Anna BECKER, Krystian WÓJCIK, Maria I. WAKSMUNDZKA, Kinga BOBEK, Anna FELDMAN-OLSZEWSKA, Anna GÓRECKA-NOWAK, Jolanta IWAŃCZUK, Marek JASIONOWSKI, Marek JAROSIŃSKI, Przemysław KARCZ, Jacek R. KASIŃSKI, Sylwia KIJEWSKA, Piotr KLECZYŃSKI, Ewa KLIMUSZKO, Aleksandra KOZŁOWSKA, Ewelina KRZYŻAK, Marta KUBERSKA, Krzysztof LESZCZYŃSKI, Barbara MASSALSKA, Lech MIŁACZEWSKI, Edyta NOWAK-KOSZLA, Tadeusz PERYT, Grzegorz PIEŃKOWSKI, Teresa PODHALAŃSKA, Krzysztof RADLICZ, Olga ROSOWIECKA, Joanna RYCHEL, Jolanta SMOLEŃ, Katarzyna SOBIEŃ, Jakub SOKOŁOWSKI, Weronika WIERNY, Tatiana WORONCOWA-MARCINOWSKA, Sara WRÓBLEWSKA

SUMMARY

The aim of drilling the Maciejowice IG 1 borehole, at the stage of its design, was to identify the lower Carboniferous section, unexplored by drilling in this area before, to reach the basement of Middle Devonian formations, as well as to provide new data on the geological structure of the marginal zone of the Precambrian Platform. In view of the lack of data on the sub-Carboniferous basement, significant variability in Devonian lithologies in relation to the previously known sections of boreholes from the Dęblin and Garwolin areas was expected to be encountered in the planned borehole. These predictions have been confirmed, as a considerable thickness variation in the Devonian section was recorded. As a result, the base of the Lower Devonian was found about 500 m deeper than predicted, which had a direct impact on the decision to continue drilling in order to reach the base of the Devonian and the topmost Silurian. It was planned to acquire data on potential reservoir rocks within the Lower Devonian formations, as well as on the lithological and tectonic character of the Devonian-Silurian boundary. The Maciejowice IG 1 borehole yielded much important data on the geological structure and prospects for raw materials in the north-western part of the Lublin region. It enabled reconstruction of tectonic development of the area, as well as confirmed its affiliation with the East European Platform.

The first lithological-stratigraphic log of the borehole was compiled at the stage of preparation of the final well report. The section presented in this volume is based on data from that report and from many subsequent studies carried out over the next decades within the framework of numerous scientific projects and tasks of the Polish Geological Survey. The volume also contains the results of new lithological, stratigraphic, sedimentological, petrographic, geochemical, geophysical, thermal maturity, and hydrocarbon generative potential studies, as well as studies on deposition rates and modelling of thermal history and burial conditions. The lithological section has been compiled using data from drill cores, well logs, and drill cuttings. The first chronostratigraphic and lithostratigraphic subdivisions have been significantly modified and updated. Up-to-date stratigraphic subdivisions have been introduced, some boundaries of the units verified and shifted, and some new units created on the basis on up-to-date schemes. The boundaries of the chronostratigraphic and, to a lesser extent, lithostratigraphic units in non-cored intervals are approximate and determined on the basis of analysis of well logs, correlations with nearby boreholes, and with reference to palaeontological data obtained from the core material.

The oldest deposits in the Maciejowice IG 1 borehole are of Silurian (Pridoli) age and were drilled within a depth interval of 5001.5–5059.0 m (57.5 m thick). The base of this system has not been reached. The succession is composed mainly of grey and dark grey siltstones, calcareous siltstones and minor limestones. The fossils include floral remains and very scarce bivalves and large tentaculites of the *Styliolina gigantea* species Urbanek and Hajłasz. The features of the deposits suggest its affiliation with the Puck Formation.

Devonian (Lochkovian–Famennian) deposits occur within an interval of 3503.7–5001.5 m (1497.8 m thick), whereby the Silurian/Devonian boundary is placed arbitrarily due to the lack of biostratigraphic indications; it is determined by the geophysical correlation level "w2a". The chronostratigraphic subdivision is based on ostracods, tentaculites and conodonts, and the auxiliary method is geophysi-

cal correlation with the nearby boreholes of Wilga IG 1, Pionki 4 and Terebin IG 5, where some intervals of the Devonian section are better dated by miospores and conodonts.

The Lower Devonian (Lochkovian and ?Pragian–?Emsian) occurs at a depth of 3959.1–5001.5 m and its thickness is 1042.4 m. It is represented by the Sycyna, Czarnolas and Zwoleń formations. The first one (608.5 m thick) is composed of claystones, silty claystones and clayey siltstones, locally marly or dolomitic, containing thin lenticular intercalations of organodetrital limestones and clayey limestones. Microscopically, these are mudstones and subordinate bioclastic packstones and grainstones. The presence of ostracods and large tentaculites is a characteristic feature here. Sediments of this formation were deposited in an open-marine environment, at depths below the storm wave base, with periodic oxygen deficiency in the bottom portion of the sediment. The tranquil sedimentation was disturbed by turbidity currents, responsible for the redeposition of skeletal material from shallower zones of the basin. The Czarnolas Formation (148 m thick) is represented by mudstones and silty claystones, interbedded with quartz sandstones. Petrographically, it is composed of various types of mudstones, wackes and quartz-mica arenites. Large tentaculites occur in the lower part of the formation. The Czarnolas Formation reflects a stage of shallowing sedimentary environment and increased erosion on land; sediment accumulation took place in transitional environments between open-marine and terrestrial, i.e. subtidal, tidal, deltaic and beach environments. Sediments of the Zwoleń Formation (285.9 m in thickness) are represented exclusively by terrigenous deposits formed in the environment of meandering rivers of an extensive alluvial plain. In the Maciejowice IG 1 borehole, sediments of river channels and crevasse splays (conglomerates, quartz sandstones and mudstones) and overbank zones (fine-grained sediments, mostly mudstones and claystones) are present. Petrographic studies revealed the presence of mudstones, quartz-mica wackes and arenites, and conglomerates. The upper boundary of the formation is erosional in nature.

The Middle Devonian occurs at a driller's depth of 3952.7–3959.1 m. It is represented by the Telatyn Formation (6.4 m thick), highly reduced in thickness due to erosion and/or non-deposition. This formation includes the Przewodów Member. Its deposits show features of very shallow-marine accumulation, locally possibly in beach and tidal environments. Upper in the section, marly-dolomitic, horizontally laminated deposits predominate, with relict algal mats. The age of the Telatyn Formation in the Maciejowice IG 1 borehole is not determined by biostratigraphic evidence, and may be Eifelian, Eifelian–Givetian or Givetian.

The Upper Devonian was encountered at a driller's depth of 3503.7–3952.7 m. It is represented by the Frasnian Modryń Formation (203.7 m in thickness), and the Famennian Bychawa "formation" (191.0 m thick) and Firlej Formation (55.0 m in thickness). The Modryń Formation is clearly tripartite. Its lower part is dominated by dolomicrites, dolosparites and marly dolomites, occasionally interlayered by dolomitic claystones and, upper in the section, by limestones with amphipores, brachiopods, calcispheres and gastropods. This part of the formation was deposited under lagoonal conditions. The middle part of the formation is represented by the Stężyca Limestone Member composed of granular stromatoporoid-coral limestones: bioclastic wakstones, packstones, rudstones and bandstones. Among the skeletal components, a characteristic feature is the presence of *Renalcis* algae and brachiopods. These deposits were accumulated on a proximal carbonate platform under normal saline conditions. The uppermost part of the formation consists of pelitic and marly bioclastic limestones representing more open-marine sedimentation below the wave base. The Bychawa "formation" is distinguished by the occurrence of carbonate-marly-clayey deposits (mudstones, wackestones and bioclastic packstones).

The characteristic feature of its deposits is the presence of nodular and banded textures. Macrofossils are represented mainly by brachiopods. The presence of conodonts suggests a Lower Famennian age of the sediments. One sample is dated to the upper *Palmatolepis crepida* Zone. Deposition of the formation took place under deep-marine conditions and oxygen depletion, below the storm wave base, as evidenced by the absence of bioturbation structures and the scarcity of skeletal material, limited to sponge spicules. The Firlej Formation is monotonous in lithological composition. These are carbonates with a characteristic nodular texture, represented by the microfacies of mudstones, wackestones and bioclastic packstones. The fossils are represented by brachiopods and fragments of crinoid stems, branches of *Aulopora* tabulate, bivalves, crustacean shells, and large bivalves. The conodonts, found in one sample, indicate a Lower Famennian age of the formation – the upper *Palmatolepis rhomboidea* Zone. The Firlej Formation in the Maciejowice IG 1 borehole represents marine sedimentary environments on a carbonate-clay shelf, but probably more isolated, bathymetrically between the carbonate platform and the shelf basin.

The Devonian in the Maciejowice IG 1 is represented by two sedimentary megacycles. The Lower Devonian (Sycyna, Czarnolas and Zwoleń formations) corresponds to a regressive phase of the lower megacycle, and the Middle and Upper Devonian (Telatyn, Modryń, Bychawa and Firlej formations) – to the upper transgressive-regressive megacycle. The Devonian/Carboniferous boundary coincides with an erosional surface and an angular unconformity.

The Devonian is separated from the upper Tournaisian by a stratigraphic gap comprising the upper Famennian – lower Tournaisian. The Carboniferous occurs at a driller's depth of 1843.0–3503.7 m (1660.7 m thick), and according to geophysical measurements at 1846.0–3504.5 m (thickness 1658.5 m). This is the most complete borehole section among those described in detail in the Lublin region, and is among the benchmark ones that were used to develop a model of sequence stratigraphy and correlation with the global Carboniferous subdivision scheme for the Carboniferous Płock-Lublin Basin. In the Carboniferous section, claystones and siltstones are the most common lithologies, sandstones are rarer, and limestones, marls, conglomerates and hard coals are least common. Mississippian deposits occur within a depth interval of 3281.0–3504.5 (3277.7–3503.7 m) and their thickness is 223.5 m (226.0 m, driller's measure). Pennsylvanian deposits are found at 1846.0–3281.0 m (1843.0–3277.7 m) and their thickness is 1435.0 m (1434.7 m, driller's measure). The Tournaisian includes also a conglomerate bed occurring at a depth of 3504.2–3504.5 m (3503.4–3503.7 m), 0.3 m thick, composed mainly of limestone clasts accompanied by clasts of volcanic and magmatic rocks. It was presumably formed in a shallow braided-river channel during a low relative sea level (RSL).

The Tournaisian is separated by a stratigraphic gap from the overlyingy Visean deposits (depth 3428.5–3503.4 m; thickness 74.9 m). The gap spans the presumed uppermost Tournaisian and the lower and middle Visean. The Visean section is dominated by claystones and limestones (rare marls) deposited on a shallow clay or carbonate shelf, possibly also in a prodeltaic environment of a shallow-water delta, under rising and high RSL conditions.

The Serpukhovian (depth 3277.7–3428.5 m; thickness 150.8 m) is dominated by claystones and mudstones deposited in shallow-water deltaic and shallow clay shelf environments, during a rising and high RSL. There is another stratigraphic gap in the Carboniferous section between the Serpukhovian and Bashkirian, comprising the lowermost Bashkirian. Within the Bashkirian deposits (depth: 2591.0–3277.7 m; thickness: 686.7 m), claystones and mudstones dominate in thickness, which are accompanied by sandstones, usually found as relatively thick beds. Coals are also encountered in the section. The sandstones were deposited in river channels that form incised valleys. They are usually accompanied by claystones and mudstones, associated with the environment of fluvial floodplains. These deposits were accumulated during a low RSL. Within the Bashkirian deposits, a new tuff horizon has been identified, which is the youngest among those described so far in the Carboniferous section of the Lublin region. It indicates the occurrence of pyroclastic volcanic eruptions also in the early Bashkirian, and not only in the Tournaisian and in the Visean as previously described. The uppermost Carboniferous, included in the Moscovian (depth 1843.0–2591.0 m; thickness 748.0 m), is composed mainly of claystones, mudstones and accompanying, fairly abundant sandstone beds, as well as rare coals. They represent a similar spectrum of fluvial sub-environments in which the Bashkirian sediments were deposited.

The results of biostratigraphic studies of Carboniferous rocks, based on conodonts, calcareous algae and foraminifers from one sample from the Terebin Formation (depth 3400.5 m), do not allow an accurate interpretation of chronostratigraphic position, indicating a wide interval at the Visean/Serpukhovian boundary. A revision of results of palynostratigraphic studies has shown the occurrence of Upper Visean, Serpukhovian, Upper Bashkirian and probably Lower Moscovian rocks. For some of the depth intervals studied, chronostratigraphic interpretation has not been possible. Among sandstones, mudstones and claystones, which are the most typical Carboniferous lithologies, conglomerates, tuffs and carbonates (siderites and clayey/marly limestones) are also locally present. The sandstones are represented by quartz arenites and wackes, subarcosic and sublithic, whose porosity, measured in thin sections, ranges from 0 to 24.8 vol.%. The results of studies on porosity, permeability and pore space parameters indicate very good to good reservoir properties of the Moscovian sandstones, and poorer properties of the Bashkirian and Serpukhovian sandstones. These properties deteriorate below a depth of 3000.0 m. Among diagenetic processes, compaction and cementation had the greatest impact on the reduction of porosity, while dissolution, particularly of feldspar grains, contributed to its increase. Sandstones containing quartz and kaolinite cements as the main binding components usually have higher porosity compared to other sandstones.

The Carboniferous deposits are overlain by the Permian succession that occurs within a depth interval of ?1774.5–1846.0 m (?1768.9–1843.0 m), and its thickness is 71.5 m (74.1 m, driller's measure). The two systems are separated by a stratigraphic gap spanning the Kazimovian–Gzelian and lower Permian (Rotliegend is absent). The Permian is represented by rocks of the Zechstein Group, including the PZ1, PZ2 and PZ3 cyclothems, and siliciclastic deposits of uncertain lithostratigraphic position. The most complete cyclothem PZ1, with a thickness of 47.0 m (45.5 m, driller's measure), consists of the Copper-bearing Shale (T1), Zechstein Limestone (Ca1) and Anhydrite (A1) interpreted as the presumed Lower Anhydrite. Cyclothem PZ2 is reduced to the clastic Recessive Series (T2r), while cyclothem PZ3 is represented by the Platy Dolomite (Ca3). It should be noted that previously, including in the well's final report, the last unit was interpreted as the Main Dolomite (Ca2). For the purpose of this volume, revision was made based on the latest palaeogeographic interpretations. Petrographic and microfacies analyses of core samples from the Ca3 unit show that the lower part of the section is dominated by strongly diagenized medium- to coarse-crystalline dolomites that reveal very rare faint traces of their original structure impossible to interpret. In the middle and upper parts of the section, microsparite and, less frequently, micrite deposits prevail, probably dominated by calcite. Although they show signs of relatively strong diagenesis, their original sedimentary structure has been in places interpreted as oncoid grainstones and laminated micrites probably of microbial origin.

The Platy Dolomite carbonates are overlain by a 58-m-thick siliciclastic succession of unclear lithostratigraphy (Zechstein? or Buntsandstein?; Top Terrigenous Series? or Baltic Formation?). Its lowermost part, composed of mudstones, is interpreted as Permian. The age of the upper part of the succession, composed mainly of red and brown sandstones, mudstones and claystones, is debatable (Permian? or Triassic?). Determination of the Permian/Triassic boundary is especially problematic in the Maciejowice IG 1 borehole, which was drilled in the marginal zone of both the Polish Zechstein Basin and the Mesozoic basin of the Polish Lowlands in the Triassic.

Drill cores taken from a significant part of this succession were subjected to sedimentological analysis. The depositional environments range from playa and sabkha, through the alluvial plain with river channels, to aeolian deposits. Interpretation of progradational and retrogradational trends in deposition has also been made. On this basis, an approximate position of the Permian/Triassic boundary is suggested at a depth of 1764.0 m (1770.0 m, logger's depth). It is placed at the base of coastal sabkha deposits, terminating the retrogradational sequence of environmental development due to a transgressive rise of the erosional base. Such position is amongst a few possible ones discussed in this volume. Petrographic analysis of two sandstone samples from the transitional succession between the Permian and Triassic revealed the presence of quartz/subarcosic arenites, the main components of which are subrounded grains of mono-, less frequently polycrystalline quartz. Among the feldspars, potassium varieties are predominant, with occasional plagioclases. Altered feldspar grains were probably the source of aluminium and silicon for kaolinite that is found in the form of small clusters. Chlorites are also present, while calcite and authigenic quartz occur in cements. The pore space is dominated by macropores. Both primary and secondary porosity were observed. The average value of effective porosity is approximately 25%.

Triassic rocks occur at a depth of ?1427.5–?1726.0 m, reaching approx. 300 m in thickness. Due to little core and the scarcity of fossils the boundaries of the individual series are approximated by the lithostratigraphic boundaries. The characteristic lithological tripartite subdivision of the system is sustained, with the sandstone-clayey Buntsandstein of predominantly alluvial origin (depths 1600.0–?1726.0 m), the carbonate-clayey Muschelkalk deposited in a shallow-marine basin (depths 1546.0–1600.0 m), and the clayey-sandstone Keuper of fluvial origin (depths 1427.5–1546.0 m). Stratigraphic gaps occur mainly in the upper Lower Triassic and in the lower and uppermost Upper Triassic. The Middle and Upper Buntsandstein (corresponding to the Lower Triassic) and Middle Keuper sections are highly reduced, and the Upper Keuper is absent. Both subunits of the Keuper are correlated with the Upper Triassic. The stratigraphic gap spans not only the uppermost Triassic but also the Lower Jurassic and lowermost Middle Jurassic.

Jurassic deposits, 402.0 m in thickness (404.1 m, driller's measure), occur at a depth of 1025.5–?1427.5 m (1023.0–1427.1 m). They are represented by the upper Middle Jurassic (Bathonian and Callovian) and incomplete Upper Jurassic (Oxfordian and Kimmeridgian). The Middle Jurassic begins with a clayey conglomerate layer containing pebbles of calcareous sandstones with limonite, passing into fine- to medium-grained, often calcareous sandstones with fossil detritus and limonite in the cement, and with scarce trace fossils. Upper in the section are sandy limestones, calcareous-dolomitic sandstones, and sandy dolomites. The succession is terminated by organodetrital crinoidal limestones. These deposits yield bivalves, echinoderms and fragments of bryozoans. The cement contains limonite; dolomite crystals are also abundant in places. At the boundary of the Middle and Upper Jurassic, a 20-cm nodular layer with ammonites, belemnites, brachiopods, echinoderms, as well as with chlorite and glauconite, was found. Age interpretation is based on infrequent foraminifers and ostracods and on stratigraphic correlation with nearby boreholes.

The Upper Jurassic occurs at a depth of 1025.5–1394.0 m (1023.0–1391.3 m) and its thickness is 368.5 m (368.3 m, driller's measure). It consists of three formations: Kraśnik, Bełżyce and Głowaczów. The Kraśnik Formation is composed of organodetrital spongy limestones with cherts, glauconite and chlorite, and contains ammonites, belemnites and echinoderms. The Bełżyce Formation is represented by a complex of oolitic and pelitic limestones. The Głowaczów Formation consists of marls and marly limestones and contains abundant bivalves (Trigonia, Mytilus, Exogyra), locally giving the appearance of coquina to the rock. Less frequent are crinoids, limestone intraclasts, peloids and ooids. An accurate determination of the boundary between the Oxfordian and Kimmeridgian is not possible in this borehole.

There is no biostratigraphic evidence for the identification of the boundary between the Middle and Upper Jurassic. In the Kraśnik Formation, at a depth of 1392.0 m, several foraminifera specimens of the species *Spirillina tenuissima* (Gümbel) were found. This species is commonly observed in Oxfordian deposits, being most abundant in the Lower and Middle Oxfordian. Fossils in the Bełżyce Formation are extremely rare and have only been found in a few samples from the upper part of the formation. It contains assemblages of foraminifers and ostracods that are not recorded in the lower parts of the Jurassic section. The ostracods are represented by the species *Cytherella suprajurassica* Oertli, known from the Lower Kimmeridgian on. Among the foraminifers, *Pseudolamarckina obliquicamerata* Dulub and *Quinqueloculina jurassica* Bielecka et Styk have been recorded; both occur in the Polish Lowlands in the *Planula* Zone, indicating the Lower Kimmeridgian. The foraminifera and ostracods from samples of the Głowaczów Formation point to an early Kimmeridgian age of the deposits.

Cretaceous deposits occur within a depth interval of 201.5–1025.5 m, reaching a thickness of 824.0 m. The Lower Cretaceous (depth 1005.0–1025.5 m; thickness 20.5 m) overlies the Upper Jurassic Kimmeridgian rocks, and the stratigraphic gap spans the uppermost Upper Jurassic and much of the Lower Cretaceous from the Berriasian through Lower Valanginian. The Lower Cretaceous section is reduced and limited to the Upper Valanginian – Lower Hauterivian marine siliciclastic-carbonate deposits (Białobrzegi Formation) and Albian siliciclastics (upper part of the Mogilno Formation). There is a gap spanning the Barremian, Aptian and possibly the lowermost Albian (lower part of the Mogilno Formation). The Upper Cretaceous section (depth 201.5–1005.0 m; thickness 803.5 m) shows typical lithologies for the Warsaw-Lublin region and is represented by a marine carbonate (mainly limestone) sequence deposited in an outer shelf, also with the participation of chalk and carbonate-siliceous rocks (opokas) towards the top.

Analysis of foraminiferal assemblages, prepared for the purpose of the well's final report on 48 drill cutting samples taken from the Upper Cretaceous, proved the presence of the following stratigraphic units: Cenomanian, Turonian, Coniacian, Santonian, lower, middle and upper Campanian, and lower and upper Maastrichtian. The analysis indicates a need for regional verification of the Upper Cretaceous stratigraphy using micropalaeontological evidence. The results of the Maciejowice IG 1 borehole, which were based only on cutting samples, cannot serve as a reliable source of data.

The Danian Puławy Formation is the oldest Paleogene lithostratigraphic unit (depth 85.7–201.5; thickness 115.8 m), overlying the Cretaceous succession and represented by marine deposits: marly opokas and grey porous gaizes with marl interbeds. The opokas and gaizes contain pseudomorphoses after spicules of sponges, and admixtures of glauconite. There is a significant stratigraphic gap between the Danian and Lower Oligocene deposits, comprising the upper Paleocene (since the Selandian) and the entire Eocene. The Lower Oligocene is represented by the Lower Mosina Formation composed of grey quartz sands and grey-green sandy muds with glauconite, representing a set of transgressive depositional systems. In the late Oligocene, erosion and denudation processes dominated in the region of the Maciejowice IG 1 borehole.

Neogene deposits (depth 45.0–85.7 m; thickness 40.7 m) are represented by the Middle Miocene Adamów Formation. Coaliferous muds of this formation locally contain small lignite clasts and coalified plant detritus. A layer of fine-grained clayey sand occurs at the base of the formation. The coal-bearing deposits can be regarded as a sedimentary equivalent of the 2ndA Lubin Lignite Seam. They were deposited in an alluvial plain.

Quaternary, largely Pleistocene deposits occur at a depth of 0.0–45.0 m. The Miocene is separated from the overlying glacial tills, 16 m thick, by a stratigraphic gap spanning the upper Miocene and Pliocene. The tills are included in the South Polish Glaciation (Sanian, MIS12). This glacial series is covered by variously grained fluvial sands of the Mazovian Interglacial (MIS11), represented by two sedimentary cycles. Upper in the section is a fluvial sandy series of the Eemian Interglacial (MIS5e). The youngest Pleistocene deposits are variously grained sands that compose the Vistula River floodplain terraces. Their formation is associated with the accumulative activity of waters during cool periods of the Vistula Glaciation (MIS2-5d) that covered only northern Poland. The section ends with Holocene brown sandy soils.

Analysis and reinterpretation of results of historical petrographic studies of organic matter and its thermal maturity were made on 14 Carboniferous samples. They are dominated by authigenic organic matter, occurring in laminae and lenses, 3–60 μm thick. The redeposited material consists of poorly rounded clasts, 5–120 μm long, transported over a relatively short distance. Vitrinite macerals, such as colotelinite and telinite, predominate. The vitrinite reflectance of the authigenic organic matter is in the range of 0.55–0.65%, which means that its maturity is at the initial stage of the so-called "oil window". The vitrinite reflectance values in three samples from Permian–Mesozoic formations are as follows: 0.62% in the Lower Cretaceous, 0.52% in the Upper Triassic, and 0.53% at the Permian/Triassic boundary.

Geochemical studies of organic matter have shown that the rocks of the Visean, Serpukhovian, Bashkirian and part of the Moscovian are "good" source rocks for hydrocarbon generation. The organic carbon content in the Silurian, Devonian and Mesozoic rocks allows them to be described as "poor" or "fair" source rocks. They contain small or very small amounts of labile constituents. Bitumen in the Carboniferous deposits is syngenetic, in contrast to epigenetic bitumen in the Silurian, Permian and Upper Triassic deposits. The parental material for the formation of organic matter was algae and, to a significant extent, bacteria. An influx of varying amounts of humic-type matter is recorded in the Upper Devonian and Carboniferous deposits. In general, the degree of organic matter alteration is difficult to determine due to the high proportion of bacteria in the original organic matter. Studies of sterane and terpane biomarkers indicate that organic matter in the Silurian deposits is highly altered, whereas in the Devonian and Carboniferous ones its degree of alteration is not high.

Rock-Eval pyrolytic analyses were carried out on 71 rock samples of the Silurian, Devonian, Carboniferous, Permian, Triassic and Jurassic deposits. They are dominated by organic matter deposited under aerobic conditions. Therefore, the majority of samples contain type IV kerogen. Few samples of Carboniferous deposits from the Terebin, Dęblin and Huczwa formations contain gas-forming type III kerogen, mixed with type IV kerogen. The Devonian Bychawa "formation" deposits contain both type III kerogen and mixed type III/II kerogen, and there is one sample from the Huczwa Formation, which most probably contains oil- and gas-bearing type IIS kerogen. The rocks show low hydrocarbon potential. Only single samples of the Terebin Formation and the Bychawa "formation" demonstrate moderate hydrocarbon potential. One sample from the Huczwa Formation has excellent hydrocarbon potential. The degree of thermal alteration of organic matter increases with burial depth, from conditions corresponding to the end of diagenesis in the Głowaczów Formation deposits (Jurassic) to the middle stage of oil window in the deposits of the Dęblin, Terebin and Huczwa formations (Carboniferous). Due to limitations of the method, thermal maturity of the Devonian and Silurian rocks has not been determined.

The burial history from the Pridoli to Quaternary reveals several phases of intense subsidence and uplift and several phases of slow changes or even stagnation. The most rapid burial rate occurred in the Early Devonian, Early Pennsylvanian, Middle and Late Triassic, Late Jurassic and latest Cretaceous. Late Devonian, Early Carboniferous and Permian times were characterized by slower subsidence rates. Periods of stagnation took place in Early Cretaceous, Paleogene and Neogene times. Uplift movements occurred in the Late Pennsylvanian and in the Early and Middle Jurassic. During the periods of maximum subsidence, large accommodation space is typically created in the sedimentary basin. Consequently, high rates of deposition of sedimentary material, reaching 180, 130 and 430 m/million years, took place in Lochkovian, Bashkirian and Moscovian times, respectively.

Reconnaissance tectonic profiling of the drill core shows the presence of four tectonic zones of thrust kinematics, determined based on analysis of low-angle slickensides and tectonized bedding planes with fine lineation indicating tectonic transport consistent with the dip direction of the slickensides. These structures are indicative of low--intensity deformation in a thrust tectonic regime. The absence of extensional structures in the form of joint and high-angle slickensides, as well as negligible manifestations of mineralization, is characteristic here.

The uppermost sample taken for porosity and permeability measurements from the Lower Cretaceous yielded the values of 29.6% and 2950 mD, respectively. Investigations of samples from the Upper Jurassic shows the effective porosity varying between 2.11 and 14.34% (average 7.83%), and the permeability exceeding 10 mD in only two samples. The Middle Jurassic deposits are characterized by clearly more favourable reservoir parameters. Their average effective porosity is 13.2%, and the permeability is 309.68 mD; both parameters show higher values in the Bathonian deposits than in Callovian, reaching a maximum of 22.9% and 2450 mD in the Bathonian, respectively. The average effective porosity of the Middle Keuper is 13.41% (max. 19.3%), and its average permeability is 12.13 mD (up to 34 mD). The effective porosity of the Muschelkalk (below 2%) was measured only in one sample from its bottom part. Higher effective porosity values, in the range of 8.75–28.9%, were found in the Upper and Middle Buntsandstein. A permeability of 500 mD was measured in one sample from the Middle Buntsandstein. In the stratigraphically undefined interval at the Permian/Triassic boundary and in the uppermost Permian, very detailed sampling revealed favourable values of reservoir parameters.

The effective porosity ranges from 13.1 to 30.9% (average 22.93%) and the permeability varies from 156 mD to 5100 mD, with more than half of its measurements showing values above 1000 mD. The other Permian formations are practically impermeable, and the average effective porosity is below 0.7%. The maximum effective porosity of the Pennsylvanian deposits is 25%, averaging 6.94%. The most favourable reservoir parameters were found in the Magnuszew Formation, where the permeability exceeds 1000 mD (max. 6750 mD) in five samples. In samples from the other Pennsylvanian formations, the permeability rarely exceeds 20 mD and is usually negligible. The Mississippian deposits are almost impermeable, and its average porosity is less than 1.88%. Similar properties are characteristic of the Upper Devonian deposits. The Middle Devonian carbonates (upper part of the Telatyn Formation) are also impermeable, and the porosity does not exceed 0.47%. The average effective porosity of the Lower Devonian rocks is 2.06%, and the permeability does not exceed 1 mD. The Silurian rocks are characterized by porosity values below 4%. Their permeability has not been determined.

The Lower Cretaceous deposits are characterized by the lowest densities (ρ), averaging 2.18 g/cm^3. The density contrast, and probably also the velocity contrast, between the Lower-Middle Albian deposits ($\rho_{śr}$ = 2.00 g/cm3) and the Upper Valanginian and Lower Hauterivian rocks ($\rho_{śr}$ = 2.41 g/cm3) can be a distinctive correlation horizon. Within the Jurassic succession, there are no such remarkable density contrasts, and the average values of ρ are 2.52 g/cm^3 and 2.48 g/cm^3 for the Upper Jurassic and Middle Jurassic deposits, respectively. The average ρ of the Triassic deposits is merely 2.28 g/cm^3. This figure is underestimated due to the poor sampling in the Middle Triassic that is characterized by high density. The density contrast, and hence the velocity contrast between the Middle (ρśr = 2.70 g/cm^3) and Lower (ρśr = 2.22 g/cm^3) Triassic is a good marker horizon for well-to-well correlations.

The Paleozoic rocks show a constant increase in average density with depth, starting from the Permian and the ?Permian/?Triassic transition (2.42 g/cm^3), through the Carboniferous (2.59 g/cm^3) and Devonian (2.72 g/cm^3), to the Silurian (2.72 g/cm^3). However, there is no clear variation within the individual systems.

Interpretation of the selected, benchmark seismic section makes it possible to observe a synclinal arrangement of strata within the Silurian, Devonian and Carboniferous successions, as well as strong tectonic deformation of Devonian and Carboniferous deposits. The faults run at different angles and antithetic faults are observed. Most of them are reverse faults and some are characterized by significant dip angles. Minor overthrusts are also evident along faults. The Permian unconformably overlies the Carboniferous and dips slightly to the south-west, as do the overlying Mesozoic sediments. The degree of tectonic deformation of these formations is relatively low and some of the faults are rooted in older formations, indicating their later reactivation.

Well log measurements were made using non-calibrated survey equipment, which causes interpretation problems. Many of the well logs are also affected by errors due to the poor technical condition of the borehole. The highest degree of cavernosity was observed in Cretaceous marls and limestones, Carboniferous claystones, and Devonian claystones, sandstones and carbonates. Down to a depth of 2925.0 m, the curvature of the borehole is low and reaches a maximum of 1°30’. The greatest curvature of 4°30’–5°was recorded in the interval 3350.0–3600.0 m. The total deviation from the vertical axis is 148 m at an azimuth of 191°. The assessment of cementation was carried out by using sonic logging. It showed that the cementation quality is sufficient only within short intervals. In order to determine the geothermal degree, temperature logging was performed within an interval of 50.0–5057.0 m after a 7-day long break in drilling. The average geothermal gradient in the borehole is 2.04°C/100 m and the average geothermal degree Hśr = 48.9 m/°C. Analysis of geophysical properties of the rocks made it possible to provide details to the lithological log and to indicate potential reservoir horizons. The best reservoir parameters are attributed to single sandstone and/or limestone intervals in the Mesozoic (Triassic, Jurassic, Cretaceous), to the rocks of the Permian-Triassic transition, and to the Carboniferous sandstones. Some of the well log measurements, including caliper, radiometric, sonic and electrical logs, have been digitized. Selected well log curves have been combined and normalized, and made available in LAS format from the Central Geological Database.

Analysis of the results of vertical seismic profiling measurements enabled to identify a number of velocity complexes. The highest complex velocity value was observed within a depth interval representing Upper Devonian compact limestones. The highest velocity contrasts, corresponding to the strongest reflections in the seismic images, are also visible at the boundaries between the lower and upper Coniacian, between the Jurassic and Triassic, and in a complex of pelitic limestones of the Jurassic Bełżyce Formation.

Oil shows were spotted on drill cores in the Visean and Frasnian limestones. Severe mud gasification by flammable gas occurred at the Silurian/Devonian boundary during borehole flushing.

Nine intervals were tested to assess reservoir properties and the potential for hydrocarbon accumulation. The Devonian horizons tested show very poor reservoir properties, although traces of high hydrocarbon content gas were found within them. Better reservoir properties are attributed to the Carboniferous rocks, from which a 4 m^3/h brine flow rate was obtained, and to the sandstones at the Permian/Triassic boundary and in the Middle Jurassic. A distinct hydrochemical zonation was found in the borehole section – the water mineralization in the Carboniferous deposits is 193 g/dm^3 and rNa/rCl = 0.45, in the Permian/Triassic transition deposits – 88 g/dm^3 and rNa/rCl = 0.63, and in the Jurassic complex – 12 g/dm^3 and rNa/rCl = 0.71. Based on hydrochemical indices, it can be concluded that favourable conditions for hydrocarbon accumulations occur in the Paleozoic and Permian-Triassic transition deposits.

Translated by Krzysztof Leszczyński