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The Permian/Triassic boundary in the Polish Basin in the light of paleomagnetic data

Magnetostratigraphic studies were carried out to verify the sedimentological and lithostratigraphical Zechstein/Buntsandstein boundary in the Polish Basin. Samples were taken from three boreholes: Brojce IG 1, Mszczonów IG 1 and Jaworzna IG 1. Both boundaries fall within the zone of normal magnetization, which includes the uppermost part of the Top Terrigenous Series or the Rewal Formation. The results of paleomagnetic, sedimentological and palynological studies shows that the Baltic Formation of the Lower Buntsandstein may be correlatable with the Lower Griesbachian.

INTRODUCTION

The Permian/Triassic boundary has been intensively studied for years however no agreement has been reached in choosing a stratotype section. There are several proposals for defining this boundary, the two most considered are:

1. The beginning of the Griesbachian or the bottom of the *Otoceras* beds (E. T. Tozer, 1988).
2. The boundary between the Lower and Upper Griesbachian or between the Gangetian and Ellesmerian (H. Kozur, 1989).

These differing proposals arise from divergent ideas concerning the evolutionary development of the biostratigraphically important fossils and their uneven distribution. This is a result of the great extinction at the end of the Paleozoic and the worldwide regression. The regression caused fragmentation of the epicontinental marine habitats and a strong endemism of their faunas. Thus there is paucity of profiles at the Permian/Triassic boundary with continuous marine sedimentation and rich biotic documentation.

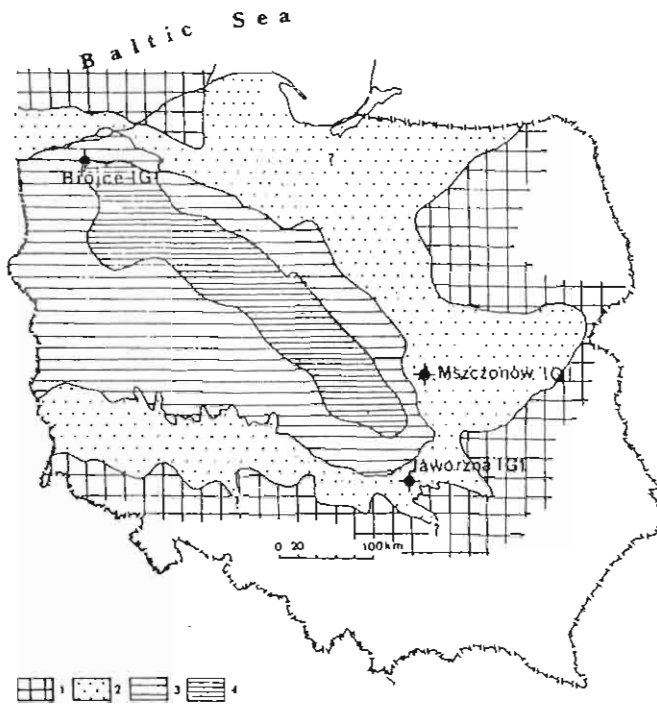


Fig. 1. The investigated boreholes on the background of synthetic lithofacies map of the Zechstein 4 (after R. Wagner, 1988, simplified)

1 — eroded land area; 2 — area of terrigenous sedimentation — Rewal Formation, Top Terrigenous Series (primary extent); 3 — area of marine evaporitic sedimentation (primary extent); 4 — area of land evaporitic sedimentation

Badane otwory wiertnicze na tle syntetycznej mapy litofacjalnej czwartego cyklotemu cechsztyńskiego (według R. Wagnera, 1988, uproszczone)

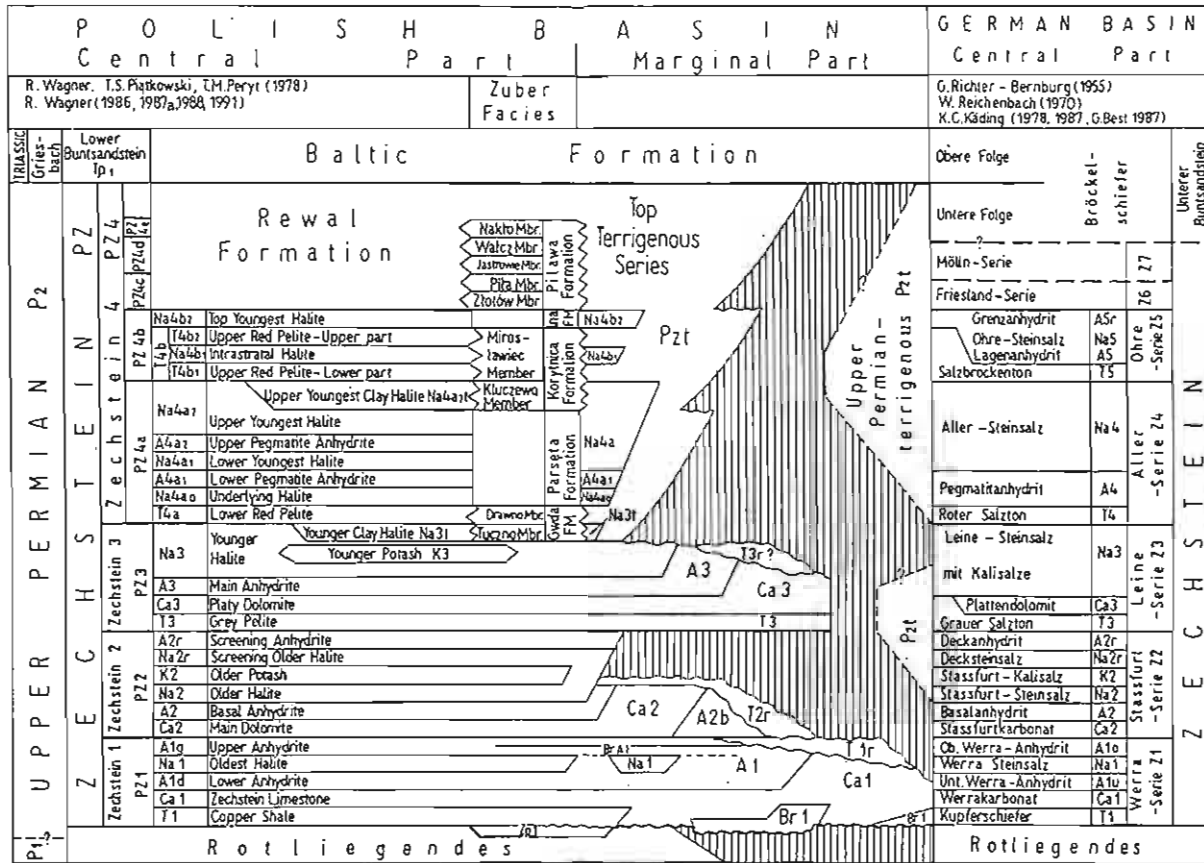
1 — erodowane obszary lądowe; 2 — obszar sedymentacji terygeniczej — formacja rcwalska, stropowa seria terygeniczna (zasięg pierwotny); 3 — obszar morskiej sedymentacji ewaporytowej (zasięg pierwotny); 4 — obszar sedymentacji ewaporytów kontynentalnych

Definition of the Permian/Triassic boundary in the Central European Basin is even more difficult, because the boundary lies among the red terrigenous deposits, which contain only poor microflora. Several methods: sedimentological, geochemical, geochronological, palynological and paleomagnetic were applied in order to elaborate the stratigraphical framework for these beds. This paper presents the report on magnetostratigraphic investigations, which complemented and verified the results of previous attempts to define the Permian/Triassic boundary using other methods.

Three boreholes were studied: one from the axial (Brojce IG 1) and two from the peripheral part of the Polish Basin (Mszczonów IG 1, Jaworzna IG 1) — Fig. 1. They are attributed to the uppermost Zechstein (Rewal Formation and the Top Terrigenous Series) and the lowermost Buntsandstein (Baltic Formation) — Tab. 1.

Table 1

Stratigraphy and correlation of the Zechstein deposits from the Polish and German Basins.



Zp1-Basal Conglomerat; Br1-Basal Breccia; BrA1-Anhydrite Breccia; T1r-Recessive Terrigenous Series PZ1; T2r-PZ2; T3r-PZ3

The Permian/Triassic boundary in the Polish Basin

PERMIAN/TRIASSIC BOUNDARY IN POLAND

At the end of the Zechstein evaporite sedimentation, salts with intercalations of red siltstones and mudstones (zuber facies) were formed in the narrow sedimentary basin in the central part of the Polish Through (Fig. 1). This basin was a salt lake (G. Czapowski, 1990) which was continuously retreating and finally disappeared (R. Wagner, 1987b, 1991). At the margins of this basin there was a broad belt of red terrigenous sebkha sedimentation, interdigitating with fluvial and aeolian deposits (G. Pieńkowski, 1989, 1991). As the salt lake retreated, the progradation of the terrigenous series towards the central part of the basin occurred, consequently clastic sedimentation replaced the evaporites. The thickness of the terrigenous series varies up to 120 m (approximately 20–40 m). They overlay the various members of the Zechstein evaporites. The age of the underlying salts increases towards the marginal parts of the basin and so do the stratigraphical gap.

In previous studies the terrigenous series were either attributed to the Lower Buntsandstein or to the uppermost Zechstein as "Permian/Triassic transition beds" or "boundary series". Finally they were included within the Zechstein as the Top Terrigenous Series — PZt (R. Wagner et al., 1978) — Table 1.

The Baltic Formation, attributed to the Lower Buntsandstein (A. Szyperko-Śliwczynska, 1979), overlies the Top Terrigenous Series. In the NW of Poland the Rewal Formation (A. Szyperko-Teller, 1982; R. Wagner, 1987a, 1988) was distinguished as the equivalent of the Top Terrigenous Series. The boundaries between these lithostratigraphical units were not always easy to identify and their ages uncertain. The Rewal and the Top Terrigenous Series were included in the uppermost Permian together with the evaporites of the uppermost Zechstein, however, there were no biostratigraphical premises for that interpretation. Therefore, only the problem of the lithostratigraphical Zechstein/Buntsandstein boundary was considered.

Palynological studies enabled estimation of the age of the uppermost Zechstein and the lowermost Buntsandstein — the Baltic Formation. The miospore assemblage characteristic for the uppermost Permian with *Lueckisporites virkkiae* NC and NBc, according to Visscher's palynodem, together with *Acritarcha* microplankton, was found in the lower part of the Top Terrigenous Series (27 m above the PZ4a evaporites) of the Piotrków IG 1 borehole (SE part of the Zechstein basin). A similar assemblage was found in the Zechstein evaporites of PZ4 and PZ4c cyclothems (S. Dybova-Jachowicz et al., 1984). At the same time a rich assemblage of miospores *Lundbladispora obsoleta* — *Protohaploxypinus pantii* was encountered in the lower part of the Baltic Formation (also in the paleomagnetically studied Mszczonów IG 1 borehole) — T. Orłowska-Zwolińska (1984). The miospores are identical with the *Protohaploxypinus* association of E Greenland, described by B. E. Balme (1979) and S. Piasecki (1984), from the Lower Griesbachian beds containing the *Otoceras* ammonites.

The results of the palynological investigations proved the Upper Permian age of the PZ4b and PZ4c Zechstein subcyclothems and the lower part of the Top Terrigenous Series (PZt). They also confirmed that the Baltic Formation of the Lower Buntsandstein may be correlated with the Lower Griesbachian of E Greenland, belonging

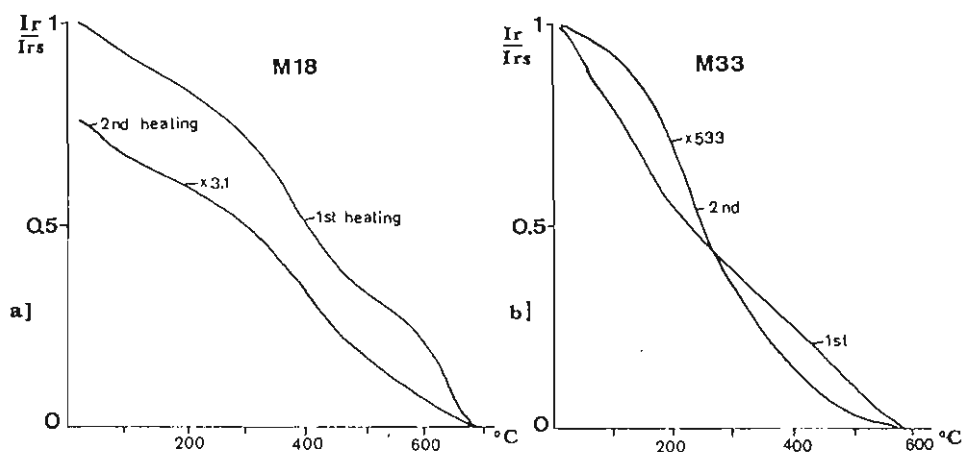
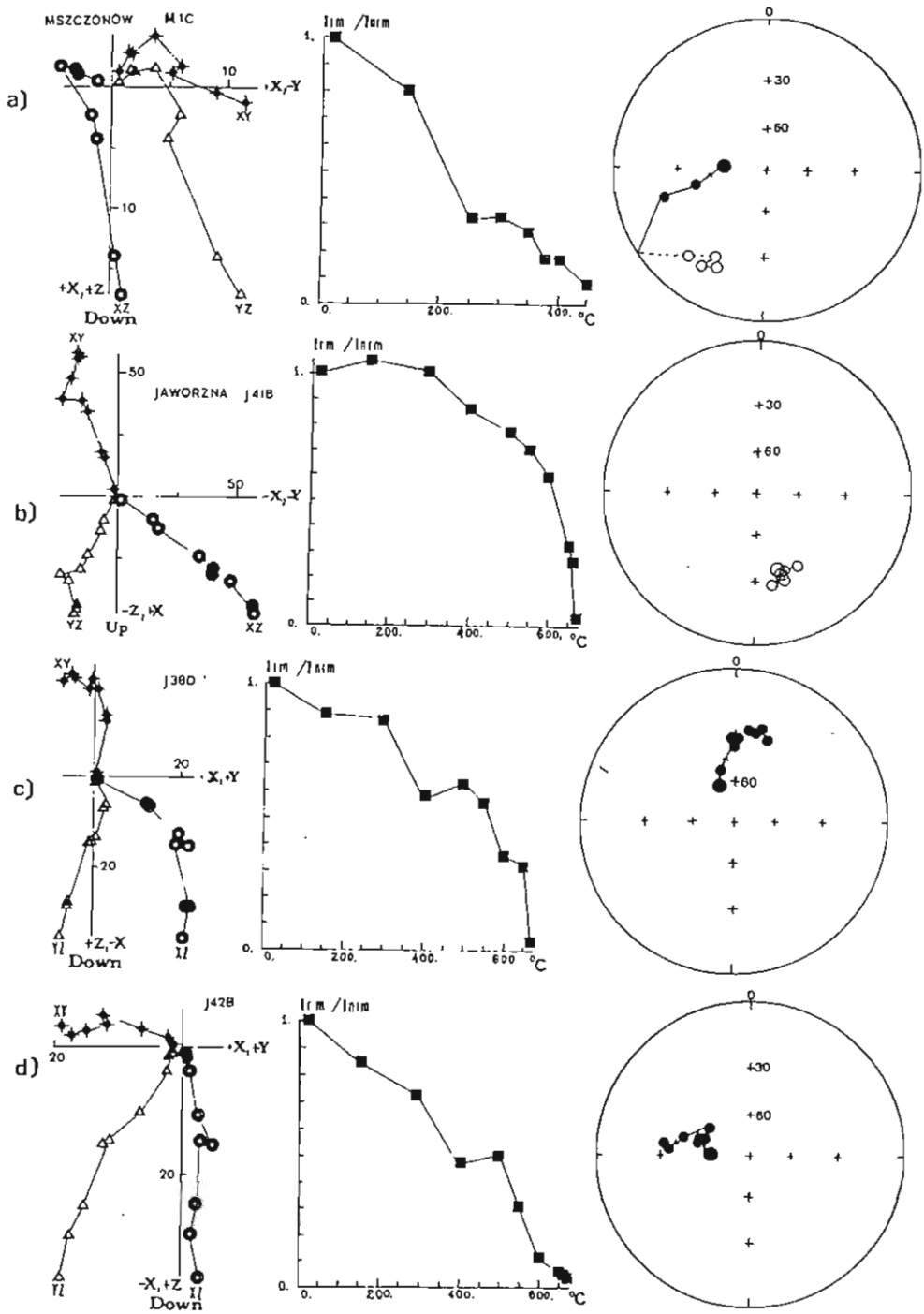


Fig. 2. Examples of intensity decay curves of saturation remanence during heating; both samples with hematite (a) and magnetite remanence carrier (b) were taken from Mszczonów IG 1 borehole

Przykłady krzywych spadku pozostałości magnetycznej nasycenia z biegiem wygrzewania; obydwie próby z hematytowym (a) i magnetytowym (b) nośnikiem pozostałości magnetycznej pobrano z otworu wiertniczego Mszczonów IG 1

to the lowermost Triassic according to E. T. Tozer (1986, 1989). These results indicated the possibility of the identification of the Permian/Triassic boundary in the Central European Basin.

Detailed sedimentological studies (G. Pieńkowski, 1989, 1991) revealed, that the Top Terrigenous Series and the Rewal Formation originated as continental deposits, while the Baltic Formation was deposited in an aquaous basin, where action took place. Sedimentological premises, the occurrence of *Acritarcha* microplankton (*Micrhystridium*, *Verychachium*, *Leiosphaeridium*) and occurrence single monoserial foraminifers suggest a marine environment (G. Pieńkowski, 1989). A new, sedimentologically defined boundary between the Top Terrigenous Series (Rewal Formation) and the Baltic Formation was established and replaced the old, lithostratigraphical one. This new boundary was presumed to be very close to the Permian/Triassic boundary, because of possible genetic links with global events. Worldwide regression, at the end of the Permian, may correspond to the continental sedimentation of the uppermost Zechstein (Pilawa Formation, Rewal Formation, Top Terrigenous Series). In the lowermost Triassic global transgression took place in the *Otoceras concavum*–*Otoceras woodwardi* Zones. This event may correspond to the transgressive deposits of the Baltic Formation in the Polish Basin. Palynological arguments seem to confirm the synchronicity of these events.



MAGNETIC POLARITY AT THE PERMIAN/TRIASSIC BOUNDARY

The magnetostratigraphic record of the Permian–Triassic transition beds is still insufficiently known. The boundary between the Paleozoic and the Mesozoic falls within the Illawarra Paleomagnetic Interval of mixed polarity (M. W. McElhinny, P. J. Burek, 1971). The beginning of the Illawarra interval (Illawarra reversal) marks the end of the long, reversed-polarity Kiaman Epoch (E. Irving, L. G. Parry, 1963). The Illawarra reversal was identified in the uppermost Permian of Australia (R. A. Facer, 1981), in the Tatarian of the Russian Platform (D. M. Pechersky, A. N. Khramov, 1973), in the Ochoan of the North America (A. E. Nairn, D. N. Peterson, 1973) and in the Upper Rotliegendes in Western Europe (W. Dachroth, 1976; M. Menning et al., 1988). A contradictory point of view was presented by C. Haichong et al. (1991). According to their studies of Chinese and Pakistan profiles, the end of the Kiaman Epoch falls at the boundary between the Lower and Upper Permian (Guadelupian, Kazanian). The recent investigations in China (M. Steiner et al., 1989; F. Heller et al., 1988; P. L. McFadden et al., 1988) proved, that the last stage of the Permian (Chang-sing) falls above the Illawarra reversal. World scale biostratigraphic correlation of the Permian/Triassic boundary has not yet been completed (M. Steiner et al., 1989). Biogeographical provincialism, predominantly continental deposits with poor biotic documentation, numerous stratigraphical gaps and variable sedimentation rates mean, that magnetostratigraphic correlation within the Illawarra mixed polarity interval is far from complete. The number of normal polarity zones within the uppermost Permian is disputed. In China and Russia there are three (D. M. Pechersky, A. N. Khramov, 1973; M. Steiner et al., 1989), whereas in Germany up to eight zones have been distinguished (W. Dachroth, 1976).

SAMPLING AND LABORATORY METHODS

A total number of 205 hand samples from three boreholes were studied: Brojce IG 1 (62 samples), Jaworzna IG 1 (90 samples), Mszczonów IG 1 (53 samples). These boreholes are located in various parts of the Polish Basin. The samples were oriented

Fig. 3. Results of thermal demagnetization (orthogonal projections, intensity decay curves and stereographic projections of demagnetization paths) for four selected group (see text) of paleomagnetic specimens

Open (solid) circles on the stereonet represent upper (lower) hemisphere directions; I_{rm} — the intensity of the remanent magnetization after thermal treatment; I_{NRM} — the intensity of the *NRM*; X, Y and Z — the planes of the projection (the units on the axes are 10^{-5} A/m)

Rezultaty termicznego rozmagnesowania (projekcje ortogonalne, krzywe spadku natężeń oraz projekcje stereograficzne ścieżek rozmagnesowania) dla czterech wyróżnionych (patrz tekst) grup próbek paleomagnetycznych

Kółka puste (zamalowane) na siatce reprezentują kierunki na górnej (dolnej) półsfery; I_{rm} — natężenie pozostałości magnetycznej po danym stopniu rozmagnesowania; I_{NRM} — natężenie *NRM*; X, Y i Z — płaszczyzny projekcji (jednostki na osi wyrażone w 10^{-5} A/m)

upwards-downwards only. Thus their polarity was determined by inclination of remanent magnetization in relation to the axis of the cores. The expected Permian/Triassic inclination of paleomagnetic direction in the studied region is 30° (E. Irving, G. A. Irving, 1982).

Samples were cut with a diamond drill in cylindrical specimens, 25 mm diameter and 22 mm height. 3–5 specimens were obtained from each sample. Thermal demagnetization up to 680°C was carried out in a non-magnetic oven. *NRM* was measured with a *JR-4* spinner magnetometer. Magnetic susceptibility was monitored by means of a x — bridge *KLY-2*. J. L. Kirschvink's (1980) algorithm was applied for statistical calculations. Magnetic minerals were determined using the thermomagnetic method. We were not able to carry out any test on the age of magnetization (P. Turner, 1980; J. P. Hodych et al., 1985). We assume, that the component of the highest blocking temperature is primary. Repeatability of the polarity changes in the investigated profiles leads us to assume, that the characteristic magnetization originated nearly synchronously with the deposition of the sediment.

DEMAGNETIZATION EXPERIMENTS

Thermal demagnetization and the structure of magnetization of the rocks studied was reported in a separate paper (J. Grabowski, J. Nawrocki, 1991), thus the description of demagnetization results and interpretation methods will be mentioned very briefly.

Hematite is the main *NRM* carrier in red sandstones (Fig. 2a). Grey sandstones and limestones contain magnetite as the magnetic mineral (Fig. 2b). *NRM* intensities range from 1 to 196 mA/m, and were usually higher in the case of red samples with hematite.

A secondary component of very steep inclination (70–90°) occurred in most samples. This component is sometimes very resistant to thermal demagnetization and it dominates the *NRM* at temperatures as high as 650°C. M. Menning et al. (1988) interpreted it as remagnetization resulting from the pressure of the overlying rocks.

In comparing the course of demagnetization paths four groups of samples can be distinguished:

1. Samples with magnetite as the *NRM* carrier. The secondary component is demagnetized at 300–350°C. At higher temperatures a decrease in the inclination of the *NRM* vector was observed and above 400°C the direction was stabilized (Fig. 3a).
2. Hematite bearing samples, where the *NRM* was a single component vector of expected Permian/Triassic inclination (Fig. 3b).
3. Hematite bearing samples, where the secondary component was relatively soft and was completely removed at a maximum temperature of 450°C. Above this temperature a low inclination component was observed. Its intensity amounts to 25% of the initial *NRM* (Fig. 3c).
4. Hematite bearing samples with a very hard secondary component. The initial *NRM* directions revealed very steep inclinations, which decreased very slowly during thermal demagnetization. Sometimes, steep inclinations were observed. Flattening of

a

b

c

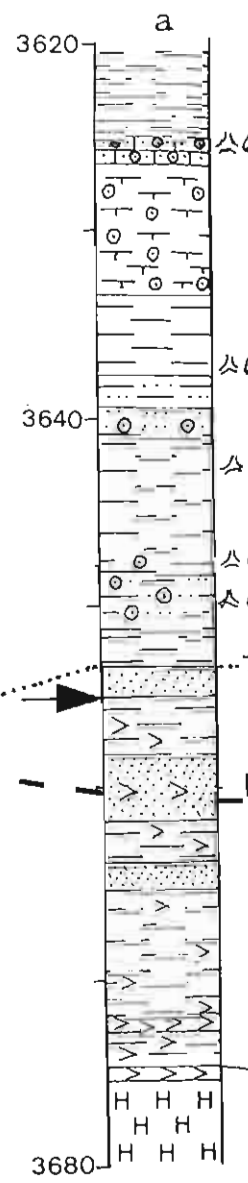
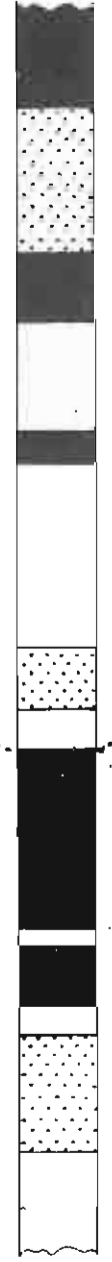
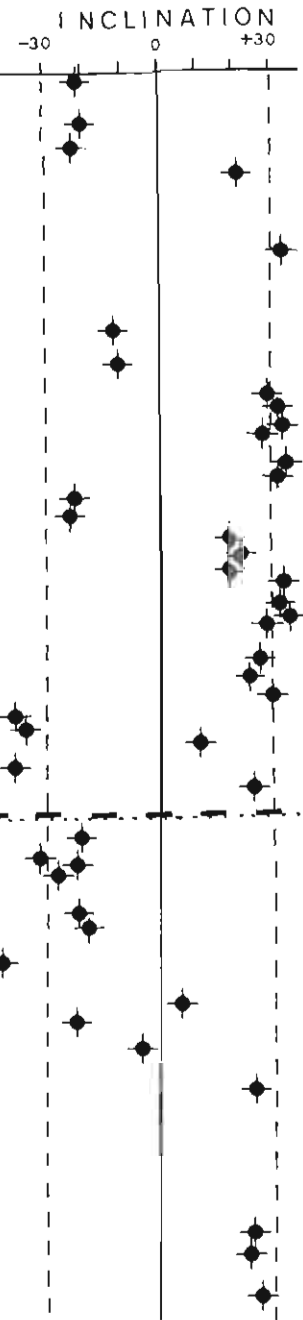
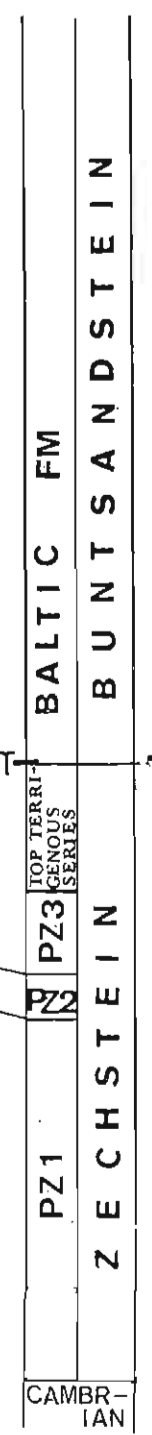
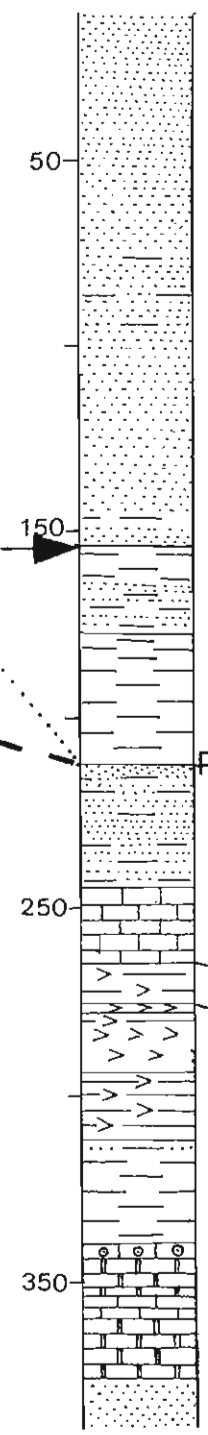
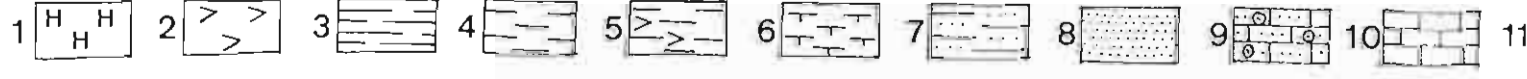
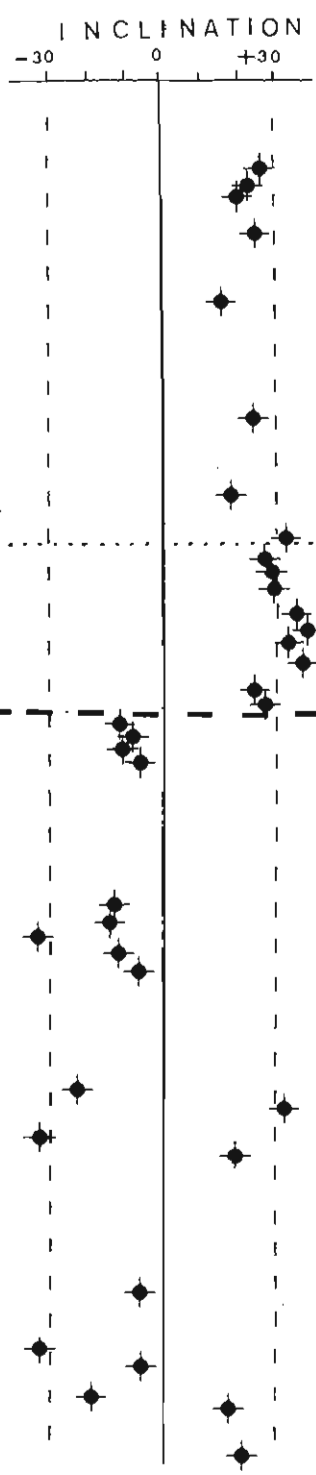
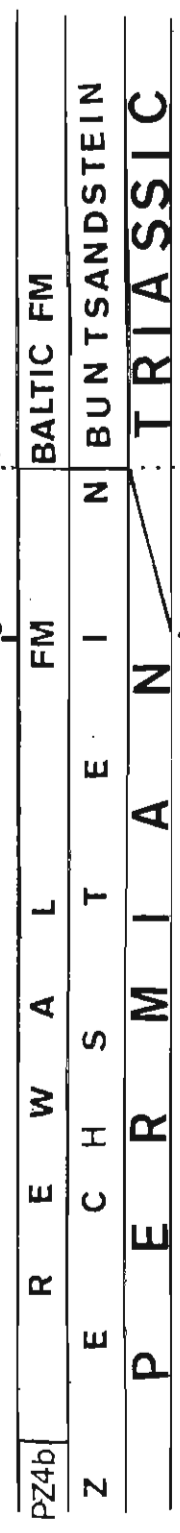
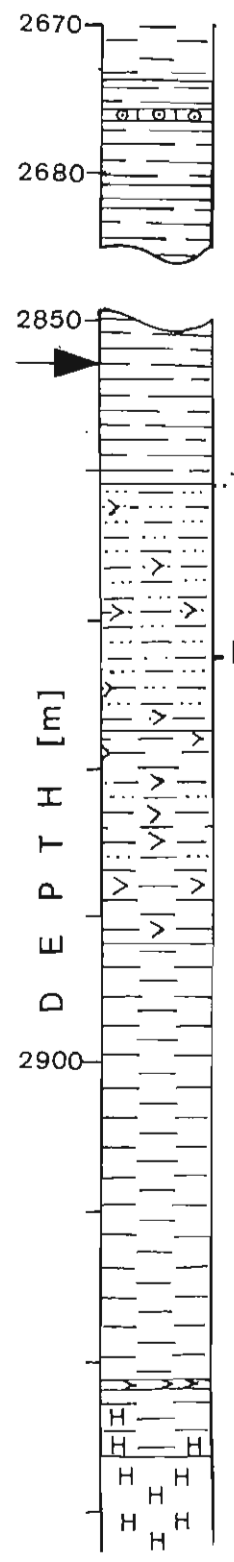
d

a

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M S Z C Z O N Ó W IG1

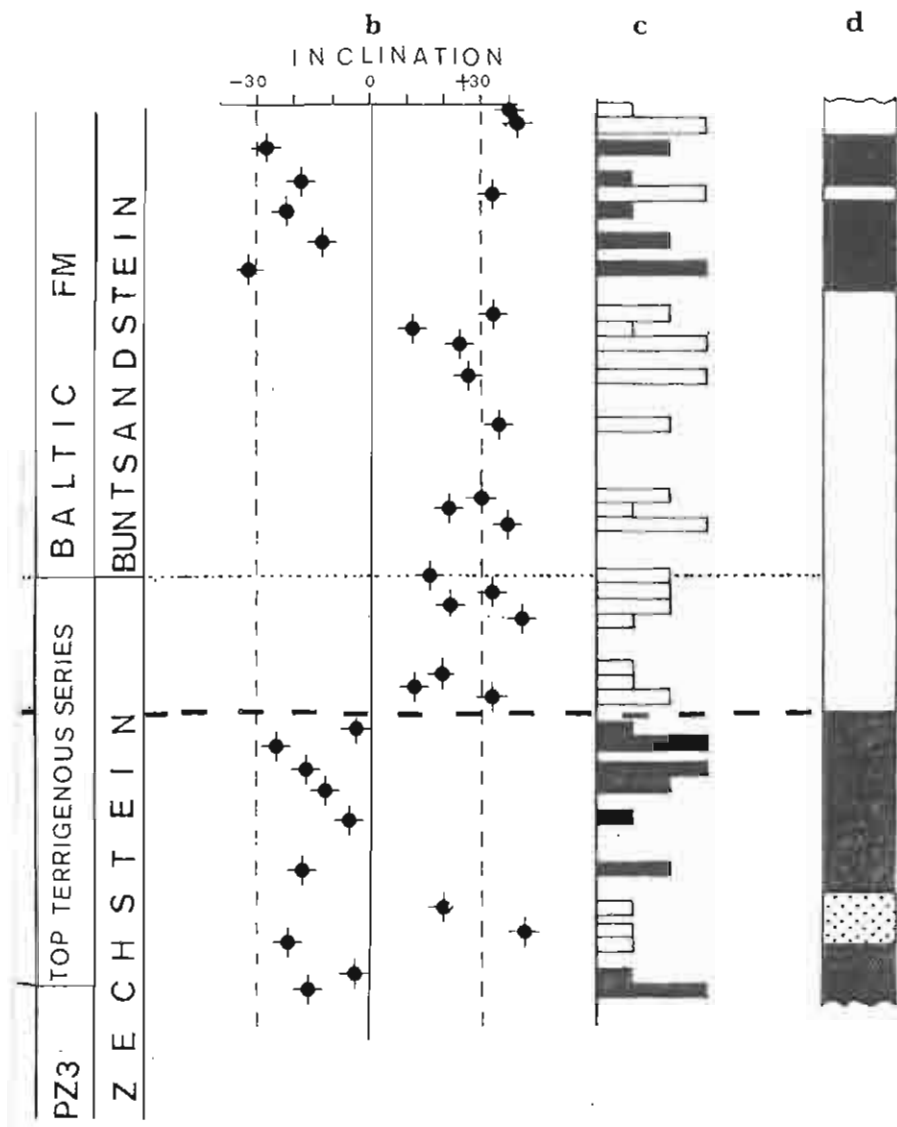


Fig. 4. Brojce IG 1, Jaworzna IG 1 and Mszczonów IG 1 boreholes

The lithological profiles with sedimentological and lithostratigraphical boundaries between Zechstein and Buntsandstein deposits (a); characteristic inclinations (b) and magnetic polarity scales (c, d) and the category of reliability of polarity interpretation (c) is indicated by length of bars: longest bars first category, medium bars — second category, shortest bars — third category (see text); 1 — rock salts, 2 — anhydrites, 3 — siltstones and claystones, 4 — siltstones, 5 — siltstones with anhydrite concretions, 6 — strongly lime siltstones, 7 — sandy siltstones, 8 — sandstones, 9 — sandy limestones with oolites, 10 — limestones, 11 — dolomites, 12 — polarity of paleomagnetic direction (a — normal, b — reversed, c — uncertain), 13 — oolites 14 — microplankton (*Acritarcha*), 15 — miospores (*Lundbledispora obsoleta* - *Protolaploxylinus pantii* Zone), 16 — lithostratigraphical boundary, 17 — sedimentological boundary (T — transgressive surface after G. Pieńkowski, 1989), 18 — magnetostratigraphic boundary

Otwory wiertnicze Brojce IG 1, Jaworzna IG 1 oraz Mszczonów IG 1 Profile litologiczne z sedymentologiczną i litostratygraficzną granicą między osadami cechsztynu i pstrego piaskowca (a); inklinacje charakterystyczne (b) oraz skale polarności magnetycznej (c, d) i kategorie wiarygodności interpretacji polarności magnetycznej (c) oznaczono za pomocą zróżnicowanej długości słupków: słupki najdłuższe — kategoria pierwsza, słupki pośredniej długości — kategoria druga, słupki najkrótsze — trzecia kategoria (patrz tekst); 1 — sole kamienne, 2 — anhydryty, 3 — mułowce i iltowce, 4 — mułowce, 5 — mułowce z kongrecjami anhydrytowymi, 6 — iltowce silnie zawapnione, 7 — mułowce zapiaszczone, 8 — piaskowce, 9 — wapień piaszczyste z oolitami, 10 — wapień, 11 — dolomity, 12 — polarność kierunku paleomagnetycznego (a — normalna, b — odwrotna, c — nieokreślona), 13 — oolity, 14 — mikroplankton (*Acritarcha*), 15 — miospory (poziom *Lundbledispora obsoleta*-*Protolaploxylinus pantii*), 16 — granica litostratygraficzna, 17 — granica sedymentologiczna (T — powierzchnia transgresywna według G. Pieńkowskiego, 1989), 18 — granica magnetostratygraficzna



the inclinations took place in the temperature range 600–670°C and the presumed Permian/Triassic component amounted to only a few percent of the initial *NRM* intensity (Fig. 3d).

POLARITY INTERPRETATION

Magnetostratigraphic profiles of the three investigated sections were constructed (Fig. 4). 158 samples were selected for the polarity interpretation. They were divided into three categories, depending on the reliability and the mode of interpretation of the characteristic direction:

1. Samples, containing at least two specimens, where the characteristic direction was calculated as the fitted line (J. L. Kirschvink, 1980). The mean direction, calculated from two or more fitted lines, revealed good internal homogeneity ($\alpha_{95} < 30^\circ$).

2. Samples, containing at least two specimens, where the characteristic direction was calculated as the stable end direction and good internal homogeneity of the mean sample direction was observed ($\alpha_{95} < 30^\circ$).

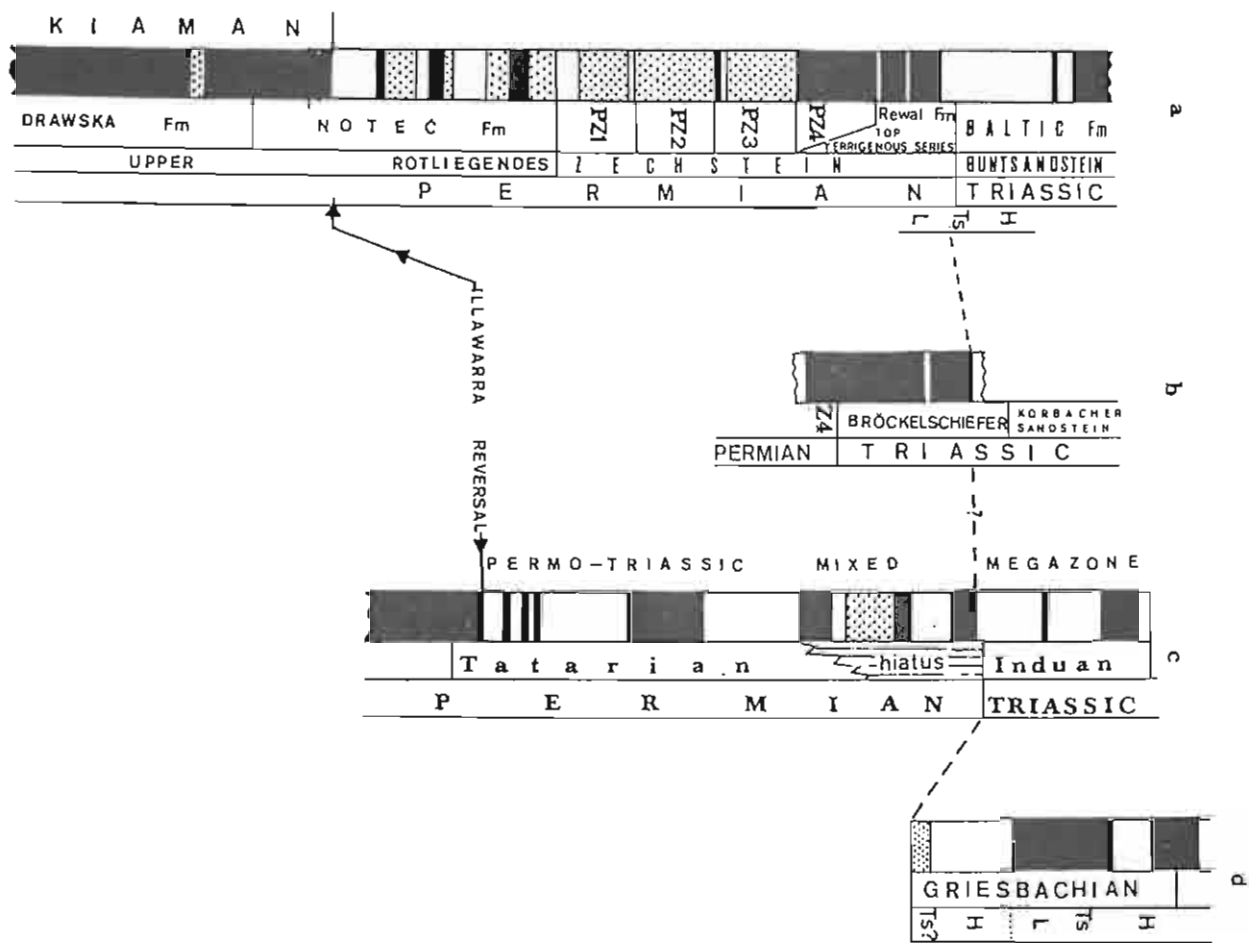
3. Samples containing only one specimen, where the characteristic direction was calculated either as the fitted line or the stable end direction.

Synthetic magnetostratigraphic profiles were constructed using the data from the first and second categories of samples.

DISCUSSION OF RESULTS

The lower boundary of the Baltic Formation was distinguished, by applying sedimentological criteria (G. Pieńkowski, 1989). In the Brojce IG 1 and Mszczonów IG 1 profiles it falls within the lower part of the normal polarity zone. In the Jaworzna IG 1 profile this boundary lies at the transition from reversed to normal polarity (Fig. 4). The duration of the polarity zones (normal or reversed), observed in the Permian/Triassic transition beds, was about one million years (M. Menning, *in press*). Thus it may be concluded that the marine transgression, indicating the bottom of the Baltic Formation, was a relatively rapid event and may be treated as a chronostratigraphic horizon in the Polish Basin. This application may be limited in the marginal parts of the basin, where several stratigraphic gaps occur and genetic interpretation of the sedimentary record is sometimes disputable (R. Wagner, 1988).

The Rewal Formation and the Top Terrigenous Series are regarded as the partial equivalents of the Bröckelschiefer-Folge in Germany (R. Wagner, 1988). Paleomagnetic data seems to confirm this correlation, however, this conclusion is only tentative. Paleomagnetic investigations have been carried out only in the Wolfshagen profile (eastern part of the Rhine Slate Mts.) and Palatinate (W. Dachroth, 1976). According to the author, the Bröckelschiefer deposits in Wolfshagen and the upper part of the Annweiler Sandstone in Palatinate are predominantly reversely magnetized. They may correlate with the reversed polarity zone covering the lower and middle



part of the Rewal Formation and the Top Terrigenous Series (Fig. 5). W. Dachroth (*op. cit.*) put the Permian/Triassic and the Zechstein/Buntsandstein boundary in the bottom of the Bröckelschiefer-Folge in Wolfshagen and in the upper part of Annweiler Sandstone in Palatinate. We suggest that boundary should, instead be put below the Korbacher Sandstone and the Trifels-Schichten respectively, therefore, between the Bröckelschiefer-Folge and Gelnhausen-Folge (G. Richter-Bernburg, 1974). It would then correspond to the boundary between the Zechstein and Buntsandstein in NW Germany (G. Best, 1987).

It is not certain, whether our boundary is identical to the Permian/Triassic boundary designated in the other basins. In the Canadian (J. G. Ogg, M. B. Steiner, 1991) and Chinese (C. Haichong et al., 1991) sections the sediments of lowermost Triassic age (Lower Griesbachian) are also normally magnetized. However, a number of normal polarity zones within the Permian part of the Illawarra interval is still unknown. In spite of this, the biostratigraphical and sedimentological evidence appears to confirm our correlations.

CONCLUSIONS

1. Most of the Zechstein/Buntsandstein transition beds in the Polish Basin (Top Terrigenous Series and Rewal Formation) are reversely magnetized. Only the uppermost part is normally magnetized. A similar polarity record had been obtained in the equivalent rocks of the German Basin.

2. The lithostratigraphic boundary between the Zechstein and the Buntsandstein lies within various parts of the zone of normal magnetization.

3. The sedimentological Zechstein/Buntsandstein boundary lies within the lower part of the normal magnetization zone.

4. The polarity change from reversed to normal lies in the vicinity of both boundaries and may be treated as the chronostratigraphic horizon for the correlation of the Upper Permian/Lower Triassic rocks.

Fig. 5. Synthetic magnetostratigraphic scale for Zechstein and Lower Buntsandstein of Polish Basin (a) and its correlation with the scale of Wolfshagen profile (SW Germany; W. Dachroth, 1976) (b) and general magnetostratigraphic scale compiled by M. Menning (*in press*) (c), and scale obtained from the Canadian Arctic sections (J. G. Ogg, M. B. Steiner, 1991; simplified) (d)

In the sequence-stratigraphy simplified column: Ts — transgressive surface, H — transgressive or high stand deposits, L — regressive or low stand deposits; in profile "a" a part of Lower Permian scale obtained from Piła IG 1 borehole is presented

Syntetyczna skala magnetostratygraficzna dla cechsztynu i dolnego pstręgo piaskowca basenu polskiego (a), jej korelacja ze skalą otrzymaną dla profilu Wolfshagen (SW Niemcy; W. Dachroth, 1976) (b), ogólna skala magnetostratygraficzna zestawiona przez M. Menninga (*w druku*) (c), a także ze skalą otrzymaną z profili arktycznej części Kanady (J. G. Ogg, M. B. Steiner, 1991, uproszczone) (d)

W kolumnie nawiązującej do stratygrafii sekwencji: Ts — powierzchnia transgresyjna, H — osady transgresyjne lub osady wysokich stanów, L — osady regresyjne lub osady niskich stanów; na profilu "a" przedstawiono część skał dolnopermjskiej opartej na danych z otworu Piła IG 1

5. The results of paleomagnetic, sedimentological and palynological studies show that the Baltic Formation of the Lower Buntsandstein may be correlatable with the Lower Griesbachian.

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GRANICA PERM/TRIAS W BASENIE POLSKIM
W ŚWIETLE DANYCH PALEOMAGNETYCZNYCH

Streszczenie

Przedmiotem badań magnetostratygraficznych były utwory cechsztynu i dolnego pstręgo piaskowca z otworów Brojce IG 1, Jaworzna IG 1 oraz Mszczonów IG 1. W ich efekcie stwierdzono, że:

- utwory wieńczące sedymentację cechsztyńską (stropowa seria terygeniczna) są namagnesowane przeważająco w kierunku odwrotnym;
- w stropie tych utworów następuje zmiana polarności na normalną, dominującą w osadach formacji bałtyckiej;
- granica litostratygraficzna między cechsztynem a pstrym piaskowcem basenu polskiego leży w różnych miejscach zony normalnej;
- granica sedymentologiczna między cechsztynem i pstrym piaskowcem basenu polskiego leży w dolnej części zony normalnego namagnesowania;
- miejsce zmiany polarności z odwrotnej na normalną, które jest położone w bliskim sąsiedztwie powyższych granic, jest reparametrem chronostratygraficznym, który może umożliwić korelację utworów z pogranicza permu i triasu z różnych basenów sedymentacyjnych.