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# SUMMARY

The Gościno IG 1 borehole was drilled within the Pomeranian Block of the Variscan tectonic settingstructural pattern. It is also located within the Permo-Mesozoic Kołobrzeg Anticline that runs N-S and is cut by a number of faults. This anticline is part of the Pomeranian Swell that formed in the Laramide phase of the Alpine orogeny. The Pomeranian Swell is bordered on the SW by the Szczecin Trough filled with Cretaceous deposits, and on the NE by the Pomeranian Trough (see Fig. 1).

The following Systems have been encountered in the Gościno IG 1 borehole: the Devonian (unpierced ?Givetian, and Upper Devonian: Frasnian and much of the Famennian), Permian (Zechstein represented by the PZ1, PZ2, PZ3 and PZ4 cyclothems), Triassic, Jurassic (Lower and Middle), and the Quaternary (see Fig. 3 – composite log).

A characteristic feature of the borehole section is the occurrence of prominent gaps not only between the individual Systems (e.g., entire Carboniferous), but also within them (e.g., lack of significant parts of the Famennian and Permian). The majority of these gaps occur on a local scale and they are not found in the whole area of Western Pomerania.

The oldest deposits drilled in this borehole are strongly diagenetically altered shales with streaks of quartzitic sandstones, representing probably the uppermost part of the Middle Devonian Wyszebórz Formation. The biostratigraphic evidence for the Devonian deposits in this borehole is not based on a direct biostratigraphic analysis (except for the Kłanino Formation), but it comes from intra-regional comparisons of the well-explored Devonian sections in Pomerania (Matyja, 1993, 2006, 2009). It has been the basis for establishing the Człuchów Formation (more than 1100 m thick in this borehole) that comprises the Strzeżewo, Gorzysław and Gościno formations in the Frasnian and Famennian (up to the marginifera conodont Zone, cf. Matyja, 2009). The Kłanino Formation represents the upper Famennian (lower and middle expansa conodont Zone), which is also confirmed by direct biostratigraphical examinations in the Gościno IG 1 borehole.

The study of lithologies, supported by a microfacies analysis, indicates that the Upper Devonian deposits were accumulated in an open-marine sedimentary basin showing continuous (from the upper Frasnian until the Famennian) regressive tendencies (cf. Matyja, 1993, 2009).

The stratigraphic gap spans the uppermost Famennian, entire Carboniferous and the lower Permian.

The Famennian is overlain by Upper Permian (Zechstein) deposits of considerable thickness (591.0 m) and a relatively complete stratigraphic record up through the PZ4b cyclothem. The Zechstein section is not undisturbed tectonically and consists of three carbonate-evaporite cyclothems: PZ1, PZ2 and PZ3, and the terrigenous-evaporite cyclothem PZ4 divided in this region into two subcyclothems PZ4a and Pz4b. In determining the age of Zechstein rocks, palynological analysis was a very important tool – very good material for the study was obtained from the Younger Halite (Na3) and the lower part of the Youngest Halite (Na4a1). Palynological studies also provided important information on the Late Permian climate. Remarkable dominance of pollen grains of coniferous-like plants that evolved from the Carboniferous Cordaitales (xerophyte vegetation), and the lack of representatives of wet-loving plants (horsetails, Lycophyta) indicate a dominant hot and dry climate at that time. Examinations of salt cores resulted in the identification of lithological and structural varieties of rocks (fraction, selection of crystals, the presence and type of mineral admixtures, optical features and textural characteristics (secondary directional texture)). Geochemical studies included the determination of bromine and boron contents, and the identification of mineral composition. These studies suggest that the salts were formed in a wide range of nearshore sedimentary environments, including a coastal salt pan, a coastal mud plain or a perennial lake basin, a shallow saline lagoon or a shallow-water sulphate lagoon.

Mesozoic deposits of in the Gościno IG 1 borehole are represented by the Triassic (over 1800 m in thickness) and the incomplete Jurassic section (Lower and Middle Jurassic only, attaining a thickness of approximately 770 m).

Based on the lithological description and original and reinterpreted geophysical well logs, the Triassic lithostratigraphy in this borehole has been verified. The Lower Triassic, represented by the Buntsandstein Group, includes all of its subgroups: the Lower, Middle and Upper Buntsandstein.

Due to the lack of chronostratigraphic data coming directly from the borehole, all chronostratigraphic boundaries are arbitrary and drawn on the nearest lithostratigraphic boundaries, based on the results of regional studies. The following formations have been distinguished (from the base): Baltic, Pomeranian, Połczyn and Barwice. The Middle Triassic is represented by the Muschelkalk Group (Lower, Middle and Upper) and the Lower Keuper Subgroup. The Upper Triassic is represented by the Middle Keuper subdivided into the Lower Gypsum Beds, Reed Sandstone, Upper Gypsum Beds, Zbąszynek Beds and Jarkowo Beds, and the Upper Keuper represented by the Trileites Beds.

The Gościno IG 1 borehole provides probably the complete Lower Jurassic section represented by the Zagaje, Ostrowiec, Łobez, Komorowo, Ciechocinek and Borucice formations, according to the lithostratigraphic scheme of Pieńkowski (2004), and part of the Middle Jurassic section represented probably the Upper Bajocian and Lower Bathonian. Due to the lack of chronostratigraphic data coming directly from the borehole, all chronostratigraphic boundaries are arbitrary and drawn on the nearest lithostratigraphic boundaries, based on the results of regional studies.

The uppermost rocks series drilled in the Gościno IG 1 borehole is non-cored Quaternary deposits represented by quartz sands, silts and clays.

The Middle Devonian through Middle Jurassic deposits contain a variable (from 0.1 to 1.2% of planimetric surface of samples) amount of organic matter. Slightly increased concentrations contents (0.9–1.2%) are reported from the Jurassic formations, some Permian horizons (0.8%) and Devonian rocks (0.7–0.8%). In the Devonian, organic matter is represented by vitrinite-like material (solid bitumens, zooclasts) and quite numerous small bituminous impregnations (Upper Devonian).

The younger sediments (Permian–Jurassic) contain humic and humic-sapropelic organic matter, whose main microcomponents are vitrinite macerals (Permian–Jurassic), solid bitumens (Permian) and liptinite (Permian, Jurassic), with a high proportion of the inertinite maceral group. Thermal maturity of organic matter, determined based on vitrinite and/or vitrinite-like material reflectance coefficient, clearly increases down the vertical borehole section from 0.42% $R_o$ at a depth of 130.20 m (Middle Jurassic) to 1.70% $R_o$ at a depth of 4304.0 m (Upper Devonian). It corresponds to the transition from the immature stage to the stage of liquid hydrocarbon generation (Upper and Middle Jurassic), through the early (Upper and Middle Triassic) and main phases of oil generation (Lower Triassic, Upper Permian) to the gas generation phase (Upper Devonian).

The results of geochemical studies in the Gościno IG 1 borehole show that there is only a short interval of Upper Permian carbonates and upper Lower Jurassic mudstone-s and claystones, which can be considered „good" source rocks for hydrocarbon generation. The Devonian and Permian deposits, as well all Triassic deposits are „poor" source rocks. The amount of bitumens found in the analysed rocks is not high. Organic matter in the Zechstein is of sapropelic type with a small amount of humic material. Primary organic matter in these deposits originates from bacteria and marine algae. It can be assumed that epigenetic and syngenetic bitumens co-occur in the Zechstein deposits.

Pyrolytic analysis was carried out on fine-clastic (claystones and siltstones) and carbonate rock samples from the Jurassic (Sinemurian), Triassic (Carnian, Middle Triassic), Permian and Devonian (Famennian–Frasnian, ?Givetian) to determine the content of organic carbon, its origin and maturity. The Devonian samples were characterized characterised by extremely low TOC contents ranging from 0.03 to 0.14 wt. %. The generation potential S2 also oscillates in the range of very low values from 0.07 to 0.26 mg HC/g of rock. The content of free hydrocarbons in the samples was also very low, about 0.02–0.08 mg HC/g of rock.

Due to the fact that the samples show very low values of these pyrolytic parameters, the rocks should be classified as non-prospective for hydrocarbon generation. Hydrocarbon potential of the Zechstein deposits, expressed as the parameter HI, falls within the limits of 115–336 mg HC/gTOC. The degree of thermal maturity of organic matter, expressed as the parameter Tmax, is 433–439°C. The TOC values, which are a measure of the abundance of organic matter, are 0.05–2.74 wt.%, and the potential generation values, expressed by the parameter S2, are in the range of 0.13–5.06 mg HC/g of rock. The values of Tmax and HI suggest that the Zechstein Dolomite samples represent three types of rocks with respect to hydrocarbon generation: moderate/good source rocks (2940.5–2940.6; 2956.9 m), very poor source rocks (2951.1 m), and non-source rocks (2955.4; 3057.3–3068.6 m). Organic matter from the samples of Permian rocks contains Type III and Type II kerogen, which is within low-temperature thermocatalytic alterations of the upper part of the oil window.

The hydrocarbon generation potential of the Triassic and Jurassic rock samples, expressed as the parameter HI, varies between 20 and 114 mg HC/gTOC, and the degree of thermal maturity of organic matter, expressed by the parameter Tmax, is 338–447°C. The TOC values, which are a measure of the abundance of organic matter, are 0.10–1.73 wt. %, and the generation potential, expressed by the parameter S2, is in the range of 0.11–0.42 mg HC/g of rock.

The values of these parameters suggest that the tested Triassic and Jurassic samples represent non-prospective rocks for hydrocarbon generation. Organic matter in the Triassic and Jurassic rocks is represented by reworked and degraded Type III kerogen. The samples contain from 0.04 to 5.02% of mineral carbon bound in carbonate minerals dominated by dolomite. Such a mineral carbon content indicates that dolomite accounts for 5–40% of the total rock mass.

To illustrate the geological structure of the area around the Gościno IG1 borehole, seismic profile T0270577 was selected. Despite its moderate quality, the profile allows tracing seismic horizons associated with the top-Triassic, top-Muschelkalk, top-Buntsandstein and top-Zechstein. Due to a dummy area in the seismic record at shallow depths (erosional boundary), it is not possible to trace reflectors shallower than top-Jurassic. The sSeismic boundaries in the sub-Zechstein basement, from the top-Devonian downwards, which can be reliably interpreted only fragmentarily, are not clearly identifiable in the seismic record.

Analysis of deposition rate shows its very high values in the Late Devonian, especially during the Frasnian, ranging from 205 to 215 m/million years. In the Famennian, the deposition rate significantly decreased to almost 30 m/million years. In the Late Carboniferous and Early Permian, during the Variscan orogeny, the area underwent uplift and erosion, therefore there are no Carboniferous and Lower Permian deposits in this borehole. Also the Upper Devonian (Famennian) deposits were partially eroded. Renewed sedimentation in the Late Permian was characterized characterised by a high rate of deposition of evaporite-carbonate sediments (about 63 m/million years). Then, the deposition rate of the Lower Triassic clastic sediments dramatically increased to 275–290 m/million years. Such a fast sedimentation rate was associated with a tectonic event that shaped the development of the Polish Basin (Dadlez et al., 1995). After that period, a clear slowdown in the deposition rate is observed during the rest of Mesozoic times. According to Poprawa (2011), the high deposition rate in the Late Permian and Early Triassic was related to subsidence during the synrift extension phase, while the subsequent phase of low deposition rate was associated with the postrift thermal subsidence. The deposition rate in the Middle Triassic to Middle Jurassic (Bajocian) varied from 12 to 65 m/million years. Upper Jurassic and Cretaceous deposits are absent in the borehole due to erosion during the Laramide orogeny at the Cretaceous/Palaeogene transition. Deposition rate of the interpreted Upper Jurassic and Cretaceous deposits was relatively low. Later in the Palaeogene and Neogene, the sedimentation ceased and was eventually resumed in the Quaternary, with the deposition rate of 55 m/million years.

One-dimensional modelling and reconstruction of thermal and burial history indicate that the Middle and Late Devonian to Early Carboniferous was the first period of increased deposition rate and burial. A thick sedimentary cover of about 2050 m developed at those times. In the Late Carboniferous and Early Permian, the area underwent uplift and erosion that led to the removal of the Lower Carboniferous and the upper part of the Upper Devonian deposits with a total thickness of about 900 m.

Later in the Permian, the sedimentation ceased. At the beginning of the Late Permian and in the Early Triassic, a very fast burial event took place, associated with the development of the Polish Basin. Intense sedimentation and subsequent burial continued towards the end of the Cretaceous. At the end of the Mesozoic, the sedimentary cover reached a thickness of about 5000 m, attaining the maximum depth of burial in the geological history of the area. The Laramide orogeny caused uplift and total erosion of the Upper Jurassic and Cretaceous deposits. A period of erosion was followed by a period of stagnation and lack of sedimentation in the Palaeogene and Neogene. The youngest, Quaternary series is 97 m thick in the Gościno IG 1 borehole.

During the drilling operations in the Gościno IG 1 borehole, a set of borehole geophysical measurements were was performed, which largely enabled interpretation of lithologies of non-cored intervals and provided important data on the petrophysical properties of rocks.

Average seismic velocities were recorded in the depth interval from 0 m to 3100 m. Interpretation of the measurements made it possible to determine the lithologic boundaries on seismic sections in this region. The obtained data show that the boundaries of velocity contrast down to a depth of about 1300 m show a downward gradual „stepwise" increase in the velocity values and occur in the Jurassic succession at the boundaries of the Bajocian, Toarcian, Pliensbachian, Sinemurian and Hettangian (also comprising the upper strata ofmost the Rhaetian strata). The next increase in the interval and complex velocities is observed in the lower part of the Rhaetian and also comprises the upper Norian down to a depth of about 1000 m. The lower Norian deposits are characterized characterised by two values of interval and complex velocities. The Norian/Carnian boundary is underlined marked by a contrast in interval velocities. The first decrease in both interval and complex velocities is recorded at the boundary of the Carnian. From this boundary downwards, there is a return to the trend of increasing interval and complex velocities with the values of 3250 m/s, 3400 m/s and 3750 m/s corresponding to the individual units of the Middle Triassic. The last one (3750 m/s) also refers to the uppermost Lower Triassic. The lower units of the Lower Triassic down to a depth of 2300 m are characterized characterised by relatively small changes in complex and interval velocities, oscillating in the range of 3950–4150 m/s, with a higher contrast observed near the Middle/Lower Buntsandstein boundary. A significant increase in both velocities to 4450 m/s is observed only in the lower Lower Buntsandstein, in a 260-m thick package. Underneath, there is a great velocity contrast of about 700 m/s, with the complex velocity values decreasing to 3750 m/s in the lowermost Lower Triassic and uppermost Upper Permian rocks. From that level, there is another increase in average complex velocities characterizing characterising the individual Zechstein cyclothems: from the youngest PZ4 to the oldest PZ2. The PZ4 cyclothem PZ4 correlates with interval velocities of 4050 m/s, corresponding to rock salt with interbeds of claystones and mudstones. The continuing systematic increase in the velocities up to the value of 5250 m/s can be associated with an increase in the proportion of anhydrite and decrease in the amount of salt in the Zechstein lithological section.

Six reservoir horizons were examined in terms of hydrocarbon accumulation. They were selected based on the interpretation of well logs, lithology of drilled intervals, observations of drilling mud, and hydrocarbon shows during drilling. Hydrocarbon shows were reported from the following intervals: (1) positive reaction with acetone and chloroform was observed in the Main Dolomite at a depth of 3048.4–3075.5 m, (2) core "sweating" and core "bleeding" in fractures occurred in the interval of 3062.2–3075.5 m; (23) core "sweating" and strong bituminous smell was reported in the Platy Dolomite at a depth of 2942.8–2956.7 m, (4) core "bleeding" in longitudinal fractures and gas shows immediately after core recovery were observed at a depth of 2943.7–2947.5 m; (35) weak reaction with acetone was observed in the Devonian Limestone at depths of 4052.0, 4143.0 and 4196.0 m.

Formation tests carried out after drilling showed no signs of hydrocarbons. The values of hydrochemical indicators, however, point to favourable conditions for hydrocarbon accumulation in this area in the Upper Permian (Platy Dolomite) and Lower Triassic. Formation tests of the Devonian and Main Dolomite horizons were negative. It was found that the brines from the Lower Triassic and Upper Permian deposits are not suitable for use in balneological medicine due to too high mineralization.

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