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SUMMARY

Drill core material obtained from the Siedliska IG 1 borehole has provided a wide spectrum of data for extensive research. Stratigraphic studies included biostratigraphic, lithostratigraphic, chronostratigraphic and sequence stratigraphic investigations. Sedimentological, ichnological, micropalaeontological, petrographic and tectonic studies were also carried out. A separate research group was geochemical and petrological studies of organic matter. Borehole geophysical measurements, petrophysical investigations and hydrogeological tests were performed.

The drilling of the Siedliska IG 1 borehole was stopped for technical reasons in the Lower Cambrian at a depth of 3010.3 m. The unpierced Cambrian succession occurs at a depth of 2597.8–3010.3 m, attaining a thickness of 412.5 m, and is represented by the Lower and Middle Cambrian. These are clastic deposits, mostly sandstones, mudstones and claystones. Lithologically homogeneous sandstone packets of considerable thicknesses occur only in the Middle Cambrian. The Cambrian deposits were accumulated in an open shallow-marine basin of nearshore and offshore zones. The Cambrian section shows records of strong erosion associated with the effect of storms.

Ordovician deposits occur at a depth of 2540.0–2597.8 m, attaining a thickness of 57.8 m. The section is represented by the standard global Ordovician stages from the Floian to the Hirnantian. The Ordovician deposits are predominantly marls, marly limestones, organodetrital limestones, and glauconitites.

Silurian deposits occur at a depth of 1487.5–2540.0 m and have a thickness of 1052.5 m, representing the Llandovery, Wenlock, Ludlow and Pridoli. The dominant lithologies are fine-grained rocks: mudstones, claystones and siltstones, calcareous at many intervals. There are also infrequent interbeds, intercalations and lenses of limestones, and thin interbeds of pyroclastic deposits – tuffites. As a result of flexural bending of the Baltica crust, there was a successive increase in subsidence rate in the Silurian basin, reaching its peak in the Ludlow and Pridoli. Due to the high subsidence rates, the thickness of the Ludlow deposits increased considerably, reaching 637.0 m.

The Carboniferous succession spans a depth interval of 851,8–1487.5 m and has a thickness of 633.0 m. The chronostratigraphic boundaries of the Carboniferous System are drawn based on the correlation of boundaries of depositional sequences with the benchmark boreholes and with the global and West European Carboniferous stratigraphic schemes. This allowed a detailed stratigraphic subdivision and corrections of the previously determined boundaries. The Carboniferous deposits are represented by limestones, marls, claystones, carbonaceous claystones and mudstones, mudstones, calcareous mudstones, sandstones and coals. The Visean deposits were accumulated in a shallow carbonate shelf environment. In the Serpukhovian, sedimentation took place in shallow-water deltas, a shallow clay shelf, and a carbonate shelf. These conditions developed during rising and high relative sea levels. In the Bashkirian, deposition occurred in river channels, incised valleys, and on floodplains during low relative sea level, while the transgressive and highstand system tracks are represented by deposits of shallow-water deltas and a shallow clay shelf. The Moscovian section is composed exclusively of fluvial deposits.

The 558.0–854.5 m depth interval represents an incomplete section of Jurassic deposits with a thickness of 296.5 m. Based on drill cores, cuttings, well logs, and microfaunal and macrofaunal evidence, the deposits have been assigned to the uppermost Middle Jurassic and lowermost Lower Jurassic. The Upper Jurassic section is represented by limestones, predominantly detrital, as well as pelitic and oolitic limestones. The Middle Jurassic is composed of limonite-rich organodetrital limestones, conglomeratic limestones, nodular limestones, and coquinal limestones with siderite concretions and limonite pisolites. The Middle Jurassic section contains infrequent sandstone interbeds with fragments of flora.

Cretaceous deposits occur at a depth of 99.0–558.0 and have a thickness of 459.0 m, including 448.5 m of Upper Cretaceous (Cenomanian–Maastrichtian) rocks. The Lower Cretaceous is represented by a 10.5-m series of Middle-Upper Albian shallow-marine sands, marls and marly sandstones with glauconite and phosphatic concretions, deposited on a siliciclastic and siliciclastic-carbonate shelf. The Upper Cretaceous section is composed of carbonates (limestones and chalk) deposited on an open-marine carbonate shelf in an epicontinental basin.

Paleogene deposits occur at a depth of 45.0–99.0 m, attaining a thickness of 54.0 m. They are represented by quartz sands, gravels, loamy sands, tills, muds and muddy sands.

At a depth of 0.0–45.0 m, the stratigraphic section of the Siedliska IG 1 borehole is terminated by Quaternary (Holocene) deposits: variously grained sands with gravel grains of crystalline rocks of the basement. The Paleozoic and Mesozoic rocks contain a variable amount of organic matter. The Jurassic rocks contain macerates of the vitrinite and huminite groups. The Carboniferous deposits exhibit up to 1.20% of organic matter. Its higher amounts are found at the tops of the Bashkirian and Moscovian. The very characteristic macerates for the Carboniferous organic matter are those of the liptinite group. In the Silurian claystones (Wenlock, Ludlow and Pridoli), the main component is vitrinite-like material represented by solid bitumens and very numerous fragments of graptolites. Liptinite macerates are found at the top of the Ludlow and Pridoli. The Cambrian rocks show contain a bituminous-type organic and mineral association.

Thermal maturity of organic matter in the vertical section of the Siedliska IG 1 borehole is very variable, ranging from 0.48% R_O in the Jurassic to 1.57% R_O in the Cambrian. Such R_O variability corresponds to the transition from the immature phase for hydrocarbon generation to the main phase of gas generation in the lower Middle and Lower Cambrian.

In the Siedliska IG 1 section, only top strata of the lower Carboniferous (Visean) and mid-Carboniferous (Bashkirian) deposits contain the amount of organic carbon that allows considering them "good" source rocks for hydrocarbon generation. The remaining rocks in the section are „very poor" or „poor" source rocks.

Results of RockEval analyses of the Cambrian and Ordovician rocks show that they are not source rocks. The Llandovery and Wenlock rocks display bipartition with respect to source rock quality features. This probably indicates variable depositional environments along the section. Compared with the other results, the lower part of the Llandovery (Rhuddanian, Aeronian and base-Telychian) is clearly distinguishable. These are very good source rocks being in the final phase of oil generation. They show geochemical features of oil- and gas-bearing shale formations. These rocks in the region of the Siedliska IG 1 borehole should be considered age equivalents to the Jantar Mudstone formation (early member) of the Baltic Basin. The top strata of the Llandovery (Telychian) are source rocks of moderate hydrocarbon potential, not differing much with respect togeochemical parameters from the overlying Wenlock rocks. The basal part of the Wenlock section (Sheinwoodian) is represented by rocks of high hydrocarbon potential, while its top part (Homerian) consists of source rocks of moderate hydrocarbon potential. Organic matter of the Wenlock deposits is in the main phase of oil generation. The Ludlow mudstones and claystones can be classified as source rocks that are in the initial phase of oil generation, but with low hydrocarbon potential. The Prodoli deposits are not source rocks. Organic matter dispersed in the Ordovician and Siluriam rocks is dominated by oil-forming type II kerogen.

The first stage of slight downdropping of the area of the Siedliska IG 1 borehole was related to thermal subsidence, with the syn-rift and post-rift stage of the basin development, which lasted from the Early Cambrian through the Late Ordovician. At the beginning, the stage was characterised by a high sediment deposition rate at 78 m/Ma, and then by its gradual drop to 1.5-5 m/Ma. A phase of rapid burial associated with the Caledonian Foredeep development lasted from the beginning of the Silurian through the Late Devonian and was characterised by a successive increase in deposition rate in the Silurian from 6 to 290 m/Ma. At the end of the Devonian, the sedimentary cover thickness attained its maximum value of 4150 m in the borehole section. At the end of the Devonian and the beginning of the Carboniferous, there was a stage of uplift and huge erosion during the Bretonian deformation phase. The erosion led to the total removal of Devonian and much of Pridoli deposits. From the beginning of the Visean through the Moscovian, there was another phase of intense burial characterised by increased deposition rate from about 5 to 143 m/Ma. At the Late Carboniferous/Early Permian transition, the Asturian uplift phase resulted in erosion of Upper Carboniferous (Moscovian) deposits. The lack of Early Permian through Middle Jurassic deposits in the section is associated with the existence of a small palaeo-elevation. In the Middle and Late Jurassic, there were two major burial phases with the sedimentation rate ranging between 9 and 45 m/Ma, followed by a phase of erosion during the Early Cretaceous Late Cimmerian uplift, and the Late Cretaceous burial phase with the sedimentation rate varying from 1 to 45 m/Ma. In the Cenozoic, a low subsidence rate and low deposition rate of 1-16 m/Ma eventually determined the thickness and depth of the sedimentary cover.

Results of one-dimensional modelling in the Siedliska IG 1 section show that the Lower Cambrian through Bashkirian deposits are in the hydrocarbon generation zone. Oil generation from the Cambrian, Ordovician and Silurian deposits, which probably started already during the phase of intense burial in the Devonian, was inhibited in the Early Carboniferous and entered the phase of gas generation at the Carboniferous/Permian transition. Oil generation from the upper Wenlock through Bashkirian deposits took place in the Carboniferous and Permian.

The well logs were the basis for the identification of aquifers. They also show that it is possible to recognise even thin coal layers in the Carboniferous section. The calculation of heat flow values in the borehole has allowed locating it in the marginal zone of a positive thermal anomaly associated with an elevated value of radiogenic heat in the crystalline basement.

Petrographic studies have shown very favourable parameters locally in the Jurassic and upper Carboniferous sections. Low porosity and permeability values around 1 mD were measured in the Silurian and Ordovician claystones and mudstones. The Cambrian sandy deposits reveal continuous hydrocarbon shows (under a UV lamp and according to methanometer measurements) or local oil shows in drill core. However, the petrophysical parameters indicate that the Cambrian rocks do not meet the criteria for good reservoir rocks. The porosity values range from 0.01 to 4.60%, whereas the permeability of the Cambrian deposits does not exceed 1.0 mD. These data suggest that this area is prospective for potential unconventional tight accumulations in the Cambrian sandstones.

For technical reasons, hydrogeological tests were made only in one Lower Cambrian horizon and one Carboniferous horizon. The Lower Cambrian contains Cl-Ca-Na-I brines. The chemical composition and hydrochemical parameters of the brine suggest hydrocarbon accumulations in close surroundings.

Translated by Krzysztof Leszczyński