

## SUMMARY

Drill core material from the Białopole IG 1 exploration borehole provided a rich set of data for biostratigraphic, chronostratigraphic, lithostratigraphic, sequence stratigraphic, sedimentological and facies, ichnological, as well as paleontological and tectonic investigations.

Another group of research included analytical studies, mainly geochemical investigations of organic matter and extrusive volcanic rocks, petrographic examinations of clastic, volcanic and carbonate rocks and organic matter, as well as mineralogical and petrophysical studies. A full set of hydrogeological tests and geophysical well logs was carried out in this borehole.

The drilling was stopped at a depth of 3017.6 m in the Ediacaran Sławatycze Formation (unpierced) represented by volcanogenic rocks: amygdoidal basalts (melaphyres) and massive and subaphiric basalts.

The Sławatycze Formation is overlain by a 203.6-m thick series of Upper Ediacaran deposits encountered at a depth of 2814.0–3017.6 m. They are represented by siliciclastic estuarine sediments of the Białopole, Łopiennik and Włodawa formations composed of interbedded sandstones, mudstones and claystones. The base of the Cambrian and of the Terreneuvian is defined based on the first occurrence of trace fossil *Trichophycus pedum* (Seilacher), thereby indicating the position of the Ediacaran/Cambrian boundary. It is in accordance with the standard boundary defined by the International Commission on Stratigraphy.

The Cambrian rocks occur at a depth of 2239.5–2814.0 m (574.5 m) and are represented by a clastic series of sandstones with interbeds of claystones/mudstones containing thin sandstone intercalations. They were deposited in a shallow-marine basin, in the shoreface and offshore zones. This was an open shore with a strong influence of waves and minimal effect of tides or their lack. Petrographic microscope examination showed that the sandstones are represented mainly by very fine- and fine-grained quartz arenites (including orthoquartzites), occasionally by quartz wackes and in one case by a subarkose. There are also calcareous claystones clayey siltstones and silty claystones. The sandstones are texturally and mineralogically mature. Dispersed pyrite is observed in many samples. Glauconite is present at the top and base.

The Ordovician deposits occur at a depth of 2131.5–2239.5 m (108.0 m) and are represented by the lower Tremadocian through the lower Ashgillian. The Tremadocian is bipartite: the lower part of the sequence is composed of mudstones and bituminous claystones, whereas the upper part is represented

by oligomictic quartz sandstones. The lower portion of the section is represented by the lower Tremadocian corresponding to the stage of Pakerort of the Baltic region. Correlation of the well logs to those from other boreholes of the Lublin region indicates that the Arenigian deposits are represented by the lower part of the Uherka Limestone Formation composed at the base of a glauconite bed and limestones with glauconite. The upper unit of the formation is represented by brown-red limestones and marly limestones corresponding to the upper Arenigian, coeval with the stage of Volkhovian in the Baltic region. The Darriwilian (Llanvirn) deposits are represented by the middle part of the Uherka Limestone Formation, composed mainly of organodetrital limestones. Correlation of the wireline logs with those from other boreholes of the region suggests that the deposits correspond to the stages of Kunda through Lasnamagi and the stage of Uhaku of the Baltic region. The Sandbian-Katian (Caradocian) deposits include the uppermost part of the Uherka Limestone Formation and the Udal Claystone Formation. The uppermost part of the Uherka Limestone Formation is considered lowest Caradocian, corresponding to the stage of Kukruse in the Baltic region. It is represented by organodetrital and marly limestones with claystone interbeds.

This part of the Caradocian, which corresponds to the stages of Oandu–Rakvere in the Baltic region, is represented by the Udal Claystone Formation composed of dark grey and grey claystones with infrequent interbeds of mudstones, marls and marly limestones. The Katian (Ashgillian) deposits are represented by the Kodeniec Limestone Formation composed of grey and brown-red marly and organodetrital limestones interbedded with marls and claystones.

The Silurian deposits (539.0 m thick) occur at a depth of 1592.5–2131.5 m. They pass into the Lower Devonian without a break in sedimentation. The Silurian succession is represented mainly by claystones and mudstones with subordinate limestone interbeds. Wenlock, Ludlow and Pridoli deposits are present in this section. The lowermost Silurian, Llandovery, is absent. The Wenlock deposits are in contact with the uppermost Ordovician. The uppermost Silurian (Pridoli) is overlain by the lowermost Devonian. The dominant fossils include graptolites, trilobites, brachiopods, cephalopods, bivalves, eurypterids and placoderms.

The Devonian in the Białopole IG 1 borehole is represented only by its lower series (depth 1031.84–1592.50, thickness 560.66 m). Three lithological complexes were identified in the Lower Devonian of the Radom–Lublin region. They are

correlated throughout the whole area on well logs. The Sycyna Formation is represented mostly by dark grey claystones, locally marly or dolomitic, containing interbeds of organodetrital limestones. The Czarnolas Formation is represented by dark grey silty claystones and mudstones, rhythmically interbedded by grey quartz sandstones. The Zwoleń Formation is composed of variegated, brown, green and grey silty claystones, occasionally mudstones and sandy mudstones containing carbonate concretions. Less common are claystones interbedded with quartz sandstones. Stratigraphy of the Lower Devonian section is based on palynological (miospores), microfossil (ostracods) and macrofaunal (trilobites and tentaculites) evidence.

The Carboniferous deposits (516.34 m thick) occur at a depth of 515.5–1031.84 m. The chronostratigraphic boundaries are placed based on the correlation of depositional sequence boundaries with the marker section and with the global and Western Europe divisions of the Carboniferous. This allowed for more precise stratigraphy and resulted in the correction of the position of the boundaries. The Carboniferous deposits are represented by limestones, marls, claystones, mudstones, sandstones, Stigmaria soil, coals, and carbonaceous claystones and mudstones. During the relative sea-level lowstand, the deposition occurred in river channels and floodplains. During the periods of sea-level rise and highstand, shallow-water deltaic and shallow carbonate and clay shelf environments developed.

The Jurassic succession is represented only by Upper Jurassic deposits. They were found directly upon Carboniferous rocks at a depth of 479.0–515.4 m (36.4 m thick). The Upper Jurassic is represented only by Oxfordian deposits and likely lowermost Kimmeridgian rocks. The Zakrzew Formation is represented by grey sandy siltstones, calcareous at the top, non-calcareous at the bottom. They contain foraminifers, sponge spicules and skeletal elements of echinoderms and sea urchin spines. There are occasional interbeds of grey fine-grained quartz sandstones. The lowermost part of the Jasieniec Formation is composed of white to grey pseudo-oolitic or organodetrital limestones, with the remains of corals, snails, bivalves, and with oncoids. Mudstones and conglomerates are very rare.

The Cretaceous succession occurs at a depth of 0.5–479.0 m (478.5 m in thickness). It includes the upper Albian and all Upper Cretaceous stages from the Cenomanian through the upper Maastrichtian. The Cretaceous lithological section is typical of the whole Chelm–Hrubieszów region. The Lower Cretaceous is probably represented by upper Albian marly sandstones with phosphorite concretions. The Cenomanian is composed of marls at the bottom, passing upwards into limestones and chalk. The undivided Turonian–lower Coniacian interval is entirely represented by chalk facies. The interval corresponding to the middle and upper Coniacian and Santonian is composed probably of predominant marly chalk-like limestones. The Campanian–Maastrichtian interval is represented by marly chalk and chalk-like limestones. The Cretaceous carbonate-dominated deposition occurred in a relatively quiescent tectonic setting in an epicontinental basin of low

and mostly stable subsidence rate, with the dominant facies of chalk and chalk-like limestones.

The Ediacaran–Upper Jurassic succession contains a variable, mostly small amount of organic matter, ranging from 0.1 to 0.3%. Elevated concentrations (0.9–1.7%) are observed in Carboniferous and Upper Jurassic layers, and (0.8–0.9%) in some strata of the Ludlow and Caradocian. Lower Paleozoic and Lower Devonian organic matter is represented by vitrinite-like material (solid bitumens and zooclasts). Liptinite material is present in trace amounts, mainly in the Silurian. Bituminous impregnations are commonly observed in these rocks. The Carboniferous–Jurassic deposits contain abundant humic-sapropelic material composed primarily of vitrinite macerals accompanied by liptinite and inertinite. Thermal maturity of organic matter, determined based on vitrinite and/or vitrinite-like material reflectance ( $R_o$ ), increases relatively constantly down in the vertical section of the succession from 0.50%  $R_o$  at a depth of 503.0 m (Upper Jurassic) to 1.79%  $R_o$  at a depth of 2893.0 m (Ediacaran). This corresponds to the transition from the early stage of liquid hydrocarbon generation (Upper Jurassic), through the main (Carboniferous 0.65–0.75%  $R_o$ ) and late phase of oil generation (Lower Devonian, 0.87–1.02%  $R_o$ ; Silurian–Pridoli, 0.9–1.07%  $R_o$ ), phase of wet gas and condensate generation (Silurian–Llandovery, Ordovician–Caradocian, 1.22–1.26%  $R_o$ ), to the main phase of gas generation (Ordovician–Caradocian, Ordovician, Arenigian 1.32–1.38%  $R_o$ , Lower Cambrian and Cambrian Ediacaran, 1.70–1.79%  $R_o$ ).

The results of geochemical studies performed in the Białopole IG 1 borehole indicate that only the top parts of Viséan deposits and the lower parts of Namurian rocks contain sufficiently enough amount of organic carbon to be considered source rocks for hydrocarbon generation. The remaining rocks are “very poor” or “poor” source rocks. The Cambrian rocks contain a very small amount of labile components, whereas the Ordovician and Silurian deposits, excluding the Upper Silurian (Pridoli), show considerable amounts of epigenetic bitumens. The organic carbon-rich Carboniferous rocks contain greater amounts of syngenetic bitumens. The highly altered lower Paleozoic organic matter is of sapropelic type. Organic matter from the Carboniferous strata is of sapropelic and humic type and shows a low degree of alteration. The weakly altered Upper Jurassic organic matter is mainly of humic type.

Several phases of rapid burial, separated by periods of stagnation or tectonic uplift, have been interpreted from the analysis of the Białopole IG 1 section. In the period spanning the Ediacaran–Middle Ordovician, syn-rift and post-rift subsidence led to the deposition of a thick sedimentary cover of around 1000–1100 m. During the Late Silurian development of a Caledonian foredeep, a very rapid burial event took place. At the end of the Devonian and in the Early Carboniferous, tectonic uplift occurred, associated with the Bretonian deformation phase. It resulted in a partial removal of Devonian sediments. The next phase of rapid burial took place in the late Viséan–Westphalian. The Stephanian and Early Permian were again the periods of uplift and erosion. Stagnation or slight uplift occurred from the Late Permian to the Early Jurassic.

The two main phases of Mesozoic burial occurred during the Late Jurassic and Late Cretaceous.

The Białopole IG 1 well was drilled on a tectonic block recognised within the Paleozoic succession. This block is bounded by faults rooted in the Precambrian basement, which are interpreted as reverse faults, active during early and late Carboniferous times. As a result, two major unconformity surfaces developed: sub-Carboniferous and sub-Jurassic.

The best reservoir rocks are the Middle Cambrian sandstones. The Silurian, Ordovician and Lower Cambrian deposits have no reservoir properties. The Middle Cambrian deposits

are saturated with Ca–Na–Cl water, very prospective for hydrocarbon accumulation. A direct indicator of the possibility of hydrocarbon accumulation is the presence of free high-methane gas in the brine. Formation tests proved that the Middle Cambrian reservoir horizons are characterised by favourable conditions for hydrocarbon accumulation.

The main drilling objective of the Białopole IG 1 well was to provide data on the stratigraphy, lithology, facies and tectonic setting of the lower Paleozoic and Ediacaran succession in south-eastern Poland.