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Lithospheric structure of the TESZ in Poland based on modern seismic experiments

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This paper presents the results of seismic investigations on the structure of the lithosphere in the area of the Trans-European Suture Zone (TESZ) in Poland that is located between the southwestern margin of the East European Craton (EEC) to the north-east, the West and Central European Palaeozoic Platform (PP) to the south-west and the Carpathians to the south. Based on results of the modern POLONAISE'97 and CELEBRATION 2000 projects, as well as older profiles, models are presented for the configuration and extent of different crustal types. In the investigated area, the EEC has a relatively uniform crustal thickness of 40 to 50 km with its three-layered crystalline crust displaying P-wave velocities of 6.1–6.4, 6.5–6.8 and 6.9–7.2 km/s in the upper, middle and lower parts, respectively. The Variscan consolidated crust is covered by 1–2 km thick sediments and consists of two layers with velocities of 5.6–6.3 and 6.5–6.65 km/s. In the Carpathians, sediments reaching to depths of some 20 km and are characterized by velocities of <5.6–5.8 km/s, whilst the underlying two-layered crystalline crust displays velocities of 6.0–6.2 and 6.5–6.9 km/s. The crust of the TESZ can be divided into the Małopolska, Kuiavia and Pomerania blocks that are overlain by up to 9–12 km thick sediments having velocities <5.4 km/s. In the area of the TESZ, the upper part of the consolidated crust has to depths of 15–20 km relatively low velocities of <6.0 km/s and is commonly regarded as consisting of deformed and slightly metamorphosed Early Palaeozoic sedimentary and volcanic series. In this area the middle and lower crust are characterized by velocities in the range of 6.3–6.6 km/s and 6.8–7.2 km/s, respectively, that are comparable to the EEC. Based on the dense network of seismic profiles the map of the depth to Moho is given for the area of Poland. Uppermost mantle reflectors occur about 10 to 15 km below the Moho whereas the deepest reflectors are recorded at depths of 90 km. Future investigations ought to aim at an integrated geological-geophysical program, including deep near-verical reflection-seismic profiling and ultimately the drilling of deep calibration boreholes.

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INTRODUCTION AND THE GEOLOGY OF THE AREA

The structure and evolution of the Trans-European Suture Zone (TESZ), forming in Poland the transition zone between Precambrian East European Craton (EEC) and the Phanerozoic terranes of Western and Central Europe, is still not fully resolved. The EEC evolved by amalganation of three major lithospheric terranes, referred to as Fennoscandia, Sarmatia and Volgo-Uralia, all of which are interpreted as large composite terranes that underwent an independent Archean and Early Proterozoic history (Bogdanova *et al*., 1996, 2001; see also Grad *et al*., 2006*b*). During the Palaeozoic accretion (amalgamation) of the TESZ terranes to the margin of the EEC three stages can be recognized: (1) Cambrian accretion of the Bruno-Silesian, Łysogóry and Małopolska terranes, (2) end Ordovician/Early Silurian accretion of Avalonia, and (3) Early Carboniferous accretion of composite Armorica (Winchester *et al*., 2002*a*; see also other scenarios by Dadlez *et al*., 1994, 2005; Narkiewicz, 2002). Armorica, more recently termed the Armorican Terrane Assemblage (ATA; e.g., Franke, 2000; Tait *et al*., 2000; Winchester *et al*., 2002*b*), extends across Europe from southern Spain to the Carpathian Mountains over a distance of about 4000 km and attains a width of up to 700 km (Paris and Robardet, 1990). The younger Carpathians and Eastern Alps and the Pannonian Basin form part of the interrelated Mediterranean system of orogenic belts and back-arc basins (Ziegler, 1990; Cavazza *et al*., 2004).

Table 1

Seismic experiments in the area of TESZ

Project	Year of experiment	Length of profile [km]	References
BABEL, Profile A	1989	410	BABEL Working Group (1993)
Baltic Sea Profile	1989	500	Ostrovsky *et al.* (1994)
BASIN’96	1996	425	Bayer *et al.* (2002)
CELEBRATION 2000, Profile CEL01	2000	880	Środa *et al.* (2006)
CELEBRATION 2000, Profile CEL02	2000	415	Malinowski *et al.* (2005)
CELEBRATION 2000, Profile CEL03	2000	430	Janik *et al.* (2005)
CELEBRATION 2000, Profile CEL05	2000	1420	Grad *et al.* (2006*a*)
CELEBRATION 2000, Profile CEL11	2000	280	Guterch *et al.* (2003*a*, *b*)
CELEBRATION 2000, Profile CEL21	2000	330	Guterch *et al.* (2003*a*, *b*)
EGT	1986	825	Ansorge *et al.* (1992)
EUGENO-S, Profile 4	1984	650	Grad *et al.* (1991)
EUROBRIDGE’95	1996	280	EUROBRIDGE Working Group (2001)
LT-2	1974	220	Guterch *et al.* (1976); Grad *et al.* (2005)
LT-4	1976	260	Guterch *et al.* (1983); Grad *et al.* (2005)
LT-5	1977	280	Guterch *et al.* (1983); Grad *et al.* (2005)
LT-7	1987, 1992	560	Guterch *et al.* (1994, 1999)
POLONAISE’97, Profile P1	1997	300	Jensen *et al.* (1999)
POLONAISE’97, Profile P2	1997	300	Janik *et al.* (2002)
POLONAISE’97, Profile P3	1997	300	Środa and POLONAISE Profile P3 Working Group (1999)
POLONAISE’97, Profile P4	1997	800	Grad *et al.* (2003*a*)
POLONAISE’97, Profile P5	1997	180	Czuba *et al.* (2001, 2002)
PQ	1996	350	Bleibinhaus *et al.* (1999)
TTZ	1993	450	Grad *et al.* (1999)

Early deep seismic sounding (DSS) studies in Central Europe showed a big contrast between the crustal structure of the Palaeozoic Platform (PP), TESZ and EEC (e.g., Guterch *et al.*, 1976, 1983, 1986; Guggisberg *et al.*, 1991; Ansorge *et al.*, 1992; see also Table 1). In Central Europe, between the Baltic and Adriatic seas, a series of large, modern seismic experiments were performed during 1997–2003, including the POLONAISE’97, CELEBRATION 2000, ALP 2002 and SUDETES 2003 surveys (Guterch *et al.*, 1998, 1999, 2001, 2003*a*, *b*; Grad *et al.*, 2003*b*; Brückl *et al.*, 2003). The aim of the present paper is to briefly summarize the results of the above experiments with respect to the TESZ area, whereas their implications for the lithospheric structure of the western EEC are outlined in a companion paper in this volume (Grad *et al.*, 2006*b*).

PREVIOUS GEOPHYSICAL INVESTIGATIONS IN POLAND

The crustal configuration of Poland has been explored during the last three decades employing a variety of geophysical methods. Early deep seismic sounding (DSS) studies, which were performed in 1970’s and 1980’s, indicate that in Poland crustal thicknesses vary between 30–35 km in the domain of Palaeozoic terranes, 42–48 km in the EEC, and up to 50–55 km in the southern parts of the Teisseyre-Tornquist Zone (TTZ). In the Carpathians and their foredeep, a crustal thickness about 40 km was found (Guterch *et al.*, 1976, 1983, 1986).

Many non-seismic studies have been undertaken in Poland and surrounding area. Heat flow measurements indicate a major change in the thermal regime across the TESZ. Čermák and Bodri (1998) divided Europe into two heat flow regimes, namely the Precambrian craton, including the Caledonides of Scandinavia (the so called pre-Variscan Europe — PVE), and the currently tectonically more active Variscan and Alpine domains (VAE) in the south. Based on over 3200 heat flow measurements, they found an average value for Europe of 57.0 W/m^2, and values of 63.7 and 48.7 mW/m^2 for the VAE and PVE, respectively. Thus, the TESZ separates the “cold” lithosphere of the EEC with a low heat flow of 30–40 mW/m^2 from the “hot” lithosphere of the Palaeozoic terranes and Carpathians that is characterized by a higher heat flow of 40–70 mW/m^2 (Majorowicz and Plewa, 1979; Čermák *et al.*, 1989; Plewa, 1998; Čermák and Bodri, 1998; Majorowicz *et al.*, 2003; Królikowski, 2006). The characteristic Moho temperature for the EEC has been estimated at 500°C (Majorowicz *et al.*, 2003) and 590–620°C (Čermák *et al.*, 1989). In the TESZ region, the Moho temperature increases to 650–750°C and beneath the Carpathians further to about 800°C (Čermák *et al.*, 1989; Majorowicz *et al.*, 2003).

Gravity and magnetic data from Poland indicate also a major change in the lithospheric structure (Królikowski and Petecki, 1995; Wybraniec *et al.*, 1998; Grabowska and Bojdys, 2001; Petecki *et al.*, 2003; Królikowski, 2006). In the area of the EEC Bouguer anomalies are relatively homogeneous (0±20 mGal) and decrease in the area of the EEC margin to about –40 mGal. In this region, the anomaly field becomes more complex with a large high occuring in the area of the Holy Cross Mountains and lower values to the north-west along the EEC margin. In the Carpathians, Bouguer anomalies reach values of about –80 mGal. The magnetic anomalies of the EEC contain many short wavelength variations from –1500 to +1500 nT that correlate well with tectonic features and intrusions in the Precambrian basement. To the south-west of the TESZ, the Carpathian foredeep and the Carpathians are charac-

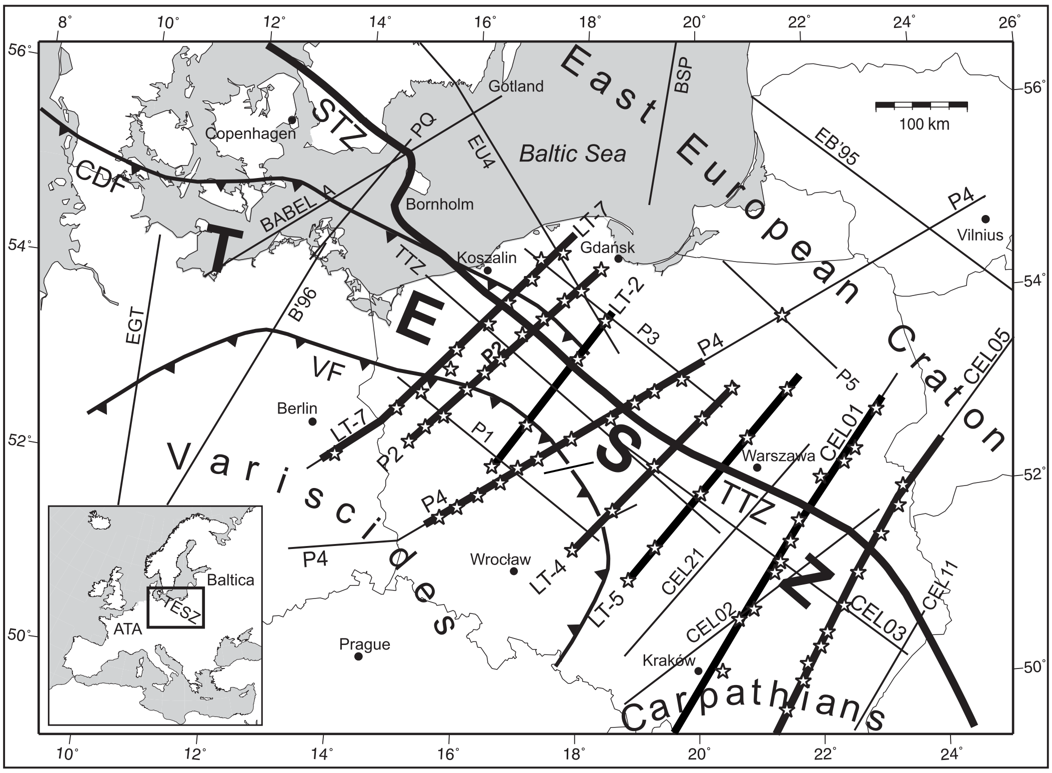

Fig. 1. Location of seismic profiles on the background of simplified tectonic map of the Trans-European Suture Zone (TESZ) in Central Europe

Stars and thick lines refer to the location of shot points and profiles for which crustal models are given in Figure 2; thin lines — other seismic profiles: B'96 — BASIN'96 profile; BSP — Baltic Sea profile; CEL01, CEL02, CEL03, CEL05, CEL11 and CEL21 — profiles from CELEBRATION 2000 experiment; EB'95 — EUROPROBE'95 profile; EU4 — EUGENO-S profile 4; P1, P2, P3, P4 and P5 — profiles from POLONAISE'97 experiment (for references see Table 1); ATA — Armorican Terrane Assemblage; CDF — Caledonian Deformation Front; STZ — Sorgenfrei-Tornquist Zone; TTZ — Teisseyre-Tornquist Zone; VF — Variscan Front; other explanations see Table 1

terized by subdued magnetic anomalies (±100 nT) presumably due to deep burial of the basement.

MODERN SEISMIC EXPERIMENTS

Beginning in 1997, Central Europe was gradually covered by an unprecedented network of modern seismic refraction experiments that focused attention on its crustal and lithospheric mantle structure and tectonic evolution. These experiments were only possible due to a massive international cooperative effort. The first of the new experiments was POLONAISE'97 (Guterch *et al.*, 1998, 1999). The obtained high quality seismic data reveal both the P- and S-wave structure of the crust and uppermost mantle. Apart from collecting 2D models along five profiles P1–P5 (Jensen *et al.*, 1999; Środa *et al.*, 1999; Czuba *et al.*, 2001; Grad *et al.*, 2002*a*, 2003*a*; Janik *et al.*, 2002; Majdański and Grad, 2005) this experiment showed how much could be learned from even modest 3D coverage (Środa *et al.*, 2002; Czuba *et al.*, 2002).

A series of even larger experiments than POLONAISE'97 followed in rapid succession, namely CELEBRATION 2000, ALP 2002 and SUDETES 2003 (Brückl *et al.*, 2003; Grad *et al.*, 2003*b*; Guterch *et al.*, 2003*a*, *b*). As a result, a dense network of seismic refraction profiles covers now the TESZ region of Poland and extends onto the EEC and Bohemian Massif (Fig. 1), through the Western Carpathians and Eastern Alps into the Pannonian Basin and across the Dinarides to the Adriatic Sea. The principal objectives of these experiments concerning the area of Poland were to:

— investigate the deep structure of the southwestern margin of the EEC (southern Baltica) and its relationship to younger terranes;

— delineate the major terranes and crustal blocks in the TESZ region (e.g., Upper Silesian Block, and blocks exposed in the Holy Cross Mountains);

— investigate the nature and extent of thrust faulting along the northern front of the Carpathian Mountains.

All four experiments were very effective and were carried out as large international cooperative efforts that involved institutions from Europe and North America. In each experiment from 613 to 1230 instruments were deployed to record seismic signals from a total of 295 shot points in Poland, Czech Republic, Hungary, Austria, Slovakia, Lithuania, Belarus, Russia, Germany, Slovenia and Croatia. The records obtained from about 7000 sites provided seismic data along profiles with a total length about 19000 km, as well as a 3D picture of the crust and upper mantle. For all profiles the acquired seismic data were interpreted using modern techniques, including modelling by two- and three-dimensional seismic tomography (e.g., Hole, 1992; Zelt and Barton, 1998) and ray tracing (Červený and Pšenčík, 1983).

SEISMIC CHARACTERISTIC OF THE CRUST IN POLAND

The profiles LT-2, LT-4 and LT-5 that were recorded in the 1970's (Guterch *et al*., 1976, 1983) were recently re-interpreted using modern ray tracing techniques (Grad *et al*., 2005). The first modern profiles LT-7 and TTZ were acquired in the early 1990's (Guterch *et al*., 1994; Grad *et al*., 1999). The more recently completed POLONAISE'97 and CELEBRATION 2000 surveys provided new results along additional profiles in the area of Poland (Jensen *et al*., 1999; Środa *et al*., 1999, 2002; Wilde-Piórko *et al*., 1999; Krysiński *et al*., 2000; Czuba *et al*., 2001, 2002; Grad *et al*., 2002*a*, 2003*a*, 2006*a*; Janik *et al*., 2002, 2005; Dadlez *et al*., 2005; Majdański and Grad, 2005; Malinowski *et al*., 2005). The location of the entire Polish network of profiles is shown in Figure 1, together with selected profiles in the neighboring countries, such as BABEL A, BASIN'96, Baltic Sea Profile, EUROBRIDGE'95, EGT Transect, PQ profile and EUGENO-S profile 4 (Grad *et al*., 1991; Ansorge *et al*., 1992; BABEL Working Group, 1993; Ostrovsky *et al*., 1994; Bleibinhaus *et al*., 1999; EUROBRIDGE Working Group, 2001; Bayer *et al*., 2002). Seismic models of the crustal structure are given in Figure 2 for the LT-7, P2, LT-2, P4, LT-4, LT-5, CEL01 and CEL05 profiles.

Results of our experiments permit to distinguish four principal crustal types, namely (1) the EEC crust in the north-east including its slope, and to the south-west (2) the TESZ, (3) Variscan and (4) the Carpathian crust. For these different crustal types P-wave velocity profiles are given in Figure 3.

EAST EUROPEAN CRATON

The area of the EEC is characterized by a thin, about 1–2 km thick sedimentary cover (Fig. 3a). In the region of Mazury–Suwałki elevation (NE Poland), the depth to basement is only 0.3–1 km but increases southwestwards to 7–8 km along the margin of the EEC (Fig. 3b). The crystalline crust of the EEC displays a three-layered structure in which the upper, middle and lower crust are characterized by P-wave velocities of 6.1–6.4 km/s, 6.5–6.8 km/s and 6.9–7.2 km/s, respectively (Fig. 2). In the study area, total crustal thicknesses reach values of 48–50 km, decreasing slightly along the EEC margin in NW Poland to 40–44 km in profiles LT-7, P4 and LT-4. The Vp velocity beneath the Moho is 8.1–8.2 km/s. A similar three-layered crystalline crust characterizes the Svecofennian region that is located east and south-east of the Sveconorwegian deformation front and the Transscandinavian Igneous Belt (Grad and Luosto, 1987, 1994; EUROBRIDGE Working Group, 2001). The same applies also for the crust of the Baltic Sea, as seen on the BABEL A profile (BABEL Working Group, 1993) that was recorded near the coast of Sweden. The relatively uniform velocity pattern and thicknesses of individual layers in the EEC crystalline crust point to its significant homogenization (see also Kozlovskaya *et al*., 2004; Grad and Tripolsky, 1995). Only in the upper crust high velocity bodies were delineated that correlate with the Kętrzyn and Suwałki anorthosite intrusions on profile P5 (Czuba *et al*., 2002) and on profile P4 (Grad *et al*., 2003*a*).

DOMAIN OF THE TESZ

In the area of Poland the TESZ contains at least three different crustal blocks or terranes. From south-east to north-west, these are the Małopolska Massif (Fig. 3c), the Kuiavia Block (Fig. 3d) and the Pomerania Block (Fig. 3e) that differ in their crustal structure and thickness, and the thickness of the sedimentary cover. The sedimentary layer attains thicknesses of up to 9–12 km with velocity <5.4 km/s. Its upper parts consist of Permian and Mesozoic sequences that reach maximum thicknesses of 7–8 km, whereas Devonian and Carboniferous epicontinental deposits form its lower part. The upper part of the consolidated crust, which has relatively low velocities <6.0 km/s and extends to depth of about 15–20 km, is generally regarded as being composed of deformed and slightly metamorphosed Early Palaeozoic sedimentary and volcanic series that albeit have not been penetrated by boreholes. Average velocities of the middle and lower crust are 6.3–6.6 km/s and 6.8–7.2 km/s, respectively and, as such, are similar to those of the EEC. The high velocity lower crust, characterized by a high velocity gradient and strong ringing reflectivity (see profile LT-7 in Fig. 2), has a distinctly laminar seismic structure (Fig. 3e; Guterch *et al*., 1992; Jensen *et al*., 1999; Grad *et al*., 2002*a*). The postulated boundary between the Kuiavia and Pomerania blocks is rather sharp at the levels of the middle and lower crust (compare Fig. 3d and e; Dadlez *et al*., 2005). The attenuated lower and middle crust of TESZ could belong to proximal terranes consisting of the EEC crust that were detached in the south-east from the EEC and that were re-accreted to the EEC in the course of the Ordovician-Early Silurian anticlockwise rotation of the Baltica palaeocontinent (Dadlez *et al*., 1994, 2005; Narkiewicz, 2002).

VARISCAN DOMAIN

Variscan consolidated crust with a 1–2 km thick sedimentary cover, is characterized by Vp = 5.6–6.3 km/s in its upper part and by Vp = 6.5–6.65 km/s in its lower part (Fig. 3f). These velocities are similar to those of other Variscan areas of Central Europe (Wever *et al*., 1990; Grad *et al*., 2002*a*), which also display a two-layered crustal structure with relatively low P-wave velocities continuing through the entire crust. The Variscan crust has a much simpler structure than the crust of the EEC and TESZ, due to the absence of a high velocity lower crust.

CARPATHIAN DOMAIN

The Carpathians are characterized by a complex supracrustal structure that reaches to depths of some 20 km with rocks displaying velocities <5.6 km/s. Beneath this cover, a two-layer crystalline crust has velocities of 6.0–6.2 and 6.5–6.9 km/s,

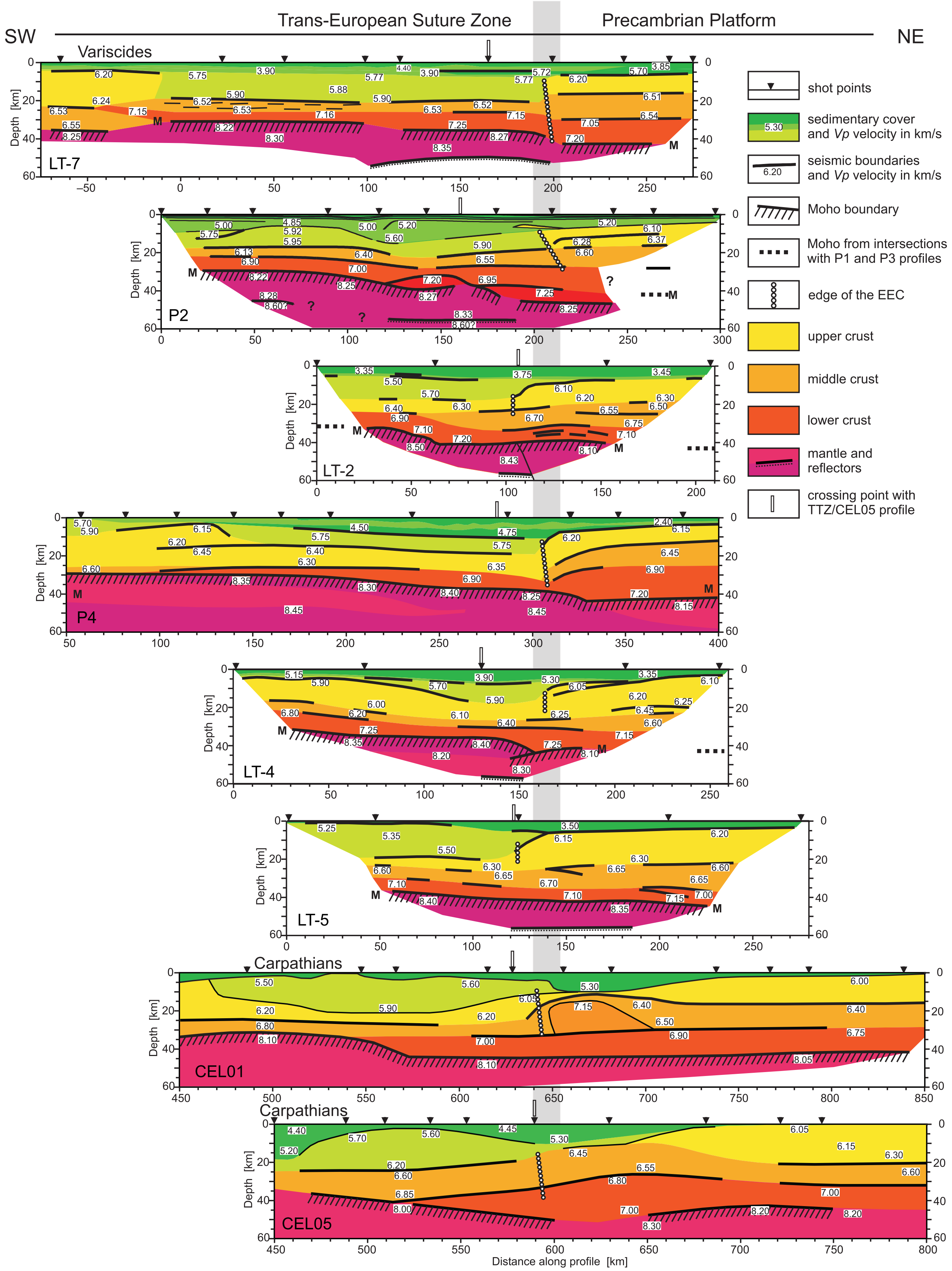

Fig. 2. Seismic models of the structure for LT-7, P2, LT-2, P4, LT-4, LT-5, CEL01 and CEL05 profiles; P-wave velocities in km/s

Grey vertical band gives location of the TTZ; for references see Table 1

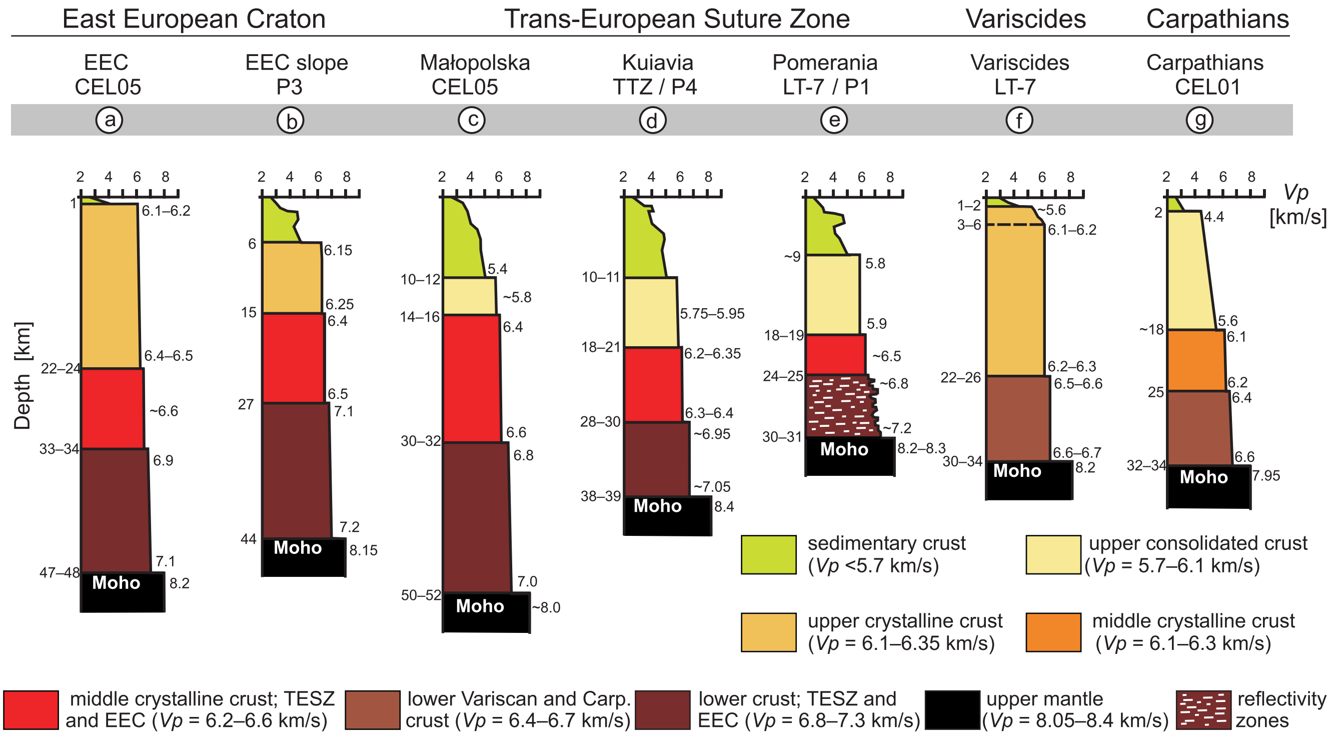

Fig. 3. Representative velocity models for the East European Craton, TESZ, Variscides and Carpathians

For location see circles marked a–g in Figure 5; see text for discussion and references

while further to north-east, a three-layer crust was found beneath the TESZ and EEC. The models presented in Figures 2 and 3g are typical for the crust of the Carpathians that has a thickness of 32–34 km. Across the Carpathians, crustal thicknesses decrease southwestwards from about 50 to around 25 km in their internal parts adjacent to the Pannonian Basin.

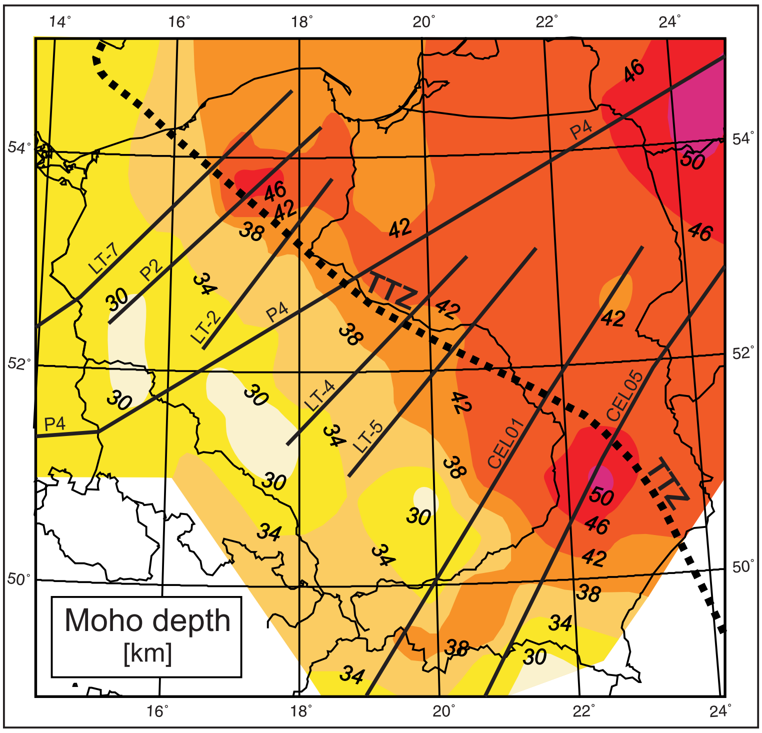

Fig. 4. Moho depth map of Poland (adapted from Grad,Tiira and Guterch, Moho map of Central Europe, in prep.)

SUMMARY ON CRUSTAL STRUCTURE

Based on results of the modern POLONAISE'97 and CELEBRATION 2000 projects, as well as older profiles a map of the depth to Moho in Poland was constructed (Fig. 4) that forms part of the Moho topography map of Central Europe that is in preparation by Grad, Tiira and Guterch. Beneath the Palaeozoic Platform the Moho occurs at depths of 30–34 km, dips steeply towards north-east in the marginal zone of the EEC where its depth ranges between 34 and 40 km, and is located beneath the EEC at depths 42–50 km.

Figure 5 gives the distribution of the different crustal types in Poland and surrounding regions, together with the layout of the available refraction and wide-angle reflection lines. The present-day assembly of crustal elements in this area resulted from tectonic processes that were active during more than one billion years. A three-layer "pure" Precambrian crystalline crust that is covered by relatively thin younger sediments characterizes the EEC (pink) that occupies the northeastern half of the map frame. There is still a controversy concerning the southwestern margin of the EEC and the adjacent belt of Avalonian and/or other terranes that were not affected by

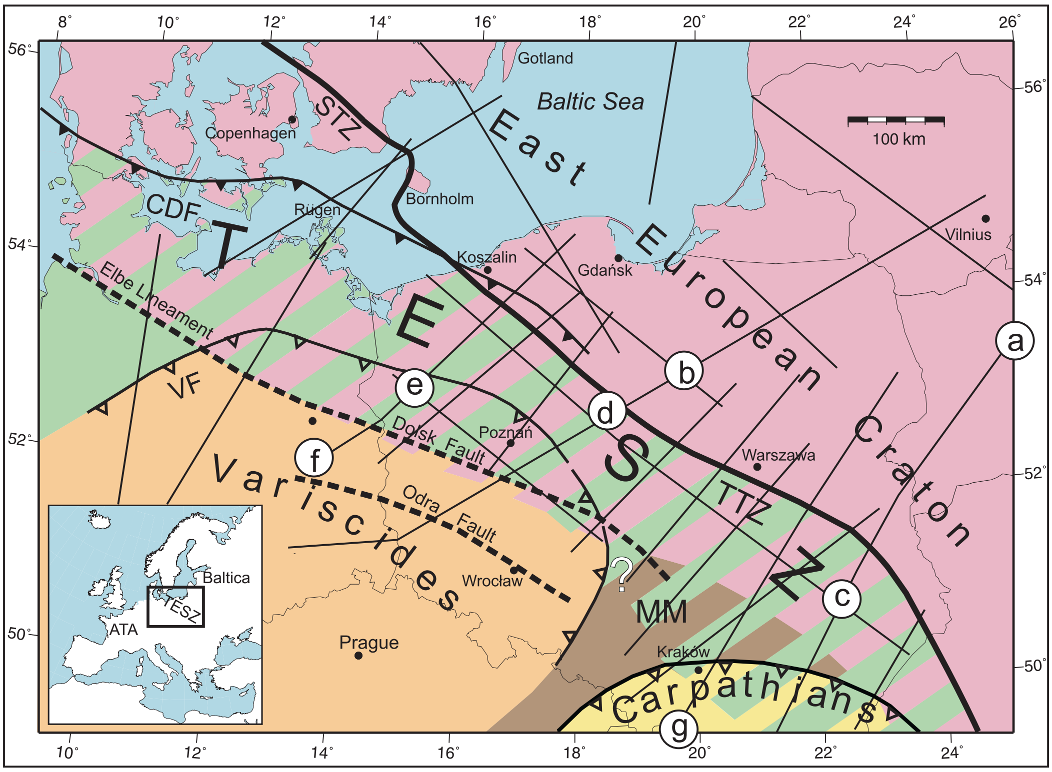

Fig. 5. Extent of the different crustal types in Poland

Pink — Precambrian crust of the East European Craton, green — Avalonian and/or other terranes, not affected by the Variscan deformation and characterized by relatively low seismic velocities (*Vp* <6.0 km/s) down to about 20 km depth, orange — two-layer Variscan crust, brown — Małopolska Massif (MM) crust, yellow — crust of the Carpathians; combination of pink and green — high velocity lower cratonic crust with thick low velocity cover; combination of green with brown and yellow — deep sedimentary cover over the Małopolska Massif and Carpathian crystalline crust, respectively; a–g — the location of 1D models given in Figure 3; black lines — network of seismic profiles; for explanation of tectonic terms see Figure 1

Variscan deformation (green belts). The crust of this belt is characterized by relatively low seismic velocities of *Vp* <6.0 km/s to depths of about 20 km depth and a high velocity (*Vp* >7.0 km/s) lower crust that is similar to that of the EEC. The northwestern part of this belt (pink and green striped in Fig. 5) was interpreted by Jensen *et al.* (1999) as being formed by East-Avalonia crust, whereas Dadlez *et al.* (2005) interpret the attenuated lower and middle crust of this part of the TESZ as consisting of proximal EEC terranes that were detached from the EEC in the south-east and re-accreted to it during the Ordovician-Early Silurian anticlockwise rotation of the Baltica palaeocontinent (see also Narkiewicz, 2002). The postulated boundary between Kuiavia and Pomerania blocks (Poznań–Bydgoszcz line) is rather sharp at middle and lower crustal levels. To the south-west of the TESZ belt, a relatively simple two-layered structure characterizes the Variscan crust (orange) with its thin sedimentary cover. In southern Poland the TESZ is bounded by crust of Carpathians (yellow) and the Małopolska Massif (MM, brown). In this area the green-brown and green-yellow striped signature in Figure 5 stands for a deep sedimentary cover of the Małopolska Massif and Carpathian crystalline crust, respectively.

LOWER LITHOSPHERE

In all seismic refraction and wide-angle reflection experiments of Central Europe, the upper mantle waves are clearly evident in many of the record sections at offsets 300–600 km (e.g., Guggisberg *et al.*, 1991; Grad *et al.*, 2002*b*, 2006*b*). In all POLONAISE'97 profiles, a shallow mantle reflector was found at depths about 8–12 km below the Moho (Jensen *et al.*, 1999; Środa and POLONAISE P3 Working Group, 1999; Grad *et al.*, 2002*b*, 2003*a*; Janik *et al.*, 2002). In the central part of the TESZ belt sub-horizontal reflectors occur at depths of about 70, 80 and 90 km in profile P4 (Grad *et al.*, 2002*b*). Also beneath the CEL05 profile a very pronounced reflector was found in TESZ at depths of 60–70 km with a large, positive velocity contrast of 8.1 km/s for the Carpathian and 8.45 km/s for the EEC mantle. High upper mantle velocities down to depths of 200–400 km were found earlier also in other regions of the EEC (see e.g., Zielhuis and Nolet, 1994; Świeczak *et al.*, 2004).

In general, the reflectivity of the uppermost mantle is stronger beneath the Palaeozoic Platform and TESZ than beneath the EEC. The deepest interpreted seismic reflectors, which are associated with a zone of high reflectivity, may mark a change in upper mantle structure from an upper zone characterized by seismic scatterers with small vertical dimensions to a lower zone with vertically larger seismic scatterers, possibly caused by the presence of partial melts. A complex high and low velocities distribution has been found in the mantle lithosphere also by other seismic experiments close to the TESZ region, as well as within EEC and the Baltic Shield. The depth to such intra-mantle reflective zones correlates with the heat flow, in so far as it is shallower in "hot" areas than in "cold" ones, a feature also observed along the FENNOLORA seismic long-range profile (e.g., Guggisberg *et al.,* 1991).

In Carpathians the mantle lithosphere reflector is located about 15 km beneath the Moho, occuring at depths of 40 to 55 km, and follows the shape of the Moho topography (CEL05 profile, Grad *et al*., 2006*a*; CEL01 profile, Środa *et al*., submitted).

CONCLUSIONS

The available geophysical control on the crustal configuration of Poland is good, particularly concerning the velocity structure of the crust and the upper parts of the lithospheric mantle. Apart from the crustal 2D models presented in this paper (Fig. 2), a 3D model for the whole of Poland is currently under development. Together with the interpretation of gravity, magnetic and heat flow data, this should improve geotectonic models and help to reconstruct processes that took place during last billion years. To achive this goal, a closer collaboration between geologists and geophysicists is required. In the future, the available refraction and wide-angle refraction data need to be integrated with as yet to be recorded deep near-vertical seismic reflection profiles that may ultimately be calibrated by deep scientific boreholes.

During the last two decades such programs were successfully completed in USA (COCORP), Canada (LITHOPROBE), Great Britain (BIRPS), Italy (CROP), Germany (DEKORP), France (ECORS), Finland (FIRE), Switzerland (NFP-20) and Russia (URSEIS). Under these programs, deep regional near-vertical seismic reflection profiles were recorded that image the entire crust, thus giving a much more detailed picture of its structure that permits a more detailed analysis of its evolution. Indeed, results of profiles recorded under the above mentioned programs have in many cases led to a break-through in the understanding of geodynamic processes controlling the evolution of orogenic belts, their collapse and the evolution of sedimentary basins. A case in point is the DEKORP-BASIN'96 profile that crosses the North-east-German Basin and its northern parts the TESZ (e.g., Bayer *et al*., 2002).

An initiative to record in Poland a first set of deep near-vertical seismic reflection profile across the TESZ was recently undertaken by Association for Deep Geological Investigation in Poland (ADGIP), identifying the central part of profile P4 and profile CEL05 as targets (length about 300 and 250 km, respectively). Ideally, such a program ought to be followed up by the drilling of deep wells, permitting to calibrate salient reflection-seismic features. Although this proposal found strong support by a wide circle of geologists and geophysicists, its funding could not yet be secured.

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REFERENCES

ANSORGE J., BLUNDELL D. and MUELLER ST. (1992) — Europe's lithosphere — seismic structure. In: A Continent Revealed — The European Geotraverse (eds. D. J. Blundell, R. Freeman and St. Mueller): 33–69. Cambridge Univ. Press. Cambridge.

BABEL WORKING GROUP (1993) — Deep seismic reflection/refraction interpretation of crustal structure along BABEL profiles A and B in the southern Baltic Sea. Geoph. J. Int., **112**: 325–343.

BAYER U., GRAD M., PHARAOH T. C., THYBO H., GUTERCH A., BANKA D., LAMARCHE J., LASSEN A., LEWERENZ B., SCHECK M. and MAROTTA A.-M. (2002) — The southern margin of the East European Craton: new results from seismic sounding and potential fields between the North Sea and Poland. Tectonophysics, **360** (1–4): 301–314.

BLEIBINHAUS F., BEILECKE T., BRAM K. and GEBRANDE H. (1999) — A seismic velocity model for the SW Baltic Sea derived from BASIN'96 refraction seismic data. Tectonophysics, **314** (1–3): 269–283.

BOGDANOVA S. V., GORBATSCHEV R., STEPHENSON R. A. and GUTERCH A. (eds.) (2001) — EUROBRIDGE: Palaeoproterozoic accretion of Fennoscandia and Sarmatia. Tectonophysics, **339** (1–2).

BOGDANOVA S. V., PASHKEVICH I. K., GORBATSCHEV R. and ORLYUK M. I. (1996) — Riphean rifting and major Palaeoproterozoic crustal boundaries in the basement of the East European Craton: geology and geophysics. Tectonophysics, **268** (1–4): 1–21.

BRÜCKL E., BODOKY T., HEGEDŰS E., HRUBCOVÁ P., GOSAR A., GRAD M., GUTERCH A., HAJNAL Z., KELLER G. R., ŠPIČÁK A., SUMANOVAC F., THYBO H., WEBER F. and ALP 2002 Working Group (2003) — ALP 2002 seismic experiment. Stud. Geoph. Geod., **47** (3): 671–679.

CAVAZZA W., ROURE F. M, SPAKMAN W., STAMPFLI G. M. and ZIEGLER P. A. (eds.) (2004) — The TRANSMED Atlas — The Mediterranean Region from Crust to Mantle. Springer. Berlin, Heidelberg, New York.

ČERMÁK V. and BODRI L. (1998) — Heat flow map of Europe revised. Deutche Geophysikalische Gesellschaft e.V., **2**: 58–63.

ČERMÁK V., ŠAFANDA J. and GUTERCH A. (1989) — Deep temperature distribution along three profiles crossing the Teisseyre-Tornquist tectonic zone in Poland. Tectonophysics, **164** (2–4): 151–163.

ČERVENÝ V. and PŠENČÍK I. (1983) — SEIS83-numerical modelling of seismic wave fields in 2-D laterally varying leyered structure by the ray method. In: Documentation of Earthquake Algoritm (ed. E. R. Enghdal): 36–40. Rep. SE-35, World Data Cent. A for Solid Earth Geoph., Boulder.

CZUBA W., GRAD M., LUOSTO U., MOTUZA G., NASEDKIN V. and POLONAISE P5 Working Group (2001) — Crustal structure of the East European craton along the POLONAISE'97 P5 profile. Acta Geoph. Pol., **49** (2): 145–168.

CZUBA W., GRAD M., LUOSTO U., MOTUZA G., NASEDKIN V. and POLONAISE P5 Working Group (2002) — Upper crustal seismic structure of the Mazury complex and Mazowsze massif within East European Craton in NE Poland. Tectonophysics, **360** (1–4): 115–128.

DADLEZ R., GRAD M. and GUTERCH A. (2005) — Crustal structure below the Polish Basin: Is it composed of proximal terranes derived from Baltica? Tectonophysics, **411** (1–4): 111–128.

DADLEZ R., KOWALCZEWSKI Z. and ZNOSKO J. (1994) — Some key problems of the pre-Permian tectonics of Poland. Geol. Quart., **38** (2): 169–189.

EUROBRIDGE SEISMIC WORKING GROUP (2001) — EUROBRIDGE'95: deep seismic profiling within the East European Craton. Tectonophysics, **339** (1–2): 153–175.

FRANKE W. (2000) — The Mid-European segment of the Variscides: tectono-stratigraphic units, terrane bounadaries and plate tectonic evolution. Geol. Soc., London, Spec. Publ., **179**: 35–62.

GRABOWSKA T. and BOJDYS G. (2001) — The border of the East-European Craton in south-eastern Poland based on gravity and magnetic data. Terra Nova, **13** (2): 92–98.

GRAD M., GUTERCH A., KELLER G. R., JANIK T., HEGEDŰS E., VOZÁR J., ŚLĄCZKA A., TIIRA T. and YLINIEMI J. (2006*a*) — Lithospheric structure beneath trans-Carphathian transect from Precambrian platform to Pannonian basin — CELEBRATION 2000 seismic profile CEL05. J. Geoph. Res., (in print).

GRAD M., GUTERCH A. and LUND C.-E. (1991) — Seismic models of the lower lithosphere beneath the southern Baltic Sea between Sweden and Poland. Tectonophysics, **189** (1–4): 219–227.

GRAD M., GUTERCH A. and MAZUR S. (2002*a*) — Seismic refraction evidence for crustal structure in the central part of the Trans-European Suture Zone in Poland. In: Palaeozoic Amalgamation of Central Europe (eds. J. A. Winchester, T. C. Pharaoh and J. Verniers). Geol. Soc., London, Spec. Publ., **201**: 295–309.

GRAD M., GUTERCH A. and POLKOWSKA-PURYS A. (2005) — Crustal structure of the Trans-European Suture Zone in Central Poland — reinterpretation of the LT-2, LT-4 and LT-5 deep seismic sounding profiles. Geol. Quart., **49** (3): 243–252.

GRAD M., JANIK T., GUTERCH A., ŚRODA P., CZUBA W., EUROBRIDGE'94–97, POLONAISE'97 and CELEBRATION 2000 Seismic Working Groups (2006*b*) — Lithospheric structure of the western part of the East European Craton investigated by deep seismic profiles. Geol. Quart., **50** (1): 9–22.

GRAD M., JANIK T., YLINIEMI J., GUTERCH A., LUOSTO U., TIIRA T., KOMMINAHO K., ŚRODA P., HÖING K., MAKRIS J. and LUND C.-E. (1999) — Crustal structure of the Mid-Polish Trough beneath the Teisseyre-Tormquist Zone seismic profile. Tectonophysics, **314** (1–3): 145–160.

GRAD M., JENSEN S. L., KELLER G. R., GUTERCH A., THYBO H., JANIK T., TIIRA T., YLINIEMI J., LUOSTO U., MOTUZA G., NASEDKIN V., CZUBA W., GACZYŃSKI E., ŚRODA P., MILLER K. C., WILDE-PIÓRKO M, KOMMINAHO K., JACYNA J. and KORABLIOVA L. (2003*a*) — Crustal Structure of the Trans-European suture zone region along POLONAISE'97 seismic profile P4. J. Geoph. Res., **108** (B11).

GRAD M., KELLER G. R., THYBO H., GUTERCH A. and POLONAISE Working Group (2002*b*) — Lower lithospheric structure beneath the Trans European Suture Zone from POLONAISE'97 seismic profiles. Tectonophysics, **360** (1–4): 153–168.

GRAD M. and LUOSTO U. (1987) — Seismic models of the crust of the Baltic Shield along the SVEKA profile in Finland. Ann. Geoph., **5B**: 639–650.

GRAD M. and LUOSTO U. (1994) — Seismic velocities and *Q*-factors in the uppermost crust beneath the SVEKA profile in Finland. Tectonophysics, **230** (1–2): 1–18.

GRAD M., ŠPIČÁK A., KELLER G. R., GUTERCH A., BROŽ M., HEGEDŰS E. and Working Group (2003*b*) — SUDETES 2003 seismic experiment. Stud. Geoph. Geod., **47** (3): 681–689.

GRAD M. and TRIPOLSKY A. A. (1995) — Crustal structure from P and S seismic waves and petrological models of the Ukrainian shield. Tectonophysics, **250** (1–3): 89–112.

GUGGISBERG B., KAMINSKI W. and PRODEHL C. (1991) — Crustal structure of the Fennoscandian Shield: a traveltime interpretation of the long-range FENNOLORA seismic refraction profile. Tectonophysics, **195** (2–4): 105–137.

GUTERCH A., GRAD M., JANIK T., MATERZOK R., LUOSTO U., YLINIEMI J., LÜCK E., SCHULZE A. and FÖRSTE K. (1994) — Crustal structure of the transitional zone between Precambrian and Variscan Europe from new seismic data along LT-7 profile (NW Poland and eastern Germany). C. R. Acad. Sc. Paris, **319**, ser. II: 1489–1496.

GUTERCH A., GRAD M., KELLER G. R. and CELEBRATION 2000 Organizing Committee (2001) — Seismologists Celebrate the New Millenium with an Experiment in Central Europe. Eos Trans. Am. Geophys. Union, **82** (45): 529, 534–535.

GUTERCH A., GRAD M., KELLER G. R., POSGAY K., VOZÁR J., ŠPIČÁK A., BRÜCKL E., HAJNAL Z., THYBO H., SELVI O. and CELEBRATION 2000 Experimant Team (2003*a*) — CELEBRATION 2000 seismic experiment. Stud. Geoph. Geod., **47** (3): 659–669.

GUTERCH A., GRAD M., MATERZOK R. and PERCHUĆ E. (1986) — Deep structure of the Earth's crust in the contact zone of the Palaeozoic and Precambrian platforms in Poland (Tornquist-Teisseyre Zone). Tectonophysics, **128** (3–4): 251–279.

GUTERCH A., GRAD M., MATERZOK R., PERCHUĆ E., JANIK T., GACZYŃSKI E., DOAN T. T., BIAŁEK T., GADOMSKI D., MŁYNARSKI S. and TOPORKIEWICZ S. (1992) — Laminated structure of the lower crust in the fore-Sudetic region in Poland, derived from seismic data. Phys. Earth Planet. Inter., **69**: 217–223.

GUTERCH A., GRAD M., MATERZOK R. and TOPORKIEWICZ S. (1983) — Structure of the Earth's crust of the Permian Basin in Poland. Acta Geoph. Pol., **31** (2): 121–138.

GUTERCH A., GRAD M., ŠPIČÁK A., BRÜCKL E., HEGEDŰS E., KELLER G. R., THYBO H. and CELEBRATION 2000, ALP 2002, SUDETES 2003 Working Groups (2003*b*) — An overview of recent seismic refraction experiments in Central Europe. Stud. Geoph. Geod., **47** (3): 651–657.

GUTERCH A., GRAD M., THYBO H., KELLER G. R. and MILLER K. (1998) — Seismic experiment spreads across Poland. Eos Trans. Am. Geoph. Union, **79** (26): 302, 305.

GUTERCH A., GRAD M., THYBO H., KELLER G. R. and the POLONAISE Working Group (1999) — POLONAISE'97 — an international seismic experiment between Precambrian and Variscan Europe in Poland. Tectonophysics, **314** (1–3): 101–121.

GUTERCH A., KOWALSKI T. J., MATERZOK R. and TOPORKIEWICZ S. (1976) — Seismic refraction study of the Earrth's crust in the Teisseyre-Tornquist line zone in Poland along the LT-2 profile. Publ. Inst. Geoph. Pol. Acad. Sc., **A-2** (101): 15–23.

HOLE, J. A. (1992) — Nonlinear high-resolution three-dimensional seismic travel time tomography. J. Geoph. Res., **97**: 6553–6562.

JANIK T., YLINIEMI J., GRAD M., THYBO H., TIIRA T. and POLONAISE P2 Working Group (2002) — Crustal structure across the TESZ along POLONAISE'97 seismic profile P2 in NW Poland. Tectonophysics, **360** (1–4): 129–152.

JANIK T., GRAD M., GUTERCH A., DADLEZ R., YLINIEMI J., TIIRA T., KELLER G. R., GACZYŃSKI E. and CELEBRATION 2000 Working Group (2005) — Lithospheric structure of the Trans-European Suture Zone along the TTZ and CEL03 profiles (from NW to SE Poland). Tectonophysics, **411 (1**–4): 129–156.

JENSEN S. L., JANIK T., THYBO H. and POLONAISE Profile P1 Working Group (1999) — Seismic structure of the Palaeozoic Platform along POLONAISE'97 profile P1 in northwestern Poland. Tectonophysics, **314** (1–3): 123–143.

KOZLOVSKAYA E., JANIK T., YLINIEMI J., KARATAYEV G. and GRAD M. (2004) — Density-velocity relationship in the upper lithosphere obtained from P- and S-wave velocity models along the EUROBRIDGE'97 seismic profile and gravity data. Acta Geoph. Pol., **52** (4): 397–424.

KRÓLIKOWSKI C. and PETECKI Z. (1995) — Gravimetric Atlas of Poland. Państw. Inst. Geol. Warszawa.

KRÓLIKOWSKI C. (2006) — Crustal-scale complexity of the contact zone between the Palaeozoic Platform and the East European Craton in the NW Poland. Geol. Quart., **50** (1): 33–42.

KRYSIŃSKI L., GRAD M. and POLONAISE Working Group (2000) — POLONAISE'97 — seismic and gravimetric modelling of the crustal structure in the Polish basin. Phys. Chem. Earth (A), **25**: 355–363.

MAJDAŃSKI M. and GRAD M. (2005) — Application of second arrivals in seismic tomography inversion for the crustal structure study. Acta Geoph. Pol., **53** (1): 13–26.

MAJOROWICZ J. and PLEWA S. (1979) — Study of heat flow in Poland with special regards to tectonophysical problems. In: Terrestrial Heat Flow in Europe (eds. V. Čermák and L. Rybach): 240–252. Springer. Berlin.

MAJOROWICZ J. A., ČERMÁK V., ŠAFANDA J., KRZYWIEC P., WRÓBLEWSKA M., GUTERCH A. and GRAD M. (2003) — Heat flow models across the Trans-European Suture Zone in the area of the POLONAISE'97 seismic experiment. Phys. Chem. Earth, **28**: 375–391.

MALINOWSKI M., ŻELAŹNIEWICZ A., GRAD M., GUTERCH A., JANIK T. and CELEBRATION 2000 Working Group (2005) — Seismic and geological structure of the crust in the transition from Baltica to Palaeozoic Europe in SE Poland — CELEBRATION 2000 experiment, profile CEL02. Tectonophysics, **401** (1–2): 55–77.

NARKIEWICZ M. (2002) — Ordovician through earliest Devonian development of the Holy Cross Mts. (Poland): constraints from subsidence analysis and thermal maturity data. Geol. Quart., **46** (3): 255–266.

OSTROVSKY A. A., FLUEH E. R. and LUOSTO U. (1994) — Deep seismic structure of the Earth's crust along the Baltic Sea profile. Tectonophysics, **233** (3–4): 279–292.

PARIS F. and ROBARDET M. (1990) — Early Palaeozoic palaeobiogeography of the Variscan regions. Tectonophysics, **177** (1–3): 193–213.

PETECKI Z., POLECHOŃSKA O., WYBRANIEC S. and CIEŚLA E. (2003) — Magnetic map of Poland at a scale of 1:500 000. Parts A and B on CD-rom. Państw. Inst. Geol. Warszawa.

PLEWA S. (1998) — Map of heat flow in Poland. In: Tectonic Atlas of Poland (ed. J. Znosko). Państw. Inst. Geol. Warszawa.

ŚRODA P., CZUBA W., GRAD M., GUTERCH A., GACZYŃSKI E. and POLONAISE Working Group (2002) — Three-dimensional seismic modelling of crustal structure in the TESZ region based on POLONAISE'97 data. Tectonophysics, **360** (1–4): 169–185.

ŚRODA P., CZUBA W., GRAD M., GUTERCH A., TOKARSKI A., JANIK T., RAUCH M., KELLER G. R., HEGEDŰS E., VOZÁR J. and CELEBRATION 2000 Working Group (2006) — Crustal structure of the Western Carpathians from CELEBRATION 2000 profiles CEL01 and CEL04: seismic models and geological implication. Geoph. J. Int., (in print).

ŚRODA P. and POLONAISE Profile P3 Working Group (1999) — P- and S-wave velocity model of the southwestern margin of the Precambrian East European Craton; POLONAISE'97, profile P3. Tectonophysics, **314** (1–3): 175–192.

ŚWIECZAK M., GRAD M., TOR and SVEKALAPKO Working Groups (2004) — Upper mantle seismic discontinuities topography variations beneath Eastern Europe. Acta Geoph. Pol., **52** (3): 251–270.

TAIT J., SCHÄTZ M., BACHTADSE V. and SOFFEL H. C. (2000) — Palaeomagnetism and Palaeozoic palaeogeography of Gondwana and European terranes. Geol. Soc., London, Spec. Publ., **179**: 21–34.

WEVER TH., MEISSNER R., SADOWIAK P. and the DEKORP Group (1990) — Deep reflection seismic data along the central part of the European Geotraverse in Germany: a review. Tectonophysics, **176** (1–2): 87–101.

WILDE-PIÓRKO M., GRAD M. and POLONAISE Working Group (1999) — Regional and teleseismic events recorded across the TESZ during POLONAISE'97. Tectonophysics, **314** (1–3): 161–174.

WINCHESTER J. A. and The PACE TMR Network Team (2002*a*) — Palaeozoic amalgamation of Central Europe: new results from recent geological and geophysical investigations. Tectonophysics, **360** (1–4): 5–21.

WINCHESTER J. A., PHARAOH T. C. and VERNIERS J. (2002*b*) — Palaeozoic amalgamation of Central Europe: an introduction and synthesis of new results from recent geological and geophysical investigations. Geol. Soc., London, Spec. Publ., **201**: 1–18.

WYBRANIEC S., ZHOU S., THYBO H., FORSBERGER R., PERCHUĆ E., LEE M., DEMIANOV G. D. and STARKOV V. N. (1998) — New map compiled of Europe's gravity field. Eos Trans. Am. Geoph. Union, **79** (37): 437, 442.

ZELT C. A. and BARTON P. J. (1998) — Three-dimensional seismic refraction tomography: a comparison of two methods applied to data from the Faeroe Basin. J. Geoph. Res., **103**: 7187–7210.

ZIEGLER P. A. (1990) — Geological Atlas of Western and Central Europe. Shell International Petroleum, Maatschappij B.V., Geol. Soc. Publ. House. Bath.

ZIELHUIS A. and NOLET G. (1994) — Shear-wave velocity in the upper mantle beneath Eastern Europe. Geoph. J. Int., **117**: 695–715.