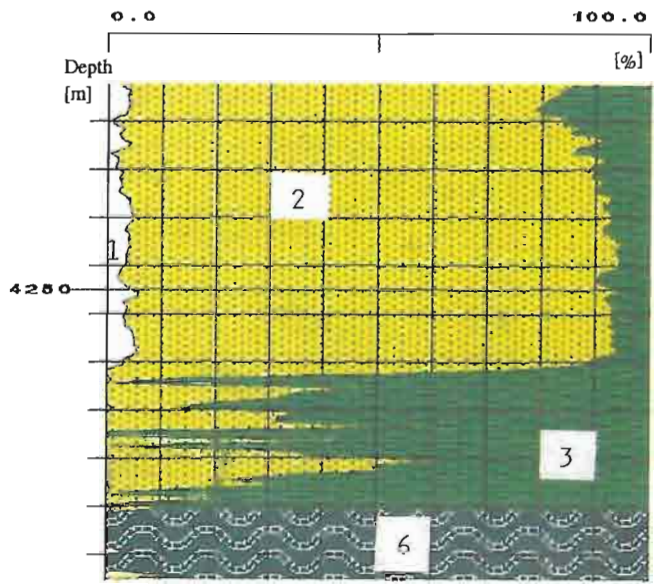


Fig. 5. Results of quantitative interpretation of well logging data in Obrzycko 1 well
Explanations as in Figs. 2, 4

Ilościowa interpretacja profilowań geofizycznych w otworze Obrzycko 1
Objaśnienia jak na fig. 2, 4

Piła 1/IG 1. The Rotliegend lies at a depth 4380.0–5468.0 m (thickness = 1088.0 m). In the section in question there are sandstone, sandstone-claystone, mudstone and conglomerate strata, with the series of volcanic rocks in the bottom part (Fig. 4).

Interpretation of well logging data was based on a two-componential model (sandstones-claystones) between 4380.0 and 5160.0 m, while below the latter depth, down to 5380.0 m, a multicomponential model was introduced as it provides for a more complex lithology. There are no logs below 5380.0 m.

The calculated porosities of the Rotliegend strata are much differentiated. In sandstone intervals, porosity ranges most often from 0.5 to 10.0%, reaching locally 17% between 4896 and 4920 m, but generally is low, 4.0% on the average. The mudstone and conglomerate series do not possess reservoir properties as their porosity is negligible (Tab. 3). The series of volcanic rocks begins with a distinct anomaly on the GR log (from 5356 to 5358 m), but below this section the GR values are low and the presence of basic volcanics (diabases) is assumed there.

Obrzycko 1. The Rotliegend strata, occurring between 4165.0 and 4381.7 m (thickness = 216.7 m), are developed as sandstones, mudstones and claystones. In their bottom part, there are volcanic rocks (Fig. 5).

The results of interpretation of well logging data, assuming a sandstone-claystone model, allowed to identify a porous sandstone series in the interval 4165.0–4285.5 m. It is under-

Fig. 4. Results of quantitative interpretation of well logging data in Piła 1/IG 1 well
6 — volcanics; other explanations as in Fig. 2

Ilościowa interpretacja profilowań geofizycznych w otworze Piła 1/IG 1
6 — seria skał wulkanicznych; pozostałe objaśnienia jak na fig. 2

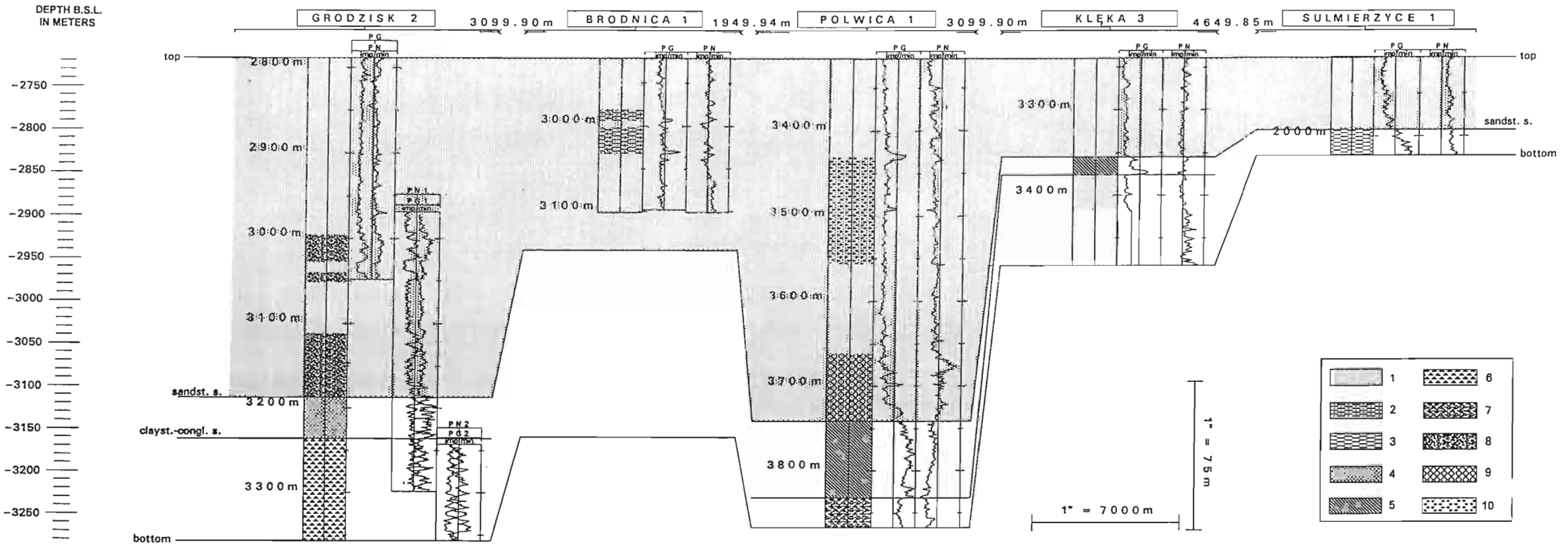


Fig. 6. Correlation of lithological series identified in wells along profile I–I; top of Rotliegend means the reference level; lithological rock profile constructed basing on geophysical interpretation

1 — sandstone series, 2 — sandstone-claystone series, 3 — claystone series, 4 — claystone-mudstone series, 5 — conglomerate-claystone series, 6 — conglomerate-claystone-sandstone series, 7 — conglomerate-claystone-mudstone series, 8 — conglomerate series, 9 — greywake sandstone series, 10 — sandstone-conglomerate-mudstone series; the vertical scale of absolute depth is marked on the margin of the graph; the depths measured from the ground level are marked on the well tracks

Korelacja serii litologicznych wydzielonych w otworach na profilu I–I; poziom odniesienia — strop czerwonego spągowca; profil litologiczny został wyznaczony na podstawie interpretacji geofizyki wiertniczej

1 — seria piaskowcowa, 2 — seria piaskowcowo-iłowcowa, 3 — seria iłowcowa, 4 — seria iłowcowo-mułowcowa, 5 — seria zlepieńcowo-iłowcowa, 6 — seria zlepieńcowo-iłowcowo-piaskowcowa, 7 — seria zlepieńcowo-iłowcowo-mułowcowa, 8 — seria zlepieńcowa, 9 — seria piaskowców szarogłazowych, 10 — seria piaskowcowo-zlepieńcowo-mułowcowa; pionowa skala na lewym brzegu rysunku przedstawia głębokość bezwzględną; na skalach pionowych przy otworach zaznaczono głębokość mierzoną od powierzchni terenu

Table 4

Lithological series and porosity distinguished in Obrzycko 1 well as a result of quantitative interpretation

Number of horizon	Depth of bottom [m]	Lithology	Porosity Φ [%]	Average porosity Φ_{av} [%]	Additional information
1	4285.5	sandstone series	0.5–8.8	4.0	
2	4342.0	sandstone-claystone series	0.0–1.5	0	transition from sandstone to mudstone
3	4381.0	volcanic rocks	0	0	core description: fragments of volcanic rocks, porosity up to 2%

lain by claystones and non-porous, highly clayey sandstones. The lower series (4342.0–4381.7 m), which shows considerable radioactivity (high GR values), may correspond to volcanic rocks (Tab. 4).

CORRELATION OF THE LITHOLOGICAL SERIES

The lithological series have been correlated along seven profiles. Four of them run along the NW–SE axis of the Rotliegend basin in the northern part of the Fore-Sudetic Monocline, and another three run perpendicularly to the basin axis. The profiles contained all the wells in which lithological series were identified and porosity was determined. In the present paper a correlation has been selected along two profiles situated in the northern part of the monocline, and a third — along the NW–SE axis of the Rotliegend basin. These profiles represent the variability of the lithological development and of porosity of rocks in the transition zone between the marginal (i.e. SW) and central parts of the Rotliegend basin (Fig. 1).

All the correlation diagrams (Figs. 6–8) were prepared with the LogX program of GMA company (GMA-Log X, 1992). Their vertical scale was automatically set by the LogX system. The vertical scales of absolute depths have been marked on the graph margins, as well as the depths measured from the ground level during logging and recorded on the well tracks. The correlation of the identified lithological series has been referred to the top of the Rotliegend strata. The scale of absolute depths, corresponding to the depths below sea level in the first well of a profile, were marked on the left margins of the Figures 6 and 7. The result of correlation of the distinguished series, with their depths reduced to the sea level, has been presented in Figure 8.

All the graphs enclose GR and neutron-gamma curves expressed in relative units, i.e. impulses/minute. In some wells, the interval of the Rotliegend strata was logged in two, and even three sections (Grodzisk 2). Since the radiometric logging was not standardized, these sections have been shown independently, on separate tracks. The logs are accompanied by lithological columns in which the lithological division is presented, accordingly well log interpretation. The whole series of reservoir rocks ("sandstone series") has been marked with the symbols of sandstones.

The tables of detailed lithological divisions (Tabs. 1–4) have been supplemented with three additional ones (Tabs. 5–7), presenting the top and bottom depths of the identified lithostratigraphic series in the wells belonging to a given profile.

Description of the lithological correlation along profile I (Fig. 6, Tab. 5). The total length of the profile I is 128.5 km. The thicknesses of the Rotliegend strata range from 114.6 m in the borehole Sulmierzyce 1 to 569.0 m in the borehole Grodzisk 2. It can be observed that these strata become thinner from NW to SE, with only the borehole Polwica 1 not following this trend (the Rotliegend is there 552.0 m thick). The profile I is approximately parallel to the Wolsztyn Range and is localized north of the range axis. The borehole Grodzisk 2 is situated west of the Poznań–Oleśnica Fault Zone while the remaining boreholes are east of it. The Książ Wlkp. Conglomerate Formation, confirmed in the borehole Grodzisk 2 (Fig. 3) by P. H. Karnkowski (1987), rests on the both sides of the Wolsztyn Range in the western part of the study area. East of the Poznań–Oleśnica Fault Zone this formation is observed only in the vicinity of Książ Wielkopolski and Wycichów (P. H. Karnkowski, 1987).

The Rotliegend strata in the boreholes belonging to the profile I (Fig. 6) represent the Upper Rotliegend — Saxonian (P. Karnkowski, 1993). They are developed as sandstone series containing also mudstone, claystone and conglomerate layers. Close to the top of the Rotliegend complex, the sandstone series prevail, while in its bottom part conglomerate-mudstone-claystone horizons occur. The changes in the lithological development reflect differences in the conditions of sedimentation, considering both the depth of the basin and the type of the deposits (alluvial or aeolian) (P. H. Karnkow-

Table 5

Identified lithostratigraphic series in the wells along the profile I (depth in m)

Series	Grodzisk 2	Brodnica 1	Polwica 1	Klęka 3	Sulmierzyce 1
Top	2788.0	2920.5	3315.0	3239.0	1907.6
Sandstone	2788.0–3187.0	2920.0–3146.0	3315.0–3741.0	3239.0–3355.0	1907.6–1992.5
Claystone-mudstone				3355.0–3376.0	1992.5–2022.0
Claystone-conglomerate	3187.0–3237.0	3146.0–3366.5	3741.0–3832.0		
Conglomerate	3237.0–3357.0		3832.0–3867.0		
Sandstone-mudstone				3376.0–3418.0	
Bottom	3357.0	3366.5	3867.0	3418.0	2022.0

ski, 1985). According to the lithostratigraphical division presented by P. H. Karnkowski (1987), the Rotliegend strata in the boreholes Brodnica 1, Polwica 1, Klęka 3 and Sulmierzyce 1 may be included into the Siekierki Sandstone Formation. In the borehole Polwica 1, a characteristic series of conglomerates occurring at the bottom of the Rotliegend and described by P. H. Karnkowski (1987) as the Polwica Conglomerate Member may be identified.

In all the boreholes of the profile I, a sandstone series has been recognized in the top part of the complex (in figures it is designated as "sandst. s."). This series contains intercalations of conglomeratic packages; e.g. in the borehole Polwica 1 between 3430–3556 m a sandstone series with insets of conglomerates and mudstones has been distinguished and this horizon may be identified with the Solec Conglomerate Member (P. H. Karnkowski, 1987). The sandstone series has porosity in the range 0–24%. Layers with the highest porosity usually occur in the top parts of the series. The lowest values of total porosity were observed in the borehole Grodzisk 2. The sandstone series represents the Siekierki Sandstone Formation in all the boreholes except for the Grodzisk 2, where it corresponds to the Książ Wlkp. Conglomerate Formation. P. H. Karnkowski (1987) states that the rocks of the two mentioned lithostratigraphical units are of the same age and may thus be correlated. The correlation line, drawn along the bottoms of the sandstone series in the boreholes of profile I, has been marked in the relevant figures.

Below the sandstone series rests a claystone-conglomerate complex (in figures designated as "clayst.-congl. s."). This complex is characterized by a high content of a clay material, and the dominating claystones are accompanied by mudstones and conglomerates. The rocks of the claystone-conglomerate series, distinguished in all the boreholes, lack porosity. They form a lithological complex strongly pronounced on curves of GR and neutron-gamma whose presence is supported by the interpretation of well logging data. In the borehole Polwica 1 the complex may be included into the Polwica Conglomerate Member, but in the remaining boreholes it probably belongs to the bottom part of the Siekierki Sandstone Formation. In Figure 6 there is a correlation line, connecting the bottom of this series in the boreholes Polwica 1and Klęka 3.

In all the boreholes of the profile I except for the Sulmierzyce 1, the authors have additionally distinguished near-bottom horizons with variable lithology and differentiated porosity. In the borehole Grodzisk 2 a conglomerate-claystone series, with insignificant amount of sandstone with the porosity of about 4.5%, has been identified. In the borehole Polwica 1 the near-bottom strata are represented by a conglomerate-claystone series with insignificant porosity associated with admixture of sandstones. The Klęka 3 rock profile shows in its lowermost part sandstones with the medium porosity of about 12%. The insets of mudstones are identified in this part of rock profile. The series described here correspond to the lowermost members of the Książ Wlkp. Conglomerate Formation (Grodzisk 2) and Siekierki Sandstone Formation (the remaining holes). No detailed divisions have been made in the borehole Brodnica 1 because of the lack of geophysical mea-surements below 3100 m. Claystone-conglomerate series has been identified in the borehole Brodnica 1 between 3146.0–3366.5 m (see Tab. 5) basing on the geological logging enclosed in well report.

Description of the lithological correlation along profile II (Fig. 7, Tab. 6). The profile runs generally from NW to SE over the length of 289 km. The thickness of the Rotliegend strata ranges from 28.0 m in the borehole Gomunice 6 to 877.2 m in the borehole Września IG 1. It can be seen that the thickness increases along the section between the boreholes Mężyk 1 and Września IG 1, and decreases again along the further section. The differences of the bottom depths of the Rotliegend strata testify that these rocks fill in the denivelations of the post-Carboniferous relief (J. Tomasik, 1992). In Figure 7 two last boreholes (Sobiesęki 2 and Gumunice 6) have not been marked because of a big distance from these boreholes to the borehole Brudzewek 1 and considering also the small thickness and rather monotonous development of the Rotliegend strata in this section of the profile II.

The vertical cross-sections through the boreholes in question show, first of all, the presence of the Upper Rotliegend — Saxonian (P. Karnkowski, 1993). In two boreholes,

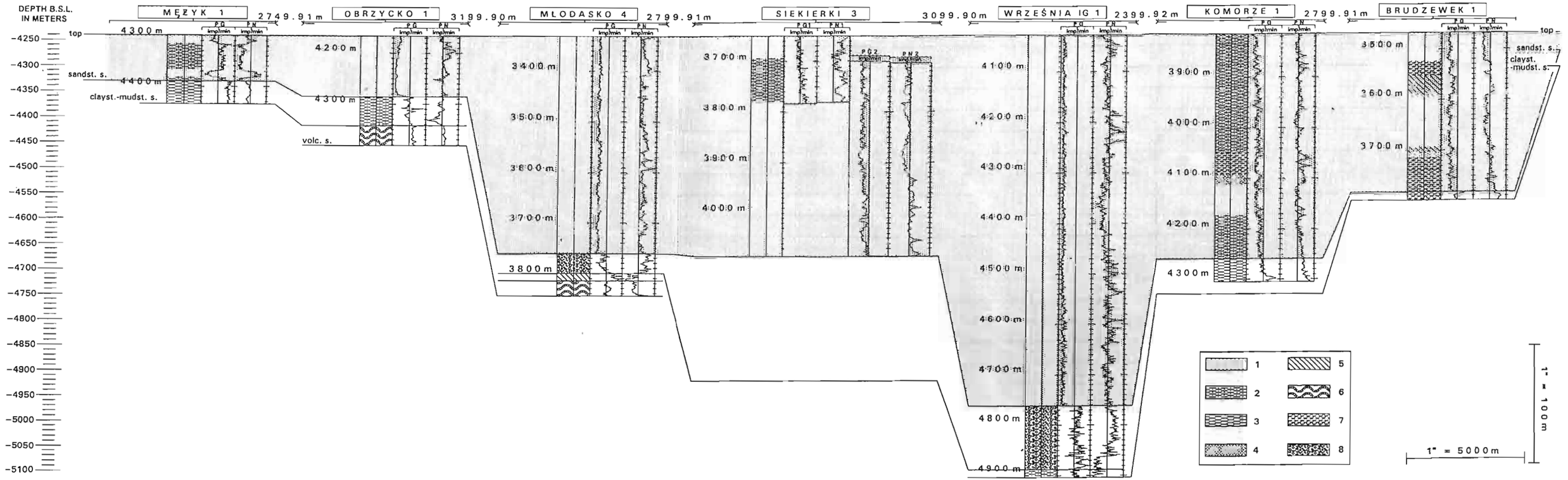


Fig. 7. Correlation of lithological series identified in wells along profile II–II (apart from Sobieseki 2 and Gomunice 6); top of Rotliegend means the reference level; lithological rock profile constructed basing on geophysical interpretation

1 — sandstone series, 2 — sandstone-claystone series, 3 — claystone series, 4 — claystone-mudstone series, 5 — conglomerate-claystone series, 6 — volcanics, 7 — sandstone-mudstone series, 8 — conglomerate series; other explanations as in Fig. 6

Korelacja serii litologicznych wydzielonych na profilu II–II (z wyjątkiem otworu Sobieseki 2 i Gomunice 6); poziom odniesienia — strop czerwonego spągowca; profil litologiczny został wyznaczony na podstawie interpretacji pomiarów geofizyki wiertniczej

1 — seria piaskowcowa, 2 — seria piaskowcowo-iłowcowa, 3 — seria iłowcowa, 4 — seria iłowcowo-mułowcowa, 5 — seria zlepieńcowo-iłowcowa, 6 — seria utworów wulkanicznych, 7 — seria piaskowcowo-mułowcowa, 8 — seria zlepieńcowa; pozostałe objaśnienia jak na fig. 6

Table 6

Identified lithostratigraphic series in the wells along the profile II (depth in m)

Series	Mężyk 1	Obrzycko 1	Młodasko 4	Siekierki 3	Września IG 1	Komorze 1	Brudzewek 1	Sobieszęki 2	Gomunice 6
Top	4298.4	4165.0	3330.0	3650.0	4027.0	3814.0	3467.0	2829.0	3090.0
Sandstone	4298.0–4389.0	4165.0–4285.5	3330.0–3760.0	3650.0–4085.5	4027.0–4762.0	3814.0–4259.0	3467.0–3783.0	2829.0–2864.0	3090.0–3098.0
Claystone-mudstone	4389.0–4434.0	4285.5–4342.5				4259.0–4305.0			3098.0–3118.0
Conglomerate			3760.0–3799.0		4762.0–4889.0			2864.0–2893.0	
Mudstone-claystone			3799.0–3815.0		4889.0–4904.2		3783.0–3799.0	2893.0–2898.0	
Volcanics		4342.5–4381.7	3815.0–3845.0						
Bottom	4434.0	4381.7	3845.0	4085.5	4904.2	4305.0	3799.0	2898.0	3118.0

Obrzycko 1 and Młodasko 4, there are volcanic rocks that may be included into the Lower Rotliegend — Autunian (J. Tomasik, 1992; P. Karnkowski, 1993). In the borehole Obrzycko 1 the lowermost horizon, developed as a complex of intermediate and acid volcanic rocks and their tuffs, was included by P. H. Karnkowski (1987) into the Wyrzeka Volcanite Formation. The well logging data have suggested the presence of acid volcanics as it may be inferred from an anomaly with a high amplitude on the GR curve. P. H. Karnkowski (1987) and J. Pokorski (1978) singled out the so-called Obrzycko Member as the complex of tuffogenic rocks. Also in the borehole Młodasko 4, the lowermost series of the Rotliegend strata included by P. H. Karnkowski (1987) into the Wyrzeka Volcanite Formation is present. In the well report of this borehole, a volcanic breccia, fragments of sandstones and tuffogenic rocks were described at this position. In Figure 7, the lowermost layer in the complex of the Rotliegend strata in the borehole Obrzycko 1 and Młodasko 4 has been described as "volc.s.", and its bottom corresponds with the bottom of the Rotliegend.

In the both mentioned boreholes, the volcanic series is overlain by a claystone-mudstone one, designated on the diagrams as "clayst.-mudst. s." In the borehole Obrzycko 1, there dominate sandy claystones grading into mudstones. P. H. Karnkowski (1987) includes this series into the Polwica Conglomerate Member. However, but the present authors, on the basis of well logging data and core descriptions in the geological well report, tend to include it into the Siekierki Sandstone Formation without distinguishing the conglomerate member. In the borehole Młodasko 4 the described series is built mainly of mudstones (P. H. Karnkowski, 1987) and forms the lowermost horizon of the Siekierki Sandstone Formation like it was in the previous borehole. The claystone-mudstone series has also been identified by the authors in the borehole Mężyk 1, where the presence of sandstones is significant. In the geological well report the fragments of volcanic rocks were also mentioned.

The claystone-mudstone series is overlain in all the boreholes of the profile II by a characteristic sandstone-claystone-mudstone horizons with the subordinate amount of conglomerates, marked in Figure 7 as "sandst. s.". It always occurs in the top part of the Rotliegend complex. In most of the boreholes this complex may be included into the Siekierki Sandstone Formation (P. H. Karnkowski, 1987) as it is in the borehole Siekierki 3, where the described series is composed of predominant sandstones with significant porosity (average 8.5%) and subordinate claystones. In the next borehole, i.e. Września IG 1, a sandstone series has been distinguished as the Siekierki Sandstone Formation. Below, a conglomerate series has been identified that according to P. H. Karnkowski (1987) constitutes the Polwica Conglomerate Member.

In the lowermost part of the Rotliegend section in the Września IG 1 borehole, a series has been distinguished with the age described by P. H. Karnkowski (1987) as older than the one of the Dolsk Formation. The map showing the extent of the Dolsk Formation in Wielkopolska places the borehole Września IG 1 in the area where the Lower Carboniferous rocks (sandstones and shales) occur. So, it cannot be excluded that the layer distinguished in the interval 4889.0–4904.2 m is of the Carboniferous age. In the borehole Komorze 1, a claystone horizon has been distinguished at the bottom of the Rotliegend. It was included into claystone-mudstone series at is seen in Figure 7. It is overlain by a sandstone series with subordinate claystones and mudstones ("sandst. s." in figures) which extends as far as the top of the Rotliegend. Similarly, in the borehole Brudzewek 1, a lowermost layer, developed as sandstones and mudstones with some claystones (3783.0–3799.0 m), has been distinguished and included in figures as the "clayst.-mudst. s.", being a complex definitely different from the "sandst. s.", containing significantly more sandstones. In the borehole Sobieszęki 2 (not shown in Fig. 7, for location see Fig. 1, for series see Tab. 6), a "clayst.-mudst. s." has also been identified (2893.0–2898.0 m) which is similar in its lithological development to the series with the same designated name in the borehole Brudzewek 1. It is overlain by a conglomerate series containing sandstones, conglomerates and mudstones, and then by a sandstone series ("sandst. s.") with rather high porosity. In the last borehole — Go-

Table 7

Identified lithostratigraphic series in the wells along the profile III (depth in m)

Series	Piła 1/IG 1	Szubin IG 1	Byczyna IG 1	Budziszewice IG 1
Top	4380.0	4318.0	5054.0	4559.5
Sandstone	4380.0–5160.0	4318.0–4878.0	5054.0–5535.0	4559.5–4813.0
Claystone-mudstone	5160.0–5272.0	4878.0–5156.0		4813.0–4930.0
Claystone-conglomerate	5272.0–5358.5			4930.0–5050.0
Volcanic	5358.5–5380.0*			
Bottom	5468.0	5156.0	5535.0	5050.0

*In Piła 1/IG 1 well lack of well logging data in interval: 5380.0–5468.0 m.

munice 6 (not shown in Fig. 7, for location see Fig. 1, for series see Tab. 6) — of the profile in question, a layer "clayst.-mudst. s." has been distinguished (3098.0–3118.0 m) followed by a sandstone series ("sandst. s."). The thickness of the Rotliegend is only 28 m in this borehole.

Description of the lithological correlation along profile III (Fig. 8, Tab. 7). The profile III runs generally NW–SE, its total length is being 284 km. The thickness of the Rotliegend strata varies along the profile from 481.0 m in the Byczyna 1 to 1088.0 m in the borehole Piła 1/IG 1, being significantly high along the profile III in comparison with the two remaining ones. So does the depth of burial of the Rotliegend rocks: their most shallow top occurs at the depth of 4318.0 m in the borehole Szubin IG 1 and the deepest bottom at the depth of 5535.0 m in the hole Byczyna 1.

The strata of the Rotliegend are represented along the profile III by its upper part — the Saxonian. Only in the borehole Piła 1/IG 1, does the lowermost layer (5356.5–5468.0 m) belong to the Lower Rotliegend — Autunian and is formed by the complex of volcanic rocks, described in the well report as rhyolites and diabases. The low value of a respective anomaly on a GR curve indicates rather basic igneous rocks (diabases). In Figures 8, this layer has been designated as a "volc. s.".

The Saxonian complex is developed in the boreholes in question as the Piła Claystone Formation (P. H. Karnkowski, 1987). The lithological profiles of the boreholes Piła 1/IG 1 and Szubin IG 1 are similar, dominated by claystone-sandstone series with subordinate mudstones and conglomerates.

In the four boreholes of the profile III, the series of reservoir rocks has been delimited, designated as before as the "sandst. s.". In the borehole Byczyna 1 the whole Rotliegend is limited to this series. The reservoir claystone-sandstone rocks are characterized by low porosity, while the porosity of locally occurring sandstones does not exceed 7%.

A series of claystones-mudstones has been distinguished below the "sandst. s." in three other boreholes (apart of the Byczyna 1) and described in Figure 8 as a "clayst.-mudst. s.". These rocks are non-porous.

In the boreholes Piła 1/IG 1 and Budziszewice 1, the claystone-mudstone series is underlain by a claystone-conglomerate series ("clayst.-congl. s." in Fig. 8). Also these rocks are non-porous.

Figure 8 illustrates the changes in the thickness of the Rotliegend complexes and the details of palaeo-relief of the sub-Permian basement. The bottom of Zechstein was the reference level in Figures 6 and 7. In Figure 8 the Rotliegend strata are referred to the sea-level, showing in this way the current depths of the rock series in question.

CONCLUSIONS

Comprehensive interpretation of well logging data, carried out in 22 boreholes in which the Rotliegend strata occur, enabled the determination of lithology and porosity of these rocks. The detailed lithological subdivision and calculation of porosity values have been made on the basis of well logs with the use of the GEO computer program. The delineated subdivision of the studied rock profiles into porous and sealing series will allow to determine the exact thicknesses of reservoir layers. The results of comprehensive interpretation of lithology on the basis of well logging data are more reliable in comparison to a qualitative appraisal, inferred from apparent values, recorded during measurements in wells.

The generalized complexes ("series") have been correlated along selected profiles. Correlations along longitudinal profiles (concordant with the NW– SE axis of the basin) and transversal ones show the trends of changes in depths, thicknesses and relations of rock sequences in individual parts of the area in question. The lack of some "series" in profiles suggests variations in conditions of sedimentation. Discontinuity of some correlation lines between the boreholes under study supports the authors' assumption about changes caused by facies differentiation.

The results of interpretation of well logging data may be applied in geological consideration aimed at evaluation of reservoir capacity of the Rotliegend rocks (generation, migration and storage of hydrocarbons). The comparison of results of geophysical interpretation with core analyses may bring about new data on the development of the Rotliegend strata.

The possibility of an integrated interpretation of geophysical data (seismic and well logging ones) in the study area, offered by the introduction of interactive workstations, gives the chance to recognize fully its geological structure. The interpretation of well logging data instead of only recording the curves makes a final geological model more reliable.

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KORELACJA UTWORÓW CZERWONEGO SPĄGOWCA NA OBSZARZE POLSKI CENTRALNEJ NA PODSTAWIE WYNIKÓW INTERPRETACJI PROFILOWAŃ GEOFIZYKI WIERTNICZEJ

Streszczenie

Interpretacja kompleksowa profilowań geofizyki wiertniczej, przeprowadzona na podstawie wybranego zestawu pomiarowego, umożliwiła określenie litologii i wyznaczenie współczynników porowatości ogólnej w utworach czerwonego spągowca na obszarze Polski centralnej. Szczegółowe rozdzielenie litologiczne oraz obliczenie współczynników porowatości wykonano za pomocą programu GEO. Przedstawiono podział badanych utworów na serie porowate i uszczelniające wraz z określeniem ich miąższości i porowatości średnich. Kompleksowa interpretacja w zakresie oceny litologii, na podstawie pełnego zestawu profilowań geofizyki wiertniczej, podwyższa wiarygodność wyników w zestawieniu z jakościową i szacunkową oceną prowadzoną jedynie na podstawie analizy wartości pozornych, rejestrowanych w czasie pomiarów otworowych.

Korelacja uogólnionych kompleksów („serii") wzdłuż wybranych profili została przeprowadzona na podstawie wyników kompleksowej interpretacji, tzn. na podstawie profilów litologicznych oraz wykresów zmian porowatości ogólnej wraz z głębokością. Korelacje wzdłuż profili podłużnych (zgodnie z osią basenu permskiego — NW–SE) oraz profili poprzecznych pokazują schemat zmian głębokości występowania, miąższości oraz wzajemnego ułożenia sekwencji osadów czerwonego spągowca w poszczególnych częściach badanego obszaru. Brak niektórych „serii" w profilach otworów sugeruje zmienność warunków sedymentacji. Brak ciągłości niektórych linii korelacyjnych, prowadzonych między otworami, potwierdza możliwość zmian związanych ze zróżnicowaniem facjalnym.

Wyniki interpretacji profilowań geofizyki wiertniczej mogą być wykorzystane do interpretacji geologicznej pod kątem określenia zdolności utworów czerwonego spągowca do gromadzenia, migracji i produkcji węglowodorów. Konfrontacja wyników interpretacji geofizycznej z analizą rdzeni może być źródłem dodatkowych informacji o budowie utworów czerwonego spągowca.