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# SUMMARY

The Gorzów Wielkopolski IG 1 borehole is among the first deep wells drilled in the Polish Lowlands. It was drilled in the period 1957–1959 in the Gorzów Block area located between the Szczecin Trough and the northern edge of the Sudetic Monocline. The purpose of the drilling was to investigate the Mesozoic succession and the upper Paleozoic section, and to examine the facies development of the Zechstein sequence.

After piercing Cretaceous, Jurassic and Triassic rocks, the borehole reached Zechstein deposits and was completed in the Upper Anhydrite rocks (Ag1) at a depth of 3100.5 m

The Zechstein section is 509.5 m thick in this borehole, and includes the cyclothems PZ1, PZ2, PZ3 and PZ4. Within the PZ1 cyclothem, only a 30.3 m long interval of the Upper Anhydrite was drilled. Younger cyclothems show typical lithologic sections. The PZ2 cyclothem (173.6 m thick) comprises the Main Dolomite (Ca2), Basal Anhydrite (A2), Oldest Halite (Na2, 120.9 m thick) and Top Anhydrite (Ar2). The PZ3 cyclothem (223.3 m thick) is represented by the Grey Salt Clay (T3), Main Anhydrite (A3) and Younger Halite (Na3, 183.0 m thick). The PZ4 cyclothem (81.5 m thick) is composed of the Lower Red Salt Clay (T4a), Lower Pegmatite Anhydrite (A4a1), Youngest Halite (Na4a), Upper Red Salt Clay (T4b) and Top Youngest Halite (Na4b2). The cycle ends terrigenous sediments of the Top Terrigenous Series, 19.9 m in thickness.

The Buntsandstein was encountered at a depth of 1967.5–2591.0 m (623.5 m thick). The Early Triassic sedimentation was a continuation of terrigenous sedimentation represented by the topmost Zechstein succession. The Lower and Middle Buntsandstein deposits accumulated in a basin of variable environments from freshwater through lagoonal to shallow-marine. The Lower Buntsandstein section is characterised by the clay facies; in the Middle Buntsandstein, there is an increase in sandy material. Oolitic limestone intercalations are also frequent. Upper in the section, marly and organodetrital limestones are dominant. The Upper Buntsandstein is represented by carbonate-clay deposits with interbeds of sulphate rocks. The Buntsandstein succession is subdivided into the Baltic, Pomeranian and ?Połczyn formations.

The Muschelkalk, drilled at a depth of 1713.0–1967.5 m (254.5 m thick), is tripartite. The lower part is dominated by limestones (Marly, Wavy and Pumiceous beds), the middle part is composed mainly of dolomites and dolomitic siltstones, in its lowest part with anhydrite interbeds, while the upper part consists of limestones, and claystones and siltstones (Glauconite and Ceratite beds).

The Lower Keuper was encountered at a depth of 1636.0–?1713.0 m (77.0 m thick) and is represented by the Sulechów Beds composed of dark grey-green claystones and siltstones, with sandstone interbeds in the lower part. These are shallow-marine nearshore sediments. In the upper part, there are alternating grey-green and chocolate-brown claystones with soil horizons, deposited in a terrestrial environment.

The Upper Keuper occurs at a depth of 1350.0–1636.0 m (286.0 m in thickness) and is represented by the Lower Gypsum Beds, Reed Sandstone and Upper Gypsum Beds. The Lower Gypsum Beds are represented by variegated claystones and siltstones with evaporites, deposited in a sabkha environment. The lower part of the Reed Sandstone is composed of fluvial sandstones, whereas the upper part consists of chocolate-brown and violet siltstones with soil horizons, representing floodplain deposits. The Upper Gypsum Beds are made up of brown-red claystones overlain by green dolomitic siltstones with anhydrite nodules. These rocks were deposited in a coastal sabkha environment, but the top part of the succession is lagoonal.

The Norian section (depth 1138.5–1350.0 m, 211.5 m in thickness) is subdivided into the Jarkowo (+? Drawno) and Zbąszynek beds. These are violet, cherry, red and variegated claystones deposited initially in a brackish basin, and then in a playa environment.

It is not certain whether the overlying claystones, distinguished as the lowest part of the Zagaje Formation, represent the Rhaetian or the lowermost Lower Jurassic.

The Lower Jurassic occurs at a depth of 757.0–1132.0 m (375.0 m in thickness). Its lowermost part (Zagaje Formation – Lower Hettangian) is dominated by sandstones deposited in a fluvial environment. The overlying Skłoby Formation (Middle and Upper Hettangian) is composed of ma-

rine nearshore and deltaic sandstone-mudstone deposits. Upper in the section, the Ostrowiec Formation (Sinemurian) is represented by deltaic-lagoonal-shallow-marine deposits. Typical marine sediments, represented by heteroliths and sandstones, compose the Gielniów Formation (Lower Pliensbachian). The Komorowo Formation (Upper Pliensbachian) deposits are also of marine origin: lagoonal and nearshore-lagoonal. The claystone-siltstone deposits of the Ciechocinek Formation (Lower Toarcian) are clearly brackish in origin. The Borucice Formation (Upper Toarcian) is represented primarily by sandstones, mostly of fluvial origin with subordinate deltaic sedimentation.

The Middle Jurassic occurs at a depth of 721.0–757.0 m, and the section is significantly reduced in this borehole (with a thickness of 36.0 m). It is represented by a conglomerate and sandstones of the Lower Bajocian (humphresianum Zone) and the Upper Bajocian (arcis Zone), as well as by lowermost Bathonian claystones and siltstones with sandstone and siderite intercalations. These deposits accumulated in a marine (nearshore and offshore) environment. The lower and upper boundaries of the Middle Jurassic are erosional, and the identified stratigraphic gaps span the Aalenian and Middle Bathonian-Callovian and Upper Jurassic.

No Upper Jurassic deposits have been found in this borehole.

The Lower Cretaceous section is 13.5 m thick and occurs at a depth of 707.5–721.0 m. It is represented by Middle and Upper Albian quartz-glauconitic sandstones and Upper Albian marls.

The Upper Cretaceous (Cenomanian through Campanian) carbonate successionis composed of predominant limestones with subordinate marly limestones and chalk. These deposits occur at depths ranging from 177.5 to 721.0 (543.5 m in thickness).

The overlying succession is represented by Lower Oligocene (Rupelian) clays, silts and sandy muds found at a depth of 147.2–177.5 m (30.3 m in thickness).

The Quaternary section occurs down to a depth of 147.2 m. In the lower part, it is represented by glacial tills passing upward into varved clays and then into sands with siltlayers, and with gravelly horizons in the uppermost part.

Most of the drilled rocks have been examined for stratigraphy. The research included micropalaeontological investigations (conodonts and foraminifers), palynological analyses and magnetostratigraphic studies. Conodont investigations allowed subdivision of the Muschelkalk into two conodont zones: *Ni. kockeli* Zone and *1* Zone. Palynological and microfaunal studies of the Lower Jurassic deposits were the basis for determining the age of the Zagaje Formation (Hettangian), Gielniów Formation (Lower Pliensbachian) and Ciechocinek Formation (Lower Toarcian). Ammonites and foraminifers provided evidence for the presence of Middle Jurassic Bajocian and Lower Bathonian deposits. Age of the Upper Cretaceous rocks was determined based on abundant foraminifers. Palynological studies yielded details on the Palaeogene deposits, providing evidence for their Oligocene (Rupelian) age.

Palaeomagnetic investigations were performed on samples of Buntsandstein rocks, which allowed determining a number of polarity zones:Tbn1, Tbr1+2, Tbn3, Tbr3, Tbr4, Tbn5, Tbr5, Tbn7.

Petrographic examinations were performed on the Buntsandstein and Jurassic rocks. The study results indicate that the Lower and Middle Buntsandstein rocks contain detrital material represented mainly by mono- and polycrystalline quartz, and weathering-resistant feldspars, including orthoclase, microcline and acid plagioclases. Some mudstones contain considerable amounts of micas: muscovite, biotite (locally passing into hydrobiotite) and chlorite being the most common product of biotite alterations. Heavy minerals are represented by pyrite, zircon, rutile, tourmaline, garnet and subordinate staurolite. In addition, the sandstones contain calcite ooids. The siltstones and claystones are composed of clay minerals and iron hydroxides transported into the basin along with clays represented by illite, montmorillonite and kaolinite; with quantitative predominance of illite.

Among the Lower Jurassic rocks, sandstones were tested on the greatest scale, which are represented in this borehole by quartz arenites and wackes. They comprise mainly monocrystalline quartz, with less frequent polycrystalline quartz. The proportion of feldspars (microcline and acid plagioclases) is negligible. Grains of transparent heavy minerals, observed in the sandstones and mudstones, originate from metamorphic rocks. Sublithic sandstones of the Gielniów Formation contain fragments of green clay rocks and brown siderites. Chamosite pseudoooids filled with the sideroplesite, ankerite and/or Fe-dolomite sparare the components of some layers of sandstones and siderites of the Gielniów Formation. These sandstones often contain cements composed of sideroplesite, occasionally also of ankerite or ferruginous dolomite, with frequent chamosite.

The Middle Jurassic sandstones are composed mainly of quartz grains showing considerable transparency and smoothed surfaces. They also contain heavy minerals that originate from metamorphic rocks resedimented many times. The Middle Jurassic deposits contain thin layers and overgrowths of clay-sandy siderites, as well as siderite cements composed of sideroplesite represented by micrite or sparite. The Middle Jurassic rocks frequently show the presence of a greenish or yellowish-brown isotropic mineral known as chamosite (leptochlorite).

Most of the Lower and Middle Jurassic sandstones display distinct intergranular porosity. Secondary intergranular porosity is observed only within aggregates of clay minerals such as kaolinite. The most compact rocks are sandstones cemented by carbonates.

After lithification, the deposits underwent diagenetic processes, among which were distinguished: mechanical compaction, cementation and replacement, as well as dissolution and diagenetic alteration.

In the Lower Jurassic sandstones, cementation processes were manifested by crystallization of carbonate minerals (calcite, dolomite, sideroplesite). The following processes have been identified: replacement of chamosite by Fe, Ca and Mg carbonates in ooids, replacement of calcite by chamosite, sideroplesite and/or ankerite and pyrite in bioclasts, alteration of certain mineral phases, for example, feldspar and muscovite into kaolinite.

In the Middle Jurassic sandstones, cementation processes are manifested by crystallization of sideroplesite and, locally, by Fe-dolomite and ankerite. Replacement processes are represented by replacement of calcite by phosphates or chamosite in bioclasts, and of chamosite or berthierine by iron hydroxides in ooids, as well as by pyritization of the deposits.

Geochemical studies of organic matter were performed selectively on the Triassic and Jurassic rocks. The Lower Triassic deposits exhibit very low values of S2, $T_{max}$ and TOC parameters, which classify them as very poor source rocks. The TOC values measured on samples from the Middle Triassic, Norian and Carnian rocks were 0.16–1.46%. The organic carbon is represented mostly by unproductive residual organic carbon (RC). The $T_{max}$ values are in the range of 415–435ºC, suggesting the presence of organic matter immature for the generation of hydrocarbons and the one that is close to the upper limit of the oil window. The Middle and Upper Triassic deposits are abundant in gas-forming kerogen of type III, and can be classified as poor and very poor source rocks. The Middle Jurassic rocks are dominated by gas-forming kerogen of type III, which mostly has not even reached the stage of thermocatalytic alteration of the oil window. The organic carbon content is in the range from 0.19 to 1.42 wt %, $T_{max}$ values are 425–445ºC, and the HI and OI values are 49–75 mgHC/gTOC and 87–269 mg$CO_2$/gTOC, respectively. These are very poor and poor source rocks.

Research on organic matter maturity shows a clear increase in thermal maturity of the Middle Jurassic–Upper Permian rocks with depth of burial from 0.61% $R_o$ (749.2 m) to 1.28% $R_o$ (3065.2 m). From the point of view of hydrocarbon generation, the values correspond to the transition from the main phase of oil generation to the early phase of gas generation. In the Permian rocks, organic material is represented by vitrinite, inertinite and bitumen macerals. In the Middle Triassic, the main constituents are bitumen and vitrinite of colotelinite type. In the Lower Jurassic, the essential components are liptinite and vitrinite.

Determinations of the amount of bitumens were carried out on the Upper Permian, Lower, Middle and Upper Triassic, Lower and Middle Jurassic, Lower and Upper Cretaceous deposits. The percentage of bitumens extracted from the Zechstein deposits ranges from 0.002 to 0.121%. In the Triassic rocks, the content of labile constituents is small and varies between 0.002 and 0.019%. The Lower Jurassic deposits contain bitumensin a very diverse range from 0.001 to 0.537%. In the Middle Jurassic deposits, the values are slightly lower (between 0.003 and 0.026%). The Cretaceous rocks show generally low amounts of bitumens: the Lower Cretaceous (Albian), and Cenomanian and Turonian (Upper Cretaceous) deposits contain an average of 0.003% of labile components. The values for the Coniacian, Santonian and Campanian are 0.008, 0.005 and 0.001%, respectively.

Several reservoir horizons were tested in the Gorzów Wielkopolski IG 1 borehole: Lower Triassic (Rot) reservoir, two Lower Jurassic reservoirs, Lower–Middle Jurassic reservoir, Lower Cretaceous reservoir and Upper Cretaceous reservoir. Technical condition of the borehole prevented testing of the reservoirs beneath the Upper Buntsandstein. The tested formations yielded a spontaneous inflow of brine and water, which indicates the existence of an artesian basin in this area. The flow rates in the Rot deposits were small (0.05 $m^3/dm^3$), while those in the Jurassic formations were 12–18 $m^3/dm^3$. Lower Cretaceous sandstones yielded a flow rate of 4.8 $m^3/dm^3$. Mineralization of the groundwater varied from 53.1 $g/dm^3$ and 64.4 $g/dm^3$ in the Lower Jurassic to 30 $g/dm^3$ in the Upper Cretaceous.

The Jurassic and Cretaceous ground waters are of sodium-chloride type. The values of hydrochemical indicators suggest that they are relict waters, partly fresh waters, being in a poor contact with meteoric waters. The degree of metamorphism of the water is low.

Studies of average seismic velocities in the borehole exhibit a gradual increase in the velocity from 1500 m/s to nearly 2700 m/s in the Cenozoic, Cretaceous, Jurassic, Upper Triassic and uppermost Middle Triassic. Down to the base of the Cenozoic, there is the most rapid increase in the velocity to 1000 m/s. In the interval corresponding to the Cretaceous, the velocity increase is milder and the velocity values range from 1900 to 2400 m/s. Down to the bottom of the measurements (1750 m), the velocity curve is gentle and the average seismic velocity values remain almost at the same level.

Complex velocities for the Cenozoic and Cretaceous deposits show a gradual, stepwise increase with depth, which is related to the proportion of carbonate rocks in the lithological section. A similar relationship is also associated with the boundaries of interval velocity contrast. A significant decrease in interval and complex velocities (about 350 m/s) is associated with a boundary at the base of the Cretaceous.

Complex velocities in the Jurassic succession reflect its dichotomy. The upper part (2600 m/s) spans the Middle Jurassic, Toarcian and Pliensbachian. An increase in the velocities to 2900 m/s due to lithological changes occurs at the Pliensbachian/Sinemurian boundary. Another significant increase of both velocities (complex and interval) is observed at the top of the Upper Keuper (complex velocity 3200 m/s). A minor increase to 3250 m/s is visible again at the boundary with the Upper Muschelkalk. There is also a contrast in the velocities on the interval velocity curve observed at the Upper/Lower Triassic boundary, corresponding to the Lower Keuper deposits.

Summative evaluation shows that the Gorzów Wielkopolski IG 1 borehole fulfilled its original geological objectives.

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