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SUMMARY

The Unisław IG 1 borehole was drilled in the southwestern part of Western Pomerania Pomorza Zachodniego (northern part of the Płock Trough), and the section consists of Devonian (unpierced Givetian, Upper Devonian – Frasnian and lower Famennian), Permian (Rotliegend and Zechstein), Triassic, Jurassic, Cretaceous, Paleogene, Neogene and Quaternary deposits (see Fig. 2 – detailed stratigraphic-lithologic log). The characteristic feature is the presence of major hiatuses, not only between the individual Series (lack of the whole Carboniferous), but also within them (e.g. lack of much of the Upper Devonian and Lower Permian). Most of these gaps are of local extent and are not typical of the whole area of Western Pomerania.

The oldest deposits drilled in the borehole, *ca*. 26.5 in thickness, are Middle Devonian siliciclastics representing the uppermost part of the Wyszebórz Formation. These are grey, low-calcareous sandstones and mudstones with no faunal evidence (except for bioturbation – traces of benthic fauna activity). They are overlain by siliciclastic-carbonate and carbonate deposits, relatively rich in organic remains (mainly massive and branching stromatoporoids), with a thickness of *ca*. 340.0 m, included in the Koczała Formation. Above the Koczała Formation, there is a 382.0-m thick clayey-marly series of the Strzeżewo Member of the Człuchów Formation. The Devonian deposits were analysed for biostratigraphy, using conodonts (H. Matyja) found in most samples of the Koczała and Człuchów formations. The analysis shows that the Devonian section is represented by the uppermost Givetian and Upper Devonian (Frasnian and lower Famennian). The Middle Devonian siliciclastics and lower Frasnian siliciclastic-carbonate deposits accumulated in an environment similar to marginal marine. The uppermost Frasnian deposits were associated with a carbonate platform and its nearest surroundings. The clayey-marly deposits of the Strzeżewo Member of the Człuchów Formation were deposited in a subtidal shelf environment, periodically in a shelf basin.

The Famennian is directly overlain by the Permian represented by Rotliegend deposits. The gap spans the upper Famennian, Carboniferous and lower Permian. The Rotliegend is represented by fine-grained sandstones, mudstones and sandy conglomerates included in the Warta Group, the Noteć Formation. Detailed petrographic analysis included identification of diagenetic processes was made for the sandstone and mudstone-claystone lithofacies (M. Kuberska). These deposits accumulated in two different sedimentary environments: marginal playa and fluvial distributary channels. The latter are the distal part of a fluvial system developed in the basin's marginal part (H. Kiersnowski). The 325-m thick Zechstein section is developed relatively completely and composed of three carbonate-evaporitic cyclothems: PZ1, PZ2 and PZ3, and the terrigenous-evaporitic cyclothem PZ4 consisting in this region of cyclothem PZ4a and the Rewal Formation (R. Wagner). Ryszard Wagner is of the opinion that the history of formation and evolution of the Unisław palaeostructure in the Late Permian is an example of Zechstein sedimentation on a local high that formed at the end of Rotliegend deposition during erosional-tectonic processes. Its peak development the structure achieved during sedimentation of the Main Dolomite (Ca2), when a small reef-like carbonate platform was formed in an open-marine environment. The Unisław palaeostrukture probably ceased to exist at the beginning of a new marine transgression (during deposition of cyclothem PZ3) that caused considerable changes in the entire Zechstein Basin. Detailed analysis of microfacies and diagenetic processes was performed for the Zechstein Limestone (M. Wichrowska).

In the Unisław IG 1 borehole, Mesozoic deposits are represented by Triassic, Jurassic and Cretaceous formations.

Triassic deposits, with a thickness of 1287.5 m, represent much of the borehole section, but unfortunately, the knowledge on the deposits is based on well logs and regional correlations (A. Becker) due to poor coring (3%). The stages and their boundaries within the Triassic are not indicated, as the chronostratigraphy is not reliable in this borehole. The Lower Triassic, represented by the Buntsandstein Group, consists of all subgroups: Lower, Middle and Upper Buntsandstein (A. Becker). The Middle Triassic is represented by the Muschelkalk Group (Lower, Middle and Upper – L. Adach). The Upper Triassic consists of the Lower Keuper, represented by the Sulechów Beds, and the Middle Keuper consisting of the Lower Gypsum Beds and the Lower Kłodawa Beds (A. Becker). In this report, the boundaries of almost all lithostratigraphic units follow those established for the final borehole report (the only modification refers to the base of the Baltic Formation). The names of the lithostratigraphic units in the Upper Triassic have been verified according to the standard of Stratigraphic Chart of Poland (Wagner, 2008).

The chrono- and lithostratigraphic interpretation of the non-cored Lower Jurassic interval is based on the correlation of well logs from Unisław IG 1 and from the fully

cored Kaszewy 1 borehole drilled *ca*. 100 km away to the southeast (G. Pieńkowski). When estimating the similarities between well logs of these boreholes, despite the smaller thickness in Unisław IG 1, G. Pieńkowski distinguished the main lithoformations of the Kamienna Group (Zagaje, Skłoby, Ostrowiec, Gielniów, Drzewica, Ciechocinek and Borucice formations) and hypothetical depositional sequences (in terms of cyclo- and chronostratigraphy) in the Lower Jurassic section. The Middle Jurassic section (similarly as the overlying Upper Jurassic and Cretaceous sections) was also drilled without coring, and the stratigraphic interpretation is based on regional correlations of well logs, especially with the Ciechocinek IG 3 section (A. Feldman). Its lower and upper boundaries show no sedimentary discontinuity. The Middle Jurassic overlies the Upper Toarcian (Lower Jurassic) and is covered by the Oxfordian limestones (Upper Jurassic). As no chronostratigraphic data are available for this interval, all boundaries between the stages and substages distinguished by A. Feldman (Lower and Upper Aalenian, Lower and Upper Bajocian, Lower, Middle and Upper Bajocian, and Callovian) should be treated as conventional. They are drawn at the nearest lithostratigraphic boundaries, based on both results of biostratigraphic data from nearby boreholes and regional evidence. The stratigraphic scheme of the Upper Jurassic–Lower Berriasian interval (A. Feldman) is based on data from drill cuttings and microfaunal evidence from cutting samples (J. Smoleń), supported by interpretation of well logs and regional correlations. The Upper Jurassic is represented by the Łyna Formation and Calcareous Group A (Oxfordian), Calcareous-Marly-Coquina Formation (Lower Kimmeridgian), Pałuki Formation (Upper Kimmeridgian, Lower Tithonian, lower Upper Tithonian) and Kcynia Formation (upper Upper Tithonian, Lower Berriasian) with the Malice Corbula Limestone Member, Wieniec Member, and Skotniki Member.

The Cretaceous section, *ca*. 1069 m in thickness, was interpreted based on well logs, data from drill cuttings, and correlations with better cored nearby boreholes (K. Leszczyński). The chronostratigraphic boundaries are thus approximate, although they correspond to the determinations of foraminifers from drill cuttings (E. Biedowa). The Lower Cretaceous section is dominated by siliciclastics representing the Berriasian–Albian interval. The stratigraphically complete Upper Cretaceous section (Cenomanian through Maastrichtian) is characterised by carbonate-siliceous (opokas), carbonate, siliciclastic-marly (in the Cenomanian) and carbonate-sandy (in the Maastrichtian) facies.

The Unisław IG 1 borehole section is crowned by non-cored Cenozoic deposits of the Paleogene and Neogene (54m in thickness) and thin (44.5 m) Quaternary sediments. The Paleogene starts probably with deposits of the Czempiń Formation (so-called „Toruń Clays"), Oligocene in age. They are separated by a sedimentary gap from the overlying alluvial deposits of the Neogene Adamów Formation included in the Miocene (J. Kasiński).

The Upper Devonian and Permian deposits were analysed for petrology of organic matter (I. Grotek). The Devonian is characterised by poor organic matter content in the range of 0.10–0.40% of the planimetric area. Its increased concentrations (0.70–1.00%) are observed only in a few horizons. The Devonian organic matter is poorly diverse as regards its genetic type and the form of occurrence. It is represented primarily by vitrinite-like material, solid bitumens and zooclasts. In the Upper Permian (Zechstein) organic matter occurs only as thin laminae, minute lenses, and fracture fills, within which vitrinite-group macerates are rare. Thermal maturity of the Upper Devonian organic matter, determined based on the vitrinite and/or vitrinite-like reflectance values, corresponds to the late phase of wet gas and condensate generation. In contrast, the Zechstein organic matter indicates the main phase of oil generation and the maximum temperature of diagenesis of approximately 100°.

The results of geochemical investigations (E. Klimuszko) show that the Devonian clastics and the Permian deposits are generally „poor" source rocks, and there are only few carbonate intervals within the Upper Devonian section, which can be considered „good" source rocks for hydrocarbon generation. Although the amount of bitumens in the Middle Devonian deposits is relatively large, however, taking into account the small content of organic matter in these deposits, the conclusion can be drawn that they are epigenetic in relation to the sediment. The amount of bitumens in the Upper Devonian deposits is highly variable, but generally small. However, it is greater at some spots or within some short depth intervals.

Rock-Eval pyrolysis (M. Janas) has confirmed that the Koczała Formation deposits (Devonian, Frasnian) contain source rocks represented by intercalations and layers with a thickness of several metres. The Wyszebórz Formation deposits (Devonian, Givetian) and the Człuchów Formation deposits (Devonian, Famennian) are barren of effective source rock horizons. However, the hypothesis for the occurrence of the Devonian petroleum play is supported by thermal maturity of organic matter in the Devonian deposits, corresponding to the main phase of oil generation (or the initial phase of condensate and wet gas generation), as well as the presence of oil-forming type II kerogen.

In search of good reservoir rocks, a number of studies have been made to enable determination of the basic physical parameters of rocks (P. Karcz): core samples were analysed for specific gravity and bulk density, effective and total porosity, carbonate content, and permeability. Based on these studies, certain lithological intervals have been indicated, which have adequate petrophysical properties suggesting good reservoir rocks. These are the Permian (Rotliegend) deposits from a depth of 4584.50 m, and the Lower Triassic deposits from a depth of 2835.50–2839.40 m.

In the area of Unisław IG 1 drilling, 2D seismic surveys were conducted (seismic profile FX228211x1). The seismic record visible on the analysed seismic profile indicates the complex tectonic structure of this area (A. Głuszyński). Two main structural levels can be distinguished: the Paleozoic–Lower Permian level and the Upper Permian–Mesozoic level, with the boundary surface at the base of the

Zechstein. The Paleozoic–Lower Permian structural level is dissected by a dense network of fault zones with the dominant NW-SE trend that is in line with the trend of the TT zone. These fault zones are crossed by transverse, NE–SW-trending faults (not visible on the analysed seismic profile), segmenting the area into a series of tilted and rotated tectonic blocks. The seismic record indicates that the fault zones that dissect the sub-Zechstein basement generally die out at the base of the Zechstein and do not continue upward into the younger formations. The Upper Permian–Mesozoic structural level reveals a number of normal listric faults with the footwalls on the south-western side. These faults are rooted in the Zechstein salts. The faults observed in this structural level, like those in the sub-Zechstein basement, also have an orientation consistent with the trend of the TT zone (NW–SE). The major fault zones are accompanied by lower-order antithetic and synthetic faults. The formation of listric faults and associated lower-order faults is related to the extensional phase of the Polish Basin evolution and the south-westward tilting of the basement in this area of the basin, which occurred synchronously with halotectonic processes.

Deposition rate analysis and modelling of thermal history and burial conditions have been performed for the Unisław IG 1 section (I. Dyrka). The modelling was carried out using the following input data: stratigraphy, lithology, thickness of stratigraphic units, and petrophysical parameters of the rocks. Results from previous studies were the comparative basis for this modelling. From the Middle Devonian onwards, the Unisław IG 1 region was located within the Pomeranian sedimentary basin. In the Late Devonian, especially during the Frasnian, the deposition rate was very high. In Late Carboniferous and Early Permian times, the area was uplifted and subjected to erosion as a result of Variscan movements; therefore no Carboniferous and Lower Permian deposits are found in the borehole. Much of the Upper Devonian (Famennian) deposits have also been removed. At the beginning of the Late Permian, during the deposition of Rotliegend clastics, the sedimentation rate was low at approximately 6 m/Ma. In contrast, the deposition rate of Zechstein carbonate-evaporitic sediments significantly increased and was about 186–190 m/Ma. In the Early Triassic, the deposition rate of clastic sediments was still high, and increased even to 252–262 m/Ma. Such a considerable increase in the sedimentation rate was related to a tectonic event characterised by the Late Permian and Early Triassic phase of rapid subsidence, followed by a period of lower subsidence later in the Mesozoic. At the beginning of the Jurassic, there was another consequent increase in the sediment deposition rate. In the Early Jurassic, the rate was 18 m/Ma, in the Middle Jurassic – 42 m/Ma, and in the Late Jurassic – 44 m/Ma. In the Early Cretaceous, the deposition rate again decreased to 12 m/Ma, and then increased in the Late Cretaceous to approximately 25 m/Ma. The Late Cretaceous increase in the deposition rate and its variations between the particular ages of this epoch are associated with the increased subsidence rate in the basin, suggesting tectonic reactivation in the Polish Basin. The Cenozoic (Paleogene, Neogene and Quaternary) deposits terminate the Unisław IG 1 borehole column. The average deposition rate of these deposits did not exceed 8 m/Ma.

Burial history modelling for the Unisław IG 1 borehole starts in the Middle Devonian. From the Middle Devonian to the Early Carboniferous, there was a phase of intense burial related to basin extension. The phase resulted in the formation of a sedimentary cover attaining a thickness of *ca*. 1,900 m. In the Late Carboniferous and Early Permian, there was a tectonic uplift phase leading to erosion of Lower Carboniferous (Mississippian) and part of Upper Devonian (Famennian) deposits. The amount of removed deposits is estimated at about 1000 m. Early to Late Permian time was a period of stagnation and accumulation of a thin sedimentary cover. During the Permian–Mesozoic evolution, from the Late Permian onward, i.e. starting with the Zechstein deposition, there was another phase of rapid burial that continued until end-Cretaceous time. The main phase of intense burial occurred in the Late Permian and Early Triassic. In the Middle Triassic, the sedimentary cover attained a thickness of as much as 3,160 m. The maximum burial recorded in the history of the borehole section occurred most probably at the end of the Cretaceous when the sedimentary cover attained a thickness of about 5490 m. In Cenozoic times, the burial continued, although its rate was slow. The one-dimensional modelling in the Unisław IG 1 borehole shows that the Givetian through middle Lower Jurassic deposits are in the hydrocarbon generation zone. The Givetian, Frasnian and lower Famennian deposits are currently in the wet gas/condensate generation window (1.1–1.4% R_O). The remaining part of the deposits is in the oil generation window (0.55–1.1% R_O). The process of oil generation in the Givetian and Frasnian deposits started in the Middle Triassic, while the subsequent phase of natural gas/condensate generation occurred at the Early/Late Cretaceous transition. The process of oil generation in the Famennian deposits started in the Late Triassic, and in the Zechstein deposits – in the Middle and Late Jurassic. The Triassic and Lower Jurassic deposits attained the oil generation window in early Cretaceous times.

Well logging in the Unisław IG 1 borehole included radiometric measurements, which were the basic geophysical borehole surveys for the determination of lithology and properties of reservoir rocks at that time, as well as acoustic and electrometric measurements (M.G. Roman). They were the basis for interpretation of lithological boundaries, identification of reservoir horizons, and determination of their saturation using the curve normalization method. It has been found that the Rotliegend and Devonian deposits are prospective for hydrocarbon accumulations. The available results of interpretations indicate the presence of both natural gas screened by the overlying Zechstein series, and oil in the Devonian rocks.

Measurements of average seismic velocities and vertical seismic profiling (VSP) covered a depth interval of 195–3495 m, every 15 m (the total borehole depth is 5,355 m). The data (L. Dziewińska and W. Jóźwiak) show that the highest velocity values are recorded in the Upper Jurassic

carbonates (Oxfordian – 4,500 m/s) and Middle Triassic deposits (Muschelkalk – 4,500 m/s), while the lowest velocities are observed in the Upper Cretaceous (2,150 m/s). The velocity contrasts are the effect of changes in the lithologies of the individual lithostratigraphic units, facilitating drawing boundaries between them.

Results of hydrogeological tests in the Unisław IG 1 borehole (L. Bojarski, A. Sokołowski and J. Sokołowski) (seven drill stem tests, one hydro-perforation procedure, two acidizing procedures, and one injectivity test) indicated the presence of anomalously high formation pressures in the Devonian deposits as well as a very high formation pressure and natural gas shows in the Rotliegend section. However, no economic flow rates have been reported, neither of crude oil (inflow rate of 250 l/d from the Devonian) nor of natural gas (non-measurable gas flow in the Rotliegend).

Tłumaczył K. Leszczyński