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SUMMARY

The Wojszyce IG 1/1a, IG 3 and IG 4 boreholes were drilled in the north-western flank of the Wojszyce Anticline, located on the north-eastern side of the Kutno Block within the Kujavian Swell, which is the middle segment of the Mid-Polish Swell. The Mid-Polish Swell was uplifted in late Cretaceous and early Paleogene times, in the place of the axial zone of the synsedimentary Mid-Polish Trough, characterized by the highest sedimentation rate during the Permian and Mesozoic in the Polish Lowlands. The sedimentation was varied also along the trough, and the area of the greatest subsidence rate was located in the Kutno Block.

The Wojszyce Anticline is a salt-cored structure representing probably a salt ridge that may locally take a diapiric form partially piercing through the overburden. On its north-western extension, within the same structural chain, there are two small twin salt stocks of Lubień and Łanięta, penetrating up to the sub-Quaternary surface. The main area from which the salt flowed into the Wojszyce Anticline, and from which it was squeezed out completely or almost completely, was the long and wide Kutno Syncline adjoining the Wojszyce Anticline to the southwest.

The objectives of the Wojszyce IG 1/1a, IG 3 and IG 4 boreholes were to examine the geological structure of the anticline, and primarily to recognize the possibility of occurrence of lithological hydrocarbon traps in the Middle Jurassic deposits, especially Aalenian, Lower Bajocian and uppermost Bajocian. Traps of this type may be associated with lithological and facies changes expressed by the wedging-out of sandstones within claystone series.

Seismic studies have shown that substantial thickness changes, characterised by a significant thickness reduction above the salt pillow, are observed within the Upper Triassic deposits and, on a slightly smaller scale, within the Lower Jurassic and lower Middle Jurassic successions. It clearly indicates an intense movement of salt within this zone of the Mid-Polish sedimentary basin.

The Wojszyce IG 1 and IG 1a boreholes, combined into the Wojszyce IG 1/1a, are located in the axial part of the salt pillow. Due to technical problems, the former was stopped at a depth of 500 m within the Upper Jurassic (Oxfordian) deposits. The second one, drilled about 100 m away to the SW, penetrated Quaternary, Neogene, Paleogene, Upper Jurassic (Oxfordian) and Middle Jurassic deposits and was stopped at a depth of 1764.0 m within the Borucice Formation (Lower Jurassic – Upper Toarcian). A similar stratigraphical section was found in the Wojszyce IG 3 borehole, situated on the SW flank of the salt pillow. It was stopped at 1935.0 m depth, within the Ciechocinek Formation (Lower Jurassic–Lower Toarcian). The Wojszyce IG 4 borehole, which attained a depth of 2125.0 m (Ciechocinek Formation), penetrated also the uppermost Upper Jurassic units (Tithonian and Kimmeridgian).

The Lower Jurassic deposits (not pierced through) occur at the following depths: ?1618.0–1764.0 m (Wojszyce IG 1a), ?1580.0–1935.0 m (Wojszyce IG 3) and ?1911.0–2125.0 m. Claystone-mudstone and heterolithic rocks of the Ciechocinek Formation (Early Toarcian) are clearly brackish in nature. The overlying series is dominated by sandstones deposited in a terrestrial environment (Borucice Formation).

Middle Jurassic deposits were encountered in all the three boreholes at the depths of: 675.0–?1618.0 m (IG 1a), 476.0–?1580.0 m (IG 3) and 977.5–1911.0 m (IG 4). They are represented by clayey-sandy sediments. The lower boundary of the Middle Jurassic is marked by the first marine ingressions in the Late Toarcian continental basin. The Lower Aalenian section is dominated by light grey sandstones with minor interbeds of claystones and mudstones deposited in the nearshore zone of a well-oxygenated marine basin or within an estuary.

Main phase of the first Middle Jurassic transgression, combined with rapid subsidence in the basin, took place in the Late Aalenian. The Lower Aalenian sandstones are overlain by a series of black clay shales with siderite nodules. In the Lower Bajocian, a significant and gradual shallowing of the basin and intensification of clastic material supply took place. There is a continuous transition from the Upper Aalenian anaerobic/disaerobic clay shales, deposited in the offshore environment, into mudstones and claystone-sandstone heteroliths of a transitional zone, and then into the Lower Bajocian sandy deposits that accumulated in the lower shoreface zone. Alternating clayey/muddy and sandy series with subordinate sandy and calcareous sediments were still deposited in the Late Bajocian and Bathonian. Clayey-muddy sedimentation in the offshore and transitional zones dominated during the early and middle Late Bajocian and in the Early and Middle Bathonian. Sandstone sedimentation in different shoreface zones dominated mainly in the latest Bajocian and Middle–Late Bathonian. The uppermost Bathonian and Callovian section is represented by calcareous sandstones, dolomites and marly or sandy limestones, sometimes with glauconite, deposited on the shallow carbonate-clastic shelf. The Middle Jurassic succession ends with the Upper Callovian conglomeratic Nodular Bed.

It represents a stratigraphic condensation layer during the maximum sea level.

Thicknesses of the Middle Jurassic in the NW part of the Wojszyce pillow are as follows: Wojszyce IG 1a – 943.0 m (axial zone of the anticline), Wojszyce IG 3 – 1104.0 m (SW flank), Wojszyce IG 4 – 933.5 m (NE flank). Thickness distribution of the Middle Jurassic rocks shows little variation, which indicates a decreasing intensity of salt movements and associated halotectonic processes at that time. In the Middle Jurassic sections of the Kutno region, the sandstone strata wedge out within the Lower Bajocian claystones towards the SW flank of the salt pillow.

Upper Jurassic deposits were encountered in the Wojszyce IG 1, IG 1a, IG 3 and IG 4 boreholes at the depths of, respectively: 85.0–500.0 m (unpierced – 415.0 m thick), 103.5–675.0 m (571.5 m thick), 57.5–476.0 m (418.5 m thick) and 102.0–977.5 m (875.5 m thick). They directly underlie Paleogene deposits and represent the Oxfordian in the Wojszyce IG 1/IG1a and IG 3 boreholes (Calcareous Group A – Spongy Limestone Formation, Marly Limestone Formation and Oolitic Formation). In the Wojszyce IG 4 borehole, these are Oxfordian, Kimmeridgian and Tithonian deposits (Spongy Limestone Formation, Marly Limestone Formation, Oolitic Formation, Calcareous-Marly-Coquina Formation, Pałuki Formation). These data indicate that the Upper Jurassic section is more complete in the north-eastern flank of the anticline. Biostratigraphic studies have allowed more precise dating of the Middle Jurassic deposits based on foraminifers and Dinoflagellata cysts. The Upper Jurassic deposits were dated by foraminifers.

The Jurassic rocks were investigated for petrography and diagenetic processes. In the Lower and Middle Jurassic, the studies focused mainly on sandstones represented by quartz arenites composed mainly of quartz. The proportions of feldspars, micas and bioclasts are negligible. The mineral composition of detrital material indicates that it comes from resedimentation of older rocks. In addition, chamosite and berthierine ooids are reported from the Upper Bathonian and Callovian. Sideritic rocks are also locally observed. Following lithification, the deposits underwent diagenetic processes, including mechanical compaction, cementation and replacement, dissolution and diagenetic alteration. Quartz and locally carbonate cementation was important in the Lower Jurassic deposits. The formation of early fringe quartz cements played a positive role in maintaining the porosity of rocks. Dissolution of feldspars and quartz cement also contributed to the increase in porosity. Late diagenetic processes included the formation of fibrous illite reducing the permeability of rocks. In the Middle Jurassic sandstones, a significant role was played by mechanical compaction and cementation with calcite, dolomite and ankerite. Fluid inclusion studies indicate that the crystallization of ankerite occurred at a temperature above 75° and even exceeding 100°. Moreover, pyrite crystallized in claystones and some sandstones in the form of framboids during the early diagenesis. Ca/Mn-sideroplesite crystallized as micrite and sparite, forming concretions. In the Upper Jurassic limestones, an important role was played by chemical compaction and cementation with subordinate dolomitization.

The Jurassic deposits are overlain by sandy clays of the Czempiń Formation (Lower Oligocene) attaining a thickness of 1.5–5.5 m, carbonaceous fine-grained sands of the Adamów Formation (Miocene), 20.0–30.0 m in thickness, variegated or grey-green clays of the Poznań Formation (Miocene) and sands and tills (Quaternary) attaining a thickness of 26.0–63.5 m.

Geochemical studies of bitumens and hydrocarbons show that the Lower Jurassic deposits are poor in organic matter and labile components in these boreholes. The Middle Jurassic rocks contain very large amounts of labile components, although their content clearly decreases in the topmost strata that are characterised by a low content of hydrocarbons and resins, and a high content of asphaltenes. The Upper Jurassic rocks are characterised by low contents of bitumens.

The content of organic carbon in the Lower Jurassic rocks is small; only in the uppermost section of the Wojszyce IG 3 borehole it reaches a value of 7.2% TOC. Organic matter is represented by vitrinite and inertinite. In the Middle Jurassic rocks, organic material is abundant and very abundant, attaining the value of 12.7% TOC in the Upper Aalenian. This is mainly a humic material (both in situ and redeposited). The primary component is vitrinite, locally huminite; inertinite is significant, too. There is also observed a clear enrichment in liptinite group macerals. In addition, two samples from the Wojszyce IG 4 borehole revealed an increased concentration of organo-mineral association of sapropelic type.

Vitrinite reflectance studies in the Mesozoic deposits generally show a gradual increase in the degree of organic matter alteration with depth. Thermal maturity of the Jurassic rocks corresponds to the early and main stage of liquid hydrocarbons generation. Mean values of the reflectance coefficient vary within a range of 0.46–0.78% Ro in the Middle Jurassic deposits and 0.66–0.78% Ro in the Lower Jurassic. The maximum palaeotemperatures affecting these deposits during diagenesis and post-diagenetic times is estimated at 50–90°C. Due to the content, genetic type and thermal maturity of organic matter, the Middle Jurassic rocks can be considered good source rocks for oil generation. However, despite significant amounts of organic matter, especially in the Middle Jurassic, the deposits are not rich in bitumens and hydrocarbons.

Average seismic velocities were measured in the Wojszyce IG 3 borehole, suggesting the presence of several velocity boundaries associated with the variable lithology within the section. Much higher values are observed in the Lower Jurassic (above 4000 m/s) than in the Middle Jurassic. Within the Middle Jurassic section, there are three intervals of different velocities ranging between 3150 and 3500 m/s. They span the Aalenian–Lower Bajocian, Upper Bajocian (excluding the uppermost) and Bathonian (including the Upper Bajocian)–Callovian strata. A strong contrast is observed in the Upper Jurassic carbonates, where averages seismic velocities are

4200–4400 m/s. Above, a clearly marked drop in the velocities to 2900 m/s is observed to be associated with the occurrence of marly rocks.

Formation tests were perfomed for the Lower Jurassic (IG 3 – 2, IG 4 – 1) and Middle Jurassic (IG 1/1a – 4, IG 3 – 5, IG 4 – 4) intervals. The study of physicochemical properties of rocks and hydrochemical studies proved that the Lower--Middle Jurassic sandy deposits show good reservoir properties. The values of effective porosity in sandstones range from a few to 30.88%, and the permeability values are mostly from 0.32 to 1880 mD, reaching in some cases the maximum values of 3950 mD. The highest inflow rates were observed in the Lower and Middle Jurassic (excluding the Upper Bathonian) in the Wojszyce IG 3 borehole (16.4–24.4 m^3/h). For all tested intervals from the two remaining boreholes (Wojszyce IG1/1a, Wojszyce IG 4) and for the Upper Bathonian interval from the Wojszyce IG 3, the values were 0.451–9.9 m^3/h or no inflow was observed. The Lower and Middle Jurassic brines contain chloride, sodium, iron, iodine, carbonate and fluorine ions. In the Wojszyce IG1/1a borehole, the test results from the upper intervals of the Middle Jurassic indicate that these are mineralized waters containing 3.934 and 12.614 g/dm^3 of TDS. The values from the Wojszyce IG 3 boreholes were 57.34 g/dm^3 for the Lower Jurassic interval, and 0.718 g/dm^3 for the uppermost interval of the Middle Jurassic.

In the Wojszyce IG 4 borehole, the mineralization values were 79.307 g/dm^3 in the Lower Jurassic, and 10.596 g/dm^3 (lowest value) in the Middle Jurassic. Some of the formation waters were contaminated with the drilling mud, making the measurements impossible. The tests proved that there is no favourable condition for hydrocarbon accumulations due to significant inflows of mineralized meteoric waters. The waters contain small amounts of natural gas with a high content of hydrocarbons, which may come from organic pollution in the drilling mud. However, it may also indicate the presence of small quantities of natural gas of a limited vertical and horizontal extent.

Translated by Krzysztof Leszczyński