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SUMMARY

The core material obtained from the Nidzica IG 1 research borehole has provided a rich collection of data over more than sixty years since the completion of the borehole, obtained as a result of extensive research work. This research consisted of direct observations of the cores and the material taken from them. It is worth mentioning the full spectrum of stratigraphic research, from biostratigraphy, chronostratigraphy and lithostratigraphy to sedimentological, facies, micro- and macropalaeontological, microtectonic and palaeomagnetic studies. Data from the Nidzica IG 1 borehole profile were used in cartographic work to prepare various types of geological maps, included in several atlases. The second group of research work consisted of analytical studies, mainly geochemical studies of crystalline rocks and organic matter, and petrographic studies of igneous and clastic rocks. A full set of hydrogeological sampling and borehole geophysical measurements were performed in the borehole in question. The borehole was completed at a depth of 2340.0 m in Paleoproterozoic crystalline rocks.

The igneous rocks identified in the top of the crystalline basement of the Nidzica IG1 profile are represented by high-potassium and shoshonite alkaline-calcium and alkaline, leucocratic quartz monzonites and granites with a monotonous mineral composition. The rocks have weak peraluminous characteristics (ANKC <1.1). They contain small amounts of normalised corundum (<1% CIPW). With a high sodium content in relation to the potassium proportion, a negative correlation between the phosphorus and silica content, and no positive correlation between P_2O_5 to Rb, they do not meet the characteristics of S-type granites and exclude the hypothesis of the sedimentary nature of the protolith. The rocks are depleted in thorium Th. They also have low values of heavy rare earth elements HREE in relation to the composition typical of the upper crust UCC. Sr-Nd isotope data for the entire rock (Nid-2311 and Nid-2321), including epsilon Nd, show slightly negative values in the ε_{Nd} range from –1.18 to –1.16, indicating relatively weak contamination with crustal material. This is also confirmed by the low value of initial strontium ($^{87}Sr/^{86}Sr$)t = 0.70312. The geochemical classification of rocks from Nidzica (Rb *versus* Y + Nb and Nb *versus* Y) indicates the characteristics of volcanic arc granites (VAG) and syncollisional granites. The age of the protolith determined on zircons (sample from a depth of 2317 m) approximately 1767 ±13 million years ago is analogous to that of the protolith of rocks from the crystalline basement of the Baltic and Pomerania regions or southern Sweden, indicating a late Palaeoproterozoic stage of orogenic magmatic activity from 1765 ±6 million years (B8-1/83) to 1760 ±5 million years ago (Hel IG 1) or TIB-1 from 1.81–1.76 billion years ago. Inclusions, metamorphic and magmatic fragments formed in the Mesoproterozoic approx. 1488 ±6.2 million years ago, which is characteristic of the bedrock rocks near the AMCG intrusion belt.

Studies based on detailed mesostructural analysis in the crystalline rock complex have shown that numerous discontinuous structures, represented by shears (mesofaults) and fractures, are observed within the granitoids in the Nidzica IG 1 borehole profile. Probably the oldest are the very steep S_2 shears (angle of inclination approx. 80°) of a normal nature. The S_2 surfaces are sometimes intersected and displaced by younger, gentle S_3 shears. Both the S_2 and S_3 shears are intersected by vertical or subvertical S_4 shears. The mesofaults found in the Nidzica IG 1 borehole are mostly steep and very steep right-lateral or right-lateral-normal faults with a small dip component. The top part of the analysed profile is dominated by gentle fractures parallel to gently inclined fluid structures.

Above the magmatic rock complex at a depth of 2310.5 m, there are chronostratigraphically undivided clastic Ediacaran and Cambrian formations. The lower part of the Ediacaran-Cambrian profile is composed of coarse-clastic, reddish-brown and variegated formations of the Żarnowiec Formation, the bottom part of which was deposited in the Ediacaran under terrestrial conditions, on alluvial cones expanding at the foot of rift fault scarps. No stratigraphic indicators were found in the formations of the Żarnowiec Formation. The Ediacaran-Cambrian boundary was drawn on the basis of lithostratigraphic and facies criteria, at the point where vertical burrows characteristic only of the Cambrian, made by organisms filtering food from the water suspension, appeared in the profile at a depth of 2287.5 m. As the Cambrian transgression progressed, the red-brown and variegated colour of the sediments in the profile disappeared, giving way to grey and greenish-grey colours. A characteristic feature of Cambrian formations is the presence of sandstone-mudstone-claystone heteroliths and numerous taxonomically diverse trace fossils. The Cambrian profile is strongly tectonically reduced and probably represents Terreneuvian and part of the Cambrian division 2. The lack of biostratigraphic indi-

cators makes it impossible to date this part of the Ediacaran--Cambrian succession with certainty.

At a depth of 2154.0 m, with an erosional unconformity on the Cambrian formations, there are Triassic formations reaching a thickness of 441.5 m. They are represented by Bunter Sandstone, Muschelkalk and Keuper formations. The profile of Bunter Sandstone begins with the Baltic Formation, composed of fine-grained sandstones with interbeds of mudstones and claystones. The formation's structure indicates its deposition within the coastal sebha, its sandstone base representing a sandy coastal plain or alluvial plain. The overlying Lidzbark Formation consists of variegated mudstones with interlayers or lenses of sandstones and mudstones. The lowest part of the formation probably represents a barrier island system or coastal zone. The main part of the formation was deposited in a shallow, open lagoon. The Malbork Formation is composed of fine-grained sandstones, mudstones and claystones and was deposited in an alluvial environment. The succession of Bunter Sandstone is closed by the Elbląg Formation, in which sandstones dominate the profile. The rocks of this formation were deposited on a coastal plain with evaporite deposits. The calcareous mudstones with limestone interbeds, which end the profile of the formation, were deposited within a shallow lagoon. The Lower Muschelkalk is lithologically bipartite. The lower part is dominated by interbedded pelitic and marly limestones, as well as marls and marly mudstones. The upper part is composed of alternating biodetritic limestones and marly limestones with a wavy texture. This division corresponds approximately to the division into marly layers (lower part) and wavy and foamy layers (upper part). The Middle Muschelkalk is composed of clayey dolomites. The Upper Muschelkalk is composed of clayey dolomites. The succession reflects the development of an epicontinental marine basin in its peripheral zone, which was the Nidzica region. The sediments of the Lower Muschelkalk represent a transition from coastal to open sea deposition conditions. The Middle Muschelkalk reflects regional regression and the development of deposition in the coastal sebha system and lagoons with increased salinity. Another transgressive pulse occurred at the end of Muschelkalk deposition. The Keuper succession is mainly composed of mudstones and sandstones with numerous dolomitic concretions. The formation of sediments indicates the regression of the epicontinental marine basin. Shelf sediments gradually transition into coastal zone sediments and alluvial plain sediments with pedogenically altered levels. The highest part of the Keuper succession is represented lithostratigraphically by the Reed sandstone formation. Reed sandstone sediments were deposited in the distal zone of a sandy plain of an alluvial or coastal nature. The Keuper profile is closed by Nidzica layers composed of variegated claystones and mudstones. The deposition of these formations took place in the distal alluvial plain. The Bartoszyce layers ending the Triassic profile are composed of fine-grained sandstones and were deposited in a fluvial environment.

Palaeomagnetic studies of the Bunter Sandstone formations revealed a component of natural magnetic remanence of a primary nature, acquired during their sedimentation or early diagenesis. The record of magnetic polarity changes in the Upper Bunter Sandstone is characterised by a number of magnetozones with normal and reverse polarity not less than that recorded in the central part of the Polish basin. This may indicate that the profile of Bunter Sandstone formations from the Nidzica IG 1 borehole does not contain significant stratigraphic gaps, and that the entire succession is rather stratigraphically condensed.

In the Nidzica IG 1 borehole, the Lower Jurassic was found at a depth of 1482.5–1712.5 m; its thickness is 230.0 m. The profile covers formations from the Hetangian to the Toarcian. Four formations have been distinguished here: Zagaje, Olsztyn, Ciechocinek and Borucice. The oldest Lower Jurassic formations have been distinguished as the Zagaje Formation, which in north-eastern Poland represents the Hettangian and Synemurian stages. These are predominantly poorly compacted, mixed-grain sandstones deposited in a river environment. The Olsztyn Formation, occurring at a higher depth, has been distinguished at a depth of 1554.0–1676.3 m and has a thickness of 122.3 m. The formation profile is dominated by sandstone formations. These are of river origin, probably formed mainly within river beds. The Ciechocinek Formation, representing the Lower Toarcian, stands out clearly on geophysical curves due to its different formation from other formations. These are grey-green claystones and mudstones with several dozen centimetres of sandstone inserts. These formations were deposited in a brackish bay environment and, in the lower section, probably also in a delta environment. The Lower Jurassic profile ends with the Borucice Formation, which is classified as Upper Toarcian in age. It covers part of the profile at a depth of 1482.5–1508.8 m and has a thickness of 26.5 m. In the lowest section, these are medium-grained sandstones, transitioning to fine-grained sandstones higher up.

In the Nidzica IG 1 borehole, Middle Jurassic formations were found at a depth of 1390.3–1482.5 m. Their thickness is 92.2 m. There are no formations of the lowest Middle Jurassic – Aalenian and almost the entire Bajocian. The Middle Jurassic profile begins at a depth of 1482.5 m with a sandstone complex. Based on correlations with boreholes located in the northern part of the Płock Basin, it can be assumed that these are formations of the uppermost Bajocian or the lowest Bathonian, forming the so-called terrestrial series. Mudstone and claystone formations typical of the Lower Bathonian were found at a depth of 1451.5–1470.6 m. Their Lower Bathonian age was assumed on the basis of correlations with boreholes in the northern Płock Basin. The overlying sandstone formations occurring at a depth of 1434.5–1451.5 m (thickness 17.5 m) should presumably be classified as part of the Middle Bathonian. The upper section of the Upper Bathonian (above a depth of 1415.0 m) is composed of sandstones, of varying grain size. The Middle Jurassic profile ends with a layer of Callovian formations, with a so-called bun layer. The described formations are typical of the Middle and Upper Callovian of the Masurian-Suwałki area.

The profile of the Upper Jurassic of the Nidzica IG 1 borehole covers an interval of depth 1046.7–1390.3 m, with a thickness of 343.6 m. Above the bun layer of the Upper Callovian, there are sediments that should be classified as the Sponge-limestone Formation, corresponding in facies to the Częstochowa Sponge limestone Formation of southern Poland. The sediments of the Sponge-limestone Formation are developed in the lower part as muddy limestones with glauconite, transitioning into dolomitic and calcareous-dolomitic marls. In the range of 1389.4–1390.1 m, the Lower Oxfordian *cordatum* stage was documented on the basis of ammonite fauna, and higher, at a depth of 1387.7–1388.2 m, ammonites of the Middle Oxfordian *densiplicatum* stage were found. This indicates the presence of very strong condensation or a stratigraphic gap in the lowest Oxfordian (*mariae* level) and a small thickness of the upper Lower Oxfordian (*cordatum* level) formations. Above the marly formations of the lowest part of the Sponge-limestone Formation, there are sponge limestone and marly limestone rocks. These rocks contain ammonites characteristic of the Middle Oxfordian *plicatilis* stage and, higher up, ammonites of the Middle Oxfordian *transversarium* stage. These layers therefore represent the Middle Oxfordian and possibly also part of the Upper Oxfordian. At a depth of 1260 m, an ammonite was found indicating the Lower Kimmeridgian *bimammatum* stage; this would suggest that the Oxfordian/Kimmeridgian boundary can be set at a depth of approximately 1270 m.

The sediments lying at a depth of 1114.9–1194.2 m, with a thickness of 79.3 m, should be attributed to the IV Oolitic Formation. It is composed of oolitic, oolitic-oncolitic and organodetritic limestones. They represent the Lower Kimmeridgian period of maximum sea level lowering and the development of a shallow carbonate platform in the Polish Lowlands, constituting the highest, markedly regressive part of the long COK ("Callovian-Oxfordian-Kimmeridgian") depositional sequence, also known as megasequence I. The next lithological package, from a depth of 1101.8–1114.9 m, with a small thickness of 13.1 m, corresponds to the Limestone-marl-conchiferous Formation. Based on the ammonite fauna found in the profiles of neighbouring boreholes, the rocks of the Limestone-marl-shell Formation V can be dated to the upper part of the Lower Kimmeridgian and the lower part of the Upper Kimmeridgian. The boundary between the Lower and Upper Kimmeridgian can be determined in the discontinuity range occurring at a depth of 1109.0 m. Another lithofacial unit belongs to the shale-marl-mudstone formation (the Pałuki Formation). It is composed of clayey and marly mudstones and clayey shales. In its lowest part, nannocardioceras fauna characteristic of the border between the *eudoxus* and *autissiodorensis* stages of the Upper Kimmeridgian has been documented. Higher up, there are ammonites characteristic of the *autissiodorensis* stage of the Upper Kimmeridgian. The youngest formations of the shale-marl-mudstone (Pałuki) formation contain ammonites typical of successive ammonite levels of the Lower Tithonian, from the *klimovian* level to the lowest part of the *scythian* level. The youngest lithofacies assemblage of the Upper Jurassic, which belongs to the limestone-evaporite formation (the Kcynia Formation), The uppermost part of the discussed facies assemblage, composed of marly shales, marls and marly mudstones, may belong to the uppermost Tithonian or even the lowest Berriasian.

In the Nidzica IG 1 borehole, Cretaceous formations occur at a depth of 442.2–1045.7 m and have a thickness of 604.5 m. The Lower Cretaceous, with a thickness of 69.2 m, was found at a depth of 977.5–1046.7 m. The Włocławek Formation (probably Upper Valanginian–Lower Hauterivian) and the Mogilno Formation (Barremian–Middle Albian) were distinguished here. These are siliciclastic rocks (claystones, mudstones, sandstones with gravel in places), calcareous, deposited in a shallow siliciclastic shelf area. The profile shows a stratigraphic gap covering the Pagórki, Gopło and probably the lowest part of the Kruszwica members. Above the Mogilno Formation lie transgressive sandy formations with Upper Albian phosphorites. Upper Cretaceous formations were found at a depth of 442.2–977.7 m. They have a thickness of 535.5 m. The Cenomanian is a continuation of the sandy sedimentation of the Upper Albian. From the Turonian to the Upper Maastrichtian, carbonate, marl and carbonate-siliceous sediments occur. Upper Cretaceous formations (from the Turonian to the Maastrichtian) were deposited on a shallow carbonate and carbonate-siliceous shelf, and only in the Cenomanian on a shallow siliciclastic shelf. As in many boreholes in the Masurian-Suwałki uplift, the Nidzica IG 1 borehole also shows a sedimentary gap covering most likely the Upper Campanian and possibly part of the Lower Campanian. A certain reduction in sediments cannot be ruled out at the border between the Cenomanian and Turonian.

The oldest Palaeogene sediments occur at a depth of 359.0–442.2 m and are formed as sandy marls with glauconite and quartz-glauconite sands and sandstones. These sediments are classified as Lower Palaeocene – Danian in the Puławy Formation, based on microfaunal dating by Waśkowska (this volume), who identified foraminifera characteristic of the Lower Palaeocene at a depth of 438.0 m. Above the Palaeocene sediments, at a depth of 310.0–359.0 m, there are sediments classified by as belonging to the Upper Eocene in the Pomeranian Formation, which are sandy-silty-clayey formations with glauconite. Between the Palaeocene and Eocene sediments, there is a stratigraphic gap covering the Upper Palaeocene and Lower Eocene. Another gap occurs in the lower and middle part of the Lower Oligocene. The higher Oligocene sediments have been classified as part of the upper Lower Oligocene – the Upper Mosina Formation. These are silty-sandy sediments with clay intercalations. Above this, there is a gap covering the Upper Oligocene, Lower Miocene and part of the Middle Miocene. The Neogene begins with sediments from the upper part of the Middle Miocene – the Adamów Formation, Konin Member, in which at a depth of 206.0–272.20 m there are muddy, clayey and sandy rocks with brown coal inserts and plant remains. At a depth of 111.0–206.0 m, there are clays, silts and muds that have been classified as Upper Miocene, Poznań Formation, Rycice Member. The youngest lithostratigraphic unit of the Neogene in this drilling, at a depth of 66.0–111.0 m, consists of grey-green clayey-silty sediments with yellow spots, classified as part of the upper part of the Poznań Formation, Karczew Member, ending the Upper Miocene sedimentation.

The Nidzica IG 1 borehole is located in an area covered by the Middle Polish glaciation within the post-glacial upland, the North Mazovian Lowland macroregion, in the Nida River basin. The vertical drilling profile documented 66 m of Pleistocene glacial sediments. From bottom to top, these are glacial clays, a layer of sand and gravel, and above that, boulder clay. The oldest Pleistocene sediments in the Nidzica IG 1 borehole are glacial clays deposited directly on Neogene formations. As a result of the retreat of the ice sheet, a series of sandy-gravel deposits were formed, deposited by meltwater. The described deposits constitute the older glacial level of the Middle Polish glaciation. The Odra glaciation period is dated to approximately 244–280 thousand years ago. From the surface to a depth of 37 m, there are glacial clays deposited during the younger Middle Polish glaciation of the Warta River, which lasted approximately 132–180 thousand years ago.

The results of laboratory measurements of bulk density (ρ) indicated that the lowest densities (ρ) are characteristic for the Cretaceous formations (the average value of ρ is only 2.09 g/cm^3). Two boundaries deserve attention here, with a clear contrast in density and probably also in velocity – potential correlation horizons. These are the boundary between Santon sediments (ρ = 2.24–2.43 g/cm^3) and the Coniacian/Turonian rocks, and the contact between the Albian-Barremian (ρ = 2.13 g/cm^3) and the Upper Valanginian and Lower Hauterivian (= 2.30 g/cm^3). The average ρ of Jurassic formations is slightly higher than in Cretaceous formations (2.31 g/cm^3), but it is worth noting the significantly greater variation in the average densities of individual stages, with the extreme values assigned to the Upper Toarcian (2.07 g/cm^3) and the Lower Toarcian (2.43 g/cm^3), also indicating a potentially good geophysical correlation horizon. Within the Triassic formations, there is a relatively low density of the Upper Triassic, which results from the internal density variation of this period, as the average density for the Bartoszyce Beds and Nidzica Beds rocks is relatively higher (2.43 g/cm^3), and what causes the average density of the entire Upper Triassic to decrease are the Schilfsandstein rocks with an average density of only 2.19 g/cm^3.

Geophysical logs carried out in the Nidzica IG 1 borehole using the analogue method made it possible to determine the resistivity, compactness, neutron porosity and spectrometric gamma radiation of the rocks making up the area where the borehole was drilled. Information on the temperature and deviation of the borehole was also obtained. Unfortunately, due to the lack of laboratory measurements, no detailed petrophysical analysis of the porosity, greasiness or permeability of the rocks was carried out.

The analysis of average velocities showed that within the Neogene formations, the results of the calculations indicate the existence of three velocity complexes with average velocities of 1768, 1842 and 1960 m/s. A clear increase in the average complex velocity from 1960 m/s to 2258 m/s is visible at a depth of 360 m within the Palaeogene. Another complex with an average velocity of 2258 m/s was identified within the Cretaceous, at a depth interval of 580 to 820 m, where marls dominate the lithological profile. At a depth of 840 m, the average wave velocity increases significantly from 2437 to 2849 m/s, which is related to the transition of the wave from green marls with lower velocities to white limestones characterised by a significantly higher average velocity. A very high velocity contrast, where the average velocity increases from 2920 m/s to 3762 m/s, was observed at a depth of 1120 m within the Upper Jurassic formations. The determined velocity boundary is related in this case to the boundary between formation V (limestone-marl-shelly) and formation IV (oolitic) and the transition of the wave from formations with relatively high silt content to high-velocity oolitic limestones. From a depth of 1260 m, in the Upper, Middle and Lower Jurassic formations, there is a slow decrease in average complex velocities. In the first complex below this boundary, occurring at a depth 1280–1320 m, the average P-wave velocity is 3556 m/s. In the borehole profile, this complex corresponds to the marly limestones of the Formation III (coral). The next velocity complex is located at a depth of 1340–1420 m, where there are limestones and marls of the Formation I (sponge-limestone). Below, at a depth of 1420 m, there is a significant decrease in the average complex velocity from 3218 to 2781 m/s, which is related to the passage of the P-wave across the boundary between the limestones and marls of the Formation I of the Upper Jurassic and the mudstones and sandstones of the Middle Jurassic. Based on the above analyses, it can be concluded that the calculated average velocity depends on the lithological variability of the drilled layers and reflects the geological structure of the area surrounding the Nidzica IG 1 borehole. In the case of the studied well, due to the limited scope of the measurements performed, the most distinct reflection will be that corresponding to Formation IV (oolitic).

As a result of hydrogeological sampling in the Nidzica IG 1 borehole profile, no hydrocarbons were found. In the Upper Triassic formations, a complete lack of inflow was found, which confirms their regionally poor reservoir properties. The reservoir conditions of the Lower Jurassic formations were determined to be favourable. The remaining Jurassic and Cretaceous levels occur in the water exchange zone. The zone of particularly intense water exchange reaches a depth of approximately 800–1000 m and is characteristic of the extreme western part of the Masurian-Suwałki Upland. Towards the north, where reservoir conditions improve in relation to the depth of occurrence, the thickness of the active exchange zone decreases. The hydrochemical profile shows a clear increase in the overall mineralisation of water with depth from approximately 1 g/dm^3 in the shallower horizons of the Upper Cretaceous to over 50 g/dm^3 in

Lower Jurassic formations. Based on the $r(Na^+/Cl^-)$ index, which is <0.86, the groundwater of the Jurassic complex should be classified as relict/synsedimentary water, typical of the hydrodynamic stagnation zone. With regard to the Lower Jurassic formations, their complete isolation is confirmed by the values of the Cl^-/Br^- ratio (<300) and the sulphate ratio, which is close to one. In the case of the Middle and Lower Jurassic complexes, the Cl index values$^-$ $/Br^-$ (>300) presumably indicate that the waters occurring in them may contain small amounts of paleoinfiltration water admixtures.