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SUMMARY

The Września IG 1 borehole is located in northwestern Poland, in the central part of the Mogilno–Łódź segment of the Szczecin–Miechów synclinorium, in the area of the Western European Paleozoic platform. The purpose of the drilling was, in addition to the implementation of research methods, to clarify the outline of the structure and prospects of the Permian oil-gas deep structures of the foredeep Variscan zone expected under the Permian-Mesozoic cover of the Fore-Sudetic monocline and the Mogilno–Łódź segment of the Szczecin–Miechów synclinorium, while it was also planned to identify the hypothetical Upper Carboniferous source rocks present there. Due to the discovery during drilling of the occurrence of individual stratigraphic boundaries at greater depths than assumed in the project, the borehole was designed to be regraded to 6,000 m for a more complete exploration of sub-Permian formations. Due to technical problems, the drilling was completed at a depth of 5904.2 m, which, however, was sufficient to meet the geological task set.

The first archival lithological and stratigraphic profile of the borehole was compiled at the stage of preparing the borehole documentation. The profile included in this volume was compiled on the basis of data from this documentation and subsequent research conducted over the following decades, as part of a number of scientific projects and tasks of the state geological survey. The profile documents formations of the Carboniferous, Permian (Rotliegend and Zechstein), Triassic, Jurassic, Cretaceous, Paleogene, Neogene and Quaternary.

During the drilling, cores were taken from intervals from the Cretaceous to Carboniferous, with core yields being highest for Carboniferous and Rotliegend formations. Physico-chemical analyses including determinations of specific gravity, bulk weight, effective porosity, total porosity and permeability, as well as moisture content and carbonate content were performed on core samples taken from the Upper Jurassic to Carboniferous intervals. Macrofaunal analyses were carried out on core samples taken from the Middle Jurassic interval, while megaspor palaeobotanical analyses were carried out for the intervals of the Bunter Sandstone, Keuper and Lower Jurassic. Petrographic analyses were carried out for samples of Rotliegend and Carboniferous rocks. Later, analyses of organic matter content were performed on Lower Jurassic and Carboniferous rock samples, vitrinite reflectance for Middle Jurassic and Lower Jurassic samples, petrographic analyses were performed on Carboniferous and Rotliegend samples, analyses of Carboniferous chlorite composition, Rock Eval analyses of Carboniferous samples, and modeling of thermal history, burial and hydrocarbon generation processes for the rock mass in the Września IG 1 well area. In addition, laboratory tests were carried out for the content of major and minor elements, including rare earths, in samples from the Carboniferous, rare earth elements from the Upper Jurassic to Carboniferous interval, ore mineralization and metal content for samples from the Lower Zechstein, and density and porosity analyses from the Upper Cretaceous to Carboniferous interval.

Well logging, temperature measurements, vertical seismic profiling and average velocity measurements were carried out in the Września IG 1 borehole. During the drilling, horizons were sampled within the Lower Jurassic, Upper Triassic (Reed Sandstone) and Lower Triassic (Bunter Sandstone) formations, as well as Zechstein, Rotliegend and Carboniferous. In addition, 2 analyses were carried out on samples of formation water taken in the borehole from Lower Jurassic and Lower Red Salt Clay formations, and 3 analyses were carried out on samples of gas taken from Reed Sandstone, Lower Red Salt Clay and Zechstein Limestone with Rotliegend.

In the profile of the Września IG 1 borehole, a significant thickness of **Carboniferous** formations of 1014.7 m was drilled at a depth of 4889.5–5904.2 m, without reaching its floor. Due to existing discrepancies in the stratigraphy developed on the basis of the results of palynological and faunal studies, a compilation of the aforementioned results was made for the purposes of this volume, assuming at a depth of 4889.5–5187.3 m the occurrence of the Westphalian D – ?Stephanian (thickness of 297.8 m), and below at a depth of 5187.3–5904.2 m – the Upper Visean – Namurian (incomplete thickness of 716.9 m). Reinterpretation of the results of the geophysical survey indicates that the actual thickness of the Carboniferous in the area of the borehole may be about 1,500 m. In the Carboniferous profile there are, in variable proportions, intercalated siltstones, siltstones, sandy siltstones, sandstones, gravelly sandstones and conglomerates. The profile is dominated by siltstone, sandy siltstone and sandstone, while claystone is less common. In the absence of separate lithostratigraphic units, the profile describes 7 hybrid lithological complexes, characterized by the lack of clear dominance of one lithological type, as well as one sandstone and shale complex. Carboniferous formations are strongly tectonically disturbed, the dip of layers is 0–60° and tectonic breccias are encountered. There is schist (clival schist), as well as cracks (veins) vertical, almost vertical, inclined at an angle of 60–80°, and sometimes arranged in a spherical manner, filled with dolomite, calcite, and less often hematite. Bi-directional cracks were also described, running at an angle of 45–70°, offset by a second system of opposing cracks with an inclination of 60° or nearly vertical. Petrography and petrophysical properties of **Carboniferous** sediments comprising sandstones and siltstones and claystones were analyzed. Sandstones are represented by wackes, less frequently arenites, sublithic and subarcose, fine- to coarse-grained. The granular skeleton made up of quartz, feldspars (albite > potassium feldspar), crumbs of mainly volcanic rocks and shales is cemented by matrix and pseudomatrix and cements (including muscovite, illite, chlorite, ankerite, calcite, siderite). These rocks were subjected to diagenetic processes, mainly compaction and cementation, and to a lesser extent, transformation, replacement and dissolution. Sandstones belong to very poorly porous rocks (total porosity 0.40–4.86%; effective porosity 0.05–3.65%) and impermeable, which is related to the large amount of clay matrix filling the pore spaces of sandstones tightly. Similarly, fine-grained rocks (claystones, siltstones) show very low porosity parametres (total porosity 0.36–2.18%; effective porosity 0.14–1.52%) and virtually no permeability.

In the Września IG 1 borehole, the total thickness of **the Rotliegend** formations is 864.2 m. In the lower part, 127 m (4762.5–4889.5 m) of lower Rotliegend (Autunian) formations were drilled, which basically represent the Obrzyckie member in the top part of the Wielkopolska volcanogenic formation, developed, as pyroclastic and epiclastic sediments. The sediments of the Lower Rotliegend are divided into two parts. In the lower part, where pyroclastic material predominates, there are sediments with a predominance of conglomerates (agglomerate tuffites), sandstone tuffites and ash tuffites, which rest on reddish-brown Carboniferous claystones. The pyroclastic sediments were dated using the Rb-Sr method and the $^{40}Ar/^{39}Ar$ method on a volcanic rock biotite sample from the Września IG 1 borehole from the depth interval of 4857–4866 m. The results of both dating are in the range of 284.6 to 289.0 million years. On the other hand, in the upper part of the Lower Red Bedrock profile, the proportion of epiclastic material in the form of sandstones and fine clastic conglomerates of the alluvial plain is increasing. Since views on the lithostratigraphy of the Lower Rotliegend formations have been reevaluated in recent years, particularly after the separation of the epiclastic, supra-volcanic Objezierze Formation, it is postulated that the upper part of the Lower Rotliegend profile should be included in this formation. Above, after a significant erosional gap and a temporally extensive hiatus, there are sediments of the Upper Rotliegend with a thickness of 737.2 m (4025.3–4762.5 m), belonging to the Lower Drawa Formation and the Upper Noteć Formation. The sediments of the Upper Rotliegend (Saxonian), are developed, as lithic and sublithic sandstones, mostly fine- and medium-grained, locally coarse-grained, with a small share of siltstone sediments, representing dune and interdune sediments, occasionally fluvial and marginal plains. The occurrence of this type of aeolian sediments corresponds to relatively regular cycles of sedimentation associated with changes in climate from drier to wetter and with the rate of subsidence and erosion of the area. Upper Rotliegend sandstones are characterized by gray, pink, grayish-red or brown color. Their characteristic feature is their directional texture highlighted by the arrangement of laminae with coarser and finer grain size. Characteristic of the uppermost part of the Rotliegend profile is the presence of more coarse-grained material, which may indicate changes in sand supply on a regional scale during the sedimentation of these sediments. These indications also point to a hypothetical, relatively high paleorelief of the area where the borehole is located. The depth of the roof of the Rotliegend formations determined in the final documentation of the Września IG 1 borehole was corrected after verification of the thickness of the Weissliegend complex. The petrography and petrophysical properties of the volcanoclastic and epiclastic rocks of the Lower **Rotliegend** (Autunian) and the epiclastic rocks of the Upper **Rotliegend** (Saxonian) were analyzed. Volcanoclastic rocks are represented by tuffites of lapillic, coarse ash and fine ash lithofacies. Epiclastic rocks, are mainly sandstones, occasionally conglomerates. On the basis of the study of the Autunian series, it was concluded that these are rocks of complex origin, formed simultaneously as a result of volcanic eruptions and the denudation and redeposition of older outcrop and sedimentary rocks, and the effects of diagenetic transformations included the processes of anhydritization, carbonatization and silicification, and bentonitization of volcanic glaze. A characteristic feature of the Saxonian series in the Września IG 1 borehole is the occurrence of a thicker package of aeolian sandstones with fluvial inserts, represented by lithic, sublithic and subarcose arenites (rarely wackes). In addition to quartz and feldspars, they contain numerous crumbs of fluvial and metamorphic rocks, while fragments of sedimentary rocks are noted occasionally. The crumb material of the sandstones is mainly derived from the denuded covers of the Autunite outcrop rocks and Carboniferous rocks. Among diagenetic processes, mechanical compaction is considered the strongest and longest-lasting. More variable in time was the effect of cementation reducing the primary porosity of the sediment. Of greatest importance for the formation of secondary porosity was the process of diagenetic dissolution. Sandstones are characterized by reservoir properties considered to be medium or weak. Their porosity is most often around 9%, and permeability is close to zero, and exceptionally around 200 mD. The microporous structure of the pore spaces and the presence of fibrous illite are considered to be the reason for such poor petrophysical properties. The sediments were infiltrated by pore solutions with both alkaline and acidic reactions. Determination of the crystallization age of illite made it possible to determine the final stage of diagenetic transformation in sandstones of the Saxonian to Early Cretaceous.

Zechstein marine sedimentation formations in the Września IG 1 borehole reach a thickness of 900.3 m and were found at a depth of 3125.0–4024.5 m. Sediments formed in all four cyclothems – PZ4 to PZ1, corresponding to the Aller, Leine, Strassfurt and Werra cyclothems of the German Basin – can be distinguished in them. Between the complex of the four Zechstein cyclothems and the sediments of the Red Bedrock, there is a thin layer of Weissliegend sediments (about 0.8 m thick; in the range 4023.5–4024.5 m), most likely formed in the sedimentary environment of the shoreline zone (in the phase of small riplemarks, perhaps in the environment of the tidal plain of the Zechstein sea and as a result of resedimentation of non-diagenized terrestrial sediments). The sandstones, which are characterized by a dark gray or light gray color with a pink tinge and the presence of various types of horizontal layering and tabular diagonals, with flat boundary surfaces, were included in the Weissliegend sandstones, in contrast to the light-brown colored sandstones below, which were included in the Rotliegend sandstone. In the upper parts, the Weissliegend contains very poor, relict sulphide mineralization, represented by irregular grains of chalcozite and sparse concentrations of pyrite, and is characterized by a relatively low content of copper and associated metals. Due to the strong disintegration of the cores, the determination of the depth of the Weissliegend floor (the Rotliegend top) is approximate. Above the Weissliegend sediments there is a copper-bearing shale of negligible thickness (2 cm; no core), developed in the form of a marly shale with sharp but uneven contact with the lower-lying sandstones. Its formation was most likely related to a short-lived episode of sedimentation of formations of anoxic genesis, probably due to rapid shallowing of the sedimentary environment. In the **Zechstein** profile, the borehole revealed the presence of two levels of carbonate formations of small thickness: the Zechstein Limestone (Ca1 – thickness of about 2.0 m) and the Main Dolomite (Ca2 – thickness of 3.5 m), while there is no the Plate Dolomite (Ca3). Carbonate sediments are separated by evaporite formations developed mainly in sulfate (anhydrite) and chloride (rock salt (halite) and potassium salts (selvinite)) phases. The Września IG 1 borehole is located in the central part of the basin, where the thickness of carbonate members is small, while evaporites (especially rock salts) reach very large thicknesses. Sediments of the Zechstein Limestone (Ca1) are developed mainly, as gray calcareous dolomite and dolomitic limestone with a tubercular structure (the upper part of the profile) and massive with clay laminae and stylolites (the lower part of the profile), containing numerous anhydrite rubble. The Września IG 1 hole is most likely located within a granular lithofacies (ooids and oncoids predominate), on the inclination of a mid-basin shallow Ca1 periodically elevated above sea level. The lower and middle Ca1 is characterized by the predominance of chalcopyrite mineralization over sphalerite and pyrite, and the upper Ca1 by the predominance of sphalerite mineralization over chalcopyrite and galena. The content of copper and associated metals in the lower Ca1 is higher than in the top of the Weissliegend, but has no economic value. The Main Dolomite (Ca2) is developed, as dark gray densely horizontally laminated carbonates with clayey material, with a definite predominance of calcite. More or less horizontally laminated mudstones are observed, built up by thicker irregular carbonate laminae and thin black laminae probably enriched in organic matter and clay minerals. The laminated mudstones are cut by vertical calcite veins of varying thickness, the thickest of which are filled with coarse crystalline calcite.

The Września IG 1 borehole is located, in the present scheme of Mesozoic structures, on the border of the Fore-Sudetic monocline and the Szczecin–Miechów synclinorium, in the zone of the greatest thickness of the Triassic. The thickness here is 1786.0 m, and **Triassic** formations occur in the depth interval of 1339.0–3125.0 m. The Triassic interval was cored only to a small extent (about 9% on average), with the greatest extent in the case of Bunter Sandstone and the smallest in the case of the Muschelkalk. The lithological description and Triassic stratigraphy presented in this volume are based on data from the final borehole documentation, analysis of wire-logging curves, available cores and regional analysis of other archival boreholes. Minor corrections, updating the stratigraphy, involved the abandonment of the separation of the Rhaetian, with unclear status (litho- vs. chronostratigraphic), a minor correction of the Reed Sandstone floor, a change in the floor of the Upper Triassic by excluding the Lower Keuper and introducing the Middle and Lower Triassic, and finally the introduction of the concept of the Röt "formation", the clay "formation", and the Pomeranian and Baltic formations. The Lower Muschelkalk was divided into the Marly Beds and Wavy Beds. Due to the poverty of chronostratigraphic indications, the separation of strata in the profile was abandoned.

The profile of the **Bunter Sandstone**, with a total thickness of 748.5 m (depth interval 2376.5–3125.0 m), begins with the Baltic Formation with a thickness of 341.0 m, which forms a complete succession of the Lower Bunter Sandstone. It is equivalent to the Calvörde and Bernburg formations in eastern Germany. It is built up of dark reddish-brown siltstone and mudstone with subordinate sandstone interbeds in the lower part of the unit, and limestone interbeds, in its middle part. In the lower part of the formation, the rock has the character of a heterolithic siltstone laminated wavy or lenticularly with fractures from desiccation, syneresis and clastic dikes, while in the highest part the siltstone is mainly massive and there are sparse anhydrite concretions. The overlying Pomeranian Formation with a thickness of 141.5 m, which is categorized as the Middle Bunter Sandstone and generally corresponds to the Volpriehausen Formation in eastern Germany, begins a not very thick sandstone complex (13 m) and a thin limestone complex (8 m). Lying above them, the main part of the formation is made up of alternating complexes of brownish-gray or gray limestone and brownish-dark red siltstone. Within this complex, high values of this parameter within silty limestones and oolitic limestones with siltstone streaks and stylolites were identified, based on measurements of natural gamma radiation on core samples. Such high values of natural gamma radiation are anomalous for carbonate sediments and are probably associated with elevated uranium content. Deposition of Pomeranian Formation sediments occurred in a shallow marine lagoon, under slightly deeper, more stable conditions than those prevailing during (shallow marine and coastal) deposition of the Baltic Formation. The profile of the Middle Bunter Sandstone ends with the so-called clay "formation", 141.5 metres thick, not formally established. It is built by claystones and siltstones mainly brownish-red with subordinate interbeds of fine-grained sandstones. The proportion of sandstones decreases towards the top of the profile. Deposition took place on a sand and silt plain, initially with the character of a coastal plain and later probably a distal alluvial plain or playa. The Upper Bunter Sandstone is constituted in the borehole by the formally unestablished so-called Röt "formation", with a thickness of 124.5 m. The formation begins with a sandstone and siltstone complex, which is dominated by sandstones, with claystones in the highest part. The higher part of the division is developed in a typical evaporite-carbonate-siltstone form and includes two anhydrite complexes, separated by a layer of dolomitic limestone and siltstone, above which is a complex of dark gray siltstone with interbeds of dolomite and limestone, passing upward into a complex of limestone with interbeds of dolomite and siltstone. These sediments document the activation of connections with the Tethys Ocean and the development of a shallow evaporite and silt shelf.

The Muschelkalk in the Września IG 1 borehole lies at a depth of 2102.5–2376.5 m (thickness of 274.0 m). The borehole is located in the zone of greatest thicknesses of this unit and drills all three subgroups: Lower, Middle and Upper Muschelkalk limestone. The Lower Muschelkalk, with a thickness of 173.5 m, forms the main part of the profile of the entire group. It has been divided into a lower part, made up of marls with interlayers of limestone (the Marly Beds), and an upper part, made up of marly limestone and limestone (the Wavy Beds). The Marly Beds are the equivalent of the lower Gogolian layers of the Silesian-Cracow area, and within the Wavy Beds it is possible to correlate separations corresponding to oolitic shoals, terebratulic shoals and foam shoals, which can be traced from Brandenburg through Greater Poland to Silesia. The Middle Muschelkalk, 52.0 m thick, is developed as a clay-anhydrite-dolomite succession with interbeds of limestone and marl. The limestones, claystones and anhydrites are gray to dark gray in color, in contrast to the light gray-yellow dolomites. Streaky laminations of claystones and anhydrites in dolomites, dolomites in anhydrites, and claystones and marls in limestones are characteristic. The succession of the Upper Muschelkalk with a thickness of 48.5 m shows a marked decrease in the proportion of limestone towards the top of the profile in favor of the dominance of siltstone. The Muschelkalk was deposited in the shallow epicontinental sea, connected to the Tethys Ocean initially, mainly in the Anisian, through the East Carpathian and Silesian-Moravian gates in the southeastern part of the basin, and later, in the Ladinian, through the Burgundian gate, in the southwestern part of the basin. Therefore, the most open-marine conditions in the Mesozoic Basin of the Polish Lowlands prevailed during the deposition of the Lower Muschelkalk, which did not occur any more later, due to the great distance from the active connection with the ocean.

The Września IG 1 borehole is characterized by the full development of all the Western Polish **Keuper** units, the total thickness of which reaches 763.5 m here (depth interval 1339.0–2102.5 m). The profile begins with the Sulechów Beds of the Lower Keuper (thickness 90.5 m), built mainly of siltstone and mudstone with a few interbeds of sandstone. Their deposition occurred on the fluvial-deltaic plain, fringing the retreating epicontinental marine basin. The Lower Gypsum Beds, which begin the Middle Keuper, are mainly built up by dark gray siltstone with intercalations and inclusions of anhydrite and clay dolomite. These intercalations are most likely concentrated in the lowest part of the unit and could be correlated with the so-called Boundary Dolomite – corresponding to the last significant marine transgression into the Mesozoic basin area of the Polish Lowlands. The claystone lying above was deposited in a shallow lagoon of elevated salinity, perhaps of sebha character. The Reed Sandstone (thickness of about 76.0 m) comprises alternating layers of sandstone and siltstone in the lowest part. Above it is a complex of gray, light gray and green-gray fine-grained sandstones with interlayers of dark gray, in the highest part of the trout, siltstone, with a total thickness of 37.0 m. The sandstones are diagonally layered and streaky laminated in places, contain kaolin dust, and are dolomitic in places. The succession is completed in the roof by a layer of brown massive claystone. The Reed Sandstone is interpreted as a sediment formed in the fluvial-deltaic system during an episode of climatic wetting in the Late Triassic. The boundary between the Reed sandstone formations and the higher lying succession of the Upper Gypsum beds, also formed mainly in the form of siltstone, is difficult to define. These layers, with a thickness of about 141.5 metres, are composed in the lower part of red claystones with anhydrite inclusions, which pass in the ceiling into alternating layers of gray claystones and anhydrites. The Middle Keuper is terminated by the Zbąszynek and Jarkowo Beds (thickness 277.5 m), which are not separated in the borehole. They are composed of massive dark reddish-brown and gray-green clayey siltstone and siltstone, spotted in places, sometimes dolomitic. In places there are thin interbeds of clay-carbonate conglomerates. The profile of the Keuper, and thus the Triassic, is completed by the Wielichowo Beds with a thickness of 46.0 m, classified as Upper Keuper. They are built by dark gray siltstone with interbeds of light gray fine-grained sandstone and siltstone. The succession of the Upper Triassic from the Upper Gypsum Beds to the Wielichowo Beds documents the gradual pluvialization of the environment – from a dry climate, through the environment of the distal alluvial plain of a semi-arid climate, ending with a fluvial system, probably already of a wetter climate, with a clear division into trough and off-trough zones.

The Jurassic profile in the Września IG 1 borehole was delineated at a depth of 210.0–1339.0 m and has a thickness of 1129.0 m. It includes Lower, Middle and Upper Jurassic formations, which lie in sedimentary continuity with Upper Triassic formations in the bottom, while covered by formations of higher Lower Cretaceous in the top. The lithological description and Jurassic stratigraphy were based on data from the borehole final documentation, analysis of wireline log curves, correlations with nearby archival boreholes and information from the few available cores.

The profile of the **Lower Jurassic** in the borehole (thickness 359.0 m, depth interval 980.0–1339.0 m) includes all chrono- and lithostratigraphic units of the Lower Jurassic of central Poland, but their thickness is reduced in relation to the axial part of the sedimentary basin. The profile of the **Lower Jurassic** begins with the sediments of the Zagaje Formation corresponding in age to the Hettangian (thickness 74.0 m), formed as mainly fine-grained, light gray sandstone with an insertion of siltstone. These are probably flood plain deposits and/or lake and marsh deposits. The Ostrowiec Formation (thickness 60.0 m), separated above, representing the Synemurian sediments, is developed in the form of fine-grained clayey sandstones and sandy siltstones in the lower part and fine- and medium-grained light-gray sandstones in the higher part. It is likely that these formations are shallow marine (in the lower part) and sediments of deltaic and river channels (in the higher part). In the Pliensbachian sediments, the Gielniów Formation (in the lower part) and the Drzewica Formation (in the upper part) have been identified. The Gielniów Formation (thickness 30.0 m) consists mainly of dark gray siltstone and claystone formations, in the middle part sandy with sandstone insertion. Most likely, these formations are of shallow-marine and coastal genesis. The Drzewica Formation (thickness 76.0 m) is developed in the lower half as light gray fine- and medium-grained sandstone, while above it there are two complexes of gray-colored siltstone and siltstone, separated by a sandstone insert. The higher of these complexes shows a gradual decrease in grain size upward, and a sandstone complex occurs in the top of the formation. These sediments were formed in a terrestrial environment, mainly riverine and, in the higher part, perhaps marshy and lakeshore. Above is the Ciechocinek Formation, comprising rocks of the Lower Toarcian (thickness 77.0 m), with a predominance of siltstone and mudstone, separated in the central part by a several-meter complex of more sandy rocks. The profile of the Lower Jurassic is completed by the Borucice Formation of the Upper Toarcian (37.0 m thick), comprising a complex of fine-grained sandstones that formed in a river environment.

The Middle Jurassic was separated in the depth interval of 875.0–980.0 m (thickness of 105.0 m), typical of the area, with Aalenian and Bajocian sediments missing from the profile. The Middle Jurassic profile begins with Lower Bathonian sediments (thickness 103.5 m) containing levels with ammonite faunas in the lower part, once included in the uppermost Upper Bajocian. The profile of the Bathonian in the lower section is developed as dark gray siltstone and siltstone with faunal remains, upwardly turning into siltstone, in the higher part with a very abundant bivalve fauna and ammonites of the genus *Oecotraustes*. In the middle Bathonian, the rocks begin to show more sandiness than in the lower Bathonian. The Upper Bathonian is developed in the lower part mainly as siltstone and siltstone formations, while its upper section is built of sandstone and sandy siltstone. The Middle Jurassic profile is terminated by Callovian sediments about 1.5 m thick, comprising sandy limestone (in the lower part) and marly marls/siltstone above.

A complete **Upper Jurassic profile** with a thickness of 665.0 m (depth interval 210.0–875.0 m) was found in the Września IG 1 borehole. It is started by Oxfordian sediments with a thickness of 130.5 m (the floor was hypothesized on the basis of microfauna and after the ICS), developed mostly in the form of compact sponge limestone of rocky limestone character, with nests of calcite, marly clay inserts and chlorite-ferruginous deposits, near the bottom. The Oxfordian sediments were categorized as the Spongy limestone Formation (I). The Kimmeridgian, with a thickness of 475 m, in the lower section is developed as limestone and limestone-marl rocks (the Lower Kimmeridgian), in the upper section as marls (the Upper Kimmeridgian). The Lower Kimmeridgian, with a thickness of 384.0 m, is divided into two formations: the ?Oolitic Formation (IV), with a thickness of 164.5 m, developed as limestones of variable porosity, probably hard, compact, with insets of more permeable rocks, and the Carbonate-marly-shell Formation (V), developed alternately as more compact and porous limestones, marly limestones and marls (thickness 219.5 m). Both lithological types have runoff structures and insets of clam shells. The higher section of the profile of the Upper Jurassic, with a thickness of 130.5 m, includes sediments of the Pałuki Formation, developed mainly as marls. It includes the Upper Kimmeridgian, the Lower Tithonian and a significant part of the Upper Tithonian. The formations of the uppermost Kimmeridgian show more limestone than the lower Tithonian. Completing the profile of the Upper Jurassic, the higher part of the Upper Tithonian (thickness 20.0 m) is developed as limestone, in places with ooliths and with marl inserts. It is the lower part of the Kcynia Formation. Presumably, there is an erosional surface in the top of this unit, as the borehole profile lacks higher members of the Kcynia Formation, categorized as the lowest Cretaceous.

The **Cretaceous** sediments occur at a depth of 82.0–210.0 metres and have a thickness of 128.0 metres. This section was not cored, hence the stratigraphy of the **Cretaceous** was determined based on the description of crumb samples and well logging measurements in comparison with neighboring boreholes. **The Lower Cretaceous** with a thickness of 77.5 m, lying with a stratigraphic gap on the Upper Jurassic rocks, was found at a depth of 132.5–210.0 m. A distinction has been made between the Włocławek Formation (probably transgressive Hauterivian sediments, sandstones with siltstone interbeds and siltstones) and the Mogilno Formation (Barremian – Middle Albian), probably represented by all three members: the Pagórki Member (Barremian? sandstones with a thickness of only 2.5 m), Gopło Member (siltstones and silty sandstones with a thickness of 5.0 m) and Kruszwica Member (fine-grained, coarse-grained and different-grained sands, with an admixture of gravel, with a thickness of 57.0 m). Above the Mogilno Formation lie transgressive marly-sandy formations with Upper Albian phosphorites. Lower Cretaceous rocks, which are calcium-free, were deposited in the area of a shallow silicoclastic shelf. **Upper Cretaceous** sediments were found at a depth of 132.5–82.0 metres. They are 50.5 m thick, cover the Cenomanian–Turonian interval, and were deposited in the area of the carbonate and carbonate-siliciclastic shelf to the SW of the Mid-Polish Trough. In the Cenomanian (13.5 m thick) they are marls and limestones with insets of marly limestones, and in the Turonian (37.0 m thick) they are limestones, marly limestones, and in the top opokas. In the Cretaceous profile of the Września IG 1 borehole, there are no higher units of the Upper Cretaceous. The upper Cretaceous boundary is erosional. Sedimentation in the Late Cretaceous continued in the area most likely up to and including the Maastrichtian, but tectonic inversion of the Fore-Sudetic monocline area caused the removal of the deposited formations.

The thickness of the **Cenozoic** formations in the borehole is a total of 82 m, of which 50 m is in the **Quaternary**, 26.5 m in the **Neogene**, and 5.5 m in the **Paleogene**. **Paleogene** formations in the area around the borehole are represented by fine-grained glauconitic sands, dark rusty in color, as well as gray silts and brown clays with a total thickness of 5.5 m, classified as Oligocene. **The Neogene** sediments (thickness of 26.5 m) begin with Middle Miocene sediments developed in the form of gray-brown silt with lignite or clayey silt in the bottom, above that fine-grained and variously grained sands, gray silt with thin insets of lignite. Above them lie Upper Miocene–Pliocene sediment, developed as gray, blue, green and chert clays, with interbedding of sands, silts and with thin inserts of lignite coal. Quaternary formations (50 m thick) generally include Pleistocene glacial deposits.

In the area where the Września IG 1 well was drilled, two distinct petroleum systems can be distinguished. The first, **an unconventional petroleum system**, is represented by the Lower Permian Rotliegend concreted sandstones and the Carboniferous sandstones and shales. Carboniferous siltstone shales are considered the source rocks for the Carboniferous – Lower Permian system. Archival and new TOC studies suggest the presence of three complexes with elevated TOC contents within the Carboniferous, reaching or just above about 1% in siltstone and claystone samples. The results of archival and new geochemical analyses (including RockEval) indicate that the thermal maturity of the Carboniferous complexes can generally be described as overmature. The second, **conventional petroleum system**, includes the Zechstein Main Dolomite rocks, with the shallow-water carbonate platform sediments, specifically its inclines, as the source rocks. In the Września IG 1 well, only 3.5 m of the Main Dolomite sediments were drilled, developed as dark gray dolomites originated in a basin plain, and were not found to have a source rock characteristics.

The modeling of **thermal history and burial conditions** for the Września IG 1 borehole was based on stratigraphic data, lithologic data, erosion magnitudes with their timeframes, palaeogeographic data, palaeobathymetric data, and contemporary heat flow and paleaoheat flow. In addition, data on contemporary borehole temperatures and rock organic matter maturity were used. The history of burial in the borehole encloses a time frame from the Carboniferous to the Quaternary, with three small-scale erosion gaps. It includes several phases of rapid burial (Carboniferous, Permian, Early Triassic, and Late Jurassic) and a slightly slower phase from the Middle Triassic to the early Late Jurassic, as well as small-scale uplift and one stagnation. In the Permian, as a result of burial, the Carboniferous formations were located in the upper oil window. In the early Triassic, Lower Permian formations entered the upper oil window, while Carboniferous formations reached the main oil window during this period and later the upper oil window, condensate and dry gas window. At the end of the Middle Jurassic, the upper part of the Permian profile was located in the main oil window. Modeling results indicate that the condensate zone covers the entire Upper Permian interval and a significant part of the Lower Permian. The dry gas zone, in turn, covers the lower part of the Lower Permian interval and the entire Carboniferous lithological interval.

Since the early 1970s, over 80 seismic profiles have been measured within a 10 km radius of the Września IG 1 well, including the most recent ones in 2011 and 2019. A section of the **seismic profile** located in close proximity to the borehole, taken in 2019 with a SW–NE strike, was selected for interpretation. Using, among other things, the lithological profile of the borehole, seismic horizons correlated with the top of the following layers were identified on the profile: Carboniferous, Lower Permian (Rotliegend), Upper Permian (Zechstein), Lower, Middle and Upper Triassic, Lower, Middle and Upper Jurassic, Lower Cretaceous, as well as a horizon associated with the regional erosion surface, which in this area is the top of the Upper Cretaceous sediments. Due to technical problems during the measurements in the borehole, the acoustic curve and vertical seismic profiling did not cover the entire depth interval, which affected the uncertainty of the correlation of the three deepest horizons on the seismic section. Within the Carboniferous formations, despite the reduced quality of the wave image, the recorded seismic horizons are consistent with the overlying layers and no visible continuous deformations were found. However, the presence of faults affecting the roof of the Rotliegend and, possibly, the top of the Carboniferous strata cannot be ruled out. A change in thickness is only visible in the Upper Triassic layer, where 5–6 km (and further) to the northeast of the borehole, seismic horizons are marked by a dip. This may be related to significant tectonic movements that took place during the Norian and Rhaetian periods. Similar changes in thickness resulting from synsedimentary tectonic movements, probably related to the formation of the Wielkopolska Uplift, can be observed within the Lower Jurassic sediments. The Middle Jurassic in the borehole and uplifted areas is characterized by a shortened profile. The thickness of the Lower Cretaceous does not change along the interpreted profile. It is not possible to determine the original thickness of the Upper Cretaceous sediments, as deep erosion occurred after the Late Cretaceous – Paleocene inversion of the Mid-Polish Trough. In the NE part of the profile (~6–7 km and further NE of the borehole), there is a clearly marked cut-off of seismic horizons, which are limited from above by a continuous reflection. It constitutes a regional erosion surface, which also marks the top of the Upper Cretaceous, on which Cenozoic sediments lie unconformably.

The Września IG 1 well was originally designed to a depth of 4,500 m. During drilling, it turned out that the individual formations were deeper than expected, so the well was extended to 6,000 m to get a better look at the sub-Permian formations. After reaching 5904.2 m, the well was terminated due to a failure, without reaching the design depth. Therefore, no **well logging geophysical measurements** were performed in the depth interval 5350–5904 m. In the Zechstein formations at depths of 3158 to 3960 m, due to technical problems during drilling, no measurements were taken in the bare hole. Only gamma and neutron-gamma measurements were taken in the cased hole in this section. **Well logging geophysical measurements** were carried out at a depth of 0–5350 m, in 10 measurement stages. The measurements were performed with uncalibrated measuring equipment, which means that even in the same section, the measured values give different results due to different technical parametres of the probe, which significantly hinders further mathematical analysis of the data. In addition, the results obtained are subject to additional error due to the poor condition of the borehole walls and numerous cavities. The longest sections with poor borehole condition occur in the complexes of high clay content (the lower Cenozoic complex, the uppermost Upper Jurassic, the Middle Jurassic, the Upper Triassic and the Rotliegend sediments). In the Lower Rotliegend and Carboniferous complexes, the borehole diameter does not differ significantly from the nominal diameter, which proves the absence of washouts in this section. Numerous cavernous sections significantly affected the cementation of the pipes in the borehole. The interpretation of the obtained geophysical curves allowed the calculation of the following parametres for selected sandstone layers with reservoir potential: oil content, porosity, formation water mineralization, water saturation coefficient, and formation water resistivity. Due to the poor condition of the borehole walls, the results of these analyses are subject to considerable uncertainty. An additional difficulty was the fact that acoustic profiling was only performed in the section from 910 to 3150 m depth, which meant that only in this section was it possible to calculate all the above-mentioned parametres. High values of **clay content** occur in the lower part of the Cenozoic, in the Lower Cretaceous, upper Jurassic, Middle Jurassic, fragmentarily in the lower part of the Lower Jurassic, in the Upper Triassic, fragmentarily in the Middle Triassic, in the lower parts of the Lower Triassic, the Lower Rotliegend (where, however, the gamma curve readings are overestimated due to the presence of volcanic formations) and the Carboniferous. High **porosity** values were found in the sandy complexes of the Lower Jurassic, with a fairly high water saturation coefficient, and in the Upper Triassic. According to inclinometer measurements, the borehole was straight to a depth of 3100 metres, with the inclination usually increasing at greater depths. Spot measurements of the maximum **temperature** at the bottom of the borehole were taken during geophysical measurements, followed by continuous temperature measurements at intervals of 5100–5350 m (maximum value 171°C). Temperature profiling at steady thermal equilibrium was performed after a 10-day well standstill, at a depth of 210–2705 m (maximum value 105°C). The geothermal gradient values estimated on this basis range from 2.8 to 4.0 °C/100 m, with lower values recorded in Cretaceous and Jurassic formations and higher values in Triassic formations.

Vertical seismic profiling (VSP) measurements in the Września IG 1 well were performed for a depth range from 0 to 2775 m, at 15 m depth intervals, corresponding to stratigraphic levels from the Quaternary to the Lower Triassic series. Based on the measurement results, individual velocity complexes were determined, in particular their average values, by applying a time measurement smoothing procedure to eliminate the influence of random value jumps caused by measurement errors. The smoothed curves were used to determine zones of maximum variability of average velocity values, which correspond to the boundaries of individual velocity complexes. It was found that the average velocity calculated as a derivative of the measured time depends on the lithological variability of the stratigraphic levels identified in the Września IG 1 borehole profile and reflects the geological structure in its immediate vicinity. The smoothed, interval, and complex velocity values obtained for the Września IG 1 well allowed the determination of the boundaries of a series of velocity complexes associated with lithological changes covering stratigraphic divisions from the Quaternary to the Lower Bunter Sandstone (Lower Triassic). The highest complex velocity values were observed in Upper Jurassic oolitic limestones and Lower Bunter Sandstone limestones and sandstones. The largest negative velocity contrast is visible in the Lower Jurassic, where mudstones and claystones dominate. The identified complex boundaries will allow the most distinct reflection echoes on seismic profiles to be linked to the appropriate lithostratigraphic units and the correct seismic interpretation to be developed in the area of the Września IG 1 well.

According to the regional classification of drinking groundwater, the Września IG 1 borehole is located in the Warta water region. **Fresh groundwater** (drinking) occurs in this area within three aquifers: Quaternary, Neogene–Paleogene, and Cretaceous, with the Neogene–Paleogene aquifer serving as the main usable aquifer. Outside the area of fresh (potable) water occurrence, Jurassic and Permian aquifers are present in the discussed well. The scope of hydrogeological investigations carried out during the drilling of the Września IG 1 borehole included sampling of water for physical and chemical analysis from aquifers occurring in Jurassic and Permian formations, while shallower aquifers were not sampled. Quaternary and Neogene–Paleogene aquifers are sampled in observation wells at the PGI-NRI Borówiec hydrogeological station located about 30 km west of the Września IG 1 well. The Quaternary aquifer comprises two shallow aquifers – a surface aquifer (ground) and an inter-clay (in the Wielkopolska fossil valley), at depths of 0.5–16.0 m and ~50 m, respectively, which are of no practical significance in the location of the well. These are fresh waters (mineralization 0.20–0.65 g/dm^3), mostly medium hard, with a slightly elevated content of iron and manganese compounds and ammonia. The Neogene–Paleogene aquifer is formed by the Miocene horizon (sands at a depth of 57.5 m, with a thickness of 9 m in the borehole, isolated by a layer of clay) and the Oligocene horizon (not present in the borehole), which remain in hydraulic contact in the borehole area. They are part of the Main Groundwater Reservoir No. 143, i.e. the Inowrocław–Gniezno sub-reservoir. The Miocene horizon contains fresh water of the HCO_3-SO_4-Ca type, with a pH of 7–9, mineralization of 0.26–0.80 g/dm^3, mostly hard and with an increased content of iron and manganese compounds. The Cretaceous aquifer is formed by fractured marl-limestone sediments of Turonian and Cenomanian age, found in the Września IG 1 borehole at a depth of 82 m, with a thickness of 50.5 m. It contains fresh water (mineralization 0.2–0.4 g/dm^3), soft or medium hard, with elevated iron and manganese content. The Jurassic aquifer, occurring much deeper, includes a series of sandstone horizons within the Lower Jurassic and contains water with relatively high mineralization, reaching 63.2 g/dm^3 (**brine**) in the deepest part. The Permian aquifer in the Września IG 1 well can be distinguished as a level of mudstones with admixtures of salt and clay in the lowest part of the Zechstein Aller cyclothem, where a small inflow of **brine** with very high mineralization (405 g/dm^3) was recorded.

During and after drilling, in order to examine the reservoir rocks for the presence of crude oil and natural gas, **reservoir tests** were performed in the Rotliegend, Zechstein, Bunter Sandstone, and Jurassic formations. In total, eight Triassic and Jurassic sandstone horizons were tested **during drilling**. The three lower Jurassic horizons tested showed saturation with reservoir water of medium-high mineralization, but the salinity values obtained are significantly underestimated due to heavy contamination with drilling mud filtrate. During sampling of the Keuper Reed Sandstone, brine with drilling fluid filtrate was obtained without clear signs of gasification, and an inflow of gasified brine heavily contaminated with drilling fluid was observed. During three tests of the Middle Bunter Sandstone, no inflow was obtained. A test of the prospective level of the Zechstein Limestone and the top parts of the Rotliegend was carried out after casing the hole, and a weak gas flow was obtained. **After drilling** was completed, a test was carried out with a sampler of Zechstein shales with admixtures of salt and clay, which resulted in spontaneous flow of mud from the borehole, caused by the inflow of saturated brine with abnormal pressure and very high mineralization. The brine inflow probably originated from the Zechstein Main Dolomite horizon and was caused by poorly cemented pipes. Sampling of the lowest Lower Jurassic sandstones was also carried out, where, as a result of injecting 105 m^3 of brine, a strong reservoir level absorbency was found.