**Krzysztof LESZCZYŃSKI**

# SUMMARY

Poddębice PIG 2 borehole was drilled in the south-western flank of the Kłodawa salt diapir anticline, in the Gopło–Ponętów–Wartkowice tectonic zone, to the NE of the axis of a syncline located between the Kłodawa salt diapir and the Wartkowice salt stock, and to the SW of a major regional fault (Figs 1–5). The zone developed upon a deeply rooted tectonic fault, being the south-western border of the Kujavian Swell. The Poddębice PIG 2 borehole, together with the other drillholes located in this region (Banachów IG 1, Koło IG 3, IG 4 and Poddębice IG 1), is an important link in exploring the geological structure of this zone.

During Mesozoic times there was a remarkable palaeomorphologic threshold extending along the Gopło–Ponętów–Wartkowice Zone. It separated two different areas in terms of subsidence rate and development of salt tectonic structures: the Wielkopolska Ridge extending in the southwest, and the Mid-Polish Trough stretching in the northeast.

The Wielkopolska Ridge is characterized by a significant reduction in the thickness of many formations, lower tectonic mobility and more poorly developed salt tectonic structures expressed only in the form of salt pillows that do not pierce the overburden. The Gopło–Ponętów–Wartkowice Zone is an area of salt walls and pillows partly piercing Triassic deposits. In the Kujavian Trough, characterized by intense subsidence, the succession of Permian-Mesozoic sediments attains a much greater thickness, and the intensity of tectonic phenomena resulted in the development of e.g. the Kłodawa Salt Diapir piercing the whole Mesozoic complex.

The Poddębice PIG 2 borehole reached the final depth of 4,730 m and provided significant supplementary data about the geological structure of the Ponętów–Wartkowice Zone. After piercing through Quaternary, Cretaceous and Jurassic deposits, it drilled through the Upper Triassic, not reaching older formations (Fig. 6).

The oldest rocks are the Keuper Lower Gypsum Beds. The total thickness of the upper Kuper, i.e. the Upper Gypsum Beds and the Reed Sandstone, is 670 m in this borehole. It is much greater than in the Krośniewice IG 1 well – 470.5 m, and it is also the greatest thickness of these units reported from the Polish Lowlands. Analysis of the Triassic section in the Poddębice PIG 2 borehole shows that the axial zone of the then-developing Mid-Polish Trough, characterised by the greatest thickness of Triassic deposits, was not in the Krośniewice region, as previously interpreted, but in the area of the Poddębice PIG 2 borehole.

The considerable thickness of the Upper Triassic deposits suggests therefore that the maximum subsidence zone expanded or moved towards the southwest and reached the Ponętów –Wartkowice Zone. Such a great thickness observed within the syncline located between the Kłodawa salt diapir and the Wartkowice salt stock can be associated with increased tectonic activity in this zone of the Mid-Polish Trough, resulting in e.g. Zechstein salt extrusion on to the bottom of the Triassic basin. The immediate reason for the observed increase of the thickness of the Upper Triassic was the activity of a normal fault stretching in the north-eastern slope of the Wartkowice salt stock.

Detailed sedimentological analysis made by H. Kiersnowski for the Upper Triassic succession (Fig. 8) allowed precise identification of depositional sequences and sedimentary environments.

An important result of the drilling was the confirmation of thickness reduction in the lower Lower Jurassic (Hettangian–Lower Pliensbachian) interval and in the Lower/Middle Jurassic (Upper Toarcian) transition sections. There is also lack of Middle Jurassic deposits from the Aalenian through the Lower Bajocian (like in the north-eastern flank of the Ponętów Anticline in the Banachów IG 1 borehole). The Lower Jurassic section is 308.5 m thick, whereas the Middle Jurassic is 155.0 m thick in this area. The oldest Middle Jurassic rocks are Upper Bajocian deposits. These facts indicate high mobility of this tectonic zone, proving the occurrence of uplifting and subsiding movements in different geological periods.

A comparison of the Lower and Middle Jurassic sections across the Wartkowice Anticline clearly shows that the axial zone of the subsequently formed anticline was a synsedimentary tectonic graben at the end of the Early Jurassic and in the early Middle Jurassic.

Worth noting is the great thickness of Quaternary deposits (272.5 m). It results from the location of the borehole within the Krzepocin tectonic graben, indicating halokinetic activity of the area at that time. No Paleogene and Neogene deposits have been found in the Poddębice PIG 2 section.

Regional geology studies indicate the existence of four parallel NW–SE-trending zones in the Early and Middle Jurassic. These are (from south to west): (1) Wielkopolska Ridge zone (Przybyłów 1, Koło IG 4, Wartkowice 1); (2) synsedimentary graben zone (Ponętów 1, 2, 3, Koło IG 3, Wartkowice 2, 3); (3) south-western slope of the Mid-Polish Trough (Poddębice PIG 2, Banachów IG 1) and (4) Mid-Polish

Trough axial zone. Tectonic activity within these zones was controlled by a system of deeply rooted NW–SE-trending synsedimentary faults.

Starting from the Late Bajocian (formerly Middle Kujavian), tectonic activity of the area became weaker, which resulted in a substantial unification of the Middle and Upper Jurassic facies. Reactivation of vertical movements, expressed by increased thickness of deposits, took place in the Early Cretaceous, from the Berriasian through late Hauterivian. Starting from the Hauterivian, there was a consistent increase in the thickness of sediments towards the northeast, towards the basin axis.

Another important result of the Poddębice PIG 2 borehole is the finding of siliciclastic sandy deposits of significant thicknesses within the Upper Cretaceous section. There were two main phases of sedimentation of these deposits: the first one in the late Santonian–early Campanian, and the second one in the late Campanian. Their origin was probably associated with Late Cretaceous tectonic inversion and diapiring processes in the Kłodawa salt structure. The consequence of these movements was erosion of earlier Upper Cretaceous and Lower Cretaceous formations (Mogilno Formation sandstones). This confirms the increased mobility of salt during Santonian–Campanian times. The strongest movements of Zechstein salt, however, occurred probably in late Maastrichtian and Paleocene times. Their activity was accentuated already in the earliest Triassic (late Carnian, Norian, Rhaetian), earliest Jurassic (Hettangian, Sinemurian, Pliensbachian), Late Jurassic and Early Cretaceous.

An attempt was made to identify depositional sequences in the Upper Jurassic succession, using a sequence stratigraphic approach. No unconformity surfaces, evidence for land erosion and stratigraphic gaps are observed in the sequence. There is also no gap at the Upper Jurassic/Lower Cretaceous (Tithonian/Berriasian) boundary.

The Poddębice PIG 2 borehole reaffirmed the possibility of occurrence of lithological-stratigraphic hydrocarbon traps in the lower Middle Jurassic and Lower Cretaceous formations of the Ponętów–Wartkowice Zone. They are associated with transgressive, westward-onlapping lower–middle Bathonian and upper Valanginian–Hauterivian mudstone-sandstone heteroliths. Moreover, stratigraphic traps are also expected in the Middle Jurassic succession in the eastern flank of the Ponętów–Wartkowice structure.

With a relatively large number of potential series of reservoir rocks in the Triassic, Lower Jurassic and Cretaceous formations, the Mesozoic succession of the Gopło–Ponętów–Wartkowice Zone is poor in source rocks, which occur in greater amounts only in the lower Middle Jurassic and, to a lesser extent, in the upper Upper Jurassic and Lower Cretaceous. The main potential source rock series is the thick complex of Middle Jurassic claystones highly enriched with sapropel-humic material containing up to 11% of $C_{org}$. Particularly poor in organic matter are the paralic-limnic Triassic and Lower Jurassic deposits. Petrographic and geochemical analysis of organic matter shows that the Jurassic and Lower Cretaceous deposits are in the initial stage of oil generation. The Triassic deposits passed through a zone of maximum oil generation; however, due to small amounts of potential source rocks, the only process that can be taken into consideration is vertical migration of hydrocarbons from the Zechstein or from beneath the Zechstein.

Tests of physical properties of rocks showed the maximum values of effective porosity in the Upper Cretaceous (26.3%), Lower Cretaceous (25.5%) and Lower Jurassic (21.3%) rocks. Slightly lower values were reported for the Middle Jurassic (18.3%) and Upper Triassic (13.5%) rocks.

The highest permeability values were measured in the Upper Cretaceous (7500 mD), Lower Cretaceous (2500 mD) and Lower Jurassic (1200 mD) sandstones.

However, the generally low pressure gradients, the low level of alteration of groundwater and its intense exchange do not favour hydrocarbon accumulations. Geochemical studies carried out by S. Klimuszko and E. Swadowska show that the Mesozoic deposits in the Poddębice PIG 2 borehole are generally poor in organic matter.

The content of organic carbon and bitumens in the Upper Cretaceous, Upper Jurassic and, especially, Upper Triassic rocks, is low. The only potential source rocks are clayey lower Middle Jurassic deposits, and possibly Upper Jurassic and lower Lower Cretaceous rocks. The bitumen content is up to 0.161%. Reflectance coefficient values of vitrinite and vitrinite-like material vary commonly between 0.59 and 0.66, reaching the maximum of 1.80%. It corresponds to the stage of oil generation (flame coals). Vitrinite reflectance and TAI measurements of palynological material confirmed that these deposits show features of source rocks for oil generation (early phase of hydrocarbon generation).

Organic matter is *in situ* (laminae, lenses) or redeposited (grains). It is mainly of a humic type (mostly vitrinite and exinite), rarely sapropelic.

Subsidence and deposition rate analysis for 1D basin modelling and reconstruction of burial and thermal history were also performed in the Poddębice PIG 2 borehole in order to determine the subsidence mechanisms, reconstruct the activity of source areas for detrital material, and identify thermal events in the evolution of this zone of the Mesozoic basins.

The deepest formation tested in the borehole was the Upper Jurassic carbonate reservoir. Triassic aquifers have not been tested due to technical problems.

Amongst reservoir horizons, the Lower Cretaceous deposits show promising reservoir parameters (sampled in the 2110.0–2145.0 m interval, with the brine inflow of 22.25 $m^3$/h, total dissolved solids 74.16 g/$dm^3$). Pretty good reservoir properties are interpreted for the Upper Cretaceous deposits (sampled in the 918.0–923.0 and 878.0–902.0 m intervals, mineralized water inflow of 8.5 $m^3$/h, containing combustible gas, and in the 849.0–855.0 m interval, water inflow of 14.75 $m^3$/h, total dissolved solids 3.75 g/$dm^3$. The gas can originate from deeper formations, indicating the possibility of its occurrence in a limited extent in both the vertical and horizontal directions.

The Cretaceous groundwater shows good properties for use in balneotherapy. Moderately mineralized groundwater from the Upper Cretaceous aquifer can be used in drinking cures and inhalations, and the Lower Cretaceous brine, after a slight dilution with fresh water to a concentration of 5–6%, can be used for bathing therapy, both in bathtubs and pools (underwater physical therapy).

The Poddębice PIG 2 borehole has provided a lot of important geological information and fully accomplished its exploratory mission. It is a very important link in the exploration of the Mesozoic succession in the Ponętów–Wartkowice Zone, close to the Kłodawa salt diapir and the slope of the present-day Mid-Polish Swell.