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SUMMARY

The Ruptawa IG 1 borehole was drilled in the western part of the Upper Silesian Coal Basin (USCB), which is a Variscan geological unit composed of Carboniferous coal-bearing molasse deposits of the Moravo-Silesian Basin. Basement of the USCB consists of Precambrian, Cambrian and Devonian rocks. Carboniferous deposits begin with the *pre-flysch carbonate* association passing into marine clastics of the flysch association, and then into coal-bearing molasse deposits. A characteristic feature of the Carboniferous coal-bearing deposits is their clear bipartition. The older part of the section is composed of sediments that developed in paralic conditions with the influence of periodic marine inundations, lithostratigraphically referred to as the Paralic Series. These deposits constitute the dominant element of the geological structure of the Carboniferous succession in the western part of the basin. Their maximum thickness reaches nearly 3800 m. The remaining, younger part is composed of sediments accumulated exclusively in terrestrial conditions. Continental sedimentation begins with the deposits known as the Upper Silesian Sandstone Series. The Carboniferous overburden consists mainly of Miocene marine molasse deposits of the Carpathian Foredeep. In some areas, there are also Triassic deposits.

The geological and economic-geology objective of the Ruptawa IG 1 borehole was to examine the whole section of Carboniferous coal-bearing deposits, in particular the stratigraphy, lithology, lithofacies, petrography and sedimentology, coal-bearing potential and coal resources, coal quality and metamorphism of organic matter, as well as hydrogeological and coalbed-gas conditions, including the performance of direct hydrogeological investigations on the field. The borehole, after reaching the geological target (drilling through the base of coal-bearing deposits), was completed at a depth of 2485.00 m. From a depth of 240 metres, the borehole was continuously cored, including the bottom part of the Miocene and the entire Carboniferous section. The drill core has been extensively studied, e.g. for lithology and lithofacies, tectonics, petrography, mineralogy and geochemistry. Detailed biostratigraphic studies (micro-and macrofauna, flora and spores), chemical-technological and *coal-bed gas* resource assessment analyses, petrophysical and geotechnical investigations as well as well logs were also made.

The stratigraphic section of the Ruptawa IG 1 borehole is as follows: 0.00–10.00 Quaternary, 10.00–395.40 Neogene (Miocene – Badenian), 395.40–2485.00 Carboniferous, including Bashkirian (Namurian B) to 563.10 m and Serpukhovian (Namurian A) to 2485.00 m. Lithostratigraphically, the Miocene deposits represent the Skawina Formation, and the Carboniferous section is divided into: Upper Silesian Sandstone Series (395.40–563.10 – Saddle Beds), Paralic Series (563.10–2351.55, Poruba Beds – 995.20, Jaklovec Beds – 1136.60, Hrušov Beds – 1841.80, Petřkovice Beds – 2351.55), Malinowice Beds (2351.55–2485.0).

Miocene deposits occur between the Quaternary cover and the top of Carboniferous coal-bearing deposits. Lithologically, they are very poorly diverse deposits, composed of monotonous series of marly silty claystones and mudstones (locally sandy), deposited in a relatively shallow sea of normal salinity. Lithostratigraphically, they correspond to the Skawina Formation – the youngest unit of Miocene autochthonous molasse sediments of the Carpathian Foredeep. Their age (Lower Badenian – Moravian) has been determined on the basis of micropaleontological, mainly foraminiferal evidence.

Underneath the Miocene deposits, there is the Carboniferous succession represented by coal-bearing formations – Upper Silesian Sandstone Series and Paralic Series – and by marine terrigenous deposits of the Malinowice Beds (so-called Culm facies). Lithologically, the Carboniferous section is composed of sedimentary rocks, almost exclusively clastics, as well as phytogenic rocks in coal-bearing series. As regards the presence of basic lithological types of rocks, the Carboniferous section is relatively varied. The lithological variability is manifested mainly by the proportion of particular lithological types and subtypes, especially in the case of sandy sediments. Sandstones with coarse grain size (coarse-, very coarse-grained and variously grained rocks) are the most common types among continental deposits in the Upper Silesian Sandstone Series.

In the Paralic Series such sandstones are subordinate, and they are absent in marine deposits of the Malinowice Beds. The reason for these differences are facies and

palaeogeographic changes that took place in sedimentary environments during deposition of Carboniferous sediments: from waning marine deposition in the environments of coastal plains and deltas, through the period of deposition of paralic sediments with repetitive sea ingressions on land which was the area of following actual deposition of coals, to the complete cut-off of marine influences and deposition of continental series on extensive alluvial plains of braided and meandering rivers, with numerous peat bogs.

The essential part of the Carboniferous coal-bearing deposits in the Ruptawa IG 1 borehole is the Paralic Series. Its characteristic feature is cyclicity of the section that is composed of clastic and phytogenic rocks, as well as the presence of sediments deposited in the marine environment, often with numerous faunal remains that make up the so-called marine levels or horizons. The marine levels Barbara (V) and Enna (VII), showing a large lateral extent, considerable thickness and a rich faunal assemblage, are – along with the Polierschiefer (polishing slate)– the basis for the division of the Paralic Series into lower-order units. The lithology of individual lithostratigraphic units of the Paralic Series is not highly diverse. Throughout the entire section, sandy-muddy deposits are dominant. A higher proportion of coarser sandstones is observed only in the Poruba Beds (lithosome of the so-called Castle Sandstones). Noticeable is also remarkably greater sandiness of the Petřkovice Beds that mark the onset of coal-bearing deposition.

Sequences of sediments forming marine levels within the Paralic Series deserve particular attention. These levels of varying thickness (up to 200 m) have a specific lithology. These are coal-free complexes of fluvial and deltaic deposits accumulated as a result of periodic sea ingressions. They consist of a number of inversely graded regressive cycles: from claystones with marine fauna passing into silty clays, through mudstones with increasing sand content, to fine- and medium-grained sandstones with inverse graded bedding. A special feature of the Paralic Series in this borehole is the presence of micrite limestone interbeds in the complexes of marine levels. This is interesting because of the generally accepted view of the lack of limestones in the Carboniferous coal-bearing deposits of the USCB. To rocks of different lithology also include the Polierschiefer which is a perfect and easily distinguishable marker horizon. In the Paralic Series the presence of sapropelic rocks also draws attention, which is indicative of different conditions of deposition and burial of organic matter.

The coal-bearing potential of the Carboniferous coal-bearing deposits is 1.58%. The total number of coal beds is 93, each 0.05–2.50 m thick, and with the total thickness (excluding intergrowths) of 25.99 m. The coal-bearing potential of the drilled section of the Upper Silesian Sandstone Series is relatively low as compared to other regions of the basin, and amounts to 3.72%. This series contains two coal seams of recoverable reserves, 1.25 m and 2.50 m in thickness. The contributions of phytogenic rocks to the thickness of the individual units of the Paralic Series in the borehole are low and similar. The coal-bearing potential of the whole series is 1.10%. Only five coal seams of recoverable reserves have been identified, each 0.80–1.10 m in thickness.

Marine terrigenous deposits (Culm facies) – lithostratigraphically referred to as the Malinowice Beds – underlie the coal-bearing deposits of the Paralic Series down to the borehole bottom. Only the top section of the upper part of the Malinowice Beds has been drilled through. In the western part of the basin, the Malinowice Beds have not been examined as a whole (their thickness exceeds 1000 m in the region of the Ruptawa IG 1 borehole). Lithologically, the drilled portion of the Malinowice Beds is represented by sandy-muddy rocks and silty claystones.

The drill core from the Ruptawa IG 1 borehole was examined for the presence of fossils and sampled for a wide range of biostratigraphic investigations. In addition to the microfaunal studies of the Miocene deposits, floristic, palynological and macrofaunal studies of the Carboniferous rocks were also made. The floristic investigations were the basis for the palaeobotanical and phytostratigraphic characteristics of the Carboniferous deposits representing the Serpukhovian and early Bashkirian (Namurian A, B, ?Namurian C). The analysis was made on 3600 samples from 435 sampling intervals, in which well-preserved and taxonomically determinable flora, and diverse remains of plants related to coal-forming flora, have been found. In total, the entire Carboniferous section has provided 4000 plant remains, representing stratigraphically significant taxa as well as guide and index taxa.

Palynological studies (microspores and megaspores) were made on 24 coal samples from the 434.10–1741.60 m depth interval. Because of both a high degree of coalification of organic matter and alteration of exines, the results of these studies are not significant for the determination of palynostratigraphic position of the Carboniferous deposits.

Carboniferous animal fossils (marine, brackish and freshwater fauna) occur in the 575.10−2481.70 m depth interval (Paralic Series and Malinowice Beds). These fossils document the presence of the Serpukhovian (Namurian A). Based on an analysis of faunal assemblages, a number of faunal horizons have been identified, which are important for the stratigraphy and stratigraphic correlations. Marine horizon Štur (XVI) have been distinguished within the Malinowice Beds, whereas the Paralic Series contains 18 intercalattions with marine fauna, 19 with freshwater fauna, and 10 with brackish fauna, including (from bottom to top) the following horizons: Geodor (XIV), Wilhelmina (XIII), Bruno (XII), Nanetta (XI), Franciszka (X), Bezimienny (VIII), Enna (VII), Barbara (V), Gabriela (IVb), Koks (IVa) and Roemer (Ib).

For the whole Carboniferous section drilled, detailed petrographic-mineralogical studies of barren rock were made. Worth noting is the wide scope of research and a large number of analyses: 308 – microscopic, 175 – planimetric, 19 – X-ray diffraction, and 54 – thermal. Values of effective porosity and permeability were determined for 84 sandstone samples. The following types of clastic rocks have been identified based on the research: sandstones, mudstones,

claystones, tuffogenous rocks (tuffs, tuffaceous sandstones and mudstones, Polierschiefer) and carbonate rocks of inorganic origin (mainly limestones, rarely siderites).

Sandstones are fundamental for the petrographic variability in the borehole section. These are sublithic and subarkosic (rarely lithic) arenites and lithic and subarkosic wackes, ranging from fine-grained to coarse-grained. The grain fabric consists of quartz, potassium feldspars and plagioclases, micas and lithoclasts (mainly quartzites, quartz-mica shales and volcanic glass). The grains are bonded by a matrix or carbonate, siliceous and clay cement. The effective porosity of the sandstones varies from 0.2 to 12.1% and decreases with depth, from an average of 8.5% in the Upper Silesian Sandstone Series to an average of 1% in the Malinowice Beds. These rocks are very poorly permeable, with the permeability values commonly below 0.1 mD (with a maximum of 0.57 mD). The most important diagenetic processes in the Carboniferous rocks include: mechanical compaction, cementation by quartz and carbonates, kaolinitization, sericitization, albitization of feldspars, and replacement of feldspar grains and lithoclasts by carbonates.

Petrographic studies were also made on the coals. They were performed on 43 coal seams and intercalations from the 435.35–2376.10 m depth interval. The scope of research included analysis of macerals and microlithotypes, and determination of vitrinite reflectance values R0. The studies show that macerals of the vitrinite group are the main components of coal, and collinite far outweighs tellinite. Among microlithotypes the highest percentages are observed for vitrinite and vitrinertite. The predominant microfacies type is the vitrinite-vitrinertite type. The vitrinite reflectance value increases with depth, ranging from 0.85% at a depth of 435.35 m to 2.70% at a depth of 2376.10 m. The values indicate that the coal occurring to a depth of about 800 m has reached the second stage of coalification, which runs within orthocoking coal and manifests itself by vitrinization of almost all liptinite. Based on the R0 values it can also be assumed that the coals from a depth of about 2200 m are near the third stage of coalification, running at the boundary between semi-anthracite and anthracite.

Technological-chemical studies were performed for 41 coal seams and layers with a thickness of 0.05 to 2.50 m. The scope of this research included: technological analysis (moisture, ash, volatiles, heat of combustion and calorific value), coking and low-temperature carbonization properties (Roga index-caking ability, contraction and dilation, productivity of the trade semi-coke – temperature tar, destructive water and gas), coal type determination, grinding ability, apparent density, sulphur content (total, ash, combustible and pyritic sulphur), elemental analysis (carbon, hydrogen, oxygen and nitrogen) and chemical composition of ashes and their temperature characteristics. There are the following coal types found in the borehole section: 35.2 B (orthocoking), 36 (metacoking), 37.1 and 37.2 (semi-coking coals), 38 (lean coal), 41 (anthracite coal), 42 (anthracite). To a depth of 1500 m, there are mainly coking coals, and below are anthracites.

Geochemical analyses of coal ashes were performed for 39 coal seams and layers to determine the content of major, minor and trace elements. The scope of the analyses also included a direct determination of content of sulphur, phosphorus, chlorine and fluorine contents in coal. Main Elements (Si, Al, Fe, Ca, Mg, Na, K, S) were determined for the ashes obtained at the temperature of 815°C. In turn, for low-temperature ashes (525°C), minor and trace elements were determined: As, Ba, Br, Co, Cr, Ga, Ge, Mn, Mo, Nb, Ni, Pb, Rb, Sr, Th, Ti, U, V , Y, Zn, Zr. These analyses were the basis for determining the concentration of the individual geochemical components and of their variability in the Carboniferous section. The average ash content in the studied coals is 14.7%. The ashes contain mainly aluminum silicate. The pyrite content ranges from 0.02 to 7.44%. The average chlorine content is relatively low (648 g/t). The total sulphur content ranges from 0.21 to 4.42% (average 1.32%), and the lowest values are found in coals of the Saddle Beds. In the Paralic Series the average values exceed 1%. The average content of phosphorus is 209 g/t, of fluorine – 124 g/t. The contents of minor and trace elements are similar to the average values in the central part of the basin. Most of the identified elements (As, Be, Co, Cr, Ge, Mn, Nb, Ni, Ti, V, Y, Zn, Zr) show increased concentrations in the ashes of coals from the lower part of the Paralic Series. In the Saddle Beds, Ba and Pb enrichments are found.

Mineralogical investigations of Carboniferous rocks were carried out on 131 samples from the 782.6–2425.5 m depth interval. The most common mineralization forms are fillings of tectonic fractures, rarely are siderite and pyrite concretions. The fractures are usually found in sandstones and are filled with quartz, dolomite, ankerite, pyrite, calcite, anhydrite, kaolinite and galena. The older generation of fractures is filled with quartz. The concretions are composed of siderite and pyrite. Septaria in the siderite concretions are filled with quartz, calcite, dolomite and anhydrite.

Analysis of deposition rate, as well as thermal and burial history modelling, using the Schlumberger PetroMod 1-D software, was performed for the Ruptawa IG 1 borehole section. The profile is characterised by the presence of two phases of increased burial and fast deposition rate which occurred in the Carboniferous and Miocene. The Carboniferous burial event was associated with the development of sedimentary cover due to flexural bending of the foreland plate of Variscan orogen. It created an accomodation space in the foredeep-type basin and enabled its filling with a great amount of detrital material. Based on the modelling results, zones of hydrocarbon generation phases and their changes in time can be determined. Gas generation from the Carboniferous deposits started between the Late Namurian and the Early Permian. Coalification of organic matter, resulting in the formation of coalbed methane and coal deposits, is an effect of primarily Variscan processes.

Geochemical studies of organic matter by were also performed on 23 samples of Carboniferous rocks (siltstones, carbonaceous clays and shales from a depth interval 491.0–2403.5 m), using the Rock-Eval method that provi-

des the parameters and indicators for determining, among others, the type of kerogen contained in the rocks, the degree of thermal maturity of organic matter, and hydrocarbon potential. The results indicate a high degree of thermal transformation of organic matter. Tested samples are characterised by a very high content of organic matter (TOC), indicating its continuous and abundant supply to the basin, where favourable physicochemical conditions for its preservation existed. Organic matter has the geochemical characteristics typical of gas-prone kerogen type III and inert type IV, and it is at the stage of three generation phases, depending on the depth: the late phase of oil (491–590 m), wet gas phase (590−1446 m), and dry gas phase generation (1445.9−2403.5 m). The results show a high variability of generation potential along the entire Carboniferous section. The upper part of the section (final phase of oil generation and wet gas phase) has a high potential generation, whereas the potential generation of the lower part of the section (dry gas phase) seems to be exhausted.

Hydrogeological conditions have been determined on the basis of drill core analysis in the laboratory and direct on-site tests of the aquifers, conducted during and after drilling. In the field laboratory, analyses of physical and hydrogeological properties of Carboniferous rocks were carried out on 142 samples taken from the drill core. The determinations point to the presence of impermeable rocks of low and medium effective porosity. Direct hydrogeological tests in the borehole were carried out using a formation sampler in two intervals: 1532.1–1601.6 and 1770.0–1878.6, using a compressor and a bailer in three intervals: 1234.4–1469.8 (in uncased borehole), 951.0–1001.0 (with perforation at depths of 990.0–1001.0 and 951.0–963.0 m) and 635.0–655.0 m. The tested Carboniferous aquifers are of subartesian nature. They contain 5.65–13.4% Cl–Na–Ca brines. The high degree of their metamorphism (rNa/rCl = 0.683–0.728) points to relict waters, highly altered during long-term geological processes that persist within the deposit under conditions of well and prolonged isolation from the surface.

A number of well logs were performed in the Ruptawa IG 1 borehole, including standard profiling then used in coal-bearing deposits, as well as drilling mud resistivity measurements, temperature measurements, spontaneous potential logging, and acoustic wave imaging. The overburden (Miocene) of Carboniferous deposits has a very invariable record on geophysical logs. Much greater differentiation is observed in the Carboniferous section, which results from variable physical properties of the Carboniferous rocks, largely due to the lithological variations. For the Carboniferous sandstones, interpretation of geophysical measurements was performed to determine the hydrogeological properties: TDS, sandstone porosity and water saturation of rocks. Temperature profiling was performed in the near-steady state. The geothermal gradient for the Carboniferous deposits is 3.47°C/100 m. The bottom hole temperature at a depth of 2485 m was 97°C.

Seismometric measurements in the Ruptawa IG 1 borehole include average velocity measurements and vertical seismic profiling. The results indicate a correlation between the increase of depth and the time of recording and the average velocity. There has been a steady systematic increase in speed with depth. Based on the velocity measurements, four velocity complexes have been distinguished: upper layers of the Miocene to a depth of approx. 230 m with the average velocity of 2100 m/s, lower layers of the Miocene to a depth of approx. 360 m – 2600 m/s, Saddle Beds – 3100 m/s, the remaining Carboniferous deposits – about 4000 m/s.

The Carboniferous samples were analysed for physical properties of rocks. The scope of research included the following measurements: bulk density, acoustic wave velocity, thermal properties, and geotechnical parameters. Bulk density measurements were performed on a mass scale for 7823 samples taken every 25 cm. In particular lithological types, the average bulk density increases with depth. Acoustic wave velocity measurements (longitudinal and transverse waves) were performed on 127 samples of sandstones and mudstones. The acoustic wave velocity increases with depth in all the analysed lithological types. Measurements of thermal properties (conductivity and capacity) were performed for 253 samples, and there were no correlations with depth. The study of geotechnical parameters were performed on drill core samples from the upper part of the Carboniferous section down to a depth of 1000 m. The scope of research included: physical properties of rocks, uniaxial and triaxial strength, elastic properties, rheological parameters. Overall, 42 samples were analysed, and 11 samples represented deposits of the Upper Silesian Sandstone Series, whereas 31 – of the Paralic Series (Poruba Beds).