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MOST IMPORTANT FINDINGS FROM THE OŚWINO IG 1 BOREHOLE

Oświno IG 1 borehole is localized in the northern area of the Szczecin Trough, near the southern margin of the Pomeranian Swell. Drilling works were conducted in 1964 and reached the depth of 2250.0 m [according to one of the geophysical depth measurements (PG) 2253.75 m]. The main objectives of the drilling were to obtain a geological profile of the Lower Cretaceous, and Middle and Upper Jurassic, as well as to explain the problematic of the increase of thickness of the aforementioned rocks at the transition zone between the Szczecin Trough and Pomeranian Swell. An additional aim was to examine the possibility of occurrence of hydrocarbon accumulations in Jurassic and Lower Cretaceous rocks.

The borehole drilled through the profile of the Quaternary, Miocene and Paleocene, as well as the complete profiles of the Upper and Lower Cretaceous, and Upper and Middle Jurassic, and was terminated within the topmost layers of the Lower Jurassic.

Lower Jurassic has been established within the depth ?2220.0–2253.75 m (30.75 m in thickness). The borehole drilled into the near-top segment of Borucice Formation (Upper Toarcian), predominantly formed from fluvial sandstones.

Middle Jurassic present at the depth of 1933.5–2220.0 m encompasses the complete stratigraphic profile (Aalenian – Callovian) which is 286.5 m in thickness. The thickness of this interval is reduced relative to its profile in the axis of the Pomeranian part of the sedimentary basin, and increased relative to the southwestern part of the Szczecin Trough. The bottommost section of the Middle Jurassic profile is represented by two sandstone complexes separated by a claystone complex. The origin of these complexes is mostly terrestrial, with visible marine influence in the lower part of the fine-grained complex. The upper part of the Middle Jurassic (Upper Bajocian–Callovian) is represented by claystone-mudstone rocks and sandstones deposited in a marine environment. The upper and lower sections of the Upper Bajocian profile is built from mudstone complexes divided by a chlorite bearing sandstone complex. The Upper and Lower Bathonian is dominated by claystones and mudstones, whereas Middle Bathonian rocks are almost entirely made of sandstones. The Callovian is represented by mudstones, claystones and shales, which were distinguished as the lower part of the Łyna Formation. The stratigraphy of Middle Jurassic was determined based on the analysis of ammonite and microfaunal index fossils.

A complete profile of the Upper Jurassic (Oxfordian, Kimmeridgian and Tithonian) with a continuous transition into the Lower Berriasian (Lower Cretaceous) was identified in the borehole. The profile occurs at the depth of 1560.0–1933.5 m, and has a thickness of 373.5 m. The Oxfordian profile comprises of: mudstones of the upper part of Łyna Formation (108.5 m), sandstones of the Chociwel Formation (45.0 m), as well as marl-muddy dolostones, dolomitic mudstones, and dolomitic, oolitic and detrital limestones forming the lower and middle section of the Brda Formation (92.5 m). The Lower Kimmeridgian encompasses the upper part of the Brda Formation, together with the sandstones of the Oświno Member (6.5 m) at the top. The Upper Kimmeridgian, and Middle and Lower Tithonian profiles were collectively assigned to the Pałuki Formation (73.5 m), which formed as marly mudstones, marly shales, sandy mudstones and marls with marly limestone inserts. The uppermost part of the Tithonian profile took form of limestones, representing the lower section of the Kcyna Formation – Corbula Limestone Member.

The thickness of the Lower Cretaceous succession in the Oświno IG 1 borehole is 279.5, and it resides at the depth of 1280.5–1560.0 m. The profile comprises of: (1) the Rogoźno Formation – Opoczki Member formed as oolite- and iron hydroxide pseudooolite-bearing mudstones (Upper Berriasian (Riazanian) – lower Lower Valanginian). (2) the Bodzanów Formation (upper Lower Valanginian) which took form of sandstones ranging from fine-grained to unsorted, and coarse-grained sandstones locally with gravel, (3) the Włocławek Formation – Wierzchosławice Member (Upper Valanginian) represented by claystones and sandstones, (4) an unresolved interval of sandstones, mudstones and claystones, most likely encompassing the Gniewkowo and Żychlin Members (Hauterivian), and (5) the Mogilno Formation (?Barremian – Middle Albian). The Mogilno Formation is tricuspid, and separates into the following members: the Pagórki Member (?Barremian) – made of sandstones, the Gopło Member (?Aptian) – composed of fine-grained sandstones with pyrite concretions, and iron and locally siderite oolites, and the Kruszwice Member (?Lower Albian – Middle Albian) – represented by sandstones, claystones and glauconite sandstones. The Upper Albian has a limited thickness, and its profile is a layer comprising of fine-grained, quartz-glauconite sandstones (glauconitite) and muddy sandstones with marl-phosphorite cement, and relatively abundant phosphorite concretions.

The Upper Cretaceous is present at the depth of 251.0–1280.5 m (1029.5 m in thickness), and the observed profile is of the Cenomanian to Campanian age. Maastrichtian was not identified in the borehole. The Cenomanian is represented by a limestone complex with a marl layer in the top. The lower section of the Turonian profile is made of claystones, and marly and marl-clayey mudstones, topped with clayey lime--siliceous (opoka) rocks. Opoka rocks are also present in the Coniacian and Upper Santonian profiles, which are separated by clayey marls and mudstones of the Lower Santonian. The lowermost section of the Campanian profile is made of opoka rocks, which transition into marly mudstones. The Upper Cretaceous profile ends with quartz-glauconite sandstones.

Paleogene (66.0 m) and Neogene (83.5 m) rocks were distinguished at the depth of 101.5–251.0. The Paleogene is represented by the Lower Mosino Formation (Lower Oligocene) which took the form of quartz-phosphorite-glauconite sands and sandstones. The lower and upper sections of the Neogene profile are made of clays and quartz sands respectively.

The Quaternary profile, found down to the depth of 101.5 m, comprises of sands with a single layer of glacial till. These rocks represent deposits of: the San Glaciation recognized as one of South-Polish Glaciations, the Odra and Warta Glaciations counted as the Middle-Polish Glaciations, and the Vistula Glaciation representing the North-Polish Glaciation.

The majority of the drilled rock succession was subject to stratigraphic analysis, which included: macrofaunistic studies of ammonites (Middle Jurassic and Lower Cretaceous) and inocerams (Upper Cretaceous), micropaleontological studies (foraminifera and ostracods – Middle and Upper Jurassic, Lower and Upper Cretaceous), palynological studies (Lower Cretaceous and nanoplankton studies (Lower Cretaceous). The obtained results led to precise dating of particular rock complexes throughout the borehole profile.

Petrographic studies were conducted on Middle and Lower Jurassic, lowermost Oxfordian (Upper Jurassic) and Lower Cretaceous rocks.

The analysis of Jurassic rocks was focused predominantly on sandstones. Their main constituent is quartz, grains of which contain very fine mineral and gaseous inclusions, some with regenerative coating. Among other mineral components are feldspars (mainly microcline, sporadically untwined feldspars, likely orthoclase), mica (mostly muscovite, rarely biotite with signs of chloritization). Rock fragments (quartzite, quartzite-shale and chert), pieces of calcitized fossil fauna (bivalves, echinoderms) and deformed berthierine ooids were observed. The cement is of basic-type, less often of contact-type, formed from clay minerals (illite, chlorite and kaolinite), organic matter, pyrite and carbonate pelite. Siderite (pure siderite, sideroplesite and pistomesite) is the most common carbonate mineral. The content of calcite increases gradually since Lower Bathonian. Most often, chlorite sandstones are cemented with berthierine matrix, which contributes to over 10% of the rock volume.

Illite, kaolinite, chlorite, hydromuscovite, siderite, organic matter and pyrite are observed among consitiuents of claystones and clayey shales. Detrital material makes up to 50% of the rock volume, and is mainly composed of quartz grains. Among other components are very fine, carbonaceous, chitinous or pyritised fossil flora. Both the shales and the sandstones contain laminated clay-sandy siderite and siderite concretions, which show pelitic-psammitic textures, and a disorganized or, less often, parallel structures. Siderite rocks are made of clay pelite and detrital material. Additionally, berthierine ooids, bethierine-kaolinite ooids, and kaolinite ooids – formed as a result of bethierine recrystallization – are identified. The observed heavy minerals are of detrital origin and include: magnetite, tourmaline, rutile, staurolite, garnet, fibrolite-type silliminite, amphibole – represented by regular hornblend and glaucophane, pyroxene and biotite.

The Lower Cretaceous limey sandstones show psamite textures, and weak directional or disorganized structures. The main detrital component is quartz. Glauconite, iron pseudooids, muscovite and siderite are also present. The sandstone cement is made of fine-crystalline calcite, shamosite or clay minerals. The main component of claystones, mudstones and the sandstone cement is illite. Very fine micrite siderite is identified as an admixture. The mudstones have alleurite and locally aleurite-psamite textures, and disorganized or weak directional structures. Detrital material mainly consists of angular quartz grains. The claystones show pelite textures, and directional structures, highlighted by the orientation of illite scales.

Organic geochemical studies were conducted for Middle and Upper Jurassic, Lower Cretaceous and lowermost Upper Cretaceous rocks.

The Middle Jurassic claystones and mudstones are both organic matter- (0.49–2.86 wt%; 1.53 wt% on average) and bitumen-rich (0.021–0.135 wt%; 0.043 wt% on average). Hydrocarbons form 3–15 wt% of bitumen substance and 0.002–0.011 wt% of the rock. The observed hydrocarbons predominantly show naphthenic character. Clearly paraffinic hydrocarbons are found in a single sample of the Lower Callovian. The non-hydrocarbon fraction of the oils characterizes with a significant contribution from aromatic compounds. Bituminous substance was submit to a relatively low degree of thermal alteration. The bitumen observed within the Middle Jurassic source rocks are considered syngenetic with the sediment.

The contribution of organic matter in the Upper Jurassic rocks is 0.39–1.44 wt%, while bitumen alone accounts for 0.012–0.079 wt%. Hydrocarbons make up 0.003–0.004 wt% of the rock. The composition of the samples indicates presence of both paraffinic and naphthenic oils. The diversification of the composition and concentration of hydrocarbons in the Upper Jurassic rocks is likely related to varying biological source or differences in the conditions of post-diagenetic alteration. Hydrocarbons present in the Upper Jurassic rocks are considered to be syngenetic with the sediment.

The contribution of organic matter in the Lower Cretaceous (Berriasian – Lower Valanginian) claystones and mudstones ranges from 0.56 to 2.22 wt%, and in sandstones (Valanginian) from 0.33 to 1.60 wt%. Concentration of bitumen is between 0.012 and 0.030 wt%. Hydrocarbons are scarce and make up 0.001–0.009 wt% of the rock. The concentration of hydrocarbons within bitumen from the lowermost part of the profile is 16–20 wt%, while in the overlaying sandstones their contribution rises to 32 wt%. Bitumen from both intervals shows the same, paraffin-naphthenic character suggesting their close genetic relationship, as well as vertical migration. In the Aptian sandstones, hydrocarbons represent merely 6 wt% of the bitumen extract, and vary from both older and younger rocks. The Aptian claystones contain low (0.009 wt% of the rock and 31 wt% of extracted bitumen) concentrations of naphthenic-type hydrocarbons. Generally, the Lower Cretaceous hydrocarbons are syngenetic. The concentrations organic matter, bitumen and hydrocarbons in Cenomanian rocks comprise are also low. The contribution of hydrocarbons in the extracted bitumen values 17 and 18 wt%, and shows clearly paraffinic qualities. Therefore, these rocks notably differ from naphthenic and paraffin-naphthenic hydrocarbons of the Lower Cretaceous. Bitumen from both the Aptian and Cenomanian rocks show low levels of thermal transformation.

The quality and quantity of the Jurassic and Cretaceous hydrocarbons extracted from the Oświno IG 1 core indicates that the preserved bitumen is largely syngenetic with the sediments, and that the general degree of thermal alteration is very low.

Results of Rock-Eval analysis were performed solely on Middle Jurassic and lowermost Upper Jurassic (Oxfordian) rock samples. The total organic carbon (TOC) content ranges from 0.14 and 17.03 wt%, whereas values exceeding 4 wt% were noted in samples of the Bajocian and Aalenian ages. The amount of free hydrocarbons present in the rock (S1) oscillates between 0.03 and 1.26 mg HC/g rock, and the amount of hydrocarbons generated during kerogen cracking (S2) is between 0.10 and 60.60 mg HC/g rock. Values of the S1/S2 (0.02–0.30) and S1/TOC (0.01–0.021) ratios are considerably below unity, which indicates autochtonous character of the bitumen. The correlation between S1, S2 and TOC parameters suggests both low thermal maturity of the studied rocks and low hydrocarbon potential. As an exception, several samples from the Lower Bajocian and Aalenian show parameter values indicating potential source rock quality ranging from fair to excellent. Hydrogen index (HI) values in all studied samples range from 14 to 356 mg HC/g TOC, and oxygen index (OI) values from 13 to 270 mg CO_2/g TOC. The obtained values are typical for type III and type IV kerogen. Therefore, the tested rocks could be a potential source to gaseous hydrocarbons at most. The sole sample showing characteristics of an oil-prone (type II kerogen) source rock is the sample collected from the depth of 2162.0 (Aalenian – Lower Bajocian). The range of the obtained T_{max} values is between 413 and 437ºC, and low production index values which do not exceed 0.23 indicate low thermal maturity of the studied kerogen.

An estimation of sedimentary deposition rate was performed for the Middle and Upper Jurassic, Cretaceous and Cenozoic rock strata. The determined deposition rate of most Middle Jurassic stages (Aalenian–Bajocian. Upper Bathonian, Middle and Upper Callovian, Lower Kimmeridgian and Upper Tithonian) is ~12–22 m/Myr. Increased subsidence, at the rate of 40–70 m/Myr, was noted for the Middle Bathonian, Lower Callovian, and Lower and Middle Oxfordian. Maximum deposition rates in the Middle Jurassic took place during the Lower Bathonian (~125 m/Myr), while decreased rates were observed in the Upper Kimmeridgian (~7 m/Myr) and the Lower Tithonian (~1 m/Myr) strata. The Lower Cretaceous rocks characterize with variable deposition rates: from 0.5 m/Myr (Upper Albian) to 16 m/Myr (Lower Berriasian, and Lower and Middle Albian). As an exception the subsidence rate in the Lower Valanginian reached ~44 m/Myr. During the Cenomanian the deposition rate was low (~3 m/Myr), in the Turonian it increased to ~30 m/Myr and in the Coniacian and Santonian to ~50 m/Myr. An exponential spike and maximal sedimentary deposition rate were designated for the Campanian stage (~444 m/Myr), which is an indication of a very rapid expansion. A return to deposition rates of ~40 m/Myr occurred during the Maastrichtian stage. However, a shift from an extensional to a compressional tectonic regime at the boundary between the Upper Cretaceous and Paleogene inflicted an erosive event which consumed part of the Campanian profile and the entire Maastrichtian profile. A return to an extensional tectonic regime halfway through the Miocene was followed by ~4 m/Myr sedimentation rate, which finally increased up to ~10 m/Myr in the Quaternary.

Bulk density and effective porosity analysis were performed for the entire rock sequence. The least dense intervals are sediments from the Neogene and Paleogene. Both the Quaternary and Cretaceous rocks show higher bulk density than the former, however, the boundary between the Paleogene and Cretaceous rocks is not marked by a clear density contrast due to the low density of the topmost Cretaceous layers (Campanian). The densest rocks of the Cretaceous come from the Cenomanian stage. The average bulk density of the Jurassic strata is significantly higher then of the Cretaceous, whereas the Upper Jurassic rocks are generally denser than Middle Jurassic rocks. The least dense rocks belong to the uppermost Lower Jurassic (Upper Toarcian). The Upper Cretaceous, in particular the Campanian, rocks are characterized by the highest effective porosity.

Borehole velocity survey was conducted at the depth of 20.0–1925.0 m, within Cenozoic, Cretaceous and Upper Jurassic rocks. The analysis of the calculated interval velocities, complex velocities and smooth velocity/depth profiles led to the identification of four complexes, each of which shows as uniform and similar characteristics of seismic velocities as possible. The Quaternary, Miocene, Paleogene and Upper Campanian rocks represent Complex I, which reaches the depth of 620.0 m and is divided into two sub-complexes: a) up to the depth of 250.0 m, with complex velocity of 1830 m/s, and b) below the depth of 250.0 m, with complex velocity of 2290 m/s. Complex II is present at the depth range of 620.0–1000.0 m, its average complex velocity is 2660 m/s, and encompasses the lower layers of the Upper Campanian, the Lower Campanian, Santonian and upper series of the Coniacian. Complex III, reaching the depth of 1520.0 m and having average complex velocity of 3100 m/s comprises the remaining stages of the Upper Cretaceous succession (a large section of the Coniacian, the Turonian, Cenomanian) and the entire Lower Cretaceous (Albian–Upper Beriassian). Complex IV beginning at the depth of 1520,0 m and ending with the depth of termination of the velocity survey (1925,0 m), featuring the lowermost Cretaceous and the entire Upper Jurassic, is separated into two sub-complexes. The upper sub-complex, which comprises rocks from the Lower Berriasian to Upper Kimmeridgian (1520.0–1660.0 m), has an average complex velocity of 3510 m/s, while the lower sub-complex, encompassing the Lower Kimmeridgian and Oxfordian rocks, has an average complex velocity of 4020 m/s. The latter value decreases to 3960 m/s when taking into account the terminal section of the measurement which characterises with a negative velocity contrast.

Six reservoir horizons were sampled in the borehole, which include: Lower-Middle Jurassic (Upper Toarcian–Bajocian), Middle Jurassic (Middle and Upper Bathonian), Upper Jurassic (Oxfordian), Lower Cretaceous (Lower Berriassian) – Upper Jurassic (Upper Tithonian), Lower Cretaceous (Valanginian–Hauterivian) and Upper Cretaceous (Campanian) reservoirs. The reservoir inflow in the lowermost and Lower Cretaceous (?Lower and Middle Albian–?Aptian) horizons was not measured. In the Middle Jurassic and Oxfordian reservoir horizons the brine inflow was minimal – 0.0093 m^3/h and 0.0063 m^3/h respectively. Reservoir inflow value in the Berriassian horrizon was 0,552 m^3/h whereas in the Campanian – 0.59 m^3/h. The mineralization of reservoir water varies form 99.6 g/dm^3 and 104.0 g/dm^3 in the Lower and Middle Jurassic, by 31.9 g/dm^3 in the Oxfordian, to 96.0 g/dm^3 and 98.0 g/dm^3 in the Tithonian and Lower Cretaceous horizons. The measurements in the last two horizons can be altered, due to the supposed mixing of reservoir water with water from deeper horizons. The general mineralization of brine from the Upper Cretaceous horizon is 1 g/dm^3.

Data obtained from physicochemical water analysis indicates the presence of chloride-sodium type brines in the Jurassic and Lower Cretaceous reservoir water horizons. Hydrochemical parameters, especially the $\frac{rNa}{rCl}$ which assumes values of 0,81–0,87, suggests good and long-term isolation of waters from the surface of the Earth and their intense metamorphism. The Upper Cretaceous horizon incorporates chloride-bicarbonate-sodium type brines.

To conclude, the Oświno IG 1 borehole fulfilled the imposed objectives.