Geological Quarterly, 2005, **49** (3): 243–252

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

Marek GRAD, Aleksander GUTERCH and Agnieszka POLKOWSKA-PURYS

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. Warszawa.

The paper gives a reinterpretation of data from three deep seismic sounding profiles — LT-2, LT-4 and LT-5 — acquired in 1974–1979 between the Precambrian East European Craton (EEC) and the Palaeozoic Platform (PP) in Central Poland. Good quality seismic records in the distance interval from 50–90 to 200–280 km were the input data for the modelling of the crustal and uppermost mantle structure. Clear first arrivals and later phases of waves reflected/refracted from the crustal and the Moho boundaries were interpreted using a two-dimensional (2-D) ray tracing technique. In general, the crustal thickness along the three profiles varies from 30–35 km in the Palaeozoic platform area, to 42–44 km in the Polish part of the EEC, being 35–40 km in the transition zone between the PP and the EEC. In the transition area, the P-wave velocity is very low (Vp <6.0 km/s) down to depths of 15–18 km, indicating that a very thick succession of sedimentary, metamorphosed or volcanic origin rocks is present there. All three 2-D models of the crust are discussed together with results obtained 20–30 years ago, particularly taking into account the difference in interpretation methods and new computation possibilities. Jointly with recent seismic studies along the profiles LT-7 and TTZ, as well as the POLONAISE'97 profiles P1–P4, the reinterpreted old profiles provide a collection of crustal models of the TESZ in Poland.

Marek Grad, Agnieszka Polkowska-Purys, Institute of Geophysics, University of Warsaw, Pasteura 7, PL-02-093 Warsaw, Poland; Aleksander Guterch, Institute of Geophysics, Polish Academy of Sciences, Ks. Janusza 64, PL-01-452 Warsaw, Poland *(received: December 27, 2004; accepted: April 5, 2005).*

Key words: TESZ, crustal structure, seismic refraction, ray tracing.

INTRODUCTION

The structure of the contact zone between the Precambrian Europe to the north-east and the Palaeozoic Platform to the south-west has been investigated in Poland for more than three decades. This zone, known as the Trans-European Suture Zone (TESZ) (Fig. 1), is a broad, structurally complex zone of Palaeozoic accretion and deformation that separates the Precambrian terranes of the Baltic Shield and East European Craton (EEC) from younger terranes (e.g., Znosko, 1979; Berthelsen, 1992*a*, *b*, 1998; Dadlez *et al.,* 1994; Kutek, 1997; Pharaoh *et al*., 1997). The southwestern boundary of the EEC is called the Teisseyre-Tornquist Zone or Line (TTZ) being a system of deep-seated faults, and has been previously interpreted as a zone only 50–100 km across. In addition to being a major crustal-scale feature, the TTZ appears to be a deep-seated boundary, because tomographic analysis of shear wave velocity structure of the mantle under Europe shows that the TTZ separates regions with high S-wave velocities beneath the EEC from low velocity regions under the younger terranes in the south-west (Zielhuis and Nolet, 1994). To explain the observed blockage of energy from regional seismic events by the TTZ region, the structural anomaly between eastern and western Europe must reach down to at least a depth of about 200 km (Schweitzer, 1995).

A number of recent geophysical studies have investigated this important tectonic boundary. The large international seismic experiments POLONAISE'97 and CELEBRATION 2000 targeted the TESZ region in Poland (e.g., Guterch *et al*., 1998, 1999, 2001) and analysis of the crustal structure along various profiles is now completed (Jensen *et al*., 1999; Środa *et al*., 1999, 2002; Wilde-Piórko *et al.,* 1999; Krysiński *et al*., 2000; Czuba *et al*., 2001, 2002; Janik *et al*., 2002; Grad *et al*., 2002*a*, *b*, 2003; Guterch and Grad, 2002; Majdański and Grad, 2005; Dadlez *et al.,* in press).

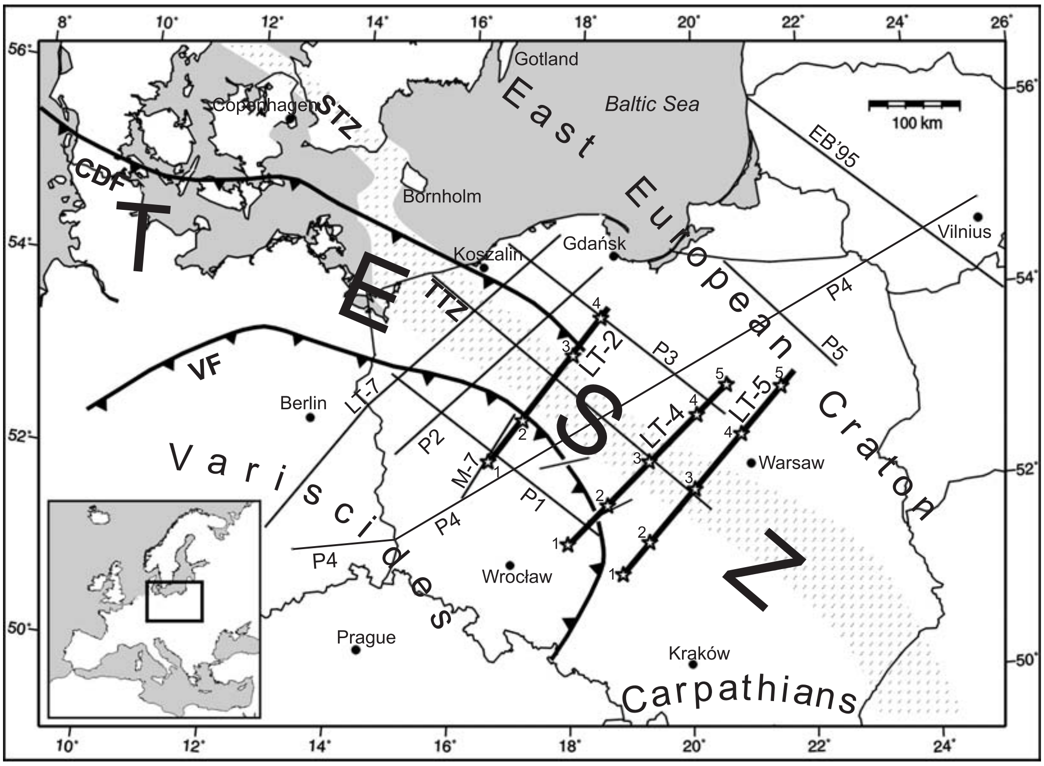

Fig. 1. Location of the LT-2, LT-4 and LT-5 profiles and other seismic refraction and wide angle reflection profiles (thinner lines: LT-7; TTZ; POLONAISE'97 P1, P2, P3, P4 and P5 profiles; EUROBRIDGE'95 — EB'95) in the context of the main features in the Trans-European Suture Zone (TESZ) area

Stars and numbers refer to the location of shot points along profiles LT-2, LT-4 and LT-5 (see Table 1); CDF — Caledonian Deformation Front, STZ — Sorgenfrei-Tornquist Zone, VF — Variscan Front

This paper provides a reinterpretation of three old deep seismic sounding profiles LT-2, LT-4 and LT-5 (Fig. 1; Table 1) acquired in 1974–1979 between the Precambrian East European Craton (EEC) and the Palaeozoic Platform in Central Poland (Guterch *et al.*, 1976, 1983, 1986). Good quality seismic records (see for example Fig. 2) and travel times (Fig. 3) were the initial data for the modelling of the crustal and uppermost mantle structure. New models are shown in Figure 4, and examples of modelling using a two-dimensional ray tracing technique are shown in Figures 5, 6 and 7. All three new 2-D models of the crust are compared with "old" cross-sections obtained 20–30 years ago, particularly taking into account the difference in interpretation methods and computation possibilities (Figs. 8 and 9).

Table 1

Location of the LT-2, LT-4 and LT-5 profiles

Profile	Beginning of profile	End of profile	Shot points location along profile
LT-2 Stęszew–Starogard	φ=52°16'09.7" λ=16°37'16.0"	φ=53°49'23.4" λ=18°26'27.3"	SP1: 0.0 km SP2: 61.8 km SP3: 152.2 km SP4: 208.2 km
LT-4 Syców–Raciąż	φ=51°19'40.0" λ=17°49'30.0"	φ=52°56'55.0" λ=20°28'55.0"	SP1: 1.0 km SP2: 67.5 km SP3: 129.6 km SP4: 204.8 km SP5: 255.2 km
LT-5 Pajęczno–Pułtusk	φ=51°04'10.0" λ=18°45'30.0"	φ=53°00'10.0" λ=21°24'10.0"	SP1: 1.1 km SP2: 47.9 km SP3: 123.0 km SP4: 203.1 km SP5: 276.3 km

PREVIOUS INTERPRETATION OF DATA FROM THE LT-2, LT-4 AND LT-5 PROFILES

Deep seismic sounding investigations (DSS) aim to determine the seismic velocity distribution and boundaries in the crust and uppermost mantle. A recording system with short distances between the receivers permits the exact phase correlation of regular refracted and reflected waves based on their kinematic and dynamic properties. For all shot points they

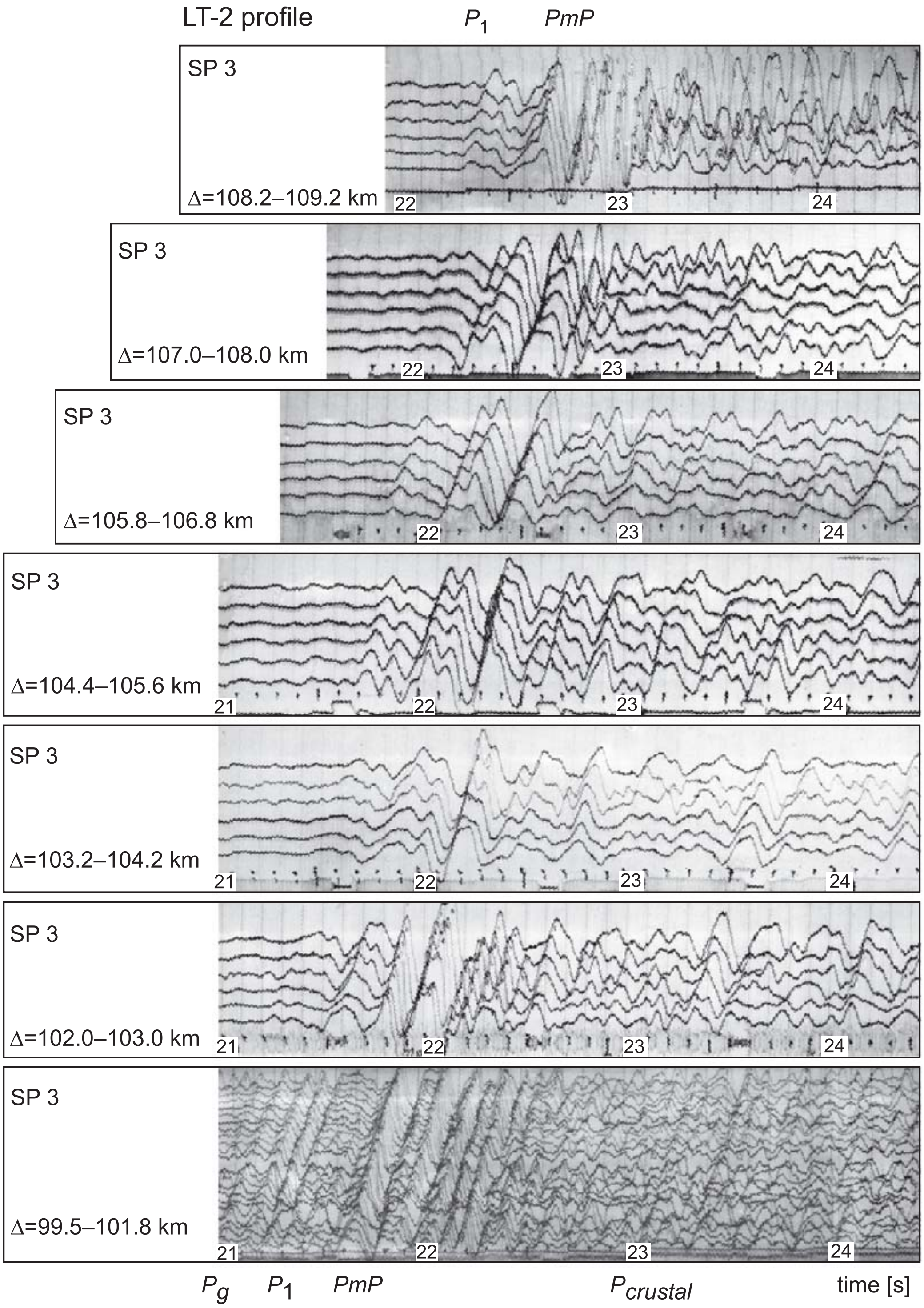

Fig. 2. Example of seismic record sections (composites of seismograms) for LT-2 profile, SP 3, for the offset 99.5–109.2 km

PmP — reflected waves from the Moho, P_1 — midcrustal waves, P_g — refracted waves from the consolidated/crystalline basement, $P_{crustal}$ — overcritical crustal waves

build a system of reversed travel times with common times at the reciprocal points, which is a basis for crustal structure determination. Seismic measurements along profiles LT-2, LT-4 and LT-5 were completed with the "continuous"profiling method in the distance interval from 50–90 to 200–280 km from shot points. The distances between the shot points were from 45–50 to 60–90 km. The shots were made by exploding dynamite in 30–40 m deep holes, which

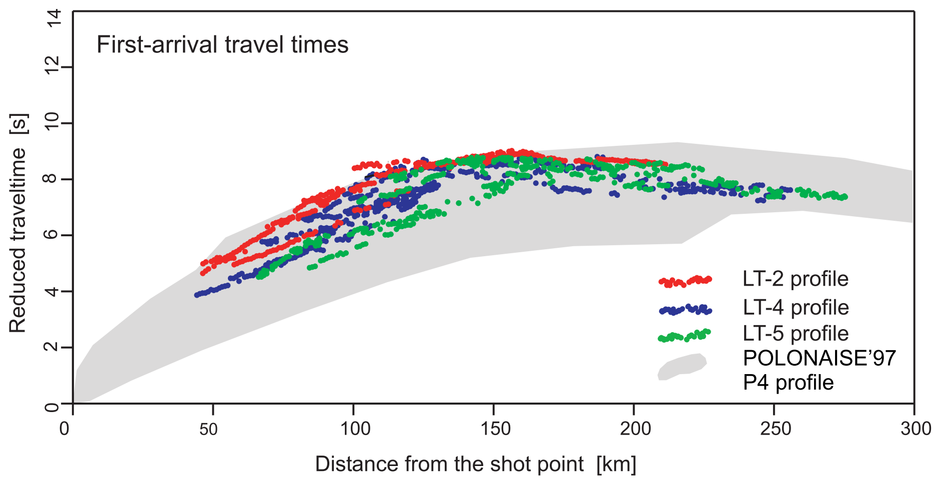

Fig. 3. P-wave first arrival travel-time picks for the LT-2, LT-4 and LT-5 profiles

Gray area shows P-wave first arrival times for POLONAISE'97 profile P4, including Precambrian Platform, TESZ and Palaeozoic Platform (Grad *et al*., 2003). The data from the LT-2, LT-4 and LT-5 profiles coincide very well with those from profile P4 for the TESZ area; the complexity of the crustal structure in the whole area is illustrated by nearly 4 seconds of deviation of first arrival travel-times along most of the offset interval; reduction velocity = 8.0 km/s

were grouped. The charges amounted to 600–800 kg on average, with a maximum of 1000–1200 kg. The recording was carried out with multi-channel seismic instruments (see the example in Fig. 2), and the distances between the channels were 100 and 200 m. This permits exact phase correlation, when the distance interval between receivers is smaller than half of the wavelength (e.g., for Vp=6 km/s and frequency 10 Hz the length of the seismic P-wave is 600 m). Identification and correlation of seismic phases was done through a manual process using composite seismogram copies. The travel times of waves from individual shot points were drawn on the scale of 1:100 000, with the time scale of 2 cm for 1 s. Correlated phases build a system of refracted and reflected travel times used in the determination of the seismic velocities and boundary depths in the crust and uppermost mantle. P-wave first arrival travel-time picks for LT-2, LT-4 and LT-5 profiles coincide very well with those from profile P4 for the TESZ area (Grad *et al.,* 2003). The complexity of the crustal structure in the whole area is illustrated by 3–4 seconds of deviation of first arrival travel-times along most of the offset interval (Fig. 3).

In the multi-stage interpretation process of LT-2, LT-4 and LT-5 data, both refracted and reflected wave travel time branches were used. The boundary velocities were determined from apparent velocities of reverse travel times of refracted waves. In the interpretation of the reflected waves the method of effective parameters was used (e.g., Egorkin, 1966; Guterch *et al.,* 1983; Grad, 1983). The effective velocity V_{ef} was determined from the formula:

$$V_{ef}(x) = (x / p(x)\ t(x))^{1/2}$$

where: $t(x)$ is the travel time of the reflected wave, x is the offset, $p=dt/dx$ is the ray parameter.

The effective depth of the reflector h_{ef} was determined from the formula:

$$h_{ef}(x/2) = \frac{1}{2}\left(V_{ef}^2 t^2 - x^2\right)^{1/2}$$

Under DSS conditions the value of the effective velocity may exceed the value of the mean velocity even by 10–15%. The effective depth h_{ef} determined from the reflected wave travel time is also greater than the true depth H of the reflecting boundary. The difference increases with increasing distance from the source, and under DSS conditions it may exceed 20–30% (Grad, 1983). Finally, the cross-sections of the crust obtained in the interpretation process were verified using 1-D calculations of theoretical travel times and amplitude curves within individual crustal blocks.

Results of the old interpretation — cross-sections of the crustal structure along profiles LT-2, LT-4 and LT-5 are shown in Figure 8. Three blocks of crust distinguished along all profiles correspond to the Palaeozoic Platform (PP), Teisseyre-Tornquist Zone (TTZ) and East European Craton (EEC). The thickness of the Earth's crust within the PP was determined to be 35–38 km and about 45 km beneath the EEC. The thickness in the 80 km wide TTZ was 48–54 km. In the light of data from the new LT-7, TTZ, P2 and P4 profiles (Fig. 1) a deep trough structure in the TESZ in Central Poland is not observed, and the Moho depth reaches 35–45 km only

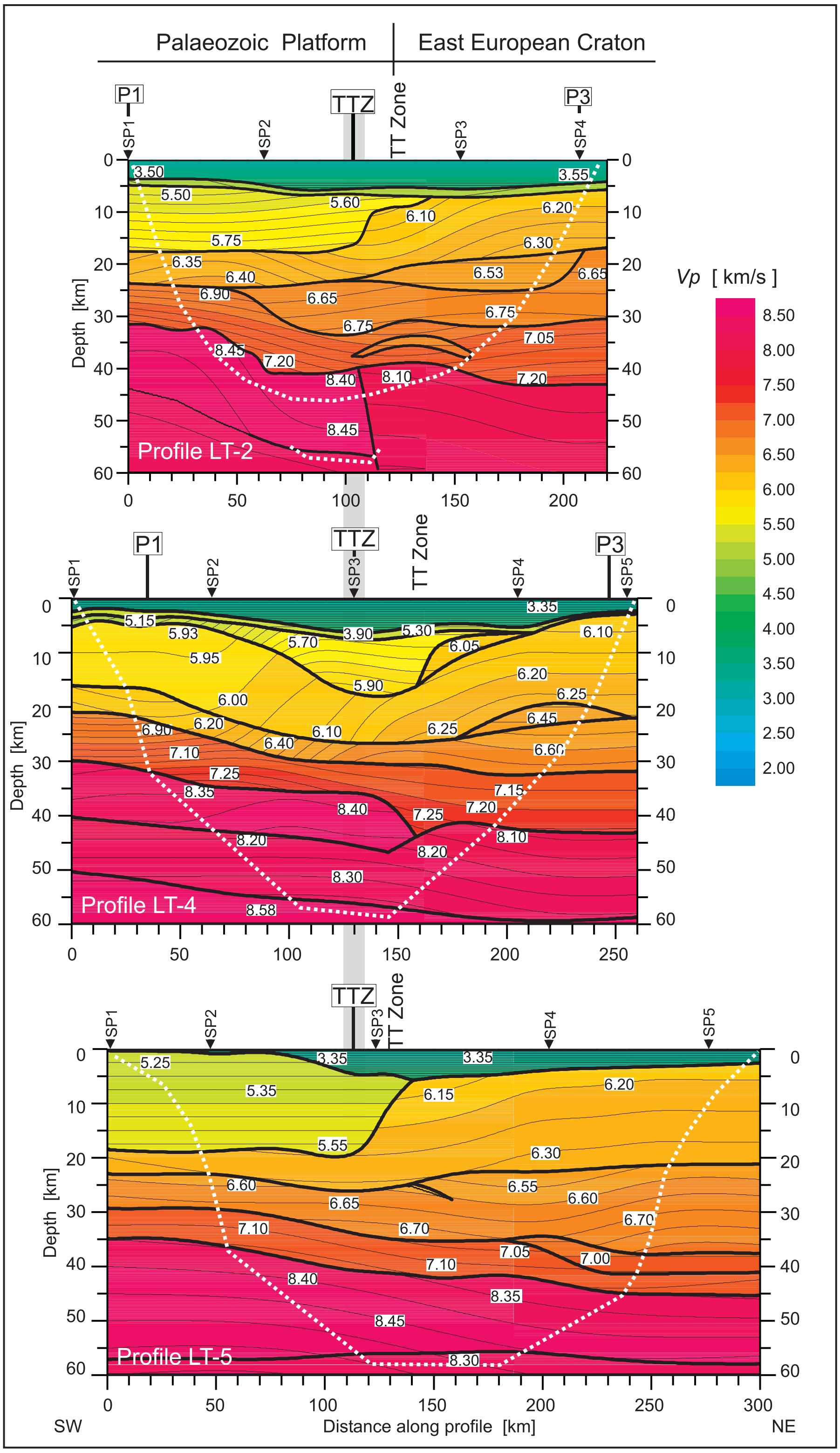

Fig. 4. Two-dimensional P-wave velocity models for the LT-2, LT-4 and LT-5 profiles

Re-interpretation of archival data was derived by a ray-tracing technique using the *SEIS83* package (Červený and Pšenčík, 1983). The thick solid lines are layer boundaries and thin lines are iso-velocity contours in km/s; boxes show intersection with the P1, TTZ and P3 profiles; white dotted lines show parts of profiles documented by refracted and reflected waves (ray coverage)

(Guterch *et al.,* 1994; Grad *et al.,* 1999, 2003; Janik *et al.,* 2002).

REINTERPRETATION OF DATA FROM THE LT-2, LT-4 AND LT-5 PROFILES

Detailed modelling of refracted and reflected phases identified for the LT-2, LT-4 and LT-5 profiles was undertaken using ray-tracing calculations of travel times and theoretical (synthetic) seismograms. For these calculations, we used the ray theory package *SEIS83* (Červený and Pšenčík, 1983) enhanced by the interactive graphical interfaces *MODEL* (Komminaho, 1997) and *ZPLOT* (Zelt, 1994, with modifications by P. Środa). In the kinematic modelling, the calculated travel times were compared with the experimental travel times. The model was successively altered by trial-and-error, and travel times were calculated many times for a suite of models until close agreement was obtained between the observed and model-derived travel times (Polkowska-Purys, 2002). Final models for the LT-2, LT-4 and LT-5 profiles are shown in Figure 4. Examples of results of the 2-D crustal structure modelling for different parts of all three profiles are shown in Figures 5–7. They illustrate some features of the observed wave field, which document important elements of the crustal structure for the LT-2, LT-4 and LT-5 profiles. In Figure 5 note a group of waves reflected in the lower crust, occurring 0.5–0.3 s in front of the *PmP* reflection, as well as the refracted P_n wave with an apparent velocity of *ca*. 8.4 km/s. In Figure 6 the apparent velocity of the refracted P_n wave is *ca*. 8.0 km/s, and the lower lithospheric wave P^I and overcritical crustal waves are observed. In Figure 7 note the refracted P_n wave with an apparent velocity of *ca*. 8.4 km/s, as well as the lower lithospheric wave P^I and an overcritical crustal wave. In all

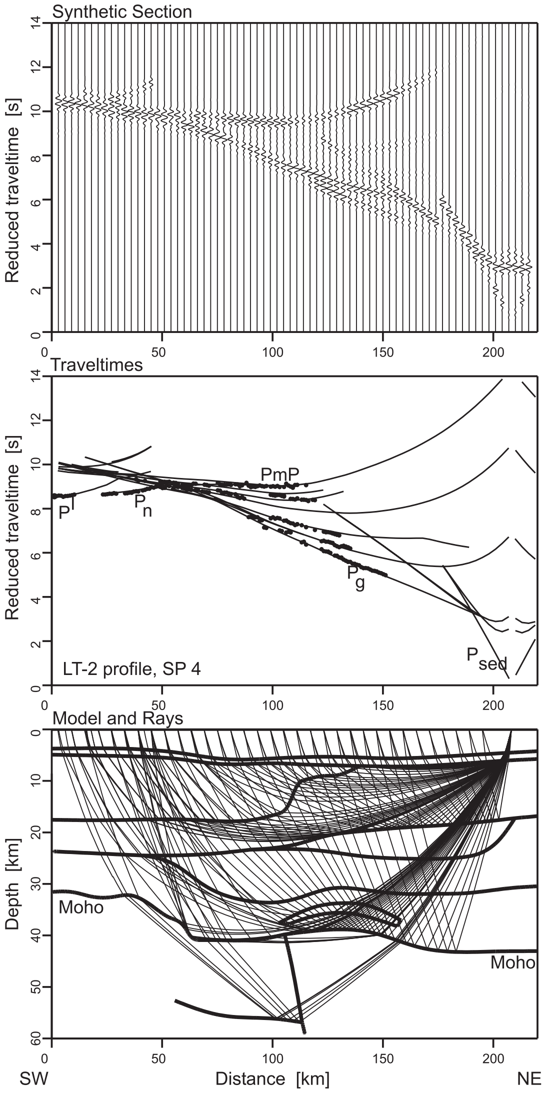

Fig. 5. Synthetic seismograms, observed (picks) and theoretical (lines) travel times of P waves and selected rays calculated for the model of the crust for LT-2 profile, SP 4

Reduction velocity = 8.0 km/s; note a group of waves reflected in the lower crust, occurring 0.5–0.3 s before the *PmP* reflection in the distance range 75–125 km along the profile, as well as the refracted P_n wave with an apparent velocity of *ca*. 8.4 km/s in the distance range 25–50 km (which correspond to offset 160–185 km)

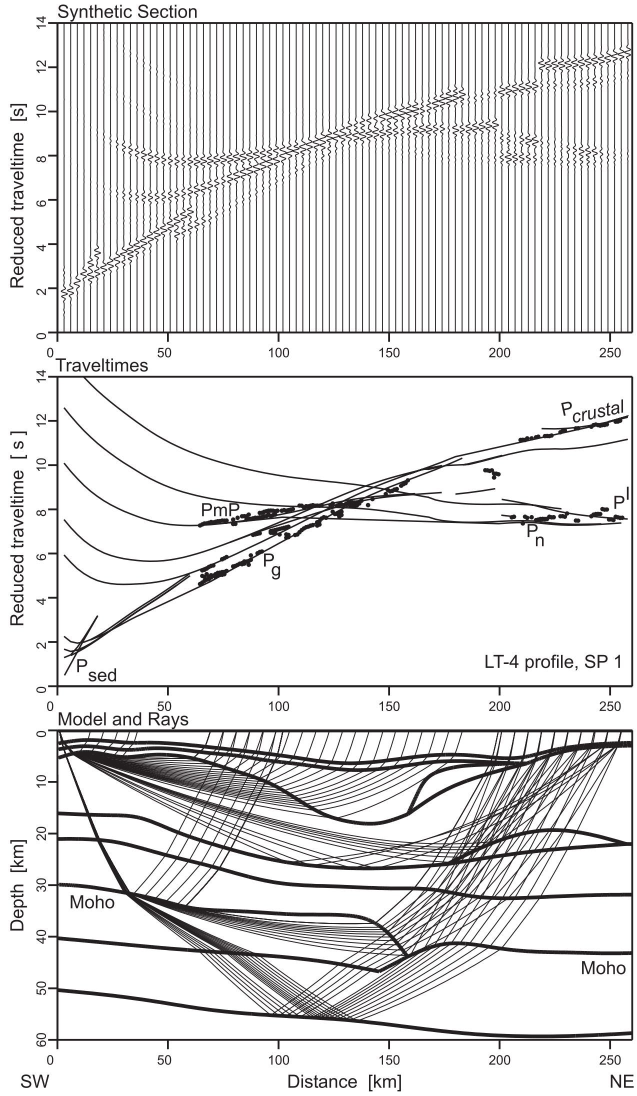

Fig. 6. Synthetic seismograms, observed (picks) and theoretical (lines) travel times of P waves and selected rays (from the upper crust and lower lithosphere) calculated for the model of the crust for LT-4 profile, SP 1

Reduction velocity = 8.0 km/s; note the refracted P_n wave with an apparent velocity of *ca*. 8.0 km/s in the distance range 200–250 km along the profile (and offset), as well as the lower lithospheric wave P^l and overcritical crustal wave $P_{crustal}$ in the distance range 200–250 km

cases, theoretical travel times fit well the observed travel times of refracted and reflected waves. Synthetic seismograms show good quantitative agreement of theoretical and observed amplitudes of the main waves.

In the new models derived for the LT-2, LT-4 and LT-5 profiles using a forward ray tracing technique with the *SEIS83* program (Fig. 4), a large thickness of relatively low velocity rocks was found in the transition between the EEC and the PP. In this area rocks with velocities of 5.3–5.5 km/s at 5 km depth extend to 17–20 km depth where velocities are 5.6–5.9 km/s, and the underlying basement has a velocity of 6.1–6.3 km/s. The models show a variable structure and depth of the basement along profiles. The top of the crystalline basement in the area of the East European Craton lies at 3–8 km, and the crystalline basement velocity is 6.1–6.2 km/s. In the NE parts of all models the crustal structure is typical of Precambrian cratons. Apart from the sedimentary cover, the crystalline crust (about 40 km thick) consists of three layers with velocities of 6.1–6.35, 6.5–6.80 and 7.0–7.25 km/s for the upper, middle and lower crust, respectively (see also Środa *et al.*, 1999; Kozlovskaya *et al.,* 2004). The middle and lower crust contains some complexities, observed as local reflectors and

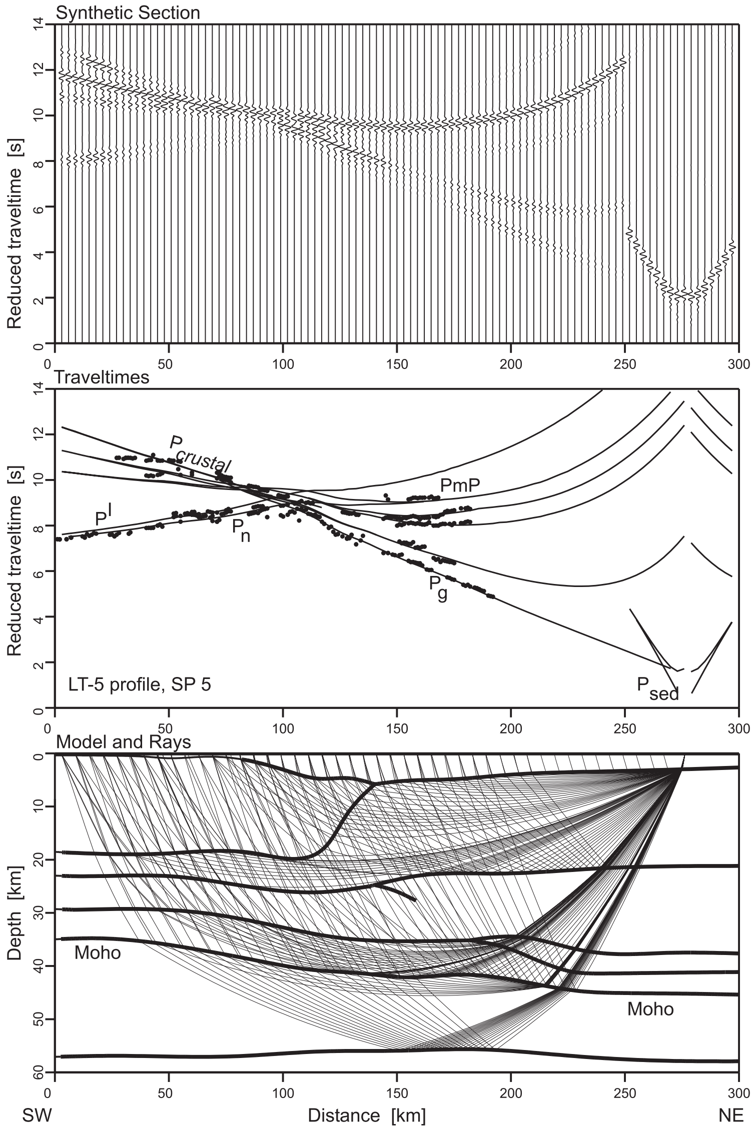

Fig. 7. Synthetic seismograms, observed (picks) and theoretical (lines) travel times of P waves and selected rays calculated for the model of the crust for LT-5 profile, SP 5

Reduction velocity = 8.0 km/s; note the refracted P_n wave with an apparent velocity of *ca*. 8.4 km/s in the distance range along profile 0–100 km (and 275–175 km of corresponding offset), as well as the lower lithospheric wave P^l and overcritical crustal wave $P_{crustal}$ in the distance interval 30–80 km (corresponding offset 190–240 km)

documented from short travel time branches. The crystalline/consolidated crust thins drastically to the SW, and beneath the TTZ and the Palaeozoic Platform it is 15–20 km thick only. The lowermost crust with velocities of 7.0 km/s is present in all profiles (more precisely their central parts) beneath the EEC, TTZ and PP. It is well documented e.g., in Figure 5 for SP 4 from profile LT-2, where overcritical crustal reflections at offset 150–200 km have a significantly higher velocity than the P_g wave closer to the shot point (offset 50–150 km). Another example of this phenomenon under the TESZ is shown in Figure 7 (for SP 5 from profile LT-5) in the distance interval 30–100 km (offset 170–240 km). The velocity beneath the Moho boundary was determined only for the central parts of all profiles where P_n waves penetrated the uppermost mantle. The velocity beneath the EEC is 8.1–8.2 km/s, while for the TTZ and PP it is much higher, being 8.35–8.45 km/s. In the TTZ lithosphere the reflector about 15 km below the Moho was found for all profiles. To explain the amplitude of the waves reflected at this boundary, it is necessary to assume a contrast of the P-wave velocity of about 0.2 km/s. However, it is not clear whether the velocity contrast is negative or positive.

CRUSTAL STRUCTURE IN CENTRAL POLAND

Five profiles, P1–P5, from the POLONAISE'97 experiment, the LT-7 and TTZ profiles and reinterpreted early deep seismic sounding studies at LT-2, LT-4 and LT-5 profiles provide a good regional picture of the crustal structure in Central Poland (Guterch *et al*., 1986, 1994; Grad *et al*., 1999, 2003; Jensen *et al*., 1999; Środa *et al*., 1999, 2002; Czuba *et al*., 2001, 2002; Janik *et al*., 2002). Based on all the profiles mentioned above, the crustal thickness of the TESZ in Central Poland is intermediate between that of the East European Craton to the east (42–44 km) and that in the Palaeozoic Platform to the south-west (30–35 km). The upper crustal structure of the PP and EEC is different, and these units are divided by a transition zone which is a large and deep structure filled with sedimentary, metamorphic or volcanic strata with *Vp* <6.0 km/s to its maximum depth of 18–20 km. The lower crust of the TESZ is relatively fast (*Vp*=6.8–7.3 km/s), and velocities in the uppermost mantle are relatively high (*Vp*>8.3 km/s). The three-layer crystalline crust of Baltica grades laterally into the two-layer Palaeozoic (Variscan) crust, due to the disappearance of the high velocity lowest layer (*Vp*~7.1 km/s).

ANALYSIS OF RESOLUTION AND UNCERTAINTIES

Uncertainties for the final models of the crustal structure for the LT 2, LT 4 and LT 5 profiles are due to a combination of several factors. Some amount of subjectivity cannot be avoided as the arrival times of phases are picked manually after correlation of phases in seismograms. However, the very dense "continuous" system of recordings at the LT-2, LT-4

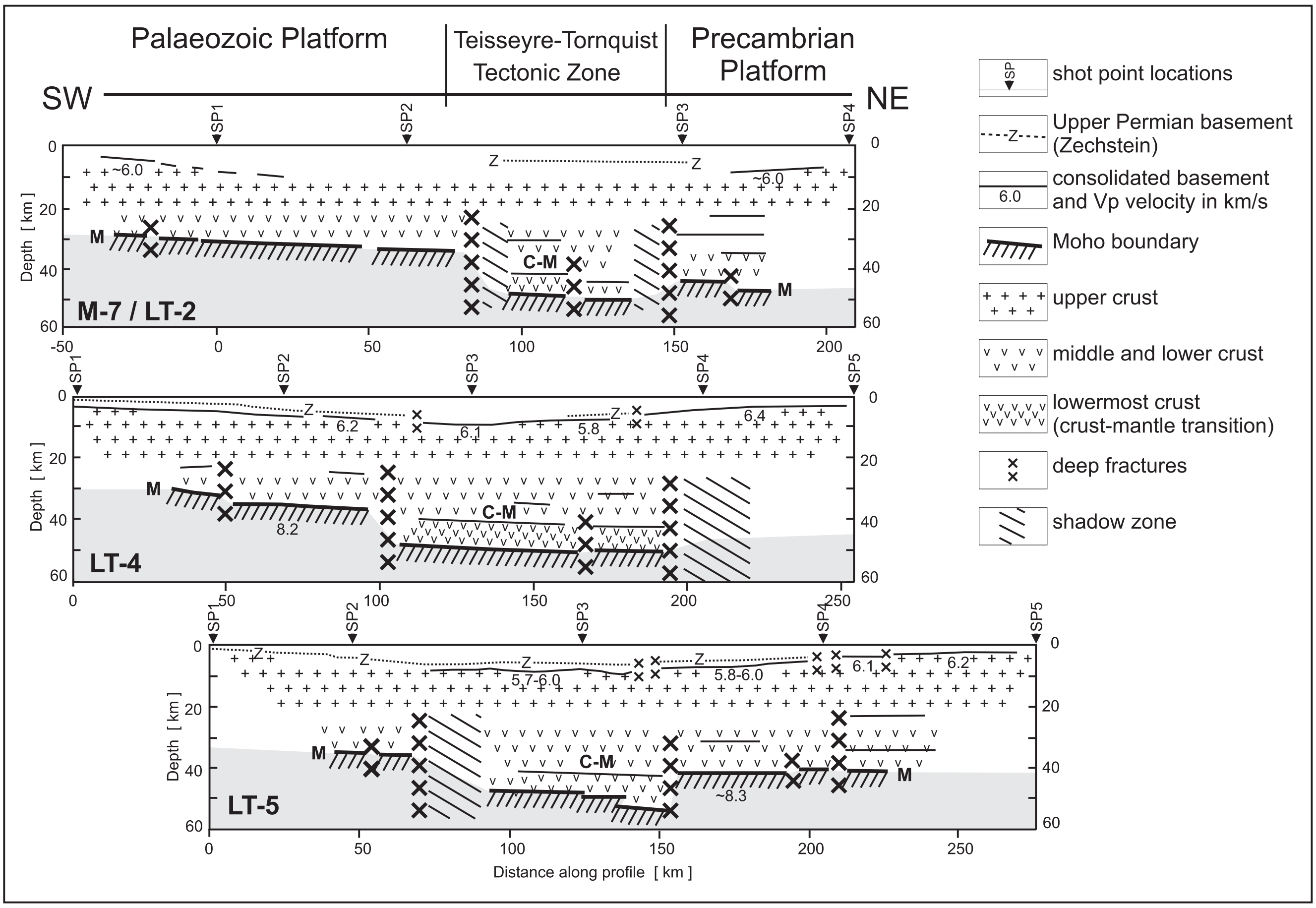

Fig. 8. Previous models of the structure for the LT-2 (with SW extension along profile M-7), LT-4 and LT-5 profiles (Guterch *et al.,* 1986)

and LT-5 profiles (100 or 200 m geophone spacing), gives an opportunity for phase correlation from trace to trace. Here the uncertainties are much lower than in the "point" recording system, where spacing of recorders is a few times larger than the wavelength (1 to 5 km geophone spacing). The subjectivity of correlation is smallest for first arrivals, but later phases provide important constraints that should not be ignored, even though their arrival times are subject to larger uncertainty than the first arrivals. We are confident that the picking accuracy was usually about 0.05 s for refracted phases (first arrivals), and about 0.1 s for reflected phases. Errors due to uncertainty in phase correlations cannot be estimated quantitatively, but the accuracy of the correlations increases with increasing quality and quantity of data. In the case of the LT-2, LT-4 and LT-5 profiles, velocity and depth uncertainties of 2-D models derived by forward modelling are of the order of ±0.1 km/s and ±1 km. However, for areas with complicated structure the accuracy could be worse, i.e., ±0.2 km/s and ±2 km for velocity and depth, respectively (Janik *et al.,* 2002; Grad *et al.,* 2003).

All three "new" 2-D models of the crust for LT-2, LT-4 and LT-5 profiles show some differences compared to "old" cross-sections obtained 20–30 years ago (Figs. 8 and 9; Guterch *et al.,* 1976, 1983). The biggest difference relates to the TESZ structure, while for the EEC and Variscan crust the velocity models are almost the same. In all "old" models the depths of the Moho boundary in the TTZ are significantly greater than in "new" models. This results from overestimated effective velocities for the crust (by about 0.2–0.3 km/s). Recordings were made starting from a distance of 50–90 km from the shot point and the uppermost crustal structure was taken from shallower refraction investigations (Skorupa, 1976). According to these investigations, the consolidated basement at about 10 km depth was characterized by a velocity about of 6.1 km/s. It was only investigations in the 1990's that showed that this basement has a velocity of 5.8 km/s only, and velocities lower than 6.1 km/s are observed down to 18–20 km depth (Guterch *et al.,* 1994; Grad *et al.,* 1999).

SUMMARY AND CONCLUSION

In "new" velocity models for the reinterpreted LT-2, LT-4 and LT-5 profiles (Fig. 4), the total thickness of the crust changes from 30–35 km beneath the Palaeozoic Platform (SW parts of profiles), to 35–40 km beneath the TESZ, and to 42–44 km beneath the EEC (NE parts of profiles). High ve-

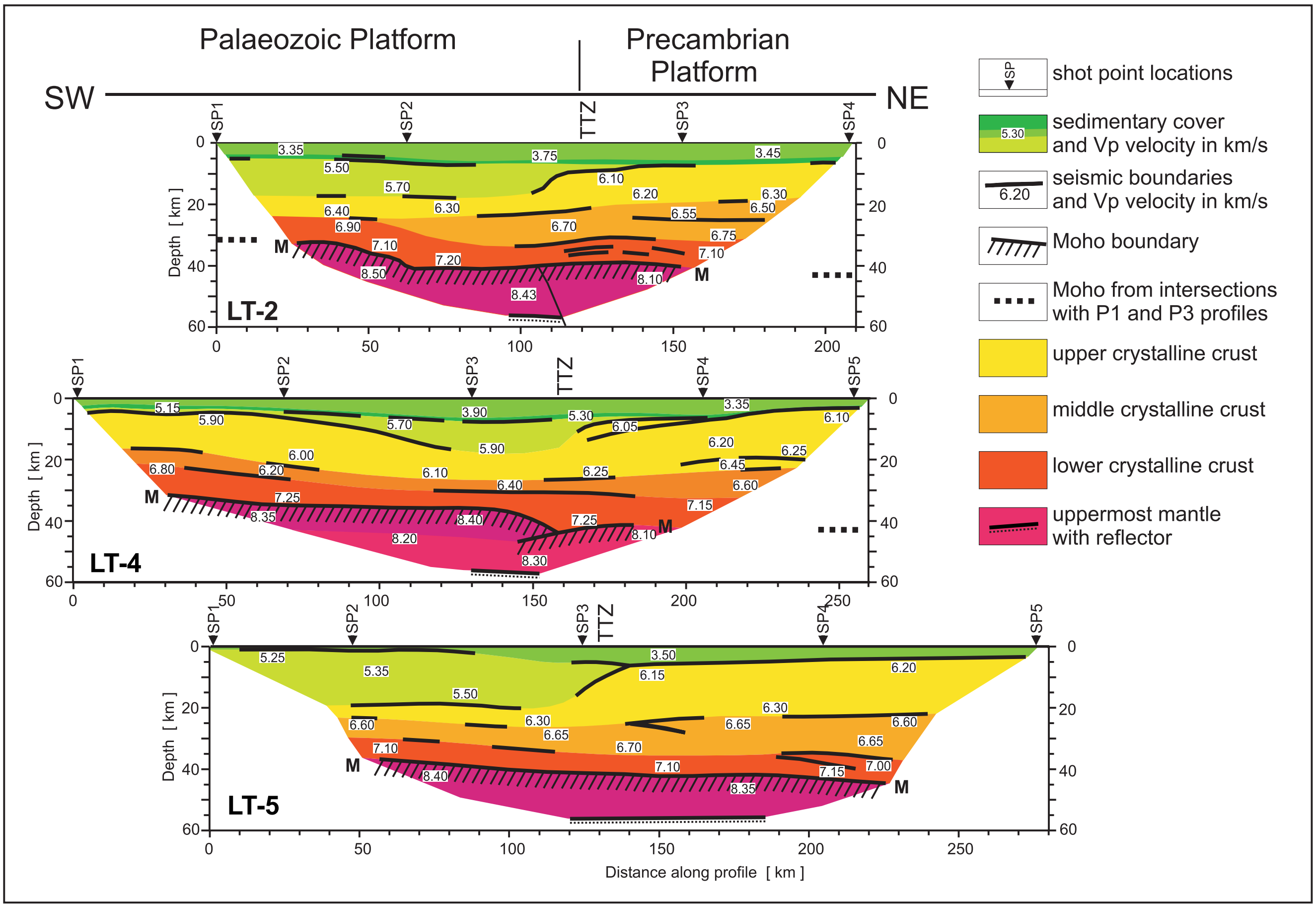

Fig. 9. New models of crustal structure for the LT-2, LT-4 and LT-5 profiles

locities (8.3–8.4 km/s) in the uppermost mantle lithosphere were only found beneath the TTZ and Palaeozoic Platform area. Similar velocities were also found in this area beneath the TTZ and P4 profiles (Grad *et al*., 1999, 2003) and P1 profile (Jensen *et al*., 1999). In the TTZ lithosphere a reflector located about 15 km below the Moho was found on all profiles (see also Grad *et al.,* 2002*a*). Both old and new crustal models derived along the LT 2, LT 4 and LT 5 profiles show generally the same strong structural variations from the Palaeozoic Platform in the south-west, across the TESZ region, on to the EEC to the north-east.

Acknowledgements. The authors are grateful to Prof. R. Dadlez, Dr. P. Krzywiec and Prof. M. Narkiewicz, for helpful comments. This work was partly supported by the NFOŚiGW research grant No 2.94.0004.00.0.

REFERENCES

BERTHELSEN A. (1992*a*) — Mobile Europe. In: A Continent Revealed — the European Geotraverse (eds. D. J. Blundell, R. Freeman and St. Mueller): 11–32. Cambridge Univ. Press.

BERTHELSEN A. (1992*b*) — From Precambrian to Variscan Europe. In: A Continent Revealed — the European Geotraverse (eds. D. J. Blundell, R. Freeman and St. Mueller): 153–164. Cambridge Univ. Press.

BERTHELSEN A. (1998) — The Tornquist Zone northwest of the Carpathians: an intraplate-pseudosuture. Geol. Förenin. Stockholm Förhandlin., **120**: 223–230.

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 Geophys., 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 POLONAISE'97 P5 profile. Acta Geophys. 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. (in press) — Crustal structure below the Polish Basin: is it composed of proximal terranes derived from Baltica? Tectonophysics, *submitted*.

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

EGORKIN A. V. (1966) — Analiz tochnosti opredeleniya skorostnykh parametrov razreza zemnoy kory po godografam otrazhennykh voln. Izv. Akad. Nauk SSSR, Fiz. Zemli, **9**: 72–81.

GRAD M. (1983) — Determination of mean velocities and depths of boundaries in the Earth's crust from reflected waves. Acta Geophys. Pol., **31**: 231–241.

GRAD M., GUTERCH A. and MAZUR S. (2002*b*) — Seismic refraction evidence for crustal structure in the central part of the Trans-European Suture Zone in Poland. Geol. Soc., London, Spec. Publ., **201**: 295–309.

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-Tornquist Zone seismic profile. Tectonophysics, **314**: 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) — Crustal structure of the Trans-European suture zone region along POLONAISE'97 seismic profile P4. J. Geophys. Res., **108** (B11), doi:10.1029/2003JB002426.

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

GUTERCH A. and GRAD M. (2002) — Lithospheric structure of the Trans-European suture zone in Poland from POLONAISE'97 experiment. Acta Geophys. Pol., **50** (4): 499–503.

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, serie II, **319** (2): 1489–1496.

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

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**: 251–279.

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

GUTERCH A., GRAD M., THYBO H., KELLER G. R. and MILLER K. (1998) — Seismic experiment spreads across Poland. Eos Trans. Am. Geophys. 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**: 101–121.

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

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.

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**: 123–143.

KOMMINAHO K. (1997) — Software manual for programs MODEL and XRAYS — a graphical interface for SEIS83 program package. Univ. Oulu, Dep. Geophys., Rep., **20**.

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 Geophys. Pol., **52**: 397–424.

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.

KUTEK J. (1997) — The Polish Permo-Mesozoic rift basin. In: IGCP Project No. 369 Comparative Evolution of Peri-Tethyan Rift Basins, Abstract Book, 4th Annual Meeting and Fieldtrip, 29 August–3 September 1997, Barcelona, Spain.

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

PHARAOH T. C., ENGLAND R. W., VERNIERS J. and ŻELAŹNIEWICZ A. (1997) — Introduction: geological and geophysical studies in the Trans-European Suture Zone. Geol. Mag., **134** (5): 585–590.

POLKOWSKA-PURYS A. (2002) — Struktura skorupy ziemskiej na obszarze TESZ w Centralnej Polsce (reinterpretacja materiałów z profili LT-2, LT-4 i LT-5). MSc thesis, Arch. Inst. Geophys. Univ. Warsaw.

SCHWEITZER J. (1995) — Blockage of regional seismic waves by the Teisseyre-Tornquist zone. Geophys. J. Int., **123**: 260–276.

SKORUPA J. (1976) — Some zones of strongly differentiated morphology of the deep basement from the contact area of the Palaeozoic and Precambrian Platforms in Central Poland. Publ. Inst. Geophys. Pol. Acad. Sc., **A-2** (101): 35–43.

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**: 169–185.

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**: 175–192.

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

ZELT C. A. (1994) — Software package ZPLOT. Bullard Laborat., Univ. Cambridge.

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

ZNOSKO J. (1979) — Teisseyre-Tornquist tectonic zone: some interpretative implications of recent geological and geophysical investigations. Acta Geol. Pol., **29**: 365–382.