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Buntsandstein magnetostratigraphy from the northern part of the Holy Cross Mountains

Jerzy NAWROCKI, Maria KULETA and Stanisława ZBROJA

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Lower and Middle Buntsandstein sediments from the northern part of the Holy Cross Mountains (Central Poland) were studied palaeomagnetically. The obtained palaeomagnetic pole fits well to the Early Triassic segment of the stable European apparent polar wander path. This indicates that there were no detectable horizontal tectonic rotations in this part of the Holy Cross Mountains after the Early Triassic. In the lowermost part of the Buntsandstein sequence (the A0 and A1 units) the basal Triassic normal polarity zone was identified, whereas a reversed polarity dominates in the youngest rocks of the studied sections. This predominantly reversed part can be correlated with the Pomorze Formation (lower part of the Middle Buntsandstein). The correlation of these magnetic polarity records with magnetostratigraphic data from the other parts of the Central European Basin as well as from the Tethyan sections shows that in the studied area, the Permian–Triassic boundary should be placed near the boundary between the Top Terrigenous Series (uppermost Zechstein) and the A0 unit (lowermost Buntsandstein). In the German part of the Central European Basin the Permian–Triassic boundary coincides with the boundary between the Lower and Upper Bröckelschiefer. The Buntsandstein rocks from the localities of Wióry and Sosnowica contain numerous vertebrate tracks. According to the results of magnetostratigraphic correlation they are of Dienerian (Early Triassic) age.

Jerzy Nawrocki, Palaeomagnetic Laboratory, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, Poland; e-mail: jnaw@pgi.waw.pl; Maria Kuleta and Stanisława Zbroja, Polish Geological Institute, Holy Cross Mts. Branch, Zgoda 2, PL-25-953 Kielce, Poland; e-mail: zbroja@pgi.kielce.pl *(received: March 31, 2003; accepted: July 9, 2003).*

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INTRODUCTION

The chronostratigraphic correlation between rocks from different palaeoenvironments, including those with poor fossil content, is possible using magnetostratigraphy. In recent years significant progress has been made in the magnetostratigraphy of the Permian–Triassic transition beds from the Tethyan and Boreal domains. The polarity pattern has been defined in sections from China (Chen *et al.*, 1992; Heller *et al.*, 1995; Zhu and Liu, 1999), Pakistan (Haag and Heller, 1991), Iran (Besse *et al.*, 1998), Southern Alps (Scholger *et al.*, 2000), Canadian Arctic (Ogg and Steiner, 1991) and Spitsbergen (Hounslow *et al.*, 1996; Nawrocki and Grabowski, 2000). Valuable magnetostratigraphic data were also obtained from the topmost Zechstein and Buntsandstein strata of the Central European Basin (CEB) in Poland (Nawrocki *et al.*, 1993; Nawrocki, 1997), Lithuania (Katinas, 1997) and Germany (Szurlies *et al.*, 2000). Magnetostratigraphic data (Nawrocki *et al.*, 1993; Nawrocki, 1997) seem to support the thesis that the Permian/Triassic boundary in the Polish part of CEB should be regarded as very close to the Zechstein/Buntsandstein boundary (e.g. Pieńkowski, 1991).

The southeastern limit of the CEB stretches as far as the Holy Cross Mountains in Poland. In the NW margin of the Holy Cross Mountains the sediments of the third Zechstein cyclothem are overlain by red rocks of the continental Top Terrigenous Series. The Lower Buntsandstein rocks overlying the Top Terrigenous Series were subdivided into units A0, A1, B and C (Kuleta, 1987). The A0 unit is developed as hypersaline and fluvial sediments. To the north this unit changes lateraly into marine transgressive sediments of the Opoczno Formation (Kuleta and Nawrocki, 2000). In the A1 unit the nearshore marine sandstones and conglomerates predominate. Both units contain the miospore assemblage *Lundbladispora obsoleta–Protohaploxipinus panti* (Fijałkowska, 1994). In the newest lithostratigraphical subdivision (Kuleta and Nawrocki, 2000) the A0 and A1 lithostratigraphical units were named the Siodła and Jaworznia For-

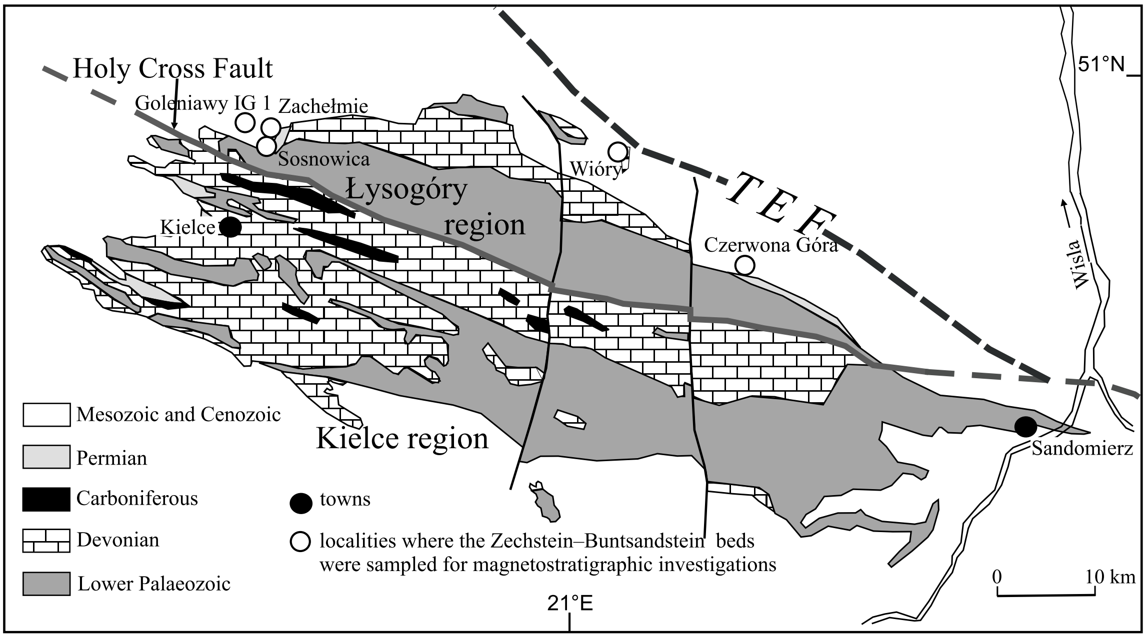

Fig. 1. The Palaeozoic core of the Holy Cross Mountain

TEF — Trans-European Fault (after Pożaryski and Nawrocki, 2000)

mation respectively. The last, uppermost unit of the Lower Buntsandstein — “C” consists mainly of fluvial sandstones, passing up into aeolian sandstones.

The palaeomagnetic properties of the Buntsandstein sediments from the Holy Cross Mountains were studied by Birkenmajer and Nairn (1964) who obtained very dispersed directions from these rocks. This was probably a result of very limited demagnetization procedures used and for this reason the new study described here has been undertaken. The Buntsandstein sediments of the Holy Cross Mountains contain numerous vertebrate tracks (Ptaszyński, 2000; Ptaszyński and Niedźwiedzki, 2002). The Buntsandstein sediments represent both terrestrial and the marginal marine facies. Such facies usually allow fairly precise sequence stratigraphy correlation. Therefore magnetostratigraphic data should be of importance for dating of these sediments. Good quality palaeomagnetic data can also allow determination of the magnitude of any post-Early Triassic horizontal tectonic rotations in this part of the Holy Cross Mountains.

SAMPLING LOCALITIES AND PALAEOMAGNETIC PROCEDURE

A total of 72 hand samples for palaeomagnetic studies were collected from the Zechstein to Middle Buntsandstein rocks drilled in the Goleniawy IG 1 vertical borehole. These samples were not azimuthally oriented. The Buntsandstein rocks were also sampled in four outcrops located in the northern region of the Holy Cross Mountains (Fig. 1). The sets from the outcrops contained 23 drill samples (Wióry and Sosnowica outcrops) and 14 hand samples which were collected from the lowermost and uppermost parts of the Lower Buntsandstein (Zachełmie and Sosnowica outcrops), and from the lower part of the Middle Buntsandstein (Czerwona Góra and Wióry outcrops). Up to three specimens were cut from each sample. A set of samples taken from the same bed was considered as one magnetostratigraphic sample. Group of specimens obtained from one independently oriented sample was regarded as one sample used for palaeopole calculation. The strata studied were characterised by less than 10° of bedding dip. Significantly larger values of bedding dip, up to 25°, were noted only in the Czerwona Góra locality.

The natural remanent magnetization (NRM) of the specimens was measured using *JR-5 spinner magnetometer* with a noise level about 0.3×10^{-5} A/m. Thermomagnetic analysis and analysis of isothermal remanent magnetization acquisition indicate the presence of hematite as the main magnetic carrier in the Buntsandstein sediments of Poland (see e.g. Nawrocki, 1997). Hence the whole sample set has been subjected to stepwise thermal demagnetization conducted in a μ-metal shielded oven, which reduces the ambient magnetic field close to a few nT. After each thermal demagnetization step magnetic susceptibility signal was monitored. Least-square line fit methods, as presented by Kirschvink (1980), were used to calculate the components of the characteristic remanence and their unblocking temperature spectra. The polarity was found as determined when at least one specimen from particular bed provided “line fit” palaeomagnetic direction.

RESULTS OF PALAEOMAGNETIC ANALYSIS

SAMPLES FROM OUTCROPS

The natural remanent magnetization of Buntsandstein sediments from Czerwona Góra, Zachełmie, Sosnowica and Wióry consists of two components. During thermal demagnetization, at

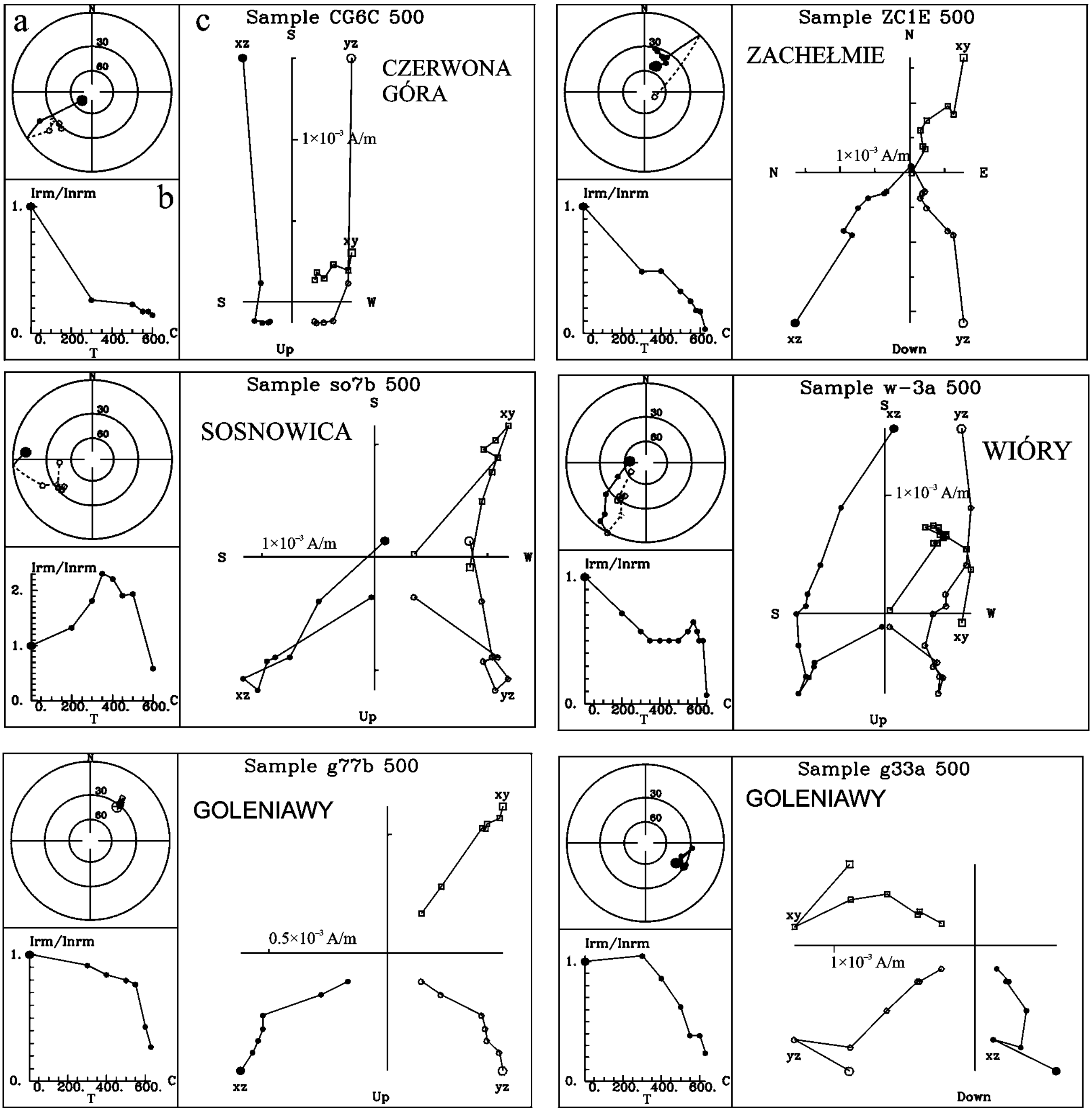

Fig. 2. Representative demagnetization data of samples from Buntsandstein sediments from Czerwona Góra, Sosnowica, Wióry and Zachełmie outcrops, and from Goleniawy IG 1 borehole

a — demagnetization tracks sterographic projections, b — intensity decay curves, c — orthogonal demagnetograms; in stereoplots, open (closed) symbols denote upward (downward) pointing inclination; Irm/Inrm — normalised intensity of remanent magnetization; T— temperature in °C

temperatures between 20–450°C, a steep, most probably present-day field component was removed (Fig. 2). The second, shallow inclination component, was fully demagnetized at temperatures higher than 600°C. The dual polarity nature of this second component and the mean inclination of *ca.* 30°, comparable with expected Early Triassic inclination, indicates its primary origin. A shallow normal polarity component was identified in one sample from the base of the Wióry profile and all samples from the Zachełmie outcrop (Fig. 2). All other outcrop samples contained a shallow reversed polarity component only. All the high temperature components (450–620°C) are grouped quite well in the NNE and SSW parts of the hemisphere (Fig. 3). Large (>10°) α 95 values were observed in the sample set from the Sosnowica outcrop only (Table 1). This scatter may be connected with the aeolian origin of these sediments, that consist of coarse-grained sandstones with dune cross-bedding.

SAMPLES FROM BOREHOLE

Nearly continuous magnetostratigraphic record was obtained from the uppermost Zechstein (Top Terrigenous Series),

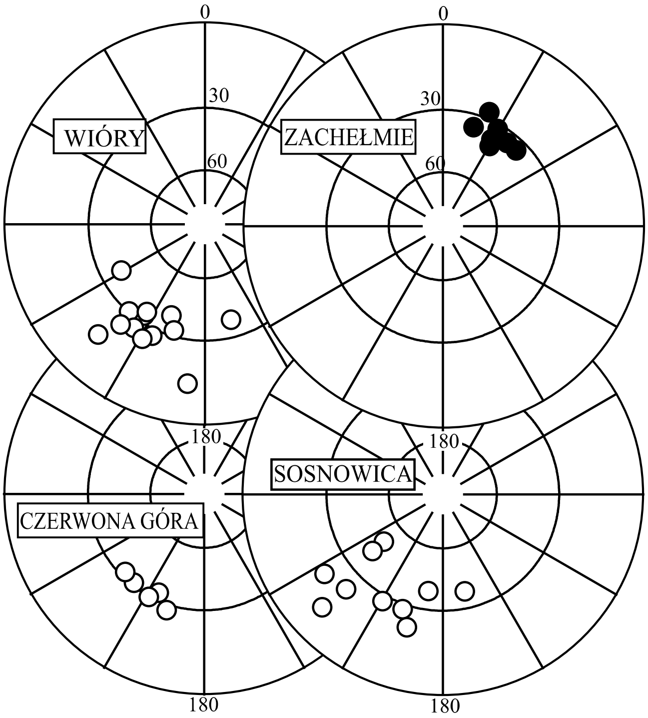

Fig. 3. Stereographic plots with palaeomagnetic line-fit directions at a sample level obtained for the Buntsandstein sediments from Czerwona Góra, Sosnowica, Wióry and Zachełmie outcrops

Open (closed) symbols denote upward (downward) pointing inclinations

lowermost Buntsandstein (A0 and A1 units) and Middle Buntsandstein rocks. However, the whole record is incomplete since middle and upper parts of the Lower Buntsandstein did not contain any suitable material for palaeomagnetic analyses.

A single distinct component of natural remanent magnetization, with maximum blocking temperatures exceeding 600°C, occurs in most of the Zechstein–Buntsandstein samples from Goleniawy IG 1 borehole (Fig. 2). The component with mean inclination 28° (Table 1) of dual polarity was recorded during the Late Permian–Early Triassic time and is most probably primary one. It was recorded in 65 samples.

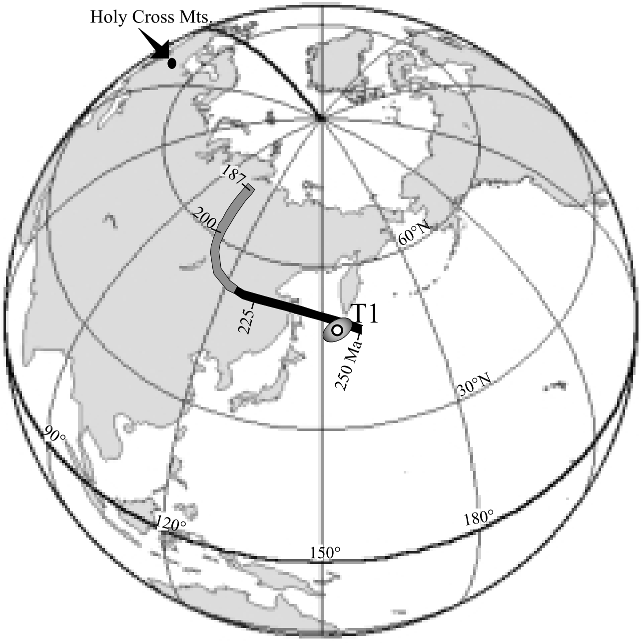

Fig. 4. Triassic–Early Jurassic apparent polar wander path for the European Plate (for construction details see text) and the Early Buntsandstein palaeopole (labeled T1) from this study

The position of the study area is indicated; the ages were adopted from the time calibration of Menning (1995) and Mundil *et al.* (1996) — Early–Middle Triassic; Kent and Olsen (1999) — Late Triassic and Palmer (1983) — Early Jurassic; they are shown in Ma

PALAEOMAGNETIC POLE

Virtual geomagnetic poles (VGP) were computed only for samples with well-defined, fitted line directions. These palaeopoles are listed in Table 1. The mean Buntsandstein VGP (labeled as "T1") has been compared with the apparent polar wander path (APWP) for stable Europe. This APWP was constructed using only good quality (Q > 4) poles. The Early Triassic poles were taken from the list of Van der Voo (1993).

Table 1

Summary of palaeomagnetic directions obtained from the Holy Cross Mts. Buntsandstein

Locality	N/n	Dabc	Iabc	α	K	Dbbc	Ibbc	α	K	Plat.	Plong.
Goleniawy (Pzt; Tp1,2)	65/117	–	28	sd = 6		–	–	–	–	–	–
Zachełmie (Tp1)	7/15	29	34	6.2	96	29	38	6.2	95	50°N	154°E
Sosnowica (Tp1)	4/10	211	–31	13.8	13.1	–	–	–	–	48°N	153°E
Wióry (Tp2)	13/17	208	–30	9.4	20.4	–	–	–	–	48°N	157°E
Czerwona Góra (Tp2)	5/11	211	–31	9.4	67.2	211	–37	20.5	14.7	48°N	154°E
summary	29 smp. 4 local.	210 210	–31 –32	4.5 2.4	36.7 1412	Plat. = 48°N, Plong. = 155°E, dp = 3°, dm = 5° Plat. = 49°N, Plong. = 155°E, dp = 2°, dm = 3°					

N — number of samples, n — number of specimens, Dabc — declination after bedding correction, Iabc — inclination after bedding correction, Dbbc — declination before bedding correction, Ibbc — inclination before bedding correction, α and K — Fisher (1953) statistics parameters, Plat. — geographic palaeolatitude of north palaeopole, Plong. — geographic palaeolongitude of north palaeopole, dp — palaeodeclination error, dm — error of the distance between the site and palaeopole, sd — standard deviation for the borehole data

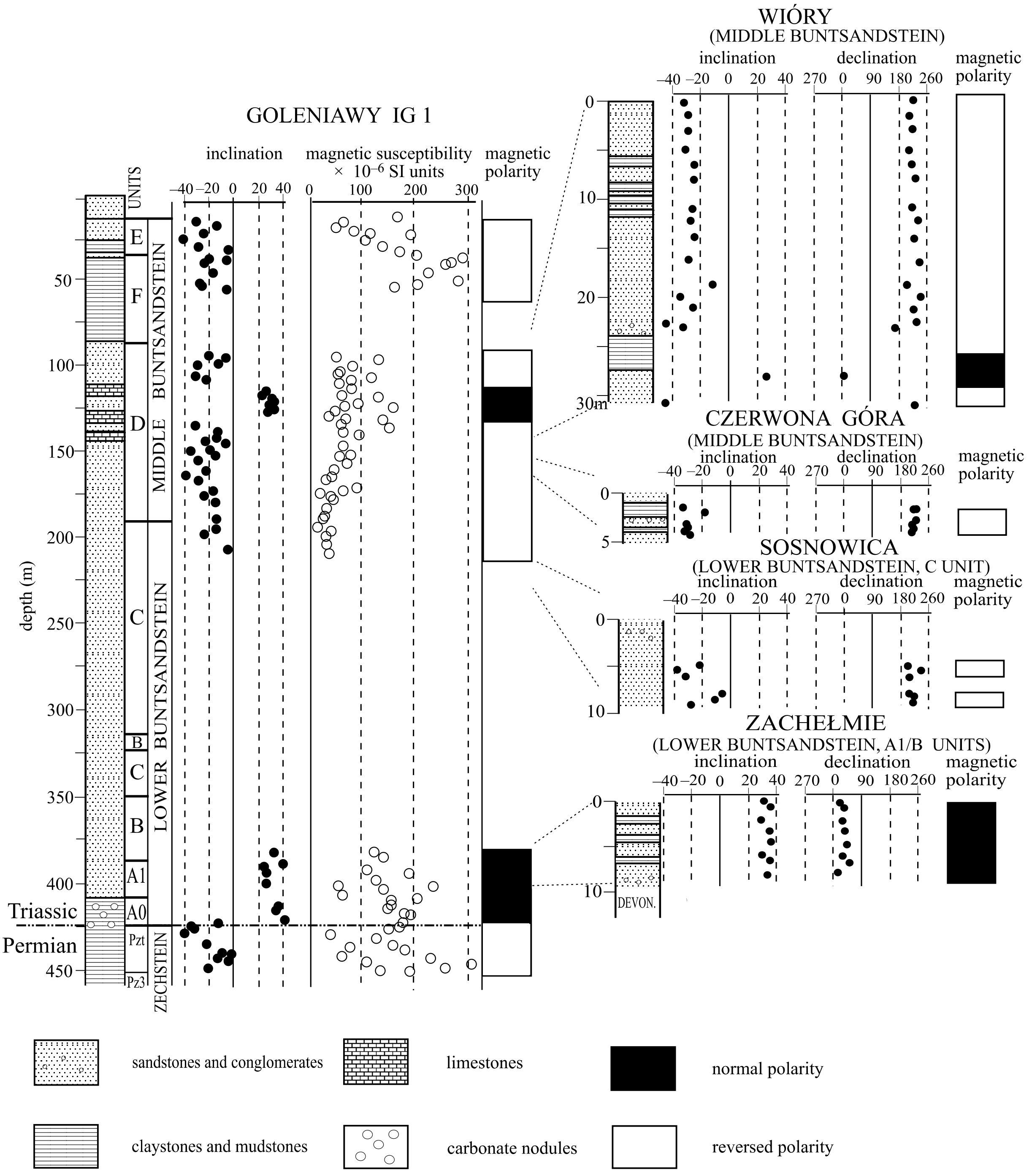

Fig. 5. Lithostratigraphy of Zechstein–Buntsandstein sequences, characteristic inclinations of magnetizations, magnetic susceptibility changes and interpreted polarity pattern recorded in the Goleniawy IG 1 borehole and its correlation with the palaeomagnetic record obtained in the Wióry, Czerwona Góra, Sosnowica and Zachełmie outcrops; the Permian–Triassic chronostratigraphic boundary is located between the A0 unit and the Top Terrigenous Series (Pzt)

They were obtained from the cratonic area of Europe (i.e. East European Platform). Six best quality Middle Triassic–Early Jurassic poles were determined in NW France and SW Germany (Theveniaut *et al.*, 1992; Edel and Duringer, 1997). The calculation and smoothing of the apparent wander path was performed using the GMAP plotting package (Torsvik and Smethurst, 1994). The smoothing procedure involves the spherical spline method and the following splining parameters have been applied: tension factor — 200, time resolution — 2.5 Ma. It is apparent that the mean palaeopole "T1" falls close to the Early Triassic (*ca.* 245 Ma) segment of the stable European APWP (Fig. 4). This indicates there were no significant horizontal tectonic rotations in this part of the Holy Cross Mountains after the Early Triassic.

The palaeolatitudinal data are important in palaeoecological and palaeoclimatic models. The mean inclination characteristic

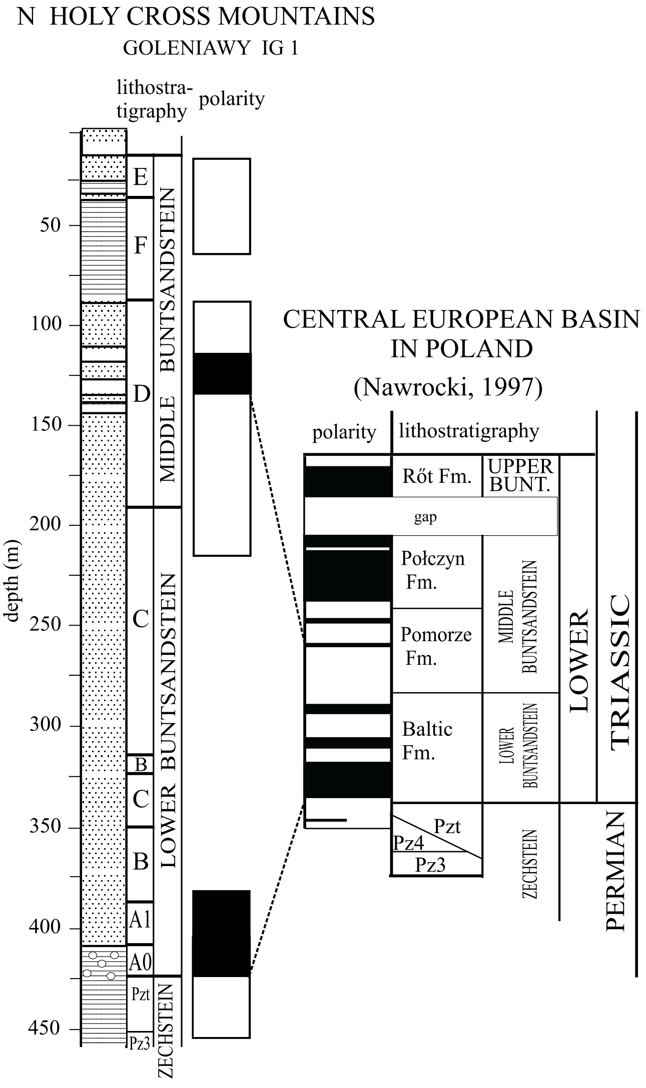

Fig. 6. Magnetic polarity pattern in the Goleniawy IG 1 borehole and its correlation with composite Permian–Buntsandstein polarity scale for Poland

for the Lower Buntsanstein sediments of the Holy Cross Mountains corresponds to a location at 17° of northern palaeolatitude.

MAGNETOSTRATIGRAPHIC CORRELATIONS

The polarity pattern in the studied rocks from Goleniawy IG 1 borehole and Zachełmie quarry is similar as that found in the other Zechstein–Buntsandstein boundary sections (Nawrocki, 1997). The Top Terrigenous Series are magnetized in a reversed polarity. The units A0 (apart from one horizon 0.7 m above the base) and A1 of the Buntsandstein have a normal polarity (Fig. 5). Hence, the Zechstein–Buntsandstein sedimentological boundary (Pieńkowski, 1991) i.e. the boundary between the Top Terrigenous Series and the A0 unit is located slightly below the level of polarity change.

In the standard magnetostratigraphic column (Nawrocki, 1997) the lower part of the Middle Buntsandstein contains predominantly reversed polarity record with two narrow normal polarity zones. The upper part of the Middle Buntsandstein is predominantly of normal polarity. The uppermost Lower Buntsandstein and Middle Buntsandstein samples from Goleniawy IG 1, Wióry, Sosnowica and Czerwona Góra are magnetized mainly in a reversed polarity. It is likely that the narrow normal polarity magnetozones observed in the Middle Buntsandstein sediments from the Goleniawy IG 1 borehole and Wióry section are coeval (Fig. 5). There is no time equivalents of the Połczyn Formation (i.e. the upper part of the Middle Buntsandstein) in the Goleniawy IG 1 borehole (Fig. 6).

The Buntsandstein rocks from the Wióry and Sosnowica localities contain numerous vertebrate tracks (Ptaszyński, 2000; Ptaszyński and Niedźwiedzki, 2002). Ptaszyński and Niedźwiedzki (2002) postulated Late Permian age for the tracks from Sosnowica. This supposition, however, seems to be unfounded. According to the magnetostratigraphic data the uppermost Lower Buntsandstein and lower Middle Buntsandstein should be correlated with the Dienarian stage of Early Triassic (Fig. 7). Accordingly, the vertebrate trace markers of Sosnowica must have been actually of the Triassic, not Permian age.

In the stratotype section at Meishan, the Permian–Triassic boundary is located within a thin reversed magnetozone (Zhu and Liu, 1999). In the another Chinese section, Wulong, this magnetozone is much thicker and the Permian–Triassic boundary is situated within its topmost part (Chen *et al.*,1992). Figure 7 shows correlation of the magnetic polarity pattern of these Chinese sections with the polarity pattern obtained for the Zechstein–Buntsandstein boundary sections from the CEB. The basic template of this correlation is the assumption that the wide normal polarity zone of the lowermost Buntsandstein should correspond to the lower Griesbachian normal polarity zone (designated TBZ) detected in the Tethyan and Boreal sections (see Ogg and Steiner, 1991; Heller *et al.*, 1995; Hounslow *et al.*, 1996; Besse *et al.*,1998; Zhu and Liu, 1999; Scholger *et al.*, 2000). This assumption is documented by the presence of the Griesbachian miospore *Lundbladispora obsoleta–Protohaploxipinus panti* assemblage in the lowermost part of the Baltic Formation (Orłowska-Zwolińska, 1984; Fijałkowska, 1994). Also the overlying magnetozones detected in the Buntsandstein provide a good match to the Lower Triassic polarity pattern known from marine sediments (Nawrocki, 1997; Nawrocki and Szulc, 2000; Schurlies *et al.*, 2000). The location of the Permian–Triassic chronostratigraphic boundary in the topmost part of the reversed magnetozone that precedes the TBZ in the Meishan section constrains the placement of this boundary in sediments from the CEB. This boundary is situated between the Lower and Upper Bröckelschiefer (German part of the CEB), and between the Top Terrigenous Series and the Baltic Formation or A0 unit in the Polish part of the CEB. Taking into consideration the results of magnetic susceptibility studies of the Permian–Triassic transitional beds (Hansen *et al.*, 1999) it is not excluded that this boundary is located slightly below the bottom of the A0 unit, in the place where susceptibility low is observed (Fig. 5). Magnetostratigraphic data do not support

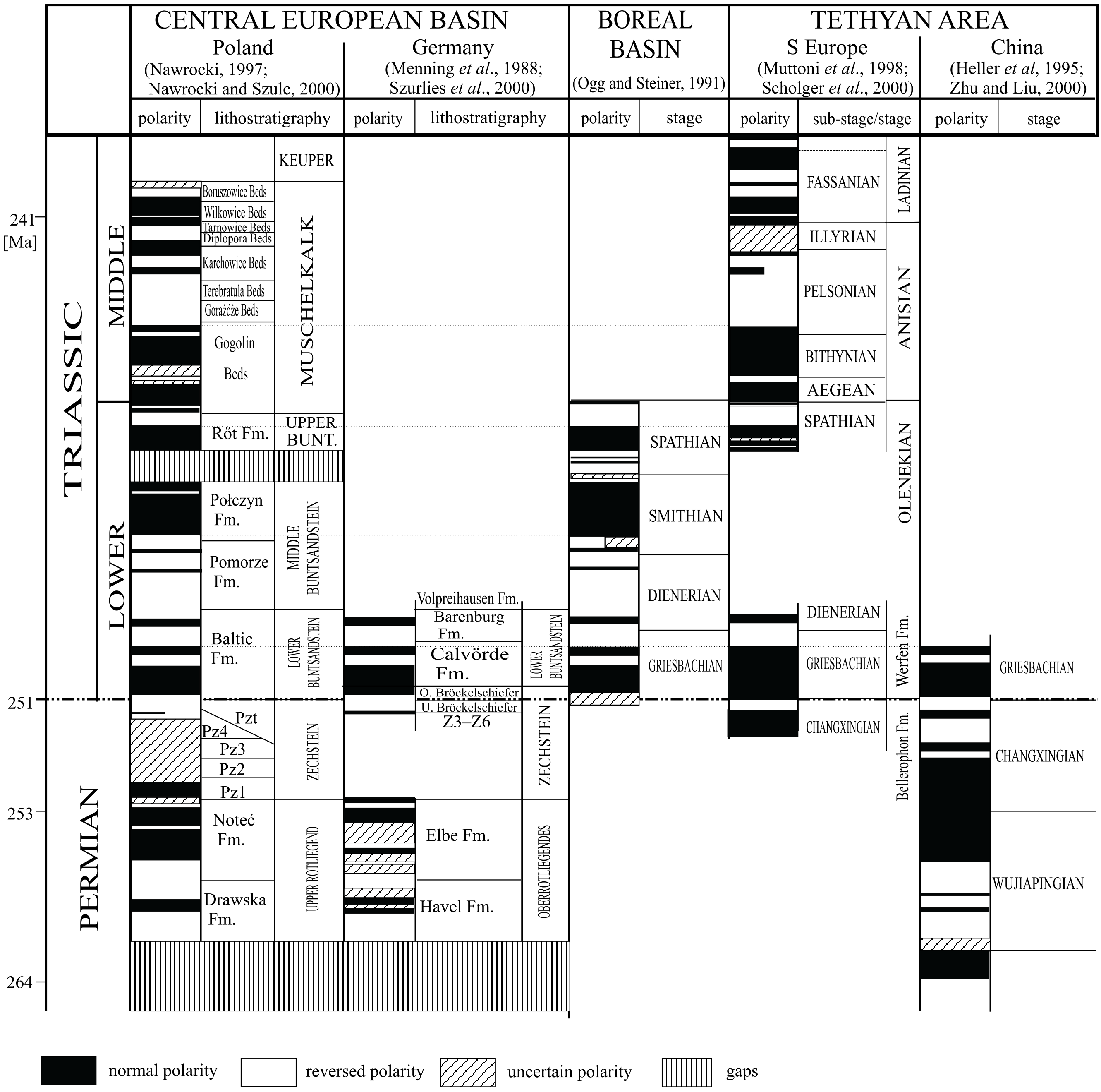

Fig. 7. Location of the Permian–Triassic boundary within the magnetostratigraphic sections from China, S Europe, N Canada (Boreal Basin) and the Central European Basin in Poland and Germany

Pzt — Top Terrigenous Series

the solution of placing the Permian–Triassic boundary in the lower part of the Calvörde Formation (Kozur, 1989). This part of the Buntsandstein is characterised by normal polarity only (Szurlies *et al*., 2000).

CONCLUSIONS

Palaeomagnetic studies of the the latest Permian–Early Triassic rocks from the northern part of the Holy Cross Mountains reveal dual polarity primary magnetizations. In the lowermost part of the Buntsandstein sequence the lower Griesbachian normal polarity zone was identified. Results of magnetostratigraphic correlation show that in the studied area the Permian–Triassic chronostratigraphic boundary should be close to the boundary between the Top Terrigenous Series (uppermost Zechstein) and the A0 unit (lowermost Buntsanstein). In the German part of the Central European Basin the Permian–Triassic chronostratigraphic boundary coincides with the boundary between the Lower and Upper Bröckelschiefer. The vertebrate tracks from the localities Wióry and Sosnowica are of Early Triassic (Dienerian) age. The obtained palaeomagnetic pole is consistent with the Early Triassic segment of the Stable European apparent polar wander path, indicating there were no detectable horizontal tectonic rotations in this part of the Holy Cross Mountains after the Early Triassic.

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