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SUMMARY

The Brześć Kujawski IG 1, IG 2 and IG 3 boreholes were drilled in the western flank of the Smólak (Brześć) Anticline closing in the north the Kutno tectonic unit of the Kujawy Swell which, in turn, is the middle segment of the Mid-Polish Swell. The swell was uplifted during the latest Cretaceous and earliest Paleogene along the axis of the former Mid-Polish Trough, characterized by the Polish Basin's highest sedimentation rate during Permian through Mesozoic times. The sedimentation was varied also along the trough. The Kujawy segment, in particular the Kutno Block, was conspicuous by especially great sedimentation rate. After the uplift removal of Cretaceous and uppermost Jurassic deposits from the Kujawy Swell, the base Zechstein surface lies at a depth of over 6,500 m. It may be claimed that the base surface of the Zechstein was at a depth of about 9,500 m before the uplifting movements.

The Brześć Kujawski region is situated in the central field of salt tectonics controlled by intensity of salt migration processes. The major zone supplying salt to the Brześć Kujawski Anticline (where almost all salt was withdrawn from) was the long and wide Krośniewice Syncline adjoining to the SW.

The Brześć Kujawski Anticline represents a salt pillow, with Zechstein salt unpierced through the Mesozoic overburden. In its southeastern extension, within the same string of tectonic structures, 2 small salt stocks are observed: the Łanięta and Lubień salt stocks where salt has pierced the overlying strata up to the base-Quaternary surface. The Brześć Kujawski Anticline is a NW–SE-stretching oval tectonic structure (length/width ratio <2:1). In an intersection image of Mesozoic subcrops at the base-Quaternary surface, the Brześć Kujawski Anticline is outlined by the extent of Oxfordian deposits surrounded to the north, west and east by younger Upper Jurassic deposits, and jammed in the south into a large Oxfordian area of the central part of the Kujawy Swell.

The northeastern flank of the anticline coincides with the northeastern flank of the Kujawy Swell.

Seismic surveys proved that the essential thickness changes, characterized by strong thickness reduction in the depositional succession above the salt pillow, are observed within the Upper Triassic deposits and, to a lesser extent, within the Lower Jurassic. It indicates intense salt movements in this area. Analysis of structural maps of the tops of individual stratigraphic units shows that the Brześć Kujawski structure has a single culmination, except in the map of the top of Middle Jurassic where 2 culminations are observed. Both the flanks steeply dip both to the SW and NE. The structure's summit in the Triassic and Zechstein levels is situated near the Brześć Kujawski IG 1 borehole. In the Jurassic levels, the summit area of the anticline widens towards the SW (towards the Brześć Kujawski IG 2 borehole) over a distance of >3,000 m.

The Brześć Kujawski IG 1 borehole, drilled at the summit of the anticline, was stopped at a depth of 4573.0 m. The wellbore pierced Jurassic and Triassic deposits and encountered the Zechstein at a depth of 4251.0 m. The Brześć Kujawski IG 2 and IG 3 boreholes were drilled in the western flank of the anticline and encountered Upper, Middle and Lower Jurassic reaching a depth of 1850.0 (IG 2) and 2204.0 m (IG 3).

The Zechstein rocks drilled in the boreholes represent the topmost series of the salt pillow whose thickness may be of up to 2,000 m. The Zechstein succession is composed here of the PZ4a–d cyclothem consisting of zuber facies, characteristic of this part of the basin. Five formations have been distinguished here: the Gwda, Parsęta, Korytnica (Kluczewo and Mirosław members), Ina and Piława (Złotów, Piła, Jastrowie and Wałcz members) formations. The rocks are overlain by the Rewal Formation terrigenous deposits. The total thickness of the Zechstein succession in the Brześć Kujawski IG 1 borehole is 322.0 m.

The Buntsandstein was encountered at a depth of 2605.0–4251.0 m (1646.0 m). Such considerable thickness is typical of the most subsident zone of the Kujawy Trough exhibiting especially strong sinking trends in this area during sedimentation of Middle Buntsandstein deposits (1085.5 m thick). The Lower Triassic sedimentation was a continuation of the latest Zechstein terrigenous sedimentation. The Lower and Middle Buntsandstein deposits accumulated in a basin of variable sedimentary environments ranging from freshwater through lagoonal to shallow marine. The Lower Buntsandstein is represented mostly by claystones, Middle Buntsandstein contains more sandy material, whereas the Upper Buntsandstein is composed by carbonate-clayey deposits with sulphate rocks interbeds. The Buntsandstein has been subdivided into the Baltic, Pomerania, "Clayey" (informal, equivalent of the Poł- czyn Formation) and Barwice formations. From the Rhaetian through Lower Keuper, the Mid-Polish Trough was less clearly marked.

The Muschelkalk was encountered at a depth of 2427.5–2605.0 m (177.5 m). The succession is tripartite: Lower Muschelkalk is represented by dominant limestones, Middle Muschelkalk is composed mostly of claystones and dolomitic and marly claystones with anhydrite-gypsum interbeds, Upper Muschelkalk is consisted of a carbonate-claystone series.

The Lower Keuper deposits are represented by the Sulechów Beds encountered at a depth of 2290.0–2427.5 m

(137.5 m) composed of a dark claystone-mudstone-sandstone series deposited during a regressive phase of the basin evolution.

The Upper Keuper occurs at a depth of 2117.5–2290.0 m (172.5 m) and is represented only by variegated claystones and mudstones with evaporite interbeds of the Lower Gypsum Beds. In the Brześć Kujawski IG 1 borehole, the rocks are directly overlain by Norian and Rhaetian deposits encountered at a depth of 1993.5–2117.5 m (136.0 m). The Brześć Kujawski structure was very active at that time, as evidenced by the lack of the Reed Sandstone and Upper Gypsum Beds. The Norian and Rhaetian sedimentation of brown and green clayey conglomerates initially took place in a brackish basin. The deposition was followed by accumulation of the Rhaetian grey claystones and mudstones in a limnic environment.

The Lower Jurassic was completely drilled through in the Brześć Kujawski IG 1 borehole (depth interval 1137.5–1993.5; thickness 856.0 m). In the other boreholes Lower Jurassic deposits were encountered at the following depths: 1206.0–1850.0 m (IG 2 — thickness 644.0 m) and 1296.0–2204.0 m (IG 3 – 908.0 m). The succession is dominated by sandstones and claystones deposited in a continental environments (Zagaje, Ostrowiec, Drzewica and Borucice formations). The only marine sediments are those representing the Skłoby Formation (part of Hettangian) and a mudstone-claystone series of the Gielniów Formation (Early Pliensbachian). Claystones and mudstones of the Ciechocinek Formation (Early Torcian) were deposited in a brackish environment.

The Middle Jurassic sequence was encountered at the following depth intervals: 398.5–1137.5 (IG 1), 460.0–1206.0 (IG 2) and 646.0–1296.0 m (IG 3). It is represented by claystones and sandstones. Its lower boundary is marked by the first marine ingressions in the Late Toarcian continental basin. The Early Aalenian sedimentation was dominated by light-grey sandstones with thin claystone and mudstone interbeds deposited in either a nearshore zone of a well-oxygenated marine basin or an estuary. The first main phase of the Middle Jurassic marine transgression, associated with a rapid drop in the basin's floor, occurred during the Late Aalenian. The Lower Aalenian sandstones are overlain by a complex of black clay shales containing siderite concretions.

A considerable gradual shallowing of the sea took place during the Early Bajocian accompanied by more intense supply of clastics to the sedimentary basin. A continuous transition is observed from the Upper Aalenian anaerobic/disaerobic clay shales deposited in the offshore environment to mudstones and claystone-sandstone heteroliths of the transitional zone followed by Lower Bajocian sandstones accumulated in the lower shoreface zone. The Late Bajocian and Early Bathonian were characterized by a deposition of alternating claystones/mudstones and sandstones with subordinate sandstone-carbonate series. Offshore and transitional zone mudrocks dominate in the lower and middle Upper Bajocian and the Lower and Middle Bathonian. Sandy sedimentation in various subzones of the shoreface was dominated mainly in the latest Bajocian and Middle–Late Bathonian. The uppermost Bathonian and Callovian are represented by dolomites and limestones with glauconite, locally marly or sandy, deposited in the shoreface zone of a carbonate-clastic shelf. The Middle Jurassic succession is terminated by the Upper Callovian conglomeratic Nodular Bed representing a stratigraphic condensation horizon developed during the maximum sea-level stand.

The Middle Jurassic deposits are relatively thin in the Brześć Kujawski region: Brześć Kujawski IG 1 – 739.0 m (anticline summit), Brześć Kujawski IG 2 – 746.0 m (SW flank), Brześć Kujawski IG 3 – 656.0 m (Kutno Syncline). The Middle Jurassic thickness distribution shows its low variability suggesting dying out of salt movement activity and related halotectonic processes at those times.

No wedging out of sandstone strata in the Aalenian and lower Upper Bathonian deposits was observed in the Middle Jurassic sections of the Brześć Kujawski region, counter to prediction. Thus, there is low chance of the occurrence of lithological gaps for hydrocarbon accumulations in the Middle Jurassic of the south-eastern flank of the anticline.

Upper Jurassic rocks were encountered in the Brześć Kujawski IG 1, IG 2 and IG 3 boreholes at depths of 76.0–398.5 (thickness 322.5 m), 101.0–460.0 (359.0 m) and 97.0–646.0 m (549.0 m), respectively. They directly underlie Paleogene or Neogene deposits and represent the Oxfordian (Limestone Group A) in the IG 1 and IG 2 boreholes, and the Oxfordian–Lower Kimmeridgian (Limestone Group A and part of Limestone-Marly-Coquina (V) Formation) in the IG 3 borehole. The data indicates a more complete Upper Jurassic section in the south-western flank of the anticline.

Biostratigraphical investigations of the Middle Jurassic succession allowed for detailed zonation based on foraminifers and Dinoflagellata cysts. The Upper Jurassic rocks were biostratigraphically dated based on foraminifers only.

Petrographical and diagenetic investigations were made on Buntsandstein and Jurassic deposits. Detrital material in the Buntsandstein rocks is represented mainly by monocrystalline quartz, feldspars, micas (muscovite and biotite) and rare lithoclasts mostly of metamorphic rocks. The Lower and Middle Buntsandstein sandstones also contain calcite ooids. Mudstones and claystones are composed of clay minerals and Fe hydroxides.

The Lower and Middle Jurassic sandstones are represented by quartz arenites composed predominantly of quartz. Feldspars, micas and bioclasts occur in minor percentages. The mineral composition of detrital material indicates that it originated from resedimentation of older rocks.

Mudstone, wackstone, packstone, floatstone, rudstone, bandstone and sparite microfacies have been identified in the Upper Juraccis carbonates.

After lithification, the rocks were subjected to diagenetic prosecces including mechanical compaction, cementation, dissolution and diagenetic alteration. The most important diagenetic processes that operation within the Buntsandstein deposits were cementation by calcite, authigenic quartz and andydrite, and alteration (kaolinitization and illitization) of feldspars and mica flakes (chloritization of biotite).

Cementation by quartz and clay minerals (locally also by carbonates) was a significant process in the Lower Jurassic deposits. Research performed on inclusions in quartz cements indicates their formation at a temperature approximating 84–104°C. Inclusions in carbonate cements formed at a temperature of about 75°C. Fibrous illite precipitated during the late diagenetic phase, reducing the permeability of the rocks.

A significant role in diagenesis of the Middle Jurassic rocks was played by mechanical compaction and cementation by dolomite, ankerite and pistomesite, locally by calcite. Fluid inclusion studies show that ankerite and pistomesite crystallization occurred at a temperature of 53–90°C, at times also up to 120°C. Moreover, during early diagenesis, pyrite framboids and Ca/Mn-sideroplesite micrite and sparite crystallized forming concretions within claystones and some of sandstones.

Among diagenetic processes operated in the Upper Jurassic rocks, mechanical compaction and cementation with subsidiary dolomitization were dominant.

Drill stem tests were run over a few reservoir horizons: Lower Triassic (IG 1 – 1 test), Middle Triassic (IG 1 – 1), Lower Jurassic (IG 1 – 2, IG 2 – 2 and IG 3 – 1) and Middle Jurassic (IG 1 – 1, IG 2 – 2 and IG 3 – 3). Investigations of physical and chemical properties of rocks and hydrochemical analyses revealed no reservoir properties of the Buntsandstein and Muschelkalk deposits, as evidenced by the lack of brine inflow. The interpolated value of formational pressure in the Buntsandstein is 504.0 at, bottom pressure is 469.6 at. Bottom pressure in the Muschelkalk horizon is 269.0 at.

The Lower and Middle Jurassic sandstones show "good" reservoir properties. Effective porosities of the sandstones vary from several to 25%, permeability values range commonly between 0.1 mD to 1000 mD, locally up to 3,200 mD. Flow rates of the individual horizons are variable. The highest flow rates were measured in two Lower Jurassic horizons of the Brześć Kujawski IG 2 borehole (10.07–14.96 m^3/h) and in one Middle Jurassic horizon of the Brześć Kujawski IG 1 borehole (24 m^3/h). Flow rates from the other horizons were similar in value (0.900–6.723 m^3/h).

The Lower and Middle Jurassic brines are Cl–Na–J, Cl–Na–Fe or Cl–Na–J–Fe in chemical composition. In the Brześć Kujawski IG 2 borehole the water was weakly metamorphosed; in the other wells there is a significant contribution of infiltration water resulting in the occurrence of unfavourable conditions for hydrocarbon accumulation.

Geochemical research of bitumens and hydrocarbons shows that the Mesozoic rocks are poor in organic matter and labile components, except for the Middle Jurassic (up to 10.5% TOC). The Permian and Triassic rocks contain mainly vitrinite. The Lower Jurassic deposits are much richer in organic matter represented by vitrinite and inertinite, frequently redeposited from older rocks. Organic matter in the Middle Jurassic rocks is very rich and represented by humic material (both *in situ* and redeposited) accompanied by sapropel-type material. Organic matter in the rocks is variably altered and originates mostly from decomposition of vascular plants. The Upper Jurassic deposits are poor in organic matter represented mainly by redeposited vitrinite and occasional amorphous inertinite. Authigenic vitrinite and huminite are found only in clay streaks.

Vitrinite reflectance analyses in the Mesozoic deposits indicate a general trend of gradually increasing degree of organic matter alteration with depth. Thermal maturity of the Jurassic rocks corresponds largely to the main phase of liquid hydrocarbon generation (average R_o = 0.47–0.97%), of the Triassic rocks to the main and late phases of liquid hydrocarbon generation (average R_o = 0.91%), of the Zechstein rocks to the main phase of gas generation (average R_o = 1.48%). The degree of organic matter alteration indicates the occurrence of favourable conditions for liquid hydrocarbon generation.

Petrological data show that source rocks for hydrocarbon generation occur chiefly in the Middle and, locally, in the Lower Jurassic sequences. However, despite considerable amounts of organic matter, especially in the Middle Jurassic rocks, they are poor in bitumens and hydrocarbons.

Average seismic velocities were measured in the Brześć Kujawski IG 1 and IG 3 boreholes. There are a few boundaries of velocity contrasts related to changes in lithology. The strongest contrasts are associated with the Muschelkalk and Callovian–Upper Jurassic carbonates. They show markedly elevated complex velocities than the immediately underlying and overlying rocks. In addition, increased average velocities are observed in the Lower Gypsum Beds of the Upper Keuper and lowermost Röt deposits. There is also marked boundaries in the Jurassic succession, related to the topmost Pliensbachian and lowermost Upper Aalenian rocks. Both these boundaries are associated with a change from sandstones to claystones.

The Brześć Kujawski IG 1, IG 2 and IG 3 boreholes fulfilled their geological goals.