Oil- and gas-bearing sediments of the Main Dolomite (Ca2) in the Międzychód region: a depositional model and the problem of the boundary between the second and third depositional sequences in the Polish Zechstein Basin

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A b s t r a c t. The Polish Zechstein Basin was a tideless sea dominated by storms. Main Dolomite deposits of the Międzychód region were deposited: a) on the carbonate platform (in the environments of the outer barrier, inner barrier and high- and low-energy platform flat); b) on the platform slope; c) at the toe-of-slope; d) on the basin floor. The best reservoir properties are recorded in shallow-marine deposits of the outer and inner barriers and in deep-sea sediments of the toe-of-slope (turbidites and debrites). Rich reserves of crude oil and natural gas were discovered both on the carbonate platform (the Międzychód and Grotów deposits) and at its toe-of-slope (the Lubiatów deposit). The Main Dolomite sediments are wholly included in the second depositional sequence (PZS2 sensu Wagner & Peryt, 1997). The maximum flooding surface of the PZS2 sequence within the platform, its slope and toe-of-slope, runs along the A1g/Ca2 boundary. In the basinal zone, its correlative equivalent is a hard ground observed within the Main Dolomite carbonate rhythmites. The boundary between the second and third (PZS2/PZS3) depositional sequences (corresponding to the ZS3/ZS4 sequence boundary in the German Basin) runs on top of the Main Dolomite carbonates (on the platform slope, at the toe-of-slope and on the basin floor) and above top of the Main Dolomite carbonates, within the lower part of the Basal Anhydrite (on the platform).

Key words: *Polish Zechstein Basin, Main Dolomite, depositional model, sequence stratigraphy*

The Międzychód region is situated in the SW part of the Polish Zechstein Basin. According to the palaeogeographic map of the Main Dolomite (Ca2), constructed by Wagner (2004), this region encompasses part of the Wielkopolska carbonate platform, referred to as the Grotów Peninsula, and the surrounding basin floor, including the Noteć Bay (Fig. 1). It was thought for many years that deep-marine deposits of the Main Dolomite are non-prospective in terms of searching for hydrocarbons. The necessity to revise the view arose after the discovery of the Sulęcin oil deposit in the carbonate toe-of-slope sediments. The deposit is located near Gorzów, within the Witnica Bay, i.e. to the SW of the study area. It is worth noting the accurate interpretation made by Dyjaczyński (1978) who assumed that the oil-bearing Main Dolomite sediments of the Sulęcin deposit resulted from subaqueous flows of carbonate clastics. An integrated geological and geophysical analysis, which enabled the yielding of positive drilling results, confirmed that the Main Dolomite rocks of the Międzychód region are prospective for hydrocarbons (Pikulski, 2002; Kwolek & Solarski, 2003; Solarska et al, 2005). Rich reserves of crude oil and natural gas have been discovered both on the carbonate platform (the Międzychód and Grotów deposits) and its toe-of-slope (the Lubiatów deposit). This paper attempts to provide a depositional model of the Main Dolomite sediments from the Międzychód region, based on examination of drill-cores. During the construction of the model there emerged a necessity to revise previous views on the boundary between the second and third depositional sequences in the Polish Zechstein Basin (PZS2/PZS3 sensu Wagner & Peryt, 1997).

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Depositional model

Depositional model of the Main Dolomite sedimentation is described here with the use of the classification of carbonate rocks proposed by Dunham (1962) and modified by Embry and Klovan (1972). Terminology of lamina/bed thickness is adopted from Tucker (2003). The term rhythmites is being used as defined by Reineck and Singh (1980). The terms turbidites and debrites are understood as characterized by Shanmugam (1997).

The terms perilittoral and sublittoral zones call for special explanations. The perilittoral zone includes the supralittoral zone extending above the high-water level and the eulittoral zone occurring between the high-water and low-water levels. The sublittoral zone extends below the low-water level. The shallow sublittoral zone is above the wave base whereas the deep sublittoral zone occurs below the wave base.

The present authors reject the assumption that the Zechstein sediments were deposited in a marine basin dominated by tides. The Zechstein basin, mostly separated from the Late Permian Ocean, was a tideless sea (cf Taylor & Colter, 1975; Paul, 1980). The high and low sea-levels in the Main Dolomite basin were associated with periods of increased and reduced activity of winds ("seasonal levels" sensu Hedgpeth, 1966). They resulted in wind "tides".

The depositional model of the Main Dolomite in the Międzychód region is shown in Fig. 2. It illustrates spatial relationships of depositional environments at the time of the maximum sedimentation rate during the sea-level highstand (cf Figs. 3–5).

Basin floor (Figs. 2, 3A, 3B)

Sediment type. Sublittoral dark grey carbonate muds and carbonate sandy muds; occasional carbonate muddy sands, thin microbial sediments.

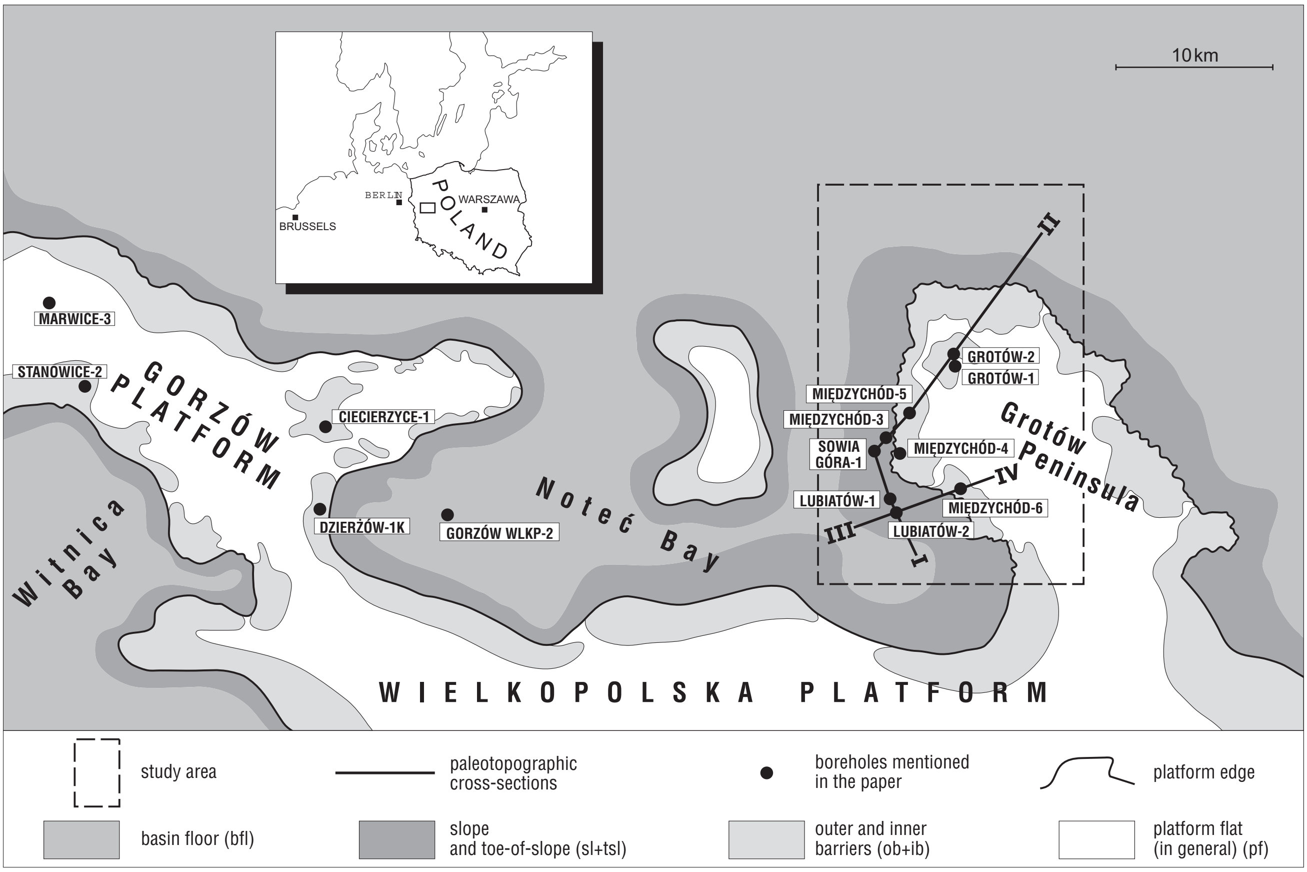


Fig. 1. Location of the study area against a map of the Main Dolomite palaeogeography in the Międzychód region (Wagner, 2004; simplified)

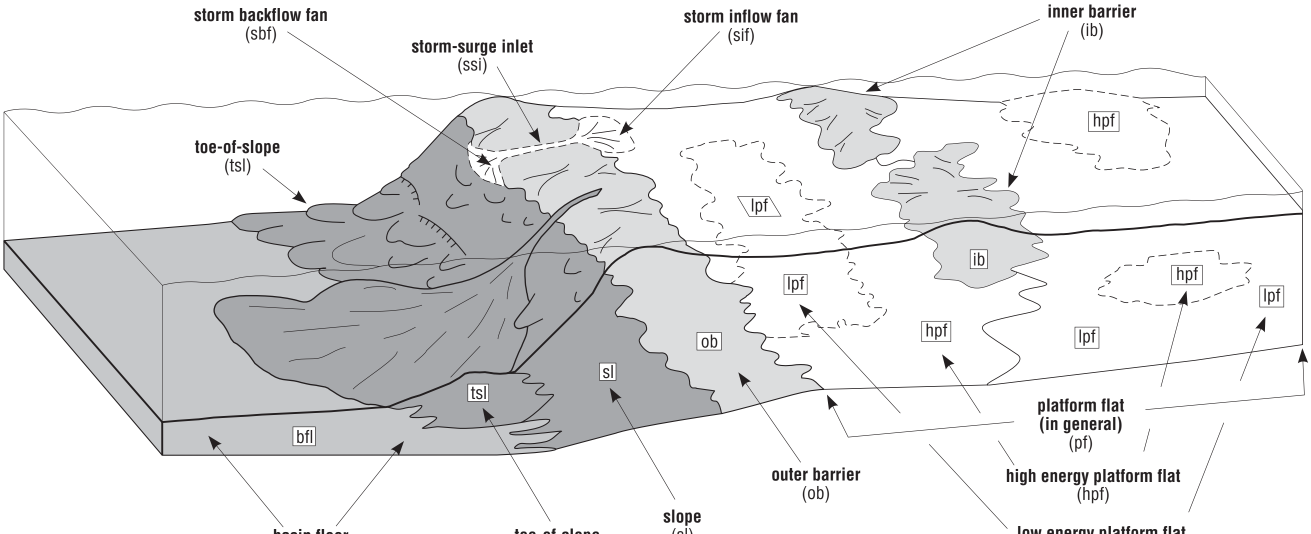


Fig. 2. Depositional model of the Main Dolomite in the Międzychód region. The model shows maximum development of sedimentation during the sea-level highstand

Sedimentary textures. Mudstones and wackestones, rare packstones and boundstones.

Sedimentary structures. Rhythmites show thin to thick horizontal lamination and thin horizontal bedding. The sediment was deposited from suspension, by bottom traction currents and diluted turbidity currents (thin turbidites). Activity of traction currents is evidenced by the presence of flaser, lenticular and cross bedding. Turbidite origin of some laminae and thin beds of muddy sands is supported by the occurrence of normal graded bedding. Irregular, mostly thin, horizontal lamination is common. Such lamination is a record of carbonate mud sedimentation resulting from alternating biogenic processes and deposition from suspension. Biogenic sedimentation is also expressed by the presence of scarce thin microbial mats. This type of sedimentation is accompanied by the presence of very fine fenestral structures developed due to

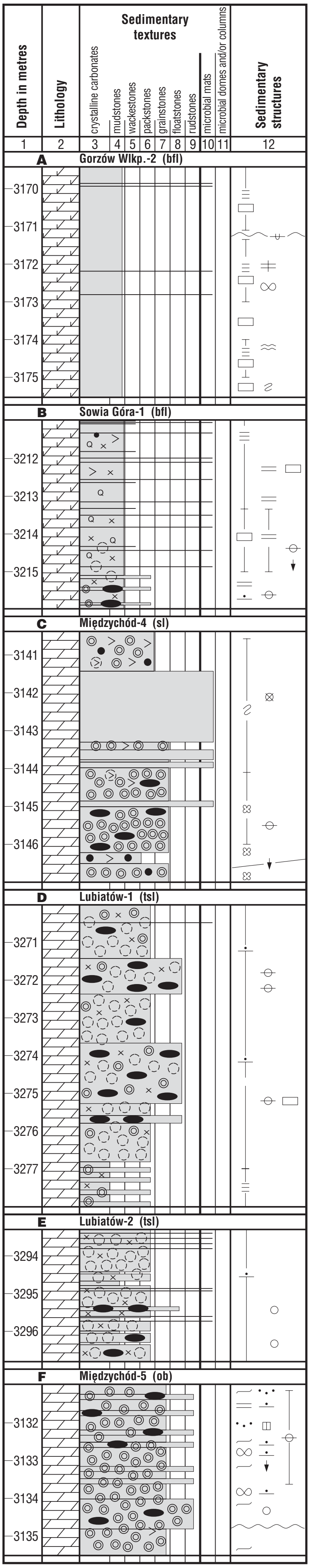
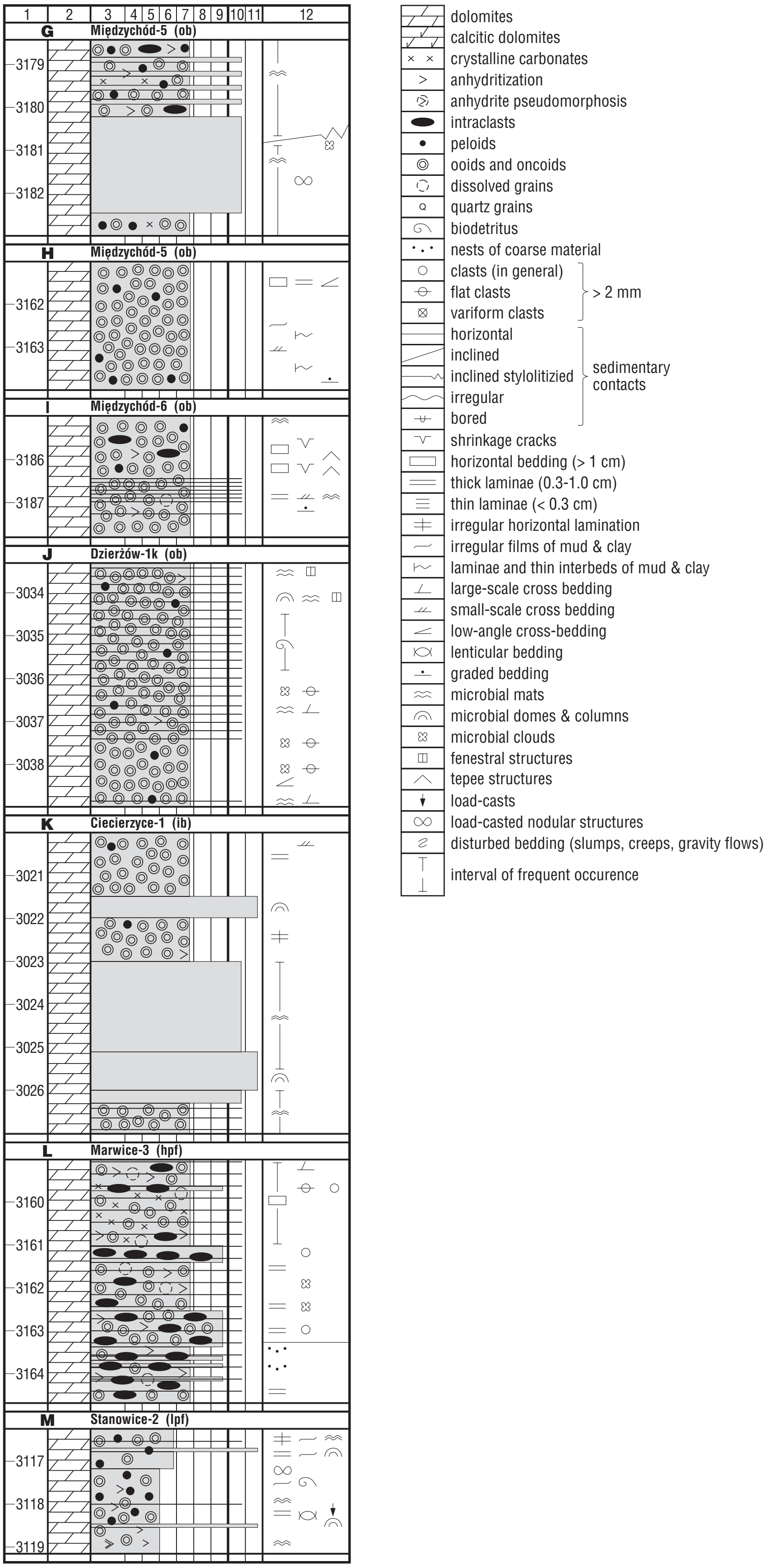


Fig. 3. Sedimentological logs of drill-cores taken from basin floor, platform slope, toe-of-slope, outer barrier, inner barrier, high-energy platform flat and low-energy platform flat deposits. For explanations see Fig. 2



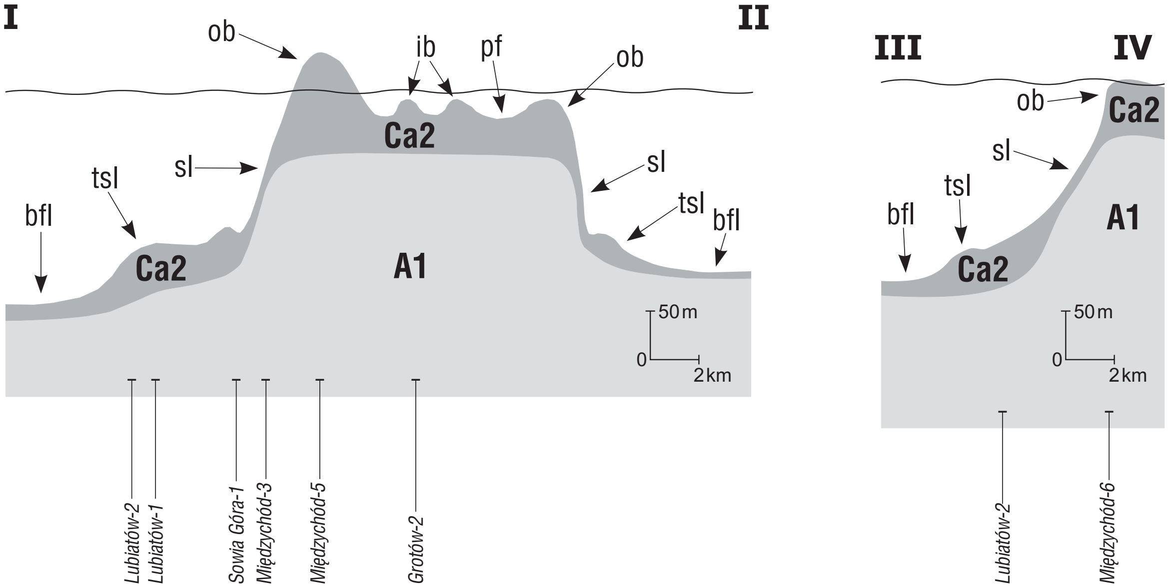


Fig. 4. Palaeotopographic cross-sections: I–II and III–IV (see Fig. 1 for location). Symbols for sedimentary environments as in Fig. 2; Ca2 — Main Dolomite, A1 — Lower and Upper Anhydrite

gas bubbles trapped within microbial matter and/or originating from its decomposition. Rare small-scale disturbed bedding, resulting from sediment creeping, may have been developed on slopes of small channels formed due to erosion of bottom currents. Worth noting is also the occurrence of borings in a thin bed of consolidated carbonate sands (Fig. 3A) representing a hard ground. In terms of sequence stratigraphy it can be considered a record of a maximum flooding surface.

Discussion. The basin floor of the Main Dolomite can be subdivided into deeper and shallower zones. The deeper zone is distinctive due to the almost exclusive occurrence of thinly laminated rhythmites and scarcity of current depositional structures. The presence of microbial intergrowths and thin microbial mats indicates sediment biostabilization. It is difficult to determine the depth of the basin floor depositional environment. Signs of sediment biostabilization suggest the depth of approximately 100 m. If there is microbial material present, accumulated as a result of biogenic sedimentation (phytoplankton “rain”), the depth could be several times greater.

Platform slope (Figs. 2, 3C)

Sediment type. Typical very high variability. Co-occurrence of sublittoral carbonate sands and muddy sands, carbonate sandy muds and muds. Carbonate conglomerates, sedimentary breccia and microbial sediments are also observed.

Sedimentary textures. Grainstones, packstones, wackestones, mudstones, floatstones and rare rudstones and boundstones.

Sedimentary structures. The most characteristic are deformation structures represented by disturbed bedding. Incoherent disturbed bedding is most common. Platform slope deposits commonly contain clasts > 2 mm in size, flat or else in shape. The largest ones, up to a dozen centimetres in size, are represented mostly by fragments of consolidated carbonate sand beds or microbial sediments coming from a barrier — a carbonate grain shoal that developed along the platform edge. Disturbed deposits are slumps moved down the platform slope. Both large- and small-scale slumps are present. The latter are characterized by relatively small thicknesses (up to ~1 m) and the occurrence of smaller clasts visible in the matrix of disturbed structure. Some of the carbonate conglomerates, sedimentary breccias and carbonate sands with scattered clasts larger than 2 mm, characteristic of platform slope deposits, represent debrites (cf Shanmugam, 1997), i.e. sediments deposited as a result of cohesive mass-gravity flows. Therefore, the deposits locally show reverse graded bedding. A more common occurrence of normal graded bedding indicates the presence of turbidites, i.e. turbidity current sediments.

Microbial clouds are frequent in platform slope deposits. They probably developed as a result of binding together very fine grains of carbonate material by microorganisms (bacteria, algae etc) operating within the unconsolidated carbonate sediment at its topmost, transparent part (probable recent equivalents of the process are described in Noffke & Krumbein, 1999). Algal mats and fenestral structures related to microbial sedimentation are rare. The platform slope was a site of biogenic sedimentation which stabilized, i.e. carbonate deposition from suspension. Irregular horizontal lamination is commonly observed. In contrast to that from the basin floor, the lamination is mostly medium and thick.

Discussion. Sedimentological features of slope deposits of the Ca2 platform in the Międzychód region indicate that they are to be classified among accretionary slopes. This opinion finds support in palaeotopographic (palaeorelief) cross-sections across the Ca2 platforms (Fig. 4). The cross-sections show that the slope angle was ranging from 2° to 3°. The values are typical of accretionary slopes (Schlager & Camber, 1986) which, despite of low angles, are the areas of common mass-gravity sediment transport (sediment creeps, slumps and gravity flows, Hunt & Tucker, 1993). The angle of accretionary slopes is also gentle enough for accumulation of sediments. Slope and basin floor sediments occasionally interfinger. An illustrative example is furnished by the Sowia Góra-1 section (see Figs. 2, 3B).

Toe-of-slope (Figs. 2, 3D, 3E)

Sediment type. Mostly the same sediments as those known from both the platform slope and basin floor. Especially characteristic is the presence of carbonate sands with carbonate mud admixture, carbonate muds and interbeds of carbonate conglomerates. Anhydrite conglomerates (50–70 cenimetres-thick interbeds) are observed in the lower portion of the section.

Sedimentary textures. Similar to those observed on the platform slope and basin floor, although packstones and mudstones with floatstone interbeds predominate.

Sedimentary structures. Similar to those known from the platform slope and basin floor. However there are characteristic differences in frequency of occurrence of individual structures. Normal graded bedding in carbonate muddy sands, accompanied with horizontal bedding and horizontal lamination in carbonate rhythmites, is predominant. Fairly frequent are structureless carbonate sands, containing more or less loosely distributed flat clasts of considerable size (several centimetres). The clasts are often oriented horizontally or subhorizontally. Grain-graded carbonate muddy sands represent turbidites, i.e. turbidity current sediments. Thickness of the turbidite beds is variable: it is thought that the average thickness is 0.3–0.5 m in sections containing carbonate sands, whereas in rhythmites the turbidite beds and laminae are very thin. These turbidites are represented by the Tab or Tad successions (sensu Bouma, 1962). It is characteristic that the Tb or Td intervals are locally represented by irregular horizontal lamination of current-microbial origin. The structureless carbonate sands of toe-of-slope environment represent sandy debrites. Among large flat intraclasts there are fragments of typical microbial mats. These deposits formed as a result of mass-gravity redeposition from a barrier — carbonate grain shoal extending along the platform edge. Quite thick complexes of carbonate sands (even up to some dozen or so metres in thickness) are most likely a result of amalgamation of turbidite and/or debrite beds. Rhythmites, commonly occurring at the toe-of-slope, are sediments deposited from suspension carried by diluted turbidity currents, as in the case of basin floor deposits. The presence of flaser, lenticular and cross bedding in the toe-of-slope deposits indicates activity of bottom traction currents. The currents reworked carbonate clastics supplied by turbidity currents.

Well-marked biostabilization of sediments, although infrequent, resulted from periods of breaks in the sedimentation or decreasing sedimentation rate. The periods intervened between the successive sedimentation episodes related to turbidity currents. Microbial intergrowths and thin interbeds are also associated with phytoplankton accumulations developed due to deposition from suspension. Episodes of decreased sedimentation rate of carbonate sand material are also evidenced by microbial clouds, in fact very rare but observed in structureless or grain-graded carbonate sands.

Discussion. Turbidites and debrites, recognized by drillings in the Międzychód region east of the Grotów Peninsula, have a shape of elongate prisms stretching more or less parallel to the platform edge of Ca2. The prisms developed as a result of coalescing neighbouring lobes of redeposited material. This is the case of the Lubiatów deposit discovered near Lubiatów and Sowia Góra. A distinct lobe of toe-of-slope deposits, occurring in the Lubiatów region, interfingers with analogous lobe observed at Sowia Góra. Hence the presence of an extensive body of reservoir rocks and a large hydrocarbon deposit is assumed.

Barriers — carbonate grain shoals
(Figs. 2, 3F, 3G, 3H, 3I, 3J, 3K)

Sediment type. Peri- and sublittoral carbonate sands and microbial sediments are dominant. Carbonate muddy sands occur fairly frequently. Carbonate sandy muds and carbonate conglomerates are rare.

Sedimentary textures. Grainstones and boundstones, subordinate packstones, rare wackestones, floatstones and rudstones.

Sedimentary structures. Symptomatic abundance of current depositional structures accompanied by very frequent clasts > 2 mm in size, most often flat in appearance. Barrier sediments were deposited within a carbonate sand bars system extending perpendicular to variable directions of periodically dominant winds. They are comparable with recent deposits of barred coasts (Davidson-Arnott & Greenwood, 1976) in particular in tideless seas (Rudowski, 1986). The sand bar system includes the sediments of: 1) a high-angle bar slope — small- and large-scale cross bedding; 2) a low-angle bar slope — low-angle cross bedding and small-scale cross bedding; 3) bar crests — horizontal bedding and lamination, large-scale cross bedding; 4) troughs between bars — small-scale cross bedding and flaser bedding; 5) fills of traction current channels and fans developed at the channels' mouths — horizontal bedding and lamination, low-angle cross bedding, small-scale cross bedding and accumulations of clasts > 2 mm in size, locally so abundant that they form matrix-supported or grain-supported conglomerate beds. Some of the latter are flat-pebble conglomerates. Nests of coarse sandy material, admixtures of faunal detritus and carbonate sand beds with normal graded bedding, represent storm deposits. The barrier sediments also show single occurrences of tepee structures and desiccation cracks. The characteristic feature of the sediments is the presence of microbial mats, domes and columns, fenestral structures, irregular horizontal lamination and microbial clouds. Especially distinctive is the greatest amount of thrombolites and microbial domes and columns, as compared to the other sedimentary environments.

Discussion. Barriers — carbonate grain shoals represent the environment of active carbonate sands related to especially high energy of sea waters. As mentioned above, besides pure carbonate sands the barrier sediments contain carbonate muddy sands. Carbonate mud, found in carbonate sands, might form as a result of grinding of coarser components of the sediment in mobile waters of a high-energy sedimentary environment (cf Purdy, 1963). Barriers — carbonate grain shoals abound in fills of storm

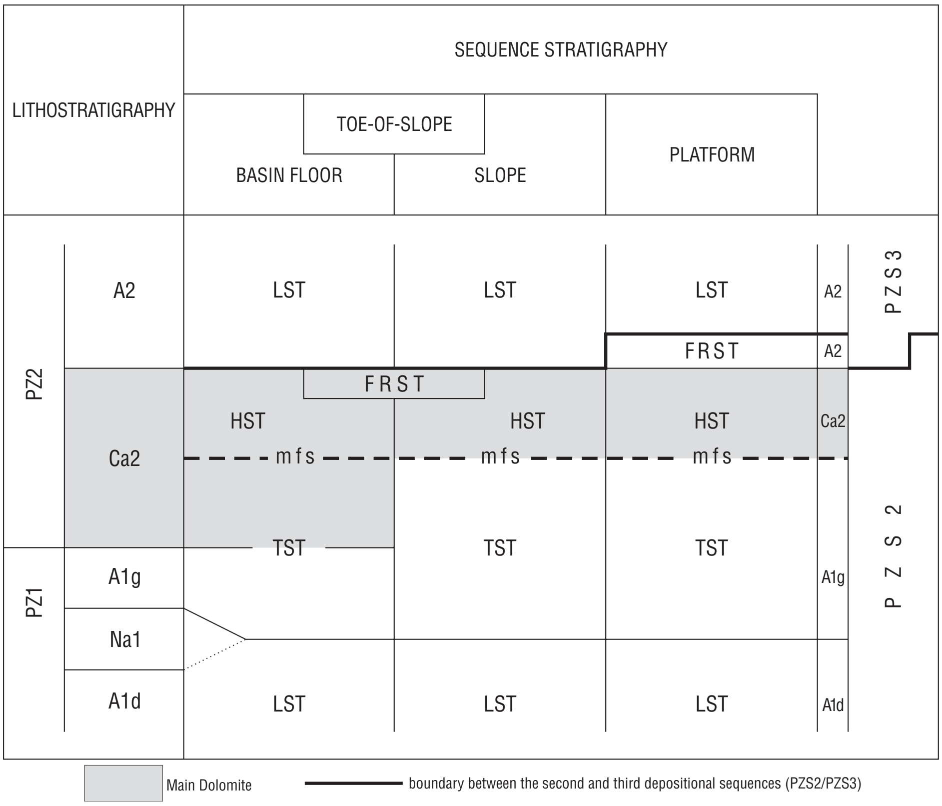


Fig. 5. Stratigraphic position of the Main Dolomite in terms of Zechstein lithostratigraphy and sequence stratigraphy, Międzychód region, SW part of the Polish Zechstein Basin; PZ1, PZ2 — first and second Zechstein cyclothems, PZS2, PZS3 — second and third depositional sequences (sensu Wagner & Peryt, 1997), A1d — Lower Anhydrite, A1g — Upper Anhydrite, Na1 — Oldest Halite, Ca2 — Main Dolomite, A2 — Basal Anhydrite, mfs — maximum flooding surface, LST — lowstand system tract, TST — transgressive system tract, HST — highstand system tract, FRST — forced regressive system tract

channels. Some of the channels cut across the whole barrier to form storm-surge inlets (Fig. 2). Subaqueous fans which developed at the mouths of the storm-surge inlets, on both sides of the barrier, were formed due to both storm-surge inflow (inner barrier slope) and storm-surge backflow (outer barrier slope). The intense development of microbial structures on the barriers resulted from a binding of storm-derived fine-grained carbonate material by living microbial films.

Barriers — carbonate grain shoals composed of active carbonate sands occur not only along the platform edge as outer barriers (Figs. 3F, 3G, 3H, 3I, 3J) but also in the platform flat, forming inner barriers there (Fig. 3K). They divide the platform flat into depositional areas of low- and high-energy environments. A "crazy" pattern of low- and high-energy environments (Fig. 2) on platforms was associated with synsedimentary tectonic movements that mostly resulted from a complexity of flow of evaporites. These processes caused variations in the relative depth of the sedimentary basin. It is very difficult to make a distinction between the outer and inner barrier sediments in a single drilling log. Proper interpretation can be done when the regional palaeogeographic setting is considered.

High-energy platform flat (Figs. 2, 3L)

Sediment type. Mainly sublittoral carbonate muddy sands; also carbonate sands and carbonate sandy muds. Microbial sediments are frequent.

Sedimentary textures. Packstones. Grainstones and wackestones are rarer; frequent boundstones.

Sedimentary structures. Common occurrence of horizontal bedding and thick horizontal lamination, accompanied by low-angle cross bedding and rare large-scale cross bedding, flaser bedding and lenticular bedding. Frequent nests of coarse sandy material, admixture of faunal detritus and clasts > 2 mm in size, in particular flat in appearance, usually scattered in carbonate sands. Channel and fan sediments of traction currents operating on the platform flat during strong storms are commonly observed. Infrequent interbeds with normal graded bedding are also related to storm events. The characteristic feature is the presence of disturbed bedding indicating the occurrence of small-scale slumps and sediment creeps. These structures probably developed on slopes of shallow channels cut by bottom currents.

Microbial mats are commonly observed. Fairly frequent are fenestral structures developed due to biosedimentary processes. Microbial domes, columns and clouds are scarce.

Discussion. The sediments of the high-energy platform flat are very similar to those representing outer and inner barriers, differing from them in remarkably smaller proportion of sediments of the perilittoral environment (if present at all) and of microbial domes and columns. They also show greater proportion of carbonate muddy sands and abundance of horizontal bedding and thick horizontal lamination.

Low-energy platform flat (Figs. 2, 3M)

Sediment type. Mainly dark grey sublittoral carbonate sandy muds and carbonate muds; carbonate muddy sands and microbial sediments are frequent.

Sedimentary textures. Wackestones and mudstones are predominant. Packstones and boundstones are also observed.

Sedimentary structures. Rhythmites: thin and thick lamination, rare thin horizontal bedding. These are deposits from suspension and bottom traction currents, with quite frequent occurrence of flaser and lenticular bedding.

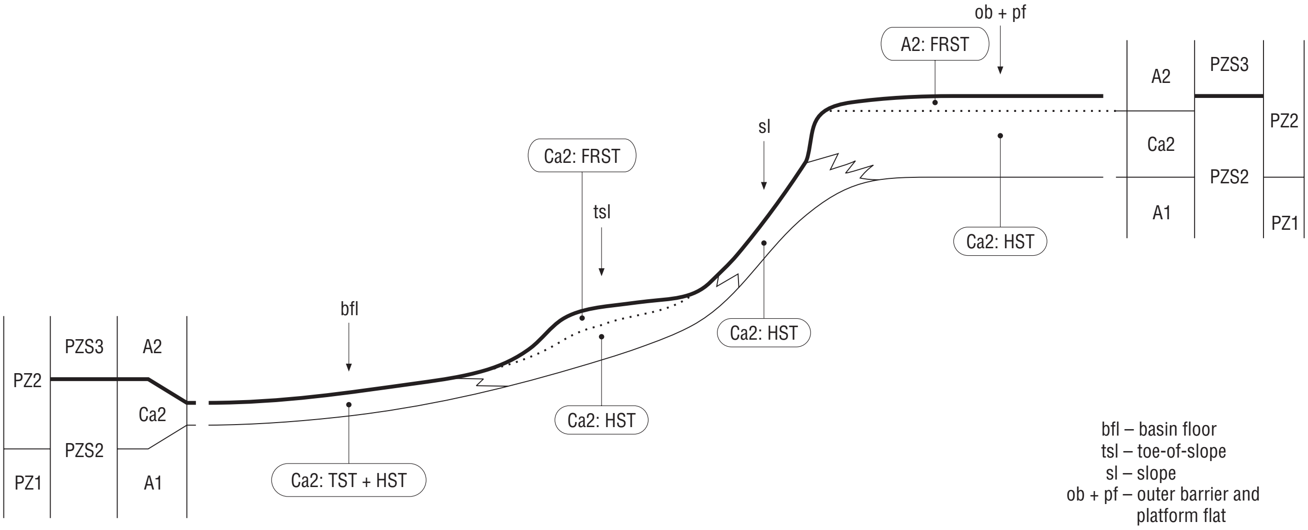


Fig. 6. Sequence stratigraphic model for the Main Dolomite in the Międzychód region. A1 — Lower and Upper Anhydrite. Remaining symbols as in Fig. 5

Low-angle cross bedding is rare. Equally rare is normal graded bedding indicating that some of the laminae and thin carbonate muddy sand beds originate from storms. Storm-induced traction currents resulted in the formation of nests of coarse sandy material, accumulations of faunal detritus and admixtures of grains slightly > 2 mm in size. Microbial mats are common here while low, incipient microbial domes and columns are observed sporadically. Fenestral structures are frequent.

Discussion. Rhythmites of the low-energy platform flat are very similar to the basin floor sediments. They differ from them in the occurrence of nests of carbonate sandy material and accumulations of faunal detritus, as well as remarkably greater amount of microbial mats and structures related to bottom traction currents.

The boundary between the second and third depositional sequences in the Polish Zechstein Basin

Oil and gas-bearing rocks of the Lubiatów deposit, i.e. toe-of-slope sediments occurring west of the Grotów Peninsula, have lately been a subject of debates on the position of the Main Dolomite within the sequence stratigraphic scheme of the Zechstein. According to the sequence stratigraphic scheme proposed for the Polish Basin by Wagner and Peryt (1997), the Main Dolomite (Ca2) and the underlying upper part of the Upper Anhydrite (A1g) occur above the maximum flooding surface of the second depositional sequence (PZS2). The present authors are of the opinion that in the Międzychód region the maximum flooding surface of the second depositional sequence (PZS2), within the platform, its slope and toe-of-slope, runs along the A1g/Ca2 boundary (Fig. 5). In the basinal zone, its correlative equivalent is a hard ground observed within the Main Dolomite carbonate rhythmites (Figs. 3, 5).

According to Wagner and Peryt (1997), the Main Dolomite and the underlying upper part of the Upper Anhydrite represent the highstand systems tract (HST) of the second depositional sequence in the Polish Zechstein Basin. However, according to the cited authors, it does not refer to the whole Main Dolomite succession because its upper part *in the zone of the carbonate platform slope can be treated as the beginning of LST* [lowstand system tract] *deposition of the next, third Zechstein sequence* (Wagner & Peryt, 1997, p. 463). This last statement refers to the views of Strohmenger et al (1996a, b) on the Main Dolomite of the southern German Basin. In the platform area of the southern German Basin the upper boundary of the sequence containing the Main Dolomite is placed within the Basal Anhydrite above its lower part is showing ghost sedimentary structures characteristic of the Main Dolomite carbonates. The lower part of the Basal Anhydrite is interpreted as a result of anhydritization of carbonates of the Main Dolomite platform due to emersion and development of sabkha (Strohmenger et al, 1996a, b). The same phenomena are observed in the Międzychód region. The present authors are of the opinion that the lower part of the Basal Anhydrite represents the forced regression system tract (FRST) (sensu Helland-Hansen & Gjelberg, 1994) related to a relative sea-level drop at the final stage of the sequence formation (PZS2).

Zdanowski (2003, 2004) postulated that the upper portion of toe-of-slope deposits of the Międzychód region represents lowstand system fan (LSF) and lowstand system wedge (LSW), the latter being developed on a small carbonate platform. Such interpretation implies that, at the toe-of-slope, the PZS2/PZS3 boundary runs within the Main Dolomite deposits. According to the present authors the interpretation is incorrect. There is no evidence of emersion of the Main Dolomite platform, which must have taken place in order that LSF + LSW deposits could be formed. Carbonate toe-of-slope sediments of the Międzychód region are composed almost exclusively of material redeposited by turbidity currents and debrite flows. Thin interbeds of matrix-supported anhydrite conglomerates, found underlying the redeposited toe-of-slope sediments, belong to the PZS2 representing TST deposits. A similar situation is observed in northeast Germany (cf Kaiser et al, 2003). Especially important is the fact that the redeposited material in the Międzychód region contains fragments of microbial mats and carbonate grains produced in a shallow-marine environment of the submerged Main Dolomite platform (ooids, peloids). A significant proportion of carbonate sandy material in deposits around the Grotów Peninsula indicates high carbonate productivity of the platform environment, resulting in progradation of outer barrier and platform slope deposits, so characteristic for the HST and FRST.

The case of the Międzychód region, west of the Grotów Peninsula, provides no evidence to include the upper part of the carbonate deposits, occurring at the toe-of-slope of the Main Dolomite platform, in the PZS3 as its LST (= LSF + LSW). In fact, these are HST and FRST deposits of the preceding sequence, i.e. PZS2 (Figs. 5, 6). It means that, west of the Grotów Peninsula (Lubiatów deposit), the PZS2/PZS3 boundary runs on top of the Main Dolomite carbonates (i.e. on top of the carbonate turbidite/debrite sand and mud prism), being coincident with the lithostratigraphic boundary between the Main Dolomite and Basal Anhydrite (Ca2/A2). The same refers to the basin floor and platform slope (Fig. 6). In the carbonate platform area the PZS2/PZS3 sequence boundary lies above top of the Main Dolomite carbonates: within the lower part of the Basal Anhydrite (Figs. 5, 6). It should be added that the boundary between the second and third depositional sequences (PZS2/PZS3) in the Polish Zechstein Basin corresponds to the sequence boundary ZS3/ZS4 in the German Basin.

Conclusions

1. Main Dolomite sediments (Ca2, PZ2 cyclothem) of the Międzychód region were deposited: a) on the carbonate platform (in the environments of inner and outer barriers, and high- and low-energy platform flat); b) on the platform slope; c) at the toe-of-slope of platform; d) on the basin floor.

2. The best reservoir properties occur in the shallow-marine deposits of inner and outer barriers, and in the deep-marine toe-of-slope deposits (turbidites and debrites).

3. The Main Dolomite deposits wholly belong to the PZS2 sequence (sensu Wagner & Peryt, 1997) and are developed as follows: a) on the platform: HST progradational carbonates; b) on the platform slope: HST progradational carbonates; c) at the toe-of-slope of platform: a prism of redeposited carbonate material whose deposition was initiated in the HST and subsequently developed during the FRST; d) on the basin floor: TST and HST carbonate rhythmites.

4. The maximum flooding surface of the PZS2 sequence within the platform, its slope and toe-of-slope, runs along the A1g/Ca2 boundary. In the basinal zone, its correlative equivalent is a hard ground observed within the Main Dolomite carbonate rhythmites.

5. In the platform, the sediments of the lower part of the Basal Anhydrite (A2, PZ2 cyclothem) grade into the underlying Main Dolomite carbonates and make a platform segment of the FRST within the PZS2 sequence.

6. The PZS2/PZS3 sequence boundary runs on top of the Main Dolomite carbonates (on the platform slope, at the toe-of-slope and on the basin floor) and above top of the Main Dolomite carbonates, within the lower part of the Basal Anhydrite (on the platform).

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References

BOUMA A.H. 1962 — Sedimentology of some flysch deposits. A graphic approach to facies interpretation. Elsevier, Amsterdam-New York.
DAVIDSON-ARNOTT R.G.D & GREENWOOD B. 1976 — Facies relationship on a barred coast, Kouchibougac Bay, New Brunswick, Canada. Soc. Econ. Paleon. Miner., Spec. Publ., 24: 126–148.
DUNHAM R.J. 1962 — Classification of carbonate rocks according to depositional texture. [In:] Ham W.E. (ed) Classification of carbonate rocks. Amer. Assoc. Petrol. Geol., Mem. 1: 108–121.
DYJACZYŃSKI K. 1978 — Budowa geologiczna. [In:] Piela J. (ed) Aneks nr 2 do projektu badań geologicznych za ropą naftową i gazem ziemnym w rejonie Sulęcina. Arch. PGNiG, Zielona Góra.
EMBRY A.F. & KLOVAN J.E. 1972 — Absolute water depth limits of Late Devonian paleoecological zones. Geol. Rundsch., 61, 2.
HEDGPETH J.W. 1966 — Classification of marine environments. [In:] Hedgpeth J.W. (ed) Treatise on marine ecology and paleoecology. Geol. Soc. Amer., Mem., 67: 17–27.
HELLAND-HANSEN W. & GJELBERG J.G. 1994 — Conceptual basis and variability in sequence stratigraphy: a different perspective. Sediment. Geol., 92: 31–52.
HUNT D. & TUCKER M.E. 1993 — Sequence stratigraphy of carbonate shelves with an example from the mid-Cretaceous (Urgonian) of southeast France. Spec. Publ. Int. Ass. Sediment., 18: 307–341.
KAISER R., NÖTH S. & RICKEN W. 2003 — Sequence stratigraphy with emphasis on platform-related parasequences of the Zechstein 2 carbonate (Ca2) – the northern platform margin of the Southern Permian Basin (NE Germany). Geol. Rundsch., 92: 54–57.
KWOLEK K. & SOLARSKI T. 2003 — Projekt prac poszukiwawczych w rejonie Lubiatów — Sowia Góra. Arch. PGNiG, Warszawa.
NOFFKE N. & KRUMBEIN W.E. 1999 — A quantitative approach to sedimentary surface structures contoured by the interplay of microbial colonization and physical dynamics. Sedimentology, 46, 3: 417–426.
PAUL J. 1980 — Upper Permian algal stromatolite reefs, Harz Mountains (F.R. Germany). Contr. Sed., 9: 253–268.
PIKULSKI L. 2002 — Projekt prac poszukiwawczych w rejonie Grotów — Lubiatów. Arch. PGNiG, Warszawa.
PURDY E.G. 1963 — Recent calcium carbonate facies of the Great Bahama Bank. 2. Sedimentary facies. J. Geol., 37, 3-4: 472–497.
REINECK H.E. & SINGH I.B. 1980 — Depositional sedimentary environments. Springer-Verlag.
RUDOWSKI S. 1986 — Sedimentary environment at the barred coast of a tideless sea; Southern Baltic, Poland (in Polish with English Sumary). Stud. Geol. Pol., 87: 5–76.
SCHLAGER W. & CAMBER O. 1986 — Submarine slope angles, drowning unconformities and self-erosion of limestone escarpments. Geology, 14: 762–765.
SHANMUGAM G. 1997 — The Bouma sequence and the turbidite mind set. Earth Sc. Rev., 42, 4: 201–229.
SOLARSKA A., SOLARSKI T. & MIKOŁAJEWSKI Z. 2005 — History of exploration of lithologic traps in Main Dolomite in western Poland. [In:] 67th EAGE Conference & Exhibition. Madrid. Abstracts. http://www.earthdoc.org/detail.php?paperid=P232&edition=1
STROHMENGER C., ANTONNINI M., JAGER G., ROCKENBAUCH K. & STRAUSS C. 1996a — Zechstein 2 Carbonate reservoir facies distribution in relation to Zechstein sequence stratigraphy (Upper Permian, northwest Germany): an integrated approach. Bulletin Centres Recherche Exploration-Production Elf-Aquitaine, 20: 1–35.
STROHMENGER C., VOIGT E. & ZIMDARS J. 1996b — Sequence stratigraphy and cyclic development of Basal Zechstein carbonate-evaporite deposits with emphasis on Zechstein 2 off-platform carbonates (Upper Permian, Northeast Germany). Sediment. Geol., 102: 33–54.
TAYLOR J.C.M. & COLTER V.S. 1975 — Zechstein of the English sector of the Southern North Sea Basin. [In:] Woodland A.V. (ed) Petroleum and the continental shelf of North West Europe. Applied Sci. Publ., 1: 249–263.
TUCKER M.E. 2003 — Sedimentary rocks in the field. Wiley.
WAGNER R. 2004 — Paleogeografia dolomitu głównego — Platforma Gorzowa i N część Platformy Wielkopolskiej, 1 : 200 000. [In:] Wagner R. & Kotarba M. (ed) Algowe skały macierzyste dolomitu głównego i ich potencjał węglowodorowy jako podstawa dla genetycznej oceny zasobów ropy naftowej i gazu ziemnego w rejonie Gorzowa — Międzychodu. Cz. I Charakterystyka geologiczna. Arch. PGNiG, Warszawa.
WAGNER R. & PERYT T.M. 1997 — Possibility of sequence stratigraphic subdivision of the Zechstein in the Polish Basin. Geol. Quart., 42, 4: 457–474.
ZDANOWSKI P. 2003 — Lowstand Systems Tracts Deposition of the Main Dolomite in the Gorzów Region (Polish Zechstein Basin). [In:] 22nd IAS Meeting of Sedimentology — Opatija 2003. Abstracts Book. Institute of Geology, Zagreb: 225.
ZDANOWSKI P. 2004 — Systemy depozycyjne niskiego stanu względnego poziomu morza dolomitu głównego w rejonie Gorzowa Wielkopolskiego jako potencjalne pułapki facjalne dla ropy naftowej. Pol. J. Miner. Resour., 8: 177–181.