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SUMMARY

The rich core material from the Terebin IG 5 borehole was examined with regard to the stratigraphy, including biostratigraphy, chronostratigraphy, lithostratigraphy and sequence stratigraphy, sedimentology, ichnology and facies development, as well as micro- and macropalaeontology and tectonics. The second group of studies were analytical investigations, mainly geochemical analyses of organic matter and extrusive volcanic rocks, petrographic studies of clastic, carbonate and volcanic rocks and organic matter, as well as mineralogical and petrophysical studies. A full set of formation tests and geophysical borehole measurements were made in this borehole.

The Ediacaran deposits occur at a depth of 3650.0–3850.5 m and attain a thickness of 200.5 m. The Terebin IG 5 borehole was stopped at a depth of 3850.5 m in the Ediacaran deposits within the unpierced Sławatycze Formation represented by volcanogenic rocks of the basalt group, showing porphyric and aphyric textures. The Sławatycze Formation is overlain by siliciclastics of the Białopole, Łopiennik and Włodawa formations represented by interbedded sandstones, siltstones and claystones. The clastic section of Ediacaran deposits reflects evolution of an estuary. In the initial stage, it was a tide and wave-dominated estuary that evolved in its peak phase into a hypersynchronic macrotidal estuary. At the end of its existence, the estuary again turned into a tide and wave-dominated estuary. At the beginning of the Cambrian, the estuarine basin came to a decline as a result of sediment filling.

The Cambrian succession occurs at a depth of 3072.5–3650.0 m and attains a thickness of 577.5 m. These are exclusively clastic deposits represented by sandstones with several-metre thick interbeds of claystones and mudstones. The Cambrian deposits were accumulated in a shallow, open-marine basin, in shoreface and offshore environments. The sediments bear a record of waves and heavy storms. The Cambrian section has been subdivided into the Lower and Middle Cambrian. According to a global Cambrian chronostratigraphic scheme, the Terreneuvian and Series 2 correspond approximately to the Lower Cambrian, and Series 3 corresponds to the Middle Cambrian.

Ordovician deposits were encountered in a depth interval of 2964.7–3075.0 m, and their thickness is 110.3 m. The Ordovician section of this borehole is represented by deposits of the standard global stages from the Tremadocian through the Katian. In the British scheme, they correspond to the sequence spanning the Tremadocian through the Lower Ashgill. The mudstone-siltstone deposits, occurring in the lower part of the Ordovician section, correspond to the Lower Tremadocian correlated with the Baltic stage of Packerort. The undivided stages of Floian and Dapingian are composed of dolomitic, organodetrital and marly limestones. The lower part of the Darriwilian (Llanvirn) consists of recrystallized organodetrital limestones. This part of the section may correspond to the Baltic stage of Uhaku. The Sandbian stage (lower Caradoc) is correlated with the Baltic stage of Kukruse and is represented by organodetrital limestones, marls, marly limestones and calcareous claystones. The upper part of the Sandbian section corresponds to the Baltic stages of Idavere through Keila and is represented by calcareous claystones with bentonite laminae. A complex of calcareous claystones with trilobite and graptolite fauna is included in the Katian, corresponding to the Baltic stages of Oand–Rakvere. The overlying claystones and clayey marls, marls and marly limestones represent the Baltic stages of Nabal–Vormsi. The uppermost part of the Katian is represented by a complex of marly and organodetrital limestones. These deposits probably correspond to the upper parts of the Baltic stage of Vormsi and to the stage of Pirgu.

Silurian deposits occur at a depth of 2463.0–2964.5 m, reaching a thickness of 501.5 m. The Silurian succession consists mostly of siltstones and claystones, in some intervals also with interbeds and lenses of limestones, included in the Wenlock, Ludlow and Pridoli. The lowest Silurian, Landowery, is absent in this borehole. These deposits were probably subjected to erosion. The Wenlock is composed of laminated and shale siltstones and claystones, containing limestone interbeds. Graptolites found in these deposits indicate the presence of the Homerian stage. As evidenced by few drill cores, the Ludlow is represented by mudstones, commonly laminated, in places with limestone lenses. Taxonomic composition of the graptolite assemblage in the cored intervals documents the presence of the Ludfordian stage. The Pridoli is composed of slightly calcareous shales containing scarce fauna of nautiloids, bivalves, and fragments of graptolites and crinoids.

The Devonian succession occurs at a depth of 1259.85–2463.0 m, attaining a thickness of 1203.15 m. The section is represented by Lochkovian through Frasnian deposits. Significant part of the Upper Devonian section was eroded during the post-Famennian – pre-late Visean break in sedimentation. The erosion affected the whole of Famennian and upper Frasnian deposits. Three lithological complexes have been distinguished in the Lower Devonian section. The lithostratigraphic sequence is as follows: Sycyna Formation, Czarnolas Formation and Zwoleń Formation. The Sycyna Formation consists mainly of shales, locally dolomitic or marly, containing thin interbeds of organodetrital and clayey limestones. The Czarnolas Formation is represented by silty claystones and siltstones, interbedded with quartz sandstones. The Zwoleń Formation is composed of silty claystones, occasionally siltstones and sandy siltstones. The Middle Devonian Telatyn Formation consists of the following units (in the stratigraphic order): Przewodów, Machnów, Żniatyń, Pełcza, Rachanie, and Mircze members. The diverse lithology of the Telatyn Formation is represented by alternating packets of clastic deposits, mainly claystones, dolomitic claystones, siltstones, calcareous mudstones, rarely fine-grained and silty sandstones and carbonates: dolomites, clayey dolomicrites, and subordinate limestones. Sporadic are marls, dolomitic marls and anhydrites. The overlying Upper Devonian (Frasnian) Modryń Formation consists of the following units (in the stratigraphic sequence): Krzewica Member, Lipowiec Member, Vuggy Dolomite Complex Łosień Member, and Zubowice Member. The formation is composed of marls, dolomitic claystones, organodetrital limestones and crystalline dolomites, marly dolomites and anhydrites.

The Carboniferous is 726.8 m thick and occurs at a depth of 533.1–1259.9 m. The chronostratigraphic boundaries have been determined based on the correlation of depositional sequences with the marker borehole and with the global and Western Europe divisions of the Carboniferous. It has provided a more precise stratigraphy and resulted in correcting the previously existing boundaries. The Carboniferous deposits are represented by limestones, marls, claystones, siltstones, sandstones, Stigmaria soils, coals and carbonaceous claystones. During the relative sea-level lowstands (LST), the deposition occurred on delta plains, delta distributary channels, in river channels and floodplains. During periods of sea-level rise and highstands (HST), there was a development of shallow deltaic and shallow carbonate and clay shelf environments.

The Jurassic succession occurs at a depth of 521.0–535.0 m. It consists of a 14.0 m thick complex representing only the upper Oxfordian and probably the lowermost Kimmeridgian. The Jurassic section is highly reduced due to the location of the borehole in the extremely marginal part of the Jurassic basin. The lower part of the section is represented by the Jarczów Formation composed of medium-grained and variously grained sandstones, silty sandstones and siltstones. The sandstone complex found in the lower part of the formation probably formed in a deltaic environment, while the overlying siltstone-claystone deposits represent a swamp environment that developed probably on the delta plain. The upper part of the Jurassic succession is represented by the Tyszowiec Formation composed of mudstones deposited on land.

The Cretaceous succession is 486.0 m thick, including 0.5 m of Lower Cretaceous (upper Albian) and 485.5 m of Upper Cretaceous deposits. The entire Upper Cretaceous stratigraphic section is present, including the Cenomanian through the upper Maastrichtian.

The Cretaceous section is characterized by the dominance of open-marine carbonates (mainly pelitic limestones, organodetrital limestone (so-called Inoceramid Limestone facies) and marly limestones), which occur just above a thin transgressive conglomerate layer commencing the Cretaceous succession. Chalk-like limestones appear in the Turonian, while the Maastrichtian section is abundant in marls. Neither siliceous-carbonate rocks (opokas) nor typical chalk have been found in the Upper Cretaceous section of this borehole.

The Upper Carboniferous – Lower Cambrian deposits contain variable amounts of organic matter (0.1 to 7.5%). The most abundant in organic matter (2.0–7.5%) are the Carboniferous rocks (Bashkirian, Serpukhovian), and the main constituent is humic material composed of three basic maceral groups: vitrinite, inertinite and liptinite. The poorest in organic constituents, represented by vitrinite-like macerals (solid bitumens and zooclasts) and bituminous impregnations, are the (Lower and Middle) Devonian deposits containing 0.1–0.3% of organic matter. The lower Palaeozoic (Silurian–Ediacaran) deposits are characterized by variable amounts of organic components (0.1–2.0%). Their highest concentrations (1.1–2.0%) are found in the oldest rocks (Ediacaran) and some Ordovician horizons and Silurian levels. Their main components are solid bitumens and graptolites (Ordovician, Silurian) or phytoclasts (Cambrian, Ediacaran). Thermal maturity of organic matter in the vertical section of the rocks clearly increases with depth of burial from 0.57% R_O at a depth of 553.0 m (Bashkirian) to 2.46% R_O at a depth of 3825.0 m (Ediacaran). It corresponds to the transition from the main phase of oil generation (Upper Devonian–Carboniferous) through the phase of wet gas and condensate generation (Lower Devonian–Silurian) and the main phase of gas generation (Cambrian–Ordovician), to the overmature phase (Ediacaran).

The Palaeozoic deposits are „good" source rocks for hydrocarbon generation. These include Silurian (Wenlock) and Upper Carboniferous (Serpukhovian and Bashkirian) deposits. The remaining rocks are „poor" or "very poor" source rocks, and higher organic carbon contents are recorded only at point sites. The source of primary organic matter in the lower Palaeozoic deposits of this borehole were bacteria and marine algae. The Upper Carboniferous deposits containsome humic material. Organic matter in the lower Paleozoic deposits is altered to the stage of „oil-window". Organic matter in the Carboniferous formations is poorly altered.

The first period of increased deposition rate and rapid subsidence occurred from the Ediacaran through late Cam-

brian. During that period, the sedimentary cover reached a thickness of about 1,000 m. The highest deposition rate took place in the Silurian to reach a value of about 177 m/million years in the Ludlow, and about 203 m/million years in the Pridoli.

At the beginning of Wenlock, there was a phase of very rapid burial, which continued until the end of the Devonian. That period resulted in the increase of the thickness of the sedimentary cover to about 3,000–3,100 m. The accelerating deposition rate was associated on the one hand with a flexural bending of the plate's edge, creating an accommodation space in the basin, and on the other hand with the increase in supply of detrital material. At the beginning of the Devonian, clastic sedimentation rate was approximately 105–110 m/million years. The second phase of increased deposition rate (about 90 m/million years) occurred at the beginning of the Bashkirian. In the late Visean, there was a phase of rapid burial, which lasted until the end of the Carboniferous (Westphalian). During that time, the burial depth reached its maximum of about 3,900 m in this area. Another episode of deposition rate increasing to 87 m/million years occurred in the Maastrichtian and was associated with the Laramide tectonic reactivation in the Polish Basin. In Mesozoic times, there were two phases of burial that occurred in the late Jurassic, followed by an early Cretaceous erosional event, and in the late Cretaceous, when the sedimentary cover reached a burial depth close to that of the latest Carboniferous. The zone of hydrocarbon generation comprises deposits from the bottom of the borehole (Ediacaran) through the Lower Cretaceous. The section of Ediacaran through lower Wenlock is in the gas generation window. Generation of natural gas from these deposits started probably at the beginning of the Eocene. The upper Albian, Carboniferous and Devonian, and upper Wenlock deposits are in the early, middle and late oil generation window, respectively. Oil generation in the Wenlock deposits began probably in the Visean. The youngest deposits that reached the maturity stage of oil generation in the Eocene, were the upper Albian deposits.

Analysis of seismic data shows the clearly dipping Ediacaran and lower Palaeozoic deposits, as well as the increasingly thick Lower Devonian succession towards the SE. The complex of Devonian and Carboniferous deposits is cut by numerous SW-dipping reverse faults, most of which is rooted in the upper Lower Devonian. Their formation was associated with inversion of the Lublin Basin. Since the end of the Westphalian, transpressional regime has reigned in this area, which is manifested by the presense of inversion structures.

Detailed analysis of the borehole data suggests that the analyzed lithological intervals do not meet any standards typical of rocks with "good" reservoir properties.There are just few intervals that meet only one of the criteria. These are intervals from the following depths: 3560.7 m (Cambrian), 1390.0 m (Devonian), 645.9 and 541.0 (Carboniferous), 530.0 m (Jurassic) and 503.5 m (Cretaceous).

Negative answers have been received to the goals of the Terebin IG 5 borehole with regard to the accumulation of natural gas in the Cambrian and Devonian deposits, to the coal potential of the Carboniferous, as well as to the presence of phosphorites in the Cretaceous deposits.

Translated by Krzysztof Leszczyński