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SUMMARY

The Nowa Rola P 9 borehole was drilled in the central part of the Żary Pericline near the town of Nowa Rola, Tuplice Commune, Żary Poviat, Zielona Góra Voivodeship at the time of drilling (currently Lubuskie Voivodeship), approx. 6.5 km SW from the town of Lubsko. In the sub-Cenozoic structural pattern, the Żary Pericline borders in the north with the Fore-Sudetic Monocline, in the east with the Fore-Sudetic Block, and in the south with the Cretaceous North Sudetic Trough. Currently, in the sub-Cenozoic pattern, the northern part of the Żary Pericline is included in either the Fore-Sudetic Monocline (which adjoins the Cretaceous North Sudetic Trough in the south) or the North Sudetic Synclinorium, and in the Sub-Permo-Mesozoic pattern – to the Fore-Sudetic Block, separated from the Sudetes by the Sudetic Marginal Fault. This synclinorium, along with the Fore-Sudetic Block, is part of the Lower Silesian Block that is an element of the Fore-Sudetic segment of internides of the Variscan fold belt, bounded in the north by the Middle Odra Fault Zone.

The main purpose of the drilling was to search for copper ores in Zechstein deposits, to acquire details on the geological structure of the Żary Pericline, to identify lithologies and facies of the rock formations with particular attention to Zechstein copper deposits, to make a preliminary prospects of ore-bearing rocks, to study the oil and gas accumulations in Permian deposits, and to determine the economic usefulness of other raw materials in drilled rocks.

The Nowa Rola P 9 borehole (according to the CBDG – Nowa Rola P-9) was drilled within the framework of the *Project of prospecting for Zechstein copper ores in the areas of western Fore-Sudetic Monocline,* Żary *Pericline and North Sudetic Trough* (Wyżykowski, 1974). The drilling was stopped in volcanic rocks at a depth of 1466.0 m, after drilling through the Quaternary, Neogene, Paleogene, Triassic (Muschelkalk, Buntsandstein), Permian (Zechstein, Rotliegend) and Permian-Carboniferous deposits. Except for a few borehole sections with a total length of 102.9 m (in the Cenozoic (Quaternary, Paleogene) and Upper Permian), the drilling was fully cored. The drill core material obtained from this borehole provided geological data that became the basis for many substantive studies and all chapters of this volume.

This volume contains results of studies presented in the geological documentation entitled *Prospecting for Zechstein copper ores in the area of the* Żary *Pericline. Final geological reports of the boreholes: P-3 Górzyn, P-5 Sieciej*ów, *P-9 Nowa Rola, P-11 Grotów* (Gospodarczyk et al., 1979).

An integral part of this volume is expert reports on ore, geochemical studies of the Zechstein, palaeontological and micropalaeontological studies of Neogene and Triassic deposits, as well as the results of research on oil and gas reservoir levels. Modern verifications of the studies, reinterpretations, supplements and new results of lithological, stratigraphic, petrological and sedimentological investigations are also included. They are in particular those representing such issues as: ore petrology, geochemistry and organic matter maturity, thermal history and burial conditions, petrography of the Permian-Carboniferous deposits, microfacies of the Weissliegend, the Kupferschiefer and the Zechstein Limestone, petrography of the Weissliegend and Rotliegend sandstones, petrography and sedimentary environment of the Main Dolomite, characteristics and depositional conditions of the Zechstein salt sedimentation, petrography of the Triassic rocks, uranium mineralization in the Buntsandstein, characteristics and palaeogeography of the Paleogene, Neogene and Quaternary deposits, physical properties of the rocks, and results of reflection seismic surveys.

The company Przedsiębiorstwo Poszukiwań Geofizycznych in Warsaw performed a set of standard well logs within the depth interval down to 1455 m (radiometric, electrical, acoustic, thermal logs), using devices that, compared to modern counterparts, allowed for a limited identification of rocks.

On account of the quality of presented data and the number of different various geophysical well-logs, the results of measurements in the Nowa Rola P 9 borehole are valuable information that can be used in future for the reinterpretation or correlation of results of other geophysical surveys carried out in the vicinity of this borehole. However, a fully reliable quantitative interpretation of the data is impossible due to the lack of digitized measurements and, first of all, the specificity of the measuring devices used before modern ones had been introduced. These measurements allowed for the assessment of the technical condition of the borehole, verification of the lithological-stratigraphic section obtained from drill core logging by macroscopic description, microfaunal and petrographic studies, determination of the intervals containing useful minerals, and assessment of hydrogeological and thermal conditions.

Well-log measurements were performed in the Nowa Rola P 9 borehole in four main depth intervals. In total, 15 different measurements were made in five intervals, the purpose of which was to determine the depth intervals containing useful minerals. Hydrogeological and thermal conditions

were assessed and the lithology and stratigraphy were reinterpreted. The measurements were made using Russian analog tools that, compared to those used today, allowed for a limited identification of lithologies. An attempt was made to interpret selected research results qualitatively on the basis of macroscopic description of drill core, taking into account the influence of lithology on the characteristics of selected well-log curves. Borehole geophysics and reflection seismic measurements confirmed the presence of most lithological boundaries, primarily the boundary between the Upper Oligocene Leszno Formation and the Lower Muschelkalk, as well as within the Triassic and Zechstein deposits, including the boundaries of the Older Potash. It was found that the description of drill cores from the depth interval of 0.0–881.35 m is almost completely consistent with the section interpreted from well-log measurements, even though there are slight discrepancies with regard to the boundaries within the Triassic rocks. Significant discrepancies concern the boundaries of lithostratigraphic units within the PZ2, PZ3 and PZ4, while the greatest shifts between the boundaries from drill cores and those from well-logs do not exceed 5 m. Detailed analysis of the lithological succession within the PZ4a subcyclothem showed errors in the position of drill cores in boxes, affecting the interpretation of stratigraphy.

An attempt was made to locate volcanic and sedimentary deposits from a depth of 1405.7–1452.85 m within the lithostratigraphic section, considering their Permian-Carboniferous or Early Permian (Lower Rotliegend) age, in relation to the lithostratigraphic divisions in both the North Sudetic Basin and the Polish Lowlands. The volcanic and clastic rocks (conglomerates, sandstones, mudstones and claystones) from the lower part of the Nowa Rola P 9 borehole section in the interval 1444.8–1466.0 m (undrilled), assigned to the Carboniferous in the borehole's summary report, may as well represent the Permian-Carboniferous or Early Permian (Lower Rotliegend). Their stratigraphic affiliation is not definited, but it seems that they belong to the lowest Rotliegend (Autunian) based on regional correlations. As a result, the volcanic series (1452.85–1466.00 m) and the sedimentary series (1405.70–1452.85 m) have been included in the Lower Rotliegend, while the series from the depth interval of 1391.18–1405.70 m has been assigned to the Upper Rotliegend (Saxonian). Throughout the Rotliegend clastic deposits, there are numerous current structures, erosional gaps, carbonate cementations, and pedogenic levels.

The volcanic rocks, originally included in the Carboniferous and previously described as porphyrites and melaphyres or trachites, in the light of current research should be considered as trachyandesite-type rocks (in the lower part of the volcanic series) and dacite-type rocks (in the upper part of the series), with a porphyric structure and features characteristic of altered andesites.

The Zechstein deposits directly overlie the Upper Rotliegend rocks. The Zechstein succession is thick (509.83 m) and occurs in the interval ranging from 881.35 to 1391.18 m. The section is not disturbed tectonically and consists of three carbonate-evaporite cyclothems: PZ1, PZ2 and PZ3, and the terrigenous-evaporite cyclothem PZ4, subdivided into the PZ4a subcyclothem and the top terrigenous series PZt. The cyclothems are characterized by variable thicknesses (PZ1 – 252.68 m, PZ2 – 108.5 m, PZ3 – 112.6 m, PZ4 – 36.05 m) and a significant completeness of the sections. Detailed analysis of well-log curves showed the presence of the Older Potash (K2) in the interval of 1038.0–1050.0, not found during drill core logging due to a core gap.

The well-cored boundary section between the Zechstein and Upper Rotliegend revealed the presence of the lowermost Zechstein transgressive deposits represented by light grey, fine-grained sandstones that are a product of washing out the Upper Rotliegend alluvial and aeolian sediments by the transgressing sea. These sandstones represent the Weissliegend marine deposits (Ws1) – an equivalent of the Zechstein Basal Conglomerate (Zc1) composed of sandy facies with a thickness of 4.30 m (1386.88–1391.18 m). An erosional surface separates the Saxonian deposits from the marine Weissliegend (Ws1). The Ws1 consists of two sedimentary sequences: the lower part from a depth of 1387.16–1391.18 m (4.02 m thick) and the upper part from 1386.88–1387.16 m depth (0.28 m thick). The lower part (light grey sandstones – subarcosic and sublithic arenites, cemented with calcite and anhydrite, with current bedding, erosional scours and bioturbation) represents transgressive deposits of the Zechstein sea. The upper part (fine-grained sandstones – grey, calcite- and sulfide-cemented sublithic arenites, with irregular streaks of fine-grained terrigenous-organic material, fine cryptobioturbation, and numerous clay balls) is composed of post-transgressive marine deposits that accumulated during progressive bathymetric stabilization in a slightly deepened but still shallow sea.

Above, there is the characteristic Kupferschiefer (T1) with an average thickness of 50 cm, represented by finely laminated black clayshales and dark grey mudshales and shaly marls. The Kupferschiefer represents the mature stage of the Zechstein sea transgression, related to a deepening of the basin and deposition in the anaerobic water zone. The overlying Zechstein Limestone (Ca1) attains a considerable thickness of 13.17 m due to deposition in a depression existing between a coastal carbonate platform and the Szprotawa Elevation. It is represented by grey limestones. In the lower part, there is the micrite complex deposited in a deep sub-littoral environment, and in the upper part – the oncolite complex that accumulated in a shallow sub-littoral environment during a regressive trend. The overlying evaporite levels were deposited in shallow sedimentary basins as a result of increased seawater salinity. The rock salt was deposited in a salt lagoon that was subject to periodic shallowing, and the Older Potash (K2) was formed in a shallow salina. In turn, episodes of inflow of marine waters to the salt lagoon resulted in a change in the chemical regime in the basin, causing the deposition of sulfate layers.

The currently performed petrographic and microfacies studies of the Main Dolomite (Ca2) show the presence of mudstones, bioclastic wackestones, ooid grainstones and thin microbialite/stromatolite interlayers in the lower part, suggesting the location of the Ca2 section in the zone of intra-platform progradation of an oolitic shoal.

The Zechstein deposits are covered by Triassic rocks, 690.35 m in thickness (191.0–881.35 m), representing the Lower and Middle Triassic. Macroscopic observations, and detailed palaeontological, micropalaeontological and petrographic-microfacies studies enabled distinguishing the Lower, Middle and Upper Roetian (Röt) Buntsandstein and the Lower Muschelkalk within the Triassic section. The Induan/Olenekian boundary is located most likely in the lower part of the Middle Buntsandstein. The Buntsandstein reaches a thickness of 656.05 m (at a depth of 225.3–881.35 m), and the Muschelkalk is 34.3 m thick (in the interval 191.0–225.3 m); however, the Muschelkalk section is strongly reduced due to erosion. The use of historical lithological descriptions and well-log curves allowed correcting the boundaries of Triassic lithostratigraphic units in relation to the subdivision presented in the borehole summary report. The Lower Buntsandstein rocks have been included in the Baltic Formation, and a detailed subdivision of the Middle Buntsandstein into the informal Carbonate-Clastic Formation and the Sandstone Formation has been proposed. It should be noted that the Muschelkalk, which was originally thought to be absent in the borehole section, has ultimately been proved on the basis of both lithological features and the regional correlation of Triassic sections.

The Lower Buntsandstein is composed of sandstone-claystone heteroliths of variable colours (grey, brown and red), with laminae and interbeds of limestones, including oolite limestones. The Middle Buntsandstein is represented from the base upwards by fine-grained sandstones with clay cement, sandstones with carbonate ooids, interbedded with fossil-containing dolomites, and fine-grained sandstones with numerous claystone interbeds. Deposition of the Lower and the Middle Buntsandstein took place in the marginal zone of a very shallow epicontinental basin in transitional, terrestrial-marine environments. The Upper Buntsandstein is represented by the informal Roetian “formation” composed of calcareous-clay-evaporite deposits that accumulated in the environments of mud flat, sabkha, and a very shallow-marine basin or a vast embayment.

The Roetian deposits host varied macro- and microfossils, including the index bivalve *Costatoria costata* (Zenker), as well as numerous foraminifera, gastropods, ostracods and remains of fish. The Roetian/Muschelkalk lithological transition is gradual; therefore, it is difficult to establish a lithostratigraphic boundary between these units. The decision to draw the boundary at a depth of 225.3 m was made because it is well visible on the gamma log curve. The Lower Muschelkalk is composed of alternating dolomitic or marly limestones and marly claystones, predominantly grey in colour, with interbeds of marls and dolomites containing marine fossils. These deposits were accumulated in a very shallow zone of an epicontinental marine basin.

As in the entire area of the immediate neighbourhood of the Fore-Sudetic Block, the discussed section lacks the upper Middle and Upper Triassic, Jurassic and Cretaceous deposits that were removed as a result of tectonic inversion in the Late Cretaceous and Early Paleogene. Consequently, the 191-m thick Cenozoic formations rest directly on the Muschelkalk. The Paleogene section is represented by regressive deposits of the Leszno Formation (58 m thick) included in the Upper Oligocene, whose lower part is represented by grey fine-grained quartz sands with admixture of muscovite and glauconite, overlain by silts and silty clays with thin interbeds of carbonaceous silt containing plant detritus.

The Neogene succession is represented by the Miocene formations: Rawicz, Ścinawa and Pawłowice, with a total thickness of 90 m. The Neogene deposits were accumulated in a terrestrial environment on an alluvial plain with coastal swamps and coal-forming peat bogs. Lignite beds, from 1.6 to 8.7 m in thickness, occur within the Rawicz Formation (4th Dąbrowa Seam) and the Ścinawa Formation (3rd Ścinawa Seam and 2nd Lusatian Lignite Seam). The lignite is represented by atrite-xylite-rich coal. The Quaternary deposits are 43 m thick. These are glaciofluvial sands with gravel deposited in the Głogów-Baruth Ice-Marginal Valley that formed during the Middle Polish Wartanian Glaciation.

In accord with the main purpose of the borehole, which was the prospect for copper ores in Zechstein deposits, extremely important are the results of microscopic studies of polished sections of Zechstein copper-bearing rocks, observed in reflected light. They show the presence of rich lead-zinc mineralization represented by galena (PbS) and sphalerite (ZnS). These ore minerals are accompanied by chalcopyrite ($CuFeS_2$) and pyrite (FeS_2), and trace amounts of bornite (Cu_5FeS_4) and marcasite (FeS_2). The highest mineralization level is found in the Kupferschiefer (the high lead contents range from 0.67 to 15.96%, and zinc is from 0.78 to 3.72%), as well as in the directly overlying carbonate rocks and in the middle and upper parts of the Weissliegend sandstones. Poor copper mineralization appears in the middle part of the Weissliegend; in a 1.6-m thick interval, the copper content is in the range of 0.07–0.27, the weighted average copper content is 0.15%, and the Cu concentration is 5.6 kg/m^2.

A significant verification of the ranges of metallic zones results in the location of the Nowa Rola P 9 borehole in the peripheral part of the lead-zinc mineralization system, surrounded by the copper-bearing zone with prospective Cu-Ag deposits and areas adjoining the oxidized zone (Rote Fäule). This fact is the basis for the conclusion that copper-silver mineralization should be searched for in the Żary Pericline in the immediate vicinity of the oxidized zone. The ore-bearing deposits around the borehole are characterized by favourable temperature conditions for the potential mining industry, as the temperature under conditions of thermal equilibrium at a depth of 1366 m is 49.6°C, the average geothermal degree in the 33–1366 m depth interval is 42.8 H/m/°C, and the average gradient is 2.34 G/°C/100 m.

The analysis of natural gamma radiation of Lower Triassic rocks in the Żary Pericline showed that uranium-enriched levels are present only in the Middle Buntsandstein, where they form two uranium-bearing horizons. In this borehole, there is only level I (upper), which is characterized by variable U concentrations ranging from a few to 600 ppm, while in the northern part of the Żary Pericline, there is also level II. Uranium mineralization in the Żary Pericline area is of no raw material importance due to the low content of uranium and low thickness of the mineralized zones.

The previously performed geochemical and petrological studies of organic matter showed that it is concentrated mainly in the Kupferschiefer and subordinately in the Zechstein Limestone. The high contents of C_{org} (up to 6.0%), bitumens (up to 0.43%) and nickel, and vanadyl porphyrins, n-alkanes and isoprenoids in the Kupferschiefer indicate reducing conditions during sedimentation and early diagenesis. The composition of organic matter is dominated by allogenic (redeposited) vitrinite, accompanied by authigenic (primary) vitrinite and inertinite. Results of historical Rock-Eval analyses showed that organic matter in the Kupferschiefer is characterized by high values of TOC (7.5%), hydrogen index HI (260–316 mg HC/g TOC) and T_{max} (440°C), and by moderate reflectance of authigenic vitrinite (0.75–0.98% R_O). They also exhibit low values of the OI oxygen index (13–29 mg CO_2/g TOC), which indicates the presence of mixed type II/III kerogen, characterized by moderate thermal maturity typical of the initial stage of crude oil generation, with a very good hydrocarbon potential. These data denote the maximum palaeotemperatures of diagenesis of the sediments, not exceeding 100°C. The current studies of organic matter in the Weissliegend and the Zechstein Limestone show that the organic matter dispersed in the Zechstein Limestone is represented by type III and type IV kerogen, and the composition of the Weissliegend is dominated by hydrocarbons originating from migration. Due to the low content of organic carbon in the sandstones and limestones, these rocks exhibit no generative potential.

The porosity analysis was carried out on the Permian-Carboniferous (Lower Autunian volcanic and sedimentary) and the Rotliegend (Upper Autunian and Saxonian) deposits from the depth interval of 1402.4–1466.0 m. These deposits are of low porosity, ranging from 2 to 10%.

The use of one-dimensional modelling technique made it possible to reconstruct both the burial history of the Permian, Mesozoic, Paleogene and Neogene deposits, and the thermal evolution of this part of the basin. The borehole section reveals the presence of phases of increased burial and rapid sediment deposition rates in the Permian (up to 500 m/Ma) and Early Triassic (over 200 m/Ma). We can also see time spans of decreasing subsidence rates and deposition rates to below 20 m/Ma in the Middle and Late Triassic, Jurassic, Late Cretaceous, Paleogene and Early Neogene, when the periods of burial were interrupted by periods of uplift and erosion that lasted until the Miocene. The maximum burial depth of the base of the Permian-Triassic section is 1600 m, and about 1700 m in the Late Cretaceous, and the maximum palaeotemperature for the base of the Zechstein is in the range of 70–90°C, which means entering into the oil window phase.

The Żary Pericline area is poorly explored in terms of hydrogeological conditions. In the Nowa Rola P 9 borehole, no detailed hydrogeological test was performed (except in the Main Dolomite). Groundwater was analyzed in the nearby boreholes, obtaining limited knowledge about aquifers in the Rotliegend (strongly altered brines of Cl-Na (-Ca) type, mineralization about 250–300 g/dm^3), the Main Dolomite (Cl-Na brines, mineralization 143–330 g/dm^3) and the Buntsandstein (poorly mineralized waters).

The Main Dolomite rocks in the Nowa Rola P 9 borehole are fractured and exhibit very poor reservoir properties and the permeability coefficient of 0.65 mD. Drill stem testing showed a slight inflow (0.25 m^3/h) of brine containing 27.1% of NaCl. The brine contains a small amount of dissolved gas (11 ml/dm^3), at a formation pressure of 116.4 at and a pressure gradient of barely 1.06 at/10 m, which is a characteristic value for the marginal parts of the Permian Basin. The gas is a typical nitrogen gas with a low content of hydrocarbons: methane and ethane (4.65% of the gas mixture), and with a small admixture of helium.