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SUMMARY

Drill core material acquired from the Łopiennik IG 1 borehole has provided many important geological data as the result of a wide range of studies and investigations conducted over a 30-year period. The studies include direct observations of the drill core and collected samples which enabled stratigraphic (biostratigraphic, chronostratigraphic, lithostratigraphic and sequence stratigraphic), sedimentological, facies, ichnological, micro-and macropalaeontological and microtectonic research. Geological data from the borehole were used in analysis of sedimentary basins which evolved during various stages of the geological evolution of the Lublin region, from Ediacaran through Cambrian, Ordovician, Silurian, Devonian and Carboniferous to Jurassic and Cretaceous times.

Another group of investigations were analytical studies (geochemistry of organic matter and volcanic effusive rocks, petrography of clastics, carbonates, volcanites and organic matter, and mineralogical and petrophysical investigations). A full range of drill stem tests and wireline logs were also run in the borehole.

The drilling was stopped at a depth of 5632.0 m in Ediacaran deposits, within the Sławatycze Formation (unpierced) represented by porphyric and amygdoidal basalts with small contribution of volcaniclastic rocks, mostly fine ash tuffs, basaltic agglomerates and basalt-tuff rocks. The Sławatycze Formation is overlain by Upper Ediacaran rocks (5567.3–5306.7 m) represented by a complete clastic sequence typical of the southern part of the East European craton slope in the Lublin area.

Above the volcanic complex, the Ediacaran is composed of siliciclastic brackish deposits of the Białopole, Lublin and Włodawa formations. The region of the Łopiennik IG 1 borehole was part of the Orsha–Volhyn aulacogen during the Ediacaran. Based on subsidence curves and facies analysis of the latemost Ediacaran deposits, it was possible to document an active rift zone in this area.

The Ediacaran deposits from the Łopiennik IG 1 borehole represent successive depocenters that developed during the syn-rift phase of the Lublin–Podlasie Basin.

Biostratigraphic research performed over the last 15 years enabled identification of one biostratigraphic zone in the upper part of the Ediacaran section of the Łopiennik IG 1 borehole – the Sabellidites–Vendotaenia Zone. A new position of the Ediacaran/Cambrian boundary was also established at the top of the zone. This is consistent with the standards accepted by the International Commission on Stratigraphy. The Ediacaran deposits represent the lower part of a second order depositional sequence formed mainly during a rapid sea-level rise controlled by tectonic factors.

Cambrian deposits were encountered at a depth of 5306.7–4461.2 m (845.5 m). They are represented chiefly by an alternating sequence of sandstones, mudstones and claystones forming characteristic sandstone-mudstone-claystone heteroliths deposited in a shallow-marine basin (nearshore and offshore zones). It was an open coast with strong influences of waves and small contribution or lack of tides. The Cambrian sandstones of the Łopiennik IG 1 borehole can be considered very highly diagenetically altered rocks due to large burial depth. These are texturally and mineralogically mature deposits of arenite and quartz wacke type. The main diagenetic process in this area was silification of sandstones and mudstones.

For purposes of stratigraphic zonation of the Lower Cambrian succession, trilobites and acritarchs were used. The latter enabled detailed biostratigraphic zonation of the section because trilobite individuals are very rare in the rocks. Two ventral shells of brachiopods were found at the top of the Cambrian section at a depth of 4460.7–4460.9 m. They are well preserved and show their internal sides. There are also 2 poorly preserved specimens and one fragment of a shell resembling *Ungula ingrica* (Eichwald). These findings may suggest the presence of uppermost Upper Cambrian deposits – the *Acerocare* Zone – underlying Tremadoc rocks, and the occurrence of the so-called Obolus sandstones. Elucidation of this problem requires further research. The problem of the position of the Cambrian/Ordovician boundary in the East European craton (from studies of obolids) still awaits its solution.

The Cambrian succession was deposited during the development of the second order depositional sequence in the post-rift phase of the Lublin–Podlasie Basin, due to sea-level fluctuations (significant influence of eustatic changes). The Cambrian succession in the Łopiennik IG 1 section encompasses (from base to top) the highstand systems tract and transgressive systems tract in the Lower Cambrian, and the highstand systems tract in the Middle Cambrian.

Ordovician deposits were encountered at a depth of 4461.2–4327.5 m (79.0 m in thickness). The Ordovician succession represents a mixed clastic-carbonate type of sedimentation. The lithologies are represented mostly by organodetrital and marly limestones, quartz sandstones, mudstones, claystones and conglomerates. Most of them show advanced epigenetic processes due to considerable burial depth. Two transgressive-regressive cycles have been identified within the Ordovician succession. In the palaeotectonic plan, the Łopiennik section was situated in the Chełm Depression. In terms of facies development, it corresponds to the Central Baltoscandian confacies. The Tremadoc, Arenig, Llanvirn, Caradoc and

Ashgill stages identified in the Łopiennik IG 1 borehole were correlated with those distinguished within the Ordovician succession in the Baltic Depression.

Silurian rocks were drilled in the Łopiennik IG 1 borehole at a depth of 4327.5–3005.0 m (1322.5 m in thickness). They were deposited in the southern area of the Lublin–Podlasie Basin extending along the western slope of Baltica starting from the Late Proterozoic. The Silurian section from Łopiennik IG 1 is typical of the area. It is dominated by fine-grained sediments including claystones and minor mudstones.

Fossil associations in the Silurian sequence of Łopiennik IG 1 are poorly diversified, however they are commonly fairly abundant and well preserved. The dominant fossils are graptolites identified by H. Tomczyk. Inarticulate brachiopods as well as bivalves and cephalopods (more frequent in the Pridoli) are observed sporadically.

The stratigraphy of the borehole refers to the standard stratigraphic scheme with series and stages identified. It differs from the one proposed by Tomczyk in the geological documentation of the Łopiennik IG 1 borehole. The Tomczyk's scheme is affected by a number of discrepancies to the standard scheme. The suite of modifications includes rejection of the local stratigraphic units proposed by Tomczyk, such as the Podlasie, Siedlce, Mielnik and Pasłęk beds, and verification of positions of some stratigraphic boundaries.

All the Silurian series have been identified within the Łopiennik section in conformity with the standard scheme: Llandovery, Wenlock (Sheinwoodian and Homerian stages inclusive), Ludlow (Ghorstian and Ludfordian stages inclusive) and Přidoli.

The Silurian succession is overlain by a 1495.0 m thick series (depth 3005.0–1510.0 m) of clastic-carbonate rocks representing the Lower Devonian with the Lower Lochkovian and undivided Upper Lochkovian + Pragian + ?Emsian. The tripartite clastic spectrum of Lower Devonian deposits is composed, in its lower part corresponding to the Sycyń Formation, of black claystones interbedded with organodetrital limestones.

The Czarnolas Formation, representing the middle part of the spectrum, is composed of silty claystones and siltstones alternating with quartz sandstones. In the top part (Zwoleń Formation), quartz sandstones, siltstones and claystones are predominant. Upwards in the Lower Devonian section, a gradual shallowing of the basin is observed: from a relatively deep sea (below wave base) through a shallower basin with larger amounts of sand material derived from land areas, to fluvial and lacustrine deposition of continental environments.

In the Lower Devonian, the Łopiennik region was situated in a labile zone of south-western extremes of the Lublin Graben. The Lower Devonian stratigraphy is based on palynological (miospores), microfaunal (ostracods) and macrofaunal research (trilobites and tentaculites).

Carboniferous deposits are represented by limestones, marls, claystones, siltstones and sandstones. Stigmarian soils, carbonaceous claystones and coal beds are also observed. The Carboniferous succession reaches 704.0 m in thickness and was encountered at a depth of 806.0–1510.0 m. Its chronostratigraphic boundaries were determined on the basis of correlation between the boundaries of depositional sequences and marker sections, as well as from the global and Western European Carboniferous stratigraphic schemes. It facilitated creating a more detailed stratigraphic subdivision and gave rise to the verification of the position of the boundaries.

During the lowstand of relative sea level, the deposition took place in river channels and flood plains. During the rise and highstand of relative sea level, the sedimentation occurred in shallow-water deltas and on a shallow carbonate to clay shelf.

The Jurassic succession is 59.0 m thick and was drilled at a depth of 747.0–806.0 m. In its lower part it is represented by the Zakrzew Formation composed of clastic series, mostly sandstones, and subsidiary carbonates (sandy, marly and oolitic limestones). The middle portion of the Jurassic succession, corresponding to the Bełżyce formation, is composed of micritic, marly and oolitic limestones. The top of the succession is represented by the Ruda Lubycka formation consisting of marly and dolomitic limestones and dolomites. The entire Jurassic succession was drilled without coring and thus its stratigraphic zonation is based on wireline logs correlation to the nearby drilled wells of Kumów IG 1 and Krasnystaw IG 2, IG 3 and IG 4.

Cretaceous deposits were encountered at a depth of 5.0–747.0 m (742.0 m). The Lower Cretaceous is represented only by the Upper Albian composed of sandstones and marls with phosphatic concretions.

The Upper Crataceous succession is represented by all the stages from the Cenomanian through Maastrichtian. The main lithologies are limestones, organodetrital limestones with Inoceramus, marly limestones, marls, chalk-like limestones and siliceous marls. The rocks commonly contain cherts and a few phosphatic horizons. The Cretaceous sedimentary sequence shows a succession of a deepening sea manifested by a transition from siliciclastic and sandy-marly facies of a shallow-marine shelf (thin Upper Albian series) to an open-marine sedimentary basin of a calm tectonic regime with carbonate deposition and low, relatively constant subsidence rate. The Cretaceous section from Łopiennik IG 1 probably contains no typical chalk facies, as suggested by analysis of wireline logs and drill cuttings. Chalk deposits are known from the Campanian and Maastrichtian sections of nearby located wells.

The Upper Cretaceous deposits are overlain by a thin complex of Holocene varigrained sands with gravels, 5.0 m thick.

Petrological investigations of organic matter from the Ediacaran rocks indicate that the organic-mineral association of bitumen type and vitrinite-like material (represented mostly by pohytoclasts and solid bitumens) are the major organic constituents. The most abundant organic matter component of the Lower and Middle Cambrian, Ordovician and Silurian rocks is the organic-mineral association of bitumen type and vitrinite-like material. They are accompanied by vitrinitized and fusinitized zooclasts and bitumen bodies (solid bitumens). The Lower Devonian rocks are very poor in organic matter. Its major component is vitrinite-like material (solid bitumens and zooclasts). The Carboniferous deposits (Visean) contain mainly humic-type organic matter.

The calculated mean vitrinite reflectance value (% *R*o) related to the degree of thermal maturity of organic matter in the Ediacaran, Cambrian, Ordovician and lower Silurian

rocks varies within a broad range of 2.25 to 3.94% *R*o indicating the so-called “overmature phase of hydrocarbon generation”. At the top of the Silurian succession, the mean reflectance is 1.60–1.87%. This is the main phase of hydrocarbon generation.

Organic matter dispersed in the Lower Devonian and Carboniferous rocks shows the mean reflectance of syngenetic vitrinite-like material of 0.83–1.63% *R*o. These values correspond to the late phase of oil generation to the main gas generation phase.

The basic geochemical investigations of organic matter were made on samples from the Cambrian, Ordovician, Silurian, Lower Devonian and Carboniferous rocks. The Cambrian, Ordovician and Lower Devonian deposits are "poor" source rocks for hydrocarbon generation due to the low Corg content.

The Corg content in the lower Silurian (Wenlock) is > 1%, suggesting that these are “good” source rocks. The Lower (Visean) deposits contain 1.00% Corg average, thus representing “good” source rocks for hydrocarbon generation. Organic matter in the Silurian and Lower Devonian deposits is of sapropel type. It is highly altered and the investigations of biomarkers indicate that the Silurian organic matter was deposited in a marine environment. The Lower Devonian organic matter was deposited in transitional conditions from an open sea to a restricted basin, probably in brackish environments.

During drilling, no significant hydrocarbon shows were observed. The results of drill stem tests indicate that the Cambrian, Ordovician and Carboniferous formations show no reservoir properties. Weak flow of brine (approximately 0.4 m^3/h) was observed in the Lower Devonian formation, also suggesting poor reservoir properties of the rocks.

The main goal of the drilling was to explore the Lower Palaeozoic and Ediacaran rocks within the zone of deep seismic horizons “E”. The borehole was intended to provide new information about lithologies, stratigraphy, facies development, tectonic history and physical properties of rocks to reconstruct regional geological constraints for prospectivity of the rocks for hydrocarbon occurrence in the south-western part of the Lublin region.

Translated by Krzysztof Leszczyński