New stratigraphic scheme for Zechstein rocks in the Pogorzela High (Foresudetic Monocline) and its significance for hydrocarbon exploration

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A b s t r a c t . Results of an analysis of new 3D seismic data, obtained from the part of the Wolsztyn High in the Pogorzela High area (SW Poland), allow to test the existing knowledge regarding the geologic framework of the Zechstein rocks in this area. A characteristic arrangement of seismic reflectors within pinched-out Zechstein deposits on slopes of the high shows that they are overlapped in relation to the distinct surface of angular unconformity related to the base of the Zechstein — the Z1' seismic boundary. 3D seismic data seems to show that PZ1 strata are absent in the close vicinity of the Pogorzela High with the lower part of the PZ2 cyclothem also absent across the crest. This suggests that the interpretation of the stratigraphy of Zechstein deposits in the Pogorzela–1 and Pogorzela–2 wells (located on the crest of the high) is, in the light of 3D seismic data, questionable. Probably, the initial stages of the Zechstein transgression did not reach the most elevated part of the high, so that the Carboniferous basement is directly overlain by rocks of the Main Dolomite (Ca2), not by the Zechstein Limestone (Ca1) as was previously thought. The lack of Ca1 strata across the crest of the Pogorzela High opens new exploration perspectives in this interval and explains the apparent negative results of boreholes drilled in 1970s. Presumably it also explains differences in formation of these rocks in comparison with the central and western part of the Wolsztyn High (the Kościan–Nowy Tomyśl area).

Keywords: *Foresudetic Monocline, Wolsztyn High, Pogorzela High, Zechstein Limestone (Ca1), 3D seismics*

The Pogorzela High makes up the south–eastern part of the Wolsztyn High, a Variscan paleohigh in the Permo–Mesozoic basement of the northern part of the Foresudetic Monocline across which Upper Rotliegendes rocks are absent trough erosion (Fig.1). Possibilities of hydrocarbon discovery are connected here with two carbonate members within the Zechstein: the Zechstein Limestone (Ca1) and the Main Dolomite (Ca2). The Zechstein Limestone perspectivity is confirmed by large thicknesses of this interval identified in several boreholes (maximum up to 66 m, well Bułaków–1) drilled in the 1970s, and also by interesting results of the Ca1 sampling carried out by drill stem testers: significant brine inflow with combustible gas shows of flow rates from about 1.8 m^3/h (Pogorzela–4) up to about 7.4 m^3/h (Bułaków–1). Perspectivity of the Main Dolomite deposits is evidenced by the Siedmiorogów–1 well (1992) which, in the central and top part of Ca2, found intercalations of porous oolitic dolomites related to a barrier depositional environment. Testing of this interval with a drill stem tester resulted in an inflow of gas-cut brine with combustible gas (lack of H_2S) at a flow rate of about 9 m^3/h (Kwolek, 2000; Kwolek & Piotrowska, 2002; Kwolek & Mikołajewski, 2006).

The Pogorzela High is located in SW part of the Polish Zechstein Basin (Fig. 2). The Pogorzela–1 and Pogorzela–2 wells found a thinning of Zechstein deposits which was unparalleled in this part of the basin: reduced to 134 m and 85.5 m in Pogorzela–1 and Pogorzela–2, respectively.

In these boreholes only one carbonate interval was encountered within the Zechstein (P–1 — 19 m; P–2 — 20.5 m) deposited directly on Carboniferous rocks. This carbonate interval was included into the Zechstein Limestone (Protas, 1975; Peryt, 1978a, b; Peryt & Protas, 1978). Hence, it was considered that there was an enclave on the Pogorzela High within which Main Dolomite rocks were absent, the interpretation being originally based only on interpolated and extrapolated borehole data (Głowacki [In:] Antonowicz & Iwanowska, 1992). Attempts to specify the extent of the enclave were made on the basis of the results of 2D seismic data acquired in 1998–1999 (Drabowicz, 2000; Zubrzycka, 2000; Kwolek [In:] Kwolek, 2000). Seismic studies from that time helped to model precisely the geologic framework of Zechstein deposits pinching out on the margins of the Pogorzela High. It was suggested that, under a favorable spatial configuration of the Ca2 surface, there was a possibility of stratigraphic or structural-stratigraphic traps within the Main Dolomite deposits (Kwolek, 2000). After the analysis of all available geophysical-geological data, an exploration play concept was worked out for the Ca2 and Ca1 deposits (Kwolek, 2000). However, it was accepted that due to insufficient good-quality seismic data, hence, serious interpretation ambiguity, that verification of the play concepts by drilling would be very risky. Therefore, 3D seismic imaging was proposed (Kwolek & Piotrowska, 2002), and implemented in 2004 (Filo, 2005). Analysis of the 3D seismic data, together with reinterpretation of the well data, suggests a changed view of the geologic framework of the Zechstein deposits within the Pogorzela High. Authors of the present paper intend to show the possible importance of this change for further exploration for natural gas in the Zechstein Limestone deposits.

Stratigraphical and lithofacial characteristics of Zechstein deposits in the Pogorzela High area

Zechstein strata in the Pogorzela High lie on folded and erosionally truncated Carboniferous rocks or Upper Rotliegendes coarse-grained clastic deposits which pinch out on the eastern margin of the High and are underlain by Lower Rotliegendes volcaniclastics. Thicknesses of Zechstein deposits range from ca 100 to 400 m (Fig. 3). Their sedimentation proceeded in relatively calm tectonic conditions (Wagner, 1994; Kwolek & Protas, 2001). The observed

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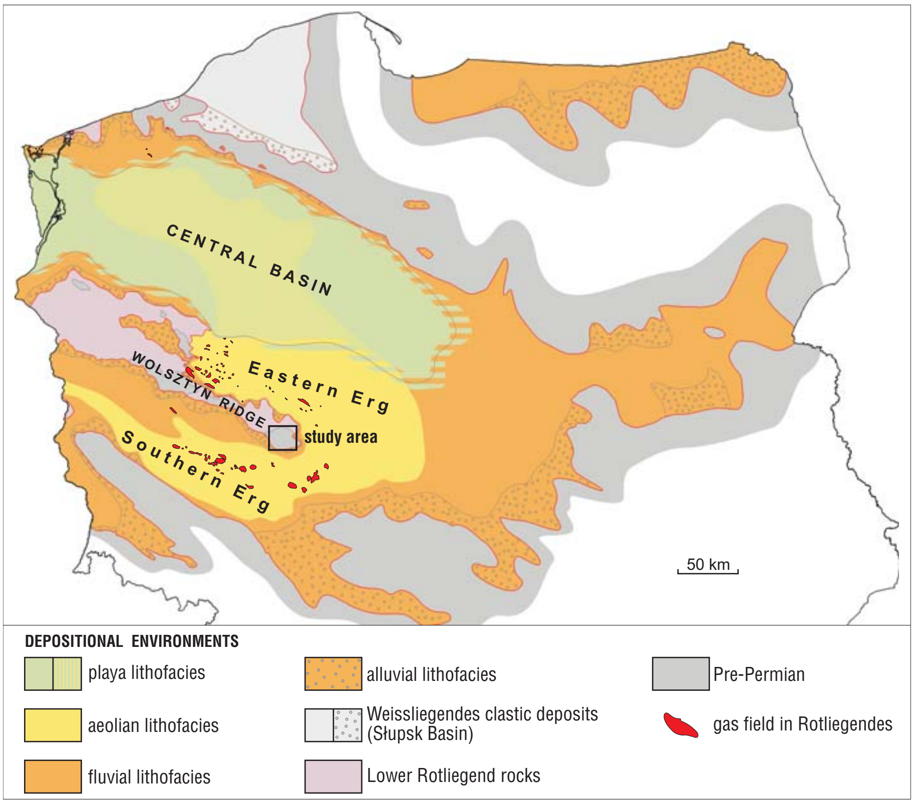


Fig. 1. Paleogeography of the late Upper Rotliegendes of Poland (A. Buniak — unpublished; after H. Kiersnowski, PIG and PGNiG SA)

thickness variation within these rocks is a consequence of relatively weak subsidence relative to adjacent areas and to differences in paleorelief of the post-Zechstein surface, together with a substantial uplift of the area causing a different geometry of transgressive-regressive carbonate-evaporite cyclothems (Wagner, 1994).

In the central, most elevated part of the high, where the top of the Carboniferous is at depth of only 1750 m, the Zechstein is significantly thinner than in the adjacent areas. In the Pogorzela–1 and Pogorzela–2 wells the Zechstein is only 134 m and 85.5 m thick, whereas on the slopes of the high, the thickness varies from 268 m in the well Siedmiorogów–1 (in the northern part) to 379 m in the Pogorzela–6 (in the southern part). The Zechstein sections encountered in all boreholes drilled along the crest of the high (Siedmiorogów–1, Pogorzela–1, –2, –4) do not contain PZ1 and PZ2 cyclothem salt members, with the PZ3 cyclothem salt member also absent in the Pogorzela–1 and Pogorzela–2 wells. Notably, only a single carbonate interval some 20 m thick lying directly on Carboniferous rocks, was encountered in both latter wells,. Up to now this carbonate interval has been referred to the Zechstein, both in the literature (Peryt, 1978a; Peryt & Protas, 1978; Kwolek & Protas, 2001), and in different studies by the Polish oil industry (e.g., Protas, 1975; Antonowicz & Iwanowska, 1992; Kwolek, 2000). Hence this is also the interpretation held

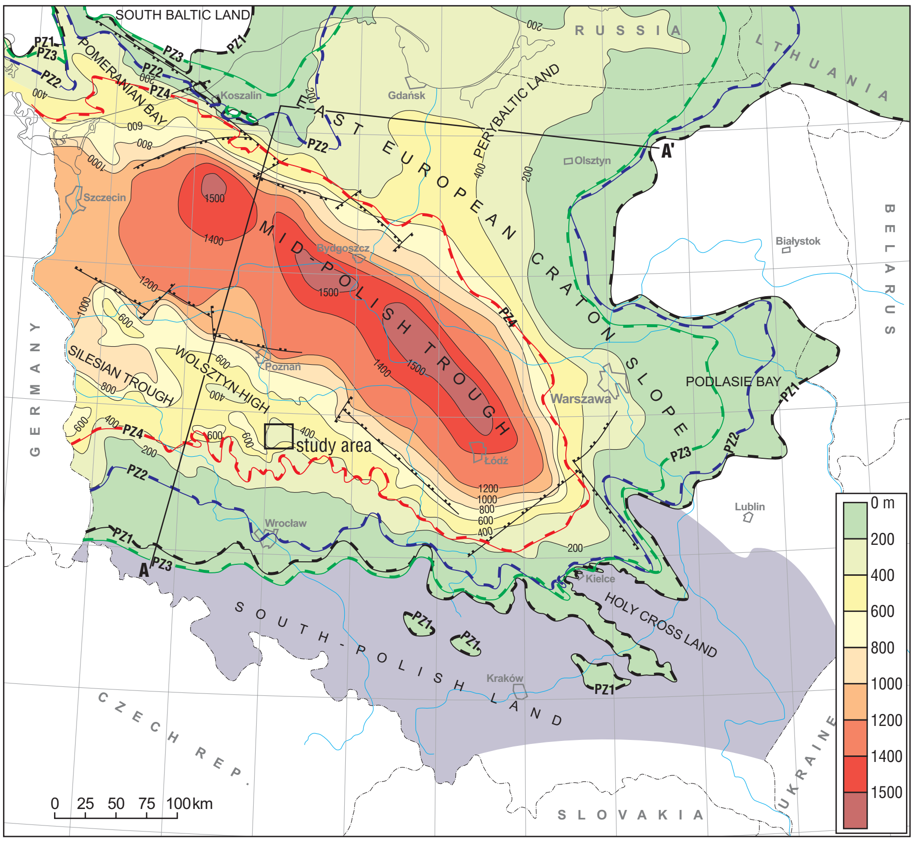


Fig. 2. Paleothickness of Zechstein deposits in Poland (Wagner, 1994). Broken lines, marked as PZ1, PZ2, PZ3 and PZ4, indicate primary extent of lithostratigraphic units (cyclothems)

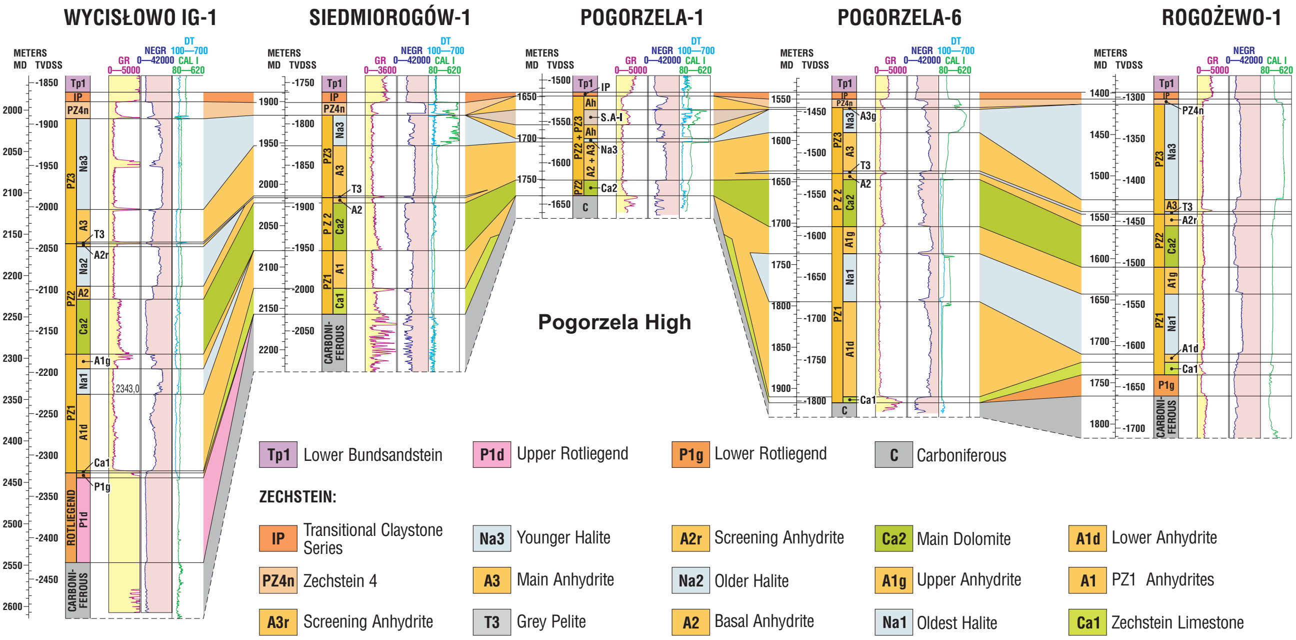


Fig. 3. Correlation of Permian rocks in the area of the Pogorzela High (reference level — top Zechstein) (Kwolek & Protas, 2001 — modified). Additional explanations in the profile of the Pogorzela–1 well: Ah — anhydrite; S.A–I — anhydritic-clayey unit

in the PITAKA borehole database.

Zechstein deposits are built of four evaporitic cyclothems: PZ1, PZ2, PZ3, and PZ4. The PZ1, PZ2 and PZ3 cyclothems comprise relatively simple carbonate-evaporite sequences, formed during transgressive-regressive cycles of the Zechstein Sea. The PZ4 cyclothem is more complex and is divided into subcyclothems named PZ4a to PZ4e, it contains terrigenous-evaporitic sequences formed as a result of cyclic climate changes, from dry to more humid. The overall trend of the Zechstein cyclothems has a regressive character: the PZ1 deposits have the largest lateral, while younger cyclothems are progressively more restricted in extent (Wagner, 1994).

The basal unit of the **PZ1 cyclothem** in the Pogorzela High area comprises the Zechstein Limestone (Ca1). Occurrence of the oldest formal Zechstein member, the Kupferschiefer, has not identified, as is characteristic for basement uplift. However, on the south-west margin of the Pogorzela High in the Pogorzela–6, a thin layer (0.2 m) of Basal Conglomerate deposits was encountered, equivalent to the Weissliegendes in the uplifted areas such as the Wolsztyn High.

The **PZ2 cyclothem** commences with the Main Dolomite (Ca2). In the area under study this member usually represents a shallow shelf environment: that is, it is developed in carbonate platform facies (Kwolek et al., 2002). In the area of the Pogorzela High the PZ2 cyclothem is continuous only in the zone located northwestward of the Siedmiorogów–1 — Bułaków–1 wells. In the crestal part of the high (area of the Pogorzela–1 and Pogorzela–2 wells), almost the whole of the Zechstein interval is represented by a stratigraphic hiatus (Fig. 3).

In the area of the Pogorzela High, with exception of its top axial part, the **PZ3 cyclothem** usually has a complete profile. It is commenced with the Grey Pelite (T3), overlaid by the Main Anhydrite (A3), and followed by the Younger Halite (Na3). The Screening Anhydrite (A3r) (ca 1 m thick) underlain by the Younger Halite is very much discontinuous: it was only found in the profiles of several wells.

The **PZ4 cyclothem** is characterized by terrigenous–evaporite deposits formed as a result of periodic changes of continuously more humid climate, narrowing connection with the Upper Permian Sea and progradation of continental terrigenous deposits into the basin (Wagner 1994). These deposits accumulated on a surface partially smoothed by deposition of older Zechstein rocks. In the Pogorzela High area, likewise across the whole Wolsztyn High, the PZ4 cyclothem is commenced with the Lower Red Pelite (T4a), overlain by the Pegmatite Anhydrite (A4a), and the Youngest Halite (Na4a). The PZ4 section terminates with the so called Top Terrigenous Series (PZt) which, according to R. Wagner (*op. cit.*), is a transitional member between Zechstein and Buntsandstein deposits. In the Polish oil industry its equivalent is possibly called the Transitional Claystone Series (IP).

Proposal for Zechstein local stratigraphy change — seismic evidence

Results of 3D seismic studies accomplished in 2004 applied to the Pogorzela High area require a review of existing knowledge on geologic framework of the Zechstein deposits. Structural interpretation of Zechstein seismic boundaries, perhaps with the exception of the Z3 boundary related to the top Main Anhydrite, is very difficult even using 3D data. Admittedly this difficulty is mainly in the zone around of the crestal part of the Pogorzela High, but because of possible occurrence of structural-lithological traps in the Zechstein carbonate deposits this area is highly important for hydrocarbon exploration. The interpretation difficulty results mostly from the complete pinch-out of salt members in the lower part of the Zechstein, whose presence determines the formation of intra-Zechstein seismic reflectors at the boundary of anhydritic members (Z2, Z1). Additional impediment to generation of seismic reflections in the zone mentioned are the convergence, thickness reduction and facial changes of the carbonate members.

The result is that, beneath a minimum thickness of a reflective layer, it becomes “invisible” in the seismic record.

Characteristic arrangement of reflectors within thinning Zechstein deposits on the slopes of the high suggests that they are overlapped in relation to the distinct surface of angular unconformity related to the base of the Zechstein — the Z1’ seismic boundary, connected with the top rocks of the sub-Permian basement (Fig. 4). A considerable

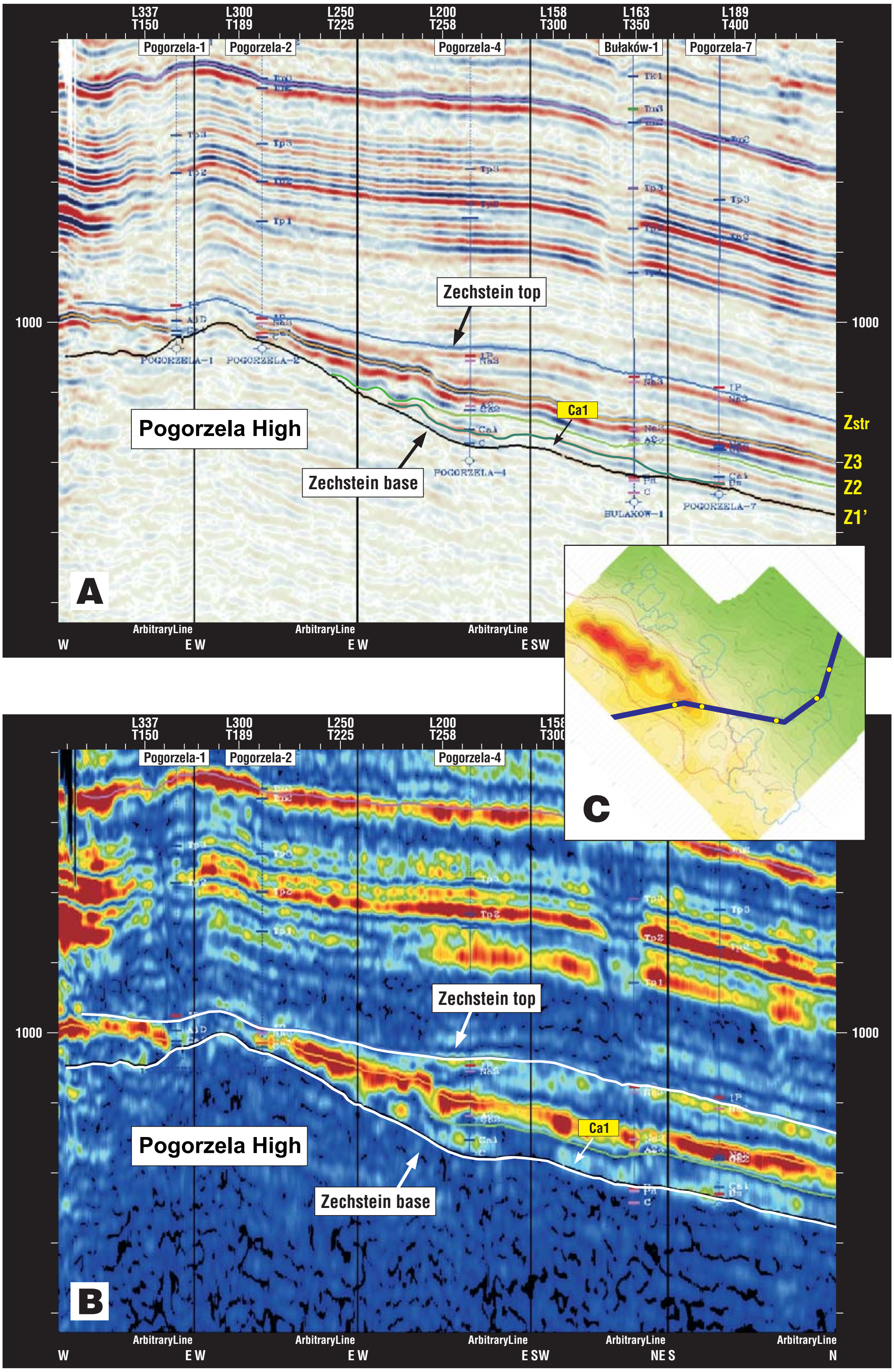


Fig. 4. Arbitrary section of the Pogorzela High (A) and its reflection strength (B) — the Siedmiorogów–Pogorzela 3D seismic image (Geofizyka Kraków 2005); C — section locality versus structural map of the base Zechstein in the Pogorzela High area (after Kwolek & Kowalczak [In:] Kwolek & Mikołajewski, 2006)

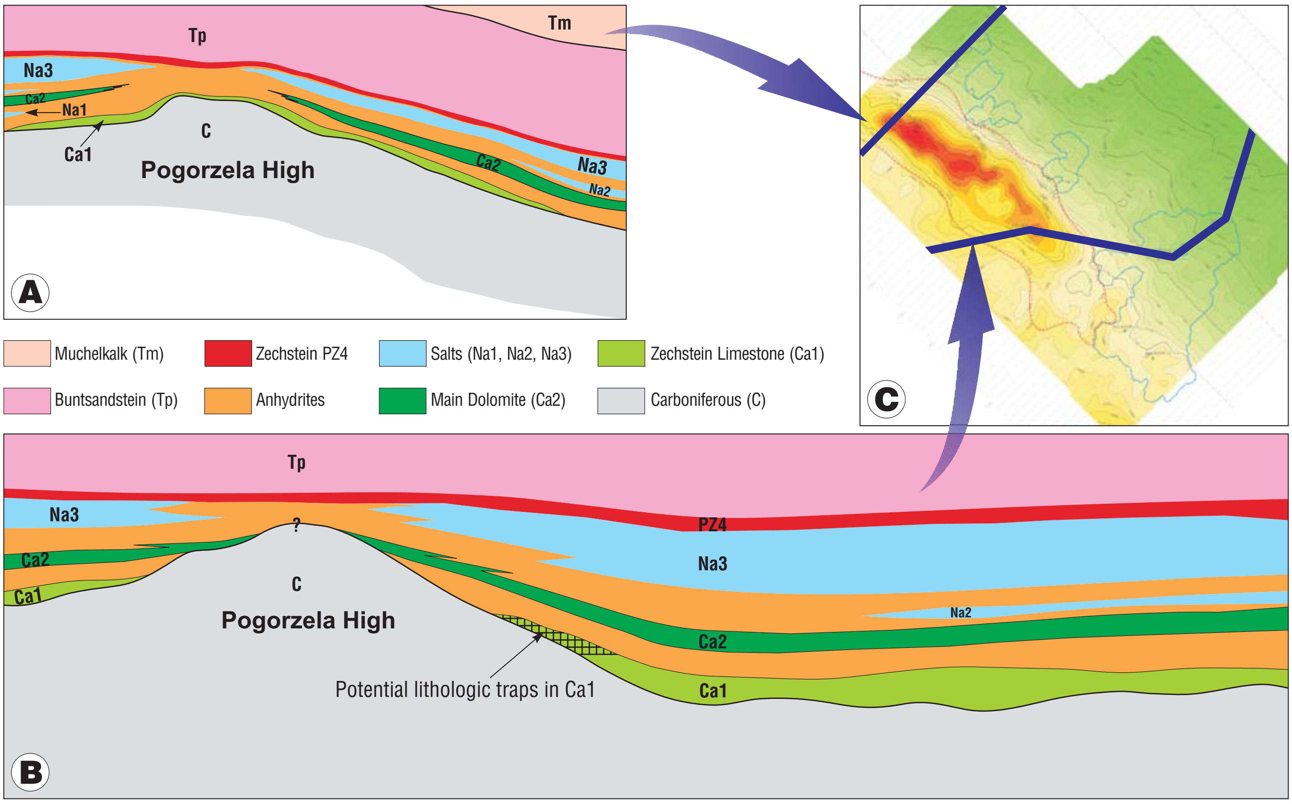


Fig. 5. Model of geologic framework of Zechstein deposits in the Pogorzela High; A — based on well and 2D seismic data (Kwolek & Protas, 2001); B — based on well and 3D seismic data; C — locality of profiles which were used to create models A and B on the structural map of base Zechstein in the Pogorzela area (after Kwolek & Kowalczak [In:] Kwolek & Mikołajewski, 2006)

improvement of 3D seismic data quality compared to the two-dimensional method (2D) has been achieved, with better resolution of both Z1' and Ca2sp (base Main Dolomite) surfaces (Kwolek, 2000). This has made easier the identification of the Ca1 reflection related to porous rocks of the Zechstein Limestone, which lies between the Z1' and Ca2sp events. The validity of the interpretation of the Z1'seismic boundary is confirmed by analysis of sections in the form of one of seismic attributes, namely reflection strength (Fig. 4B).

On the basis of interpretation of 3D seismic data it is concluded that in the close vicinity of the Pogorzela High the uppermost PZ1 strata and the lower part of the PZ2 cyclothem are missing. This means that the currently accepted stratigraphy of the Zechstein deposits in wells Pogorzela–1 and Pogorzela–2 is debatable, in the light of 3D seismic data. Thus, it can be suggested that in the most elevated part of the high, Main Dolomite deposits lie directly on the Carboniferous basement: previously, the Zechstein Limestone sediments had been interpreted to lie at this level.

Based on 3D seismic data a new model for the geologic framework of Zechstein deposits in the Pogorzela High area is proposed (Fig. 5B). The rock sequence showed in this model seems to testify that the most elevated part of the area was an island during Zechstein transgression. A similar sequence was found in the Koszalin–Chojnice zone where Zechstein transgression did not flood all basement highs (Fig.6). These highs formed islands around which were formed algal-bryozoan barriers, several tens of meters of thick,

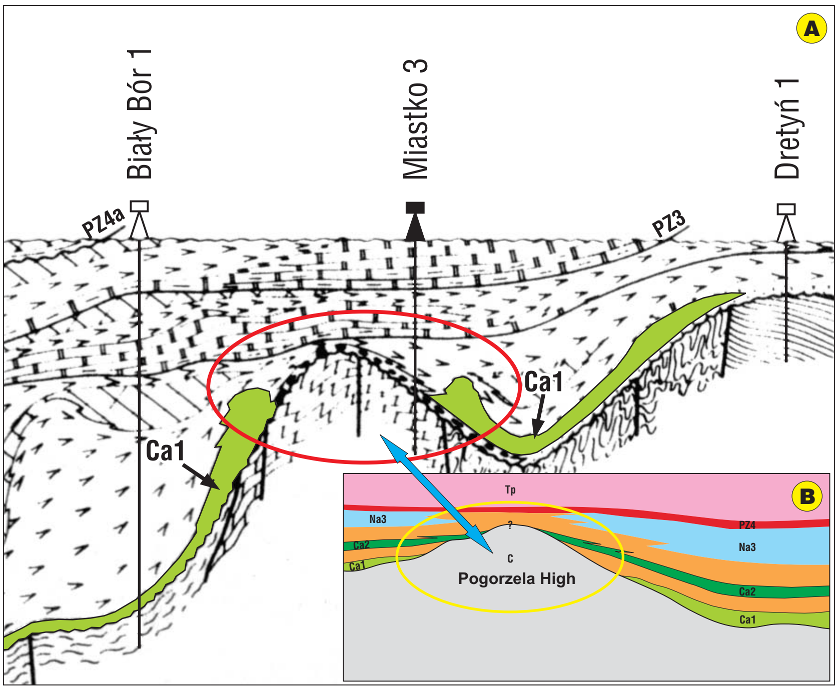
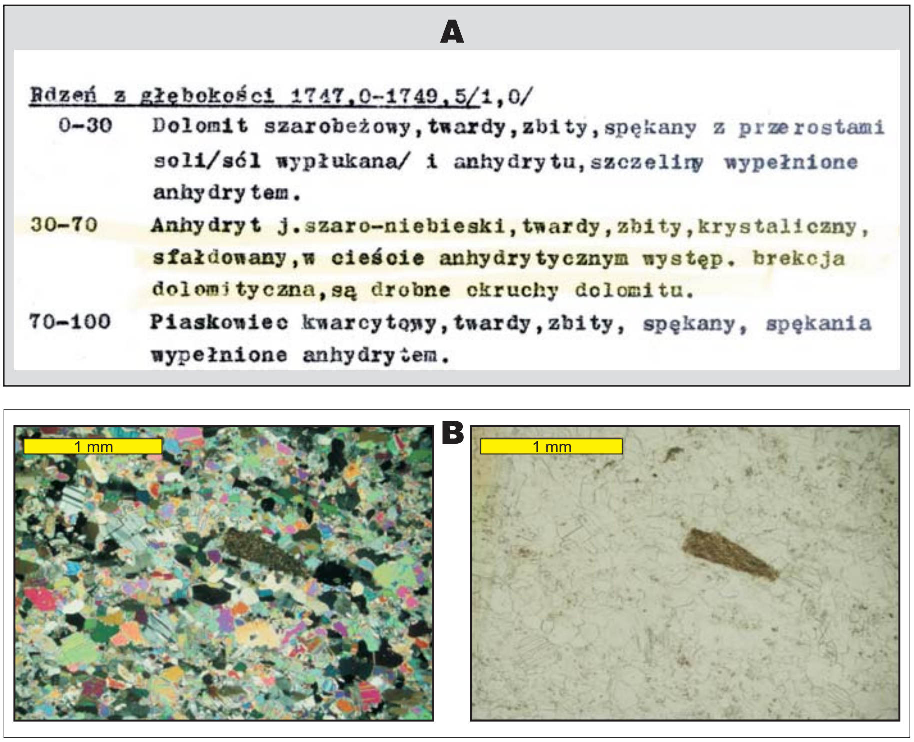


Fig. 6. Analogy of geologic framework of Zechstein deposits in the Koszalin–Chojnice zone (A) (Wagner [In:] Raczyńska, 1987), to the Pogorzela High (B). No scale


A

Rdzeń z głębokości 1747,0-1749,5/1,0/

0-30 Dolomit szarobeżowy, twardy, zbity, spękany z przerostami soli/sól wypłukana/ i anhydrytu, szczeliny wypełnione anhydrytem.

30-70 Anhydryt j.szaro-niebieski, twardy, zbity, krystaliczny, sfałdowany, w cieście anhydrytycznym występ. brekcja dolomityczna, są drobne okruchy dolomitu.

70-100 Piaskowiec kwarcytowy, twardy, zbity, spękany, spękania wypełnione anhydrytem.

Fig. 7. A — fragment of a page of the Pogorzela–2 well documentation with original core descriptions after K. Król; B — microphotographs of petrographic thin sections from the anhydrite overlain by Carboniferous deposits in the Pogorzela–2 well (ca 1747.5 m depth)

separating the lagoonal-littoral part of the basin from the open sea (Wagner [In:] Raczyńska, 1987).

Proposal for Zechstein stratigraphy change — geologic evidence

In order to find direct evidence to prove the thesis on the lack of the Zechstein Limestone deposits in wells Pogorzela–1 and Pogorzela–2, authors of the paper re-analyzed all available geological materials gathered in the relevant well documentation. Key evidence turned out to be a field core description from well Pogorzela–2, representing the Zechstein — basement (Carboniferous) transition. The description shows an intercalation of anhydrite lying directly on Carboniferous deposits (Kupferschiefer is absent) and below layers of dolomites assigned to the Zechstein Limestone (Fig. 7A). This anhydrite intercalation was completely omitted in the lithostratigraphical profile enclosed in the well documentation. Because of incomplete core recovery (ca 40%), it cannot be excluded that the thickness of this intercalation up to twice higher. This assumption seems to be confirmed by log curve analysis. Presence of clasts from the basement rocks is observed in the microscopic thin-section collected from the analyzed anhydrite layer (Fig. 7B), suggesting that sedimentation took place close to the face of basement beds uplifted above the sea level. From the analyzed succession: basement — anhydrite — dolomite, it unambiguously shows that the latter layer cannot be included into the Zechstein Limestone. Undoubtedly, these are the Main Dolomite

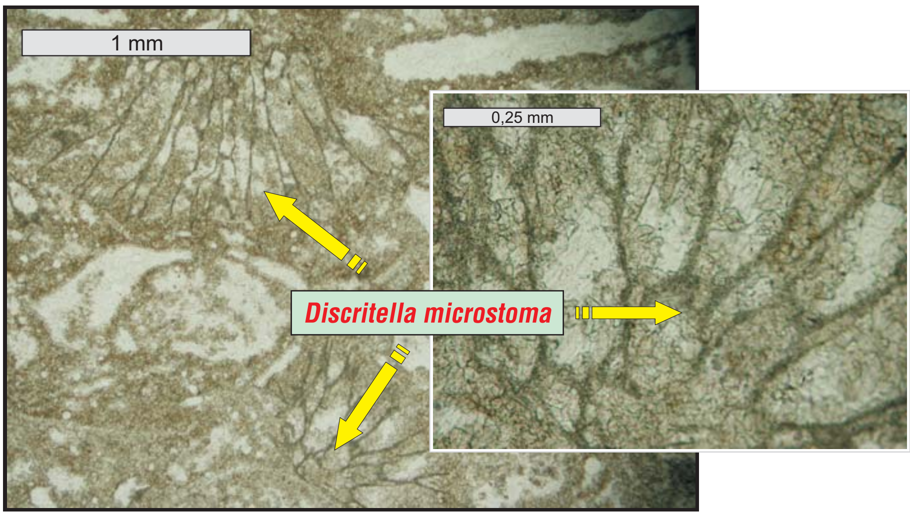


Fig. 8. Fragments of bryozoans found in the Pogorzela–2 well (depth ca 1743 m)

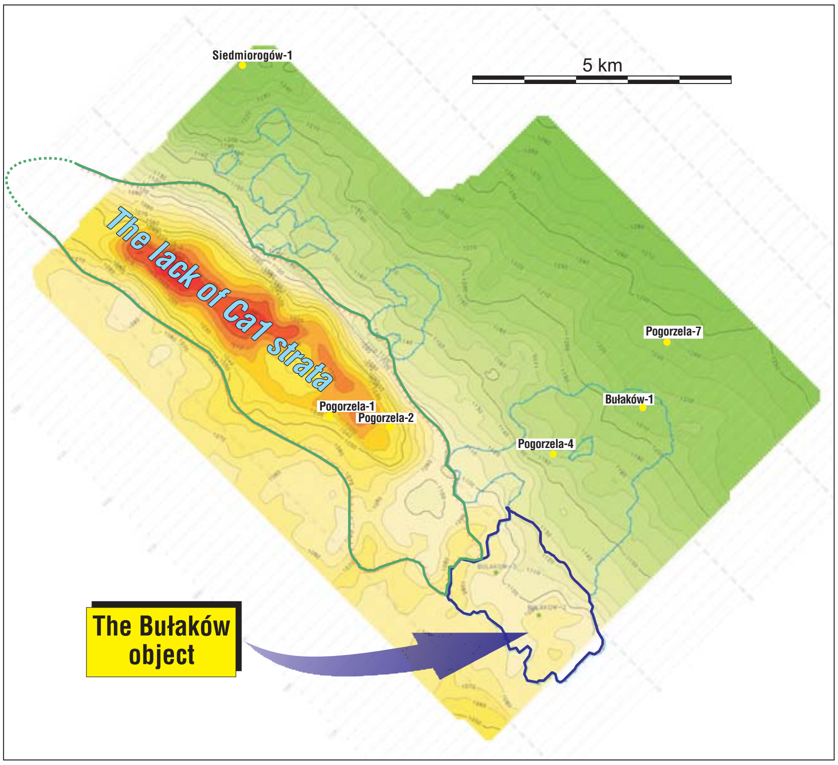


Fig. 9. Reflection map of the Z1' seismic boundary in the Pogorzela High area (after Kwolek and Kowalczak [In:] Kwolek & Mikołajewski, 2006 — based on 3D seismic data from Siedmiorogów–Pogorzela, Geofizyka Kraków 2005)

in the case of the PZ1 cyclothem. In turn, described by J. Kłapciński, *Edmondia elongata* How is considered in the European Zechstein Basin (beside *Wilkingia elegans* King) to be an index fossil for the Main Dolomite (Wagner, 1994). Moreover, this has been known for many years: an academic book Geological History (Makowski [In:] Makowski, 1977) states that this genus appeared in the Permian and was found both in the Zechstein Limestone and in Main Dolomite rocks.

An additional argument which supports including the carbonate interval in wells Pogorzela–1 and Pogorzela–2 into the Zechstein limestonae deposits was the presence of fragments of bryozoans in the basal part of the Pogorzela–2 well profile (Fig. 8). Authors of the present work managed to find thin sections from well Pogorzela–2 that indicate the presence of scarce bryozoans which, according to Dr. U. Hara (Polish Geological Institute), represent species *Discritella microstoma* (pers. comm.). This form is found both in the Zechstein Limestone of the North–Sudetic Trough and in the Main Dolomite in northern Germany and on the Unisław Platform (Dr. U. Hara — pers. comm.). Hence, the deposits underlain by anhydrites of the PZ1 cyclothem, as they are seen in the seismic sections to be pinching out on the slopes of the Pogorzela High (Fig. 4).

The basis of identification of the carbonate interval in the well Pogorzela–1, some 1,5 km away from well Pogorzela–2, was „Orzeczenie fauny cechsztyńskiej z otworów Pogorzela–6 i Pogorzela–1" written in 1973 by Prof. Jerzy Kłapciński as enclosed in the well documentation (*Dokumentacja wynikowa otworu poszukiwawczego Pogorzela–1*, 1973). In the rock chip collected from the basal part of the analyzed interval in well Pogorzela–1 (depth 1760,6 m) J. Kłapciński described mollusks from the genera *Schizodus* (*Schizodus truncatus* King) and *Edmondia* (*Edmondia elongata* How), claiming that the former represented Lower Zechstein (Werra cyclothem), and the latter Lower and Middle Zechstein (but it is more common in the Lower Zechstein). Thus J. Kłapciński admitted that the carbonate interval in the well should be included into the Werra cyclothem (PZ1) and thus should be referred to the Zechstein Limestone deposits.

Genus Schizodus is known from Upper Carboniferous. Therefore it seems that it cannot be an obvious indicator of age of the deposits, especially of such a narrow interval of time as it is

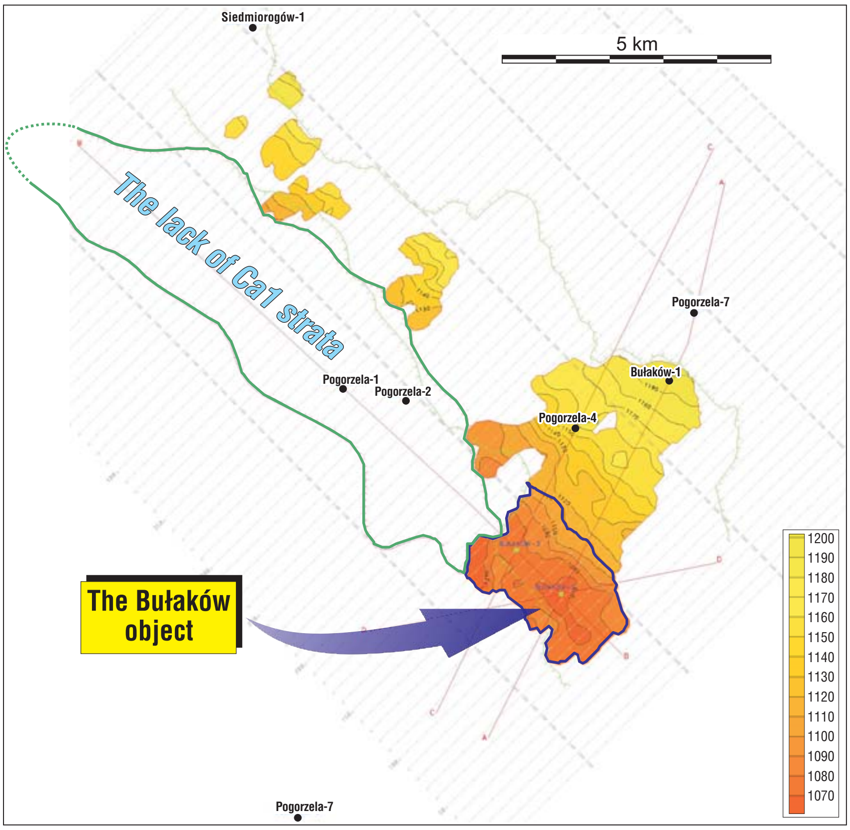


Fig. 10. Time structure map of the Ca1 seismic boundary (top porous layer of the Zechstein Limestone) in the Pogorzela High area (after Kwolek & Kowalczak [In:] Kwolek & Mikołajewski 2006 — based on 3D seismic data from Siedmiorogów–Pogorzela, Geofizyka Kraków 2005)

presence of scarce bryozoans in the carbonate interval analyzed in the Pogorzela–2 profile does not seem to be a sufficient criterion corroborating the existing stratigraphic scheme.

Change of stratigraphic assignment of the carbonate layer in the base of the wells Pogorzela–1 and Pogorzela–2 from Ca1 into Ca2 results, of course, in the need for reassignment of lithostratigraphic members higher in the profile.

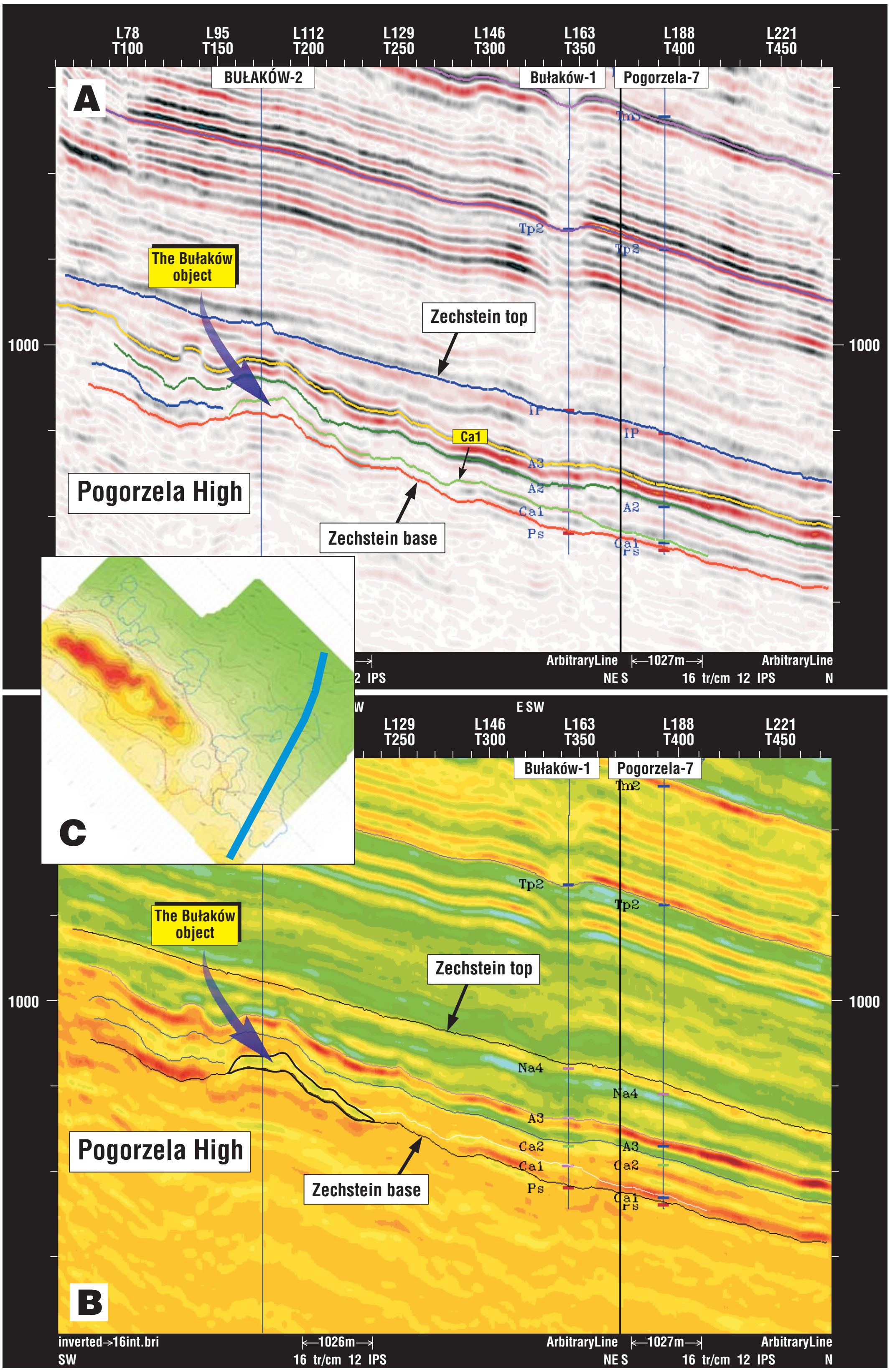


Fig. 11. Arbitrary time seismic section NE–SW through the Bułaków object (A) and its seismic inversion (B). Structural interpretation — K. Kwolek (based on 3D seismic data from Siedmiorogów–Pogorzela, Geofizyka Kraków 2005); C — locality of section on the structural map of the Zechstein base in the Pogorzela area (after Kwolek and Kowalczak [in:] Kwolek and Mikołajewski 2006)

Nota bene, that on account of very attenuated thicknesses, the lack of salt and of benchmark members (Grey Pelite, Red Pelite), it is very difficult or even impossible to make a firm identification of the higher units (Fig. 3).

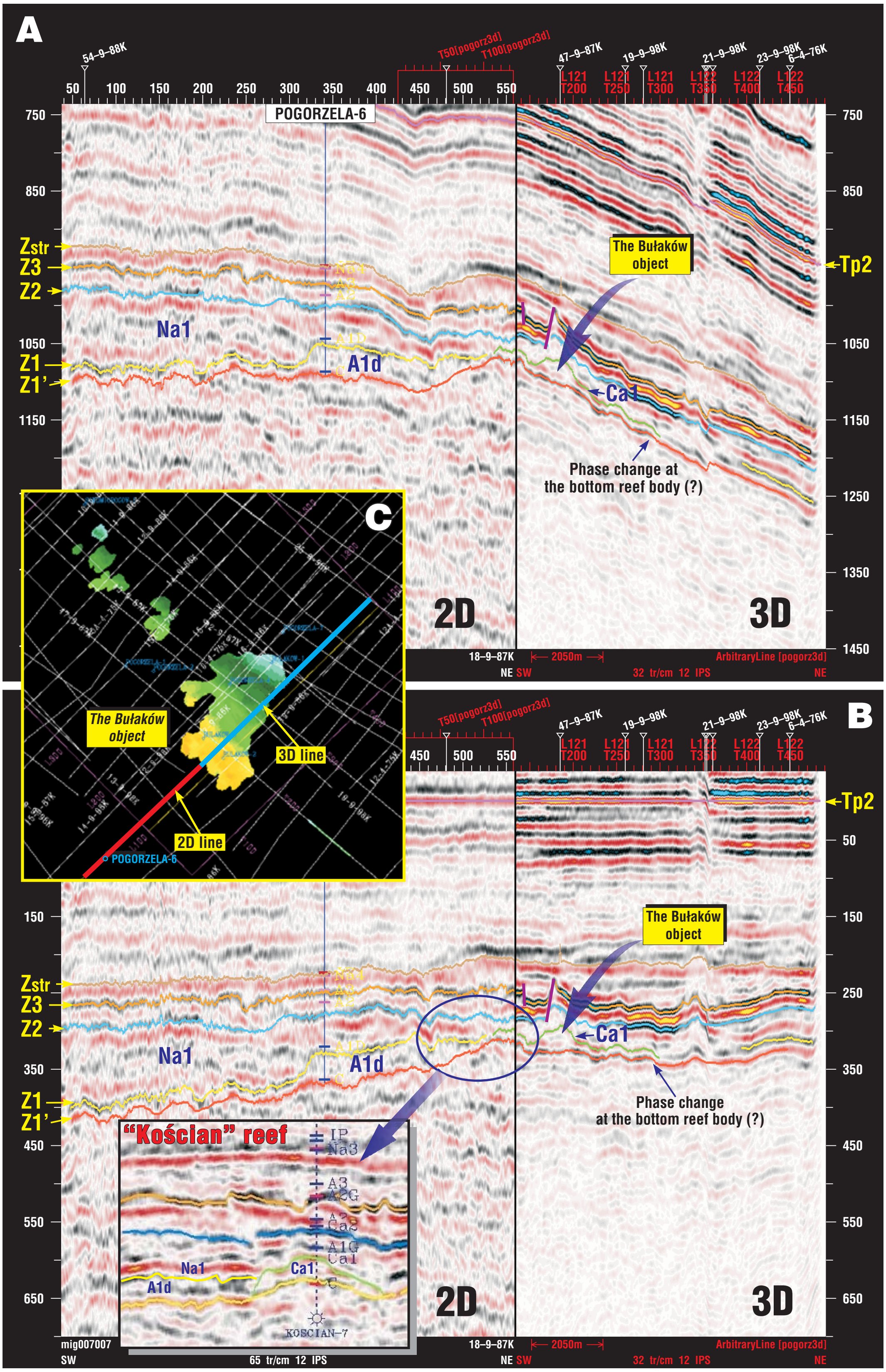


Fig. 12. Juxtaposition of the arbitrary 3D section (elaboration: Siedmiorogów–Pogorzela 3D, Geofizyka Kraków 2005) going through the Bułaków object with the 2D section number 18–9–87K (last processing in 2000; Geofizyka Kraków) — A; B — section from figure A flattened to the seismic Tp2 boundary; C — locality of 2D and 3D sections set in figures A and B

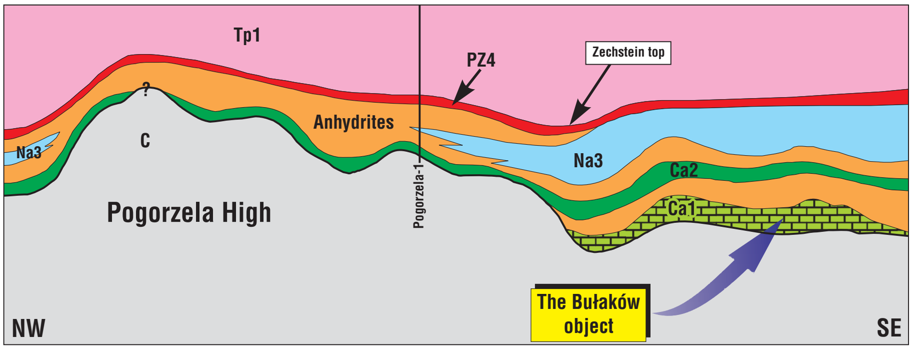


Fig. 13. Model of geologic framework of the Zechstein deposits in the Pogorzela High along with NW–SE direction (based on 3D seismic data from Siedmiorogów–Pogorzela, Geofizyka Kraków 2005)

The new model for the geologic framework of Zechstein deposits (Fig. 5B) differs seriously from the model based on 2D seismic data (Fig. 5A). Comparison of both models reveals how considerably the change of Zechstein stratigraphy model influences the exploration concepts in this area.

Significance of the new Zechstein stratigraphy in the Pogorzela High for hydrocarbon exploration

The new model for the geological framework of the Zechstein deposits in the Pogorzela High (Fig. 5B) shows that the Zechstein Limestone interval, whose prospectivity had been considered to be much reduced following negative reservoir results of boreholes drilled in the 1970s, still has high exploration importance.

The poor reservoir quality in what was considered at the time to be Zechstein Limestone deposits in wells Pogorzela–1 and Pogorzela–2, due to location of the Pogorzela High (Fig. 9), downgraded the whole region from further hydrocarbon exploration targeted at the Ca1 interval. Data quality improvement and increased seismic resolution resulting from the acquisition of 3D seismics allowed for more precise and credible interpretation of the Ca1 seismic boundary, which is connected with porous and highly thick (reef-like) deposits of the Zechstein Limestone (Fig. 10).

The change of stratigraphic assignment from Ca1 to Ca2 of the only carbonate interval in wells Pogorzela–1 and Pogorzela–2, determines that the Ca1 deposits must pinch out on the slopes of the Pogorzela High, creating potential lithologic traps (Fig. 5B). This model was confirmed by thorough geophysical-geological analysis of the Werra rocks. In this analysis experience from the last dozen years in searching for porous and thick Ca1 reef bodies in the Kościan–Nowy Tomyśl area was called upon (i.a., Dyjaczyński et al., 1993; Dyjaczyński & Kucharczyk 1998; Klecan & Łomnicki, 1998; Górski et al., 2000). Detection of these bodies is based on knowledge of reflection generation in the Werra deposits but also on indirect paleostructural premises.

Reef bodies, as such, are included into lithologic-type traps, specifically after Levorsen (1972), into primary stratigraphic traps. However, the complete pinch-out of the Ca1 deposits on the slopes of the Pogorzela High (Fig. 5B, see Fig. 6), can create an exceptional (to date) mixed trap types in these deposits — *sensu stricto* lithologic-stratigraphic. One particularly prospective potential trap of this type, the *Bułaków* feature, has been recognized from the seismic data (Fig. 9, 10). It shows some similarities to reefal forms found and recognized between Kościan and Nowy Tomyśl.

The shape of the *Bułaków* object is asymmetrical: in the currently highest structural position there is south–western part (Fig. 11). This part of the object is on the edge of the morphological margin in the basement, southwestward from which the base Zechstein abruptly deepens and the thickness of the PZ1 cyclothem deposits thickens drastically: in well the Pogorzela–6, located just ca 5.6 km from the margin PZ1 reaches a thickness of a much as 213 m (Fig. 12). However, the most important element of the geologic framework which differs between the *Bułaków* object and

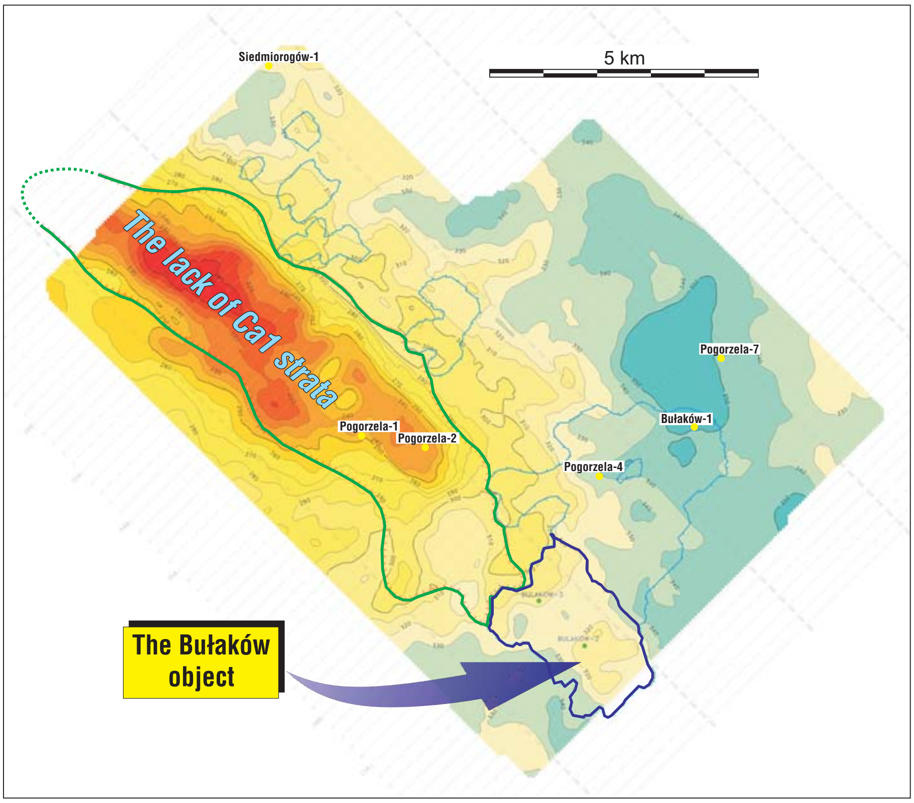


Fig. 14. Thickness map of the complex t = Z1'–Tp2 (after Kwolek & Kowalczak [In:] Kwolek & Mikołajewski 2006 — based on 3D seismic data from Siedmiorogów–Pogorzela, Geofizyka Kraków, 2005). Map of seismic the Tp2 boundary was used after Geofizyka Kraków

the reefal forms of the Kościan–Nowy Tomyśl area is the pinching out of Ca1 deposits at the base of the SE margin of the topmost part of the Pogorzela High (Fig. 13). Despite this difference, this object fulfills general criteria indicating the presence of the Ca1 reef bodies in the seismic section, namely:

❑ the Oldest Halite (Na1) pinches out on the slopes of the Pogorzela High. Because of a limited extent of the Siedmiorogów–Pogorzela 3D survey, this phenomenon is best seen on the 2D line going through well Pogorzela–6 (located in far SW slope of the Pogorzela High) joined to an arbitrary 3D line going through the *Bułaków* object (Fig. 12). Also seen is a phenomenon of „draping" of this possible reef body by the Lower Anhydrite A1d in its slopes (Fig. 11).

❑ phase change of the Z1' reflector from minimum to maximum in the base of the *Bułaków* object is very spectacular. This phenomenon is particularly well seen on sections along with layers dip or related directions (Fig. 11).

The *Bułaków* object is on the elevation in the Zechstein basement well seen on the seismic sections flattened to the seismic Tp2 boundary (Fig. 12B). This elevation comprises an extension in the SE direction (along with the Wolsztyn High axis) of the structurally highest part of the Pogorzela High. The *Bułaków* object was deposited about 100 m (ca 40 ms — Fig. 9) deeper and, at the time of Zechstein transgression when the crest was an island, could have been in an optimal place for shallow water, intensive sedimentation of organic carbonate rocks of the Zechstein Limestone (i.e., reefs). This fact clearly shows thickness map of the complex t = Z1'–Tp2 identical with the Z1' horizon map flattened to the seismic Tp2 boundary (Fig. 14). It seems that this assumption is also confirmed by inversions of seismic sections, which show that the acoustic impedance within the *Bułaków* object is far lower than in the surrounding anhydrites (Fig. 11B).

The closure the NE of the *Bułaków* reservoir trap is structural, with SE and SW closure being lithological, related to the facies change of the Ca1 deposits from the thicker and porous shallow carbonate reefs into thin (from one to several meters), non-porous and dense deepwater carbonates, representing so called condensed profiles (Peryt & Ważny, 1978). On the other hand, the NW part the trap is formed by the extent of the Ca1 deposits, pinching out to SE on the slope of the central part of the Pogorzela High (Fig. 13).

Boreholes drilled so far in the Pogorzela High area, which confirmed the occurrence of thick Ca1 deposits, were located on its highly deep, north–east slope. Gas cut formation water inflows with low combustible gas have been obtained from the Ca1 interval in these boreholes. It is assumed that most of the gas exsolved from the brine accumulated in the *Bułaków* trap located which lies on the migration path to the SW direction and updip by about 100–200 m (ca 50–80 ms) (Fig. 10, 11).

As a result of the data presented, the prospectivity of the Zechstein Limestone deposits in the Pogorzela High is still high. It must be emphasized that the crucial influence on the change of exploration value estimation of the Ca1 interval in the area was the result of 3D seismic studies and discerning analysis of their results, together with reliable reinterpretation of archived geological data.

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