Geological Quarterly, 2002, **46** (3): 235–245

Lithospheric structure across the Trans-European Suture Zone in NW Poland based on gravity data interpretation

Czesław KRÓLIKOWSKI and Zdzisław PETECKI

Królikowski C. and Petecki Z. (2002) — Lithospheric structure across the Trans-European Suture Zone in NW Poland based on gravity data interpretation. Geol. Quart., **46** (3): 235–245. Warszawa.

We provide an analysis of geophysical and geological data from the Baltic segment of the Trans-European Suture Zone (TESZ). The construction of structural and density maps of the Zechstein-Mesozoic-Cenozoic complex has allowed identification of anomalies of basement orgin. As a result of interpretation of these anomalies, major structural elements of the lithosphere have been characterised. According to gravity modelling the crustal structure is more complicated than shown on velocity model along refraction and wide-angle reflection profile LT-7. Long-wavelength anomalies have been modelled in terms of lateral heterogeneity within the lower crust and upper mantle. In order to achieve a match between the observed and calculated gravity effects, it was necessary to assume dense upper mantle beneath the TESZ. Gravity data also indicate the presence of high-density bodies in the upper crust, and a complex transitional zone between crust and upper mantle in the TESZ.

Czesław Królikowski and Zdzisław Petecki, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, Poland; e-mail: ckro@pgi.waw.pl, zpet@pgi.waw.pl *(received: December 20, 2001; accepted: May 6, 2002).*

Key words: Trans-European Suture Zone, gravity anomalies, structural-density model, gravity stripping, lithospheric structure

INTRODUCTION

The method of elimination of gravitational effects, originating from a rock complex which has a well-known structural-density characteristics, is referred to as gravity stripping (Hammer, 1963). It has been widely used during the last 15–20 years, mainly in order to identify the geological structure of the deeper basement of sedimentary basins (e.g. Bojdys and Lemberger, 1986; Hermes, 1986; Grobelny and Królikowski, 1988; Pilkington *et al*., 1995; Yegorova and Starostenko, 1999). This method is often an essential element of complex interpretation of geophysical data that relies on modelling of the Earth's crustal structure using potential field anomalies.

The purpose of this paper is to present the results of a regional analysis of gravity data across the Trans-European Suture Zone (TESZ) in NW Poland. An attempt is made to separate gravity effects of the Zechstein-Mesozoic-Cenozoic (ZMC) complex from the gravity effects of deeper crustal levels. In order to investigate the pre-Zechstein lithospheric structure, the 3D gravity stripping method has been used to eliminate the gravity effects of the ZMC complex from the Bouguer anomaly map. The interpretation is based on structural and density maps of the ZMC complex. Density maps have been constructed with regard to both laboratory and well log data, interpreted using computer techniques.

This paper, based on results of the research project no 9 T12B 036 14, financed by the State Committee for Scientific Research (Królikowski *et al*., 2001), includes the analysis of geophysical and geological data from the Baltic segment of the TESZ (Fig. 1). Valuable results, from integrated geophysical and geological data, achieved previously in the Pomeranian (area I) and Kujawy (area II) segments encouraged investigations farther into the Baltic segment (Królikowski and Petecki, 1997, 1999; Petecki, 2000).

GEOLOGICAL SETTING AND RESULTS OF PREVIOUS GEOPHYSICAL INVESTIGATIONS

The study area covers the Baltic segment of the TESZ together with marginal areas of the Palaeozoic platform (adjoining to the SW) and East European Craton (EEC). Evolution of this wide zone, characterised by a complicated geological structure, began in the Early Palaeozoic (Dadlez, 1974; Pożaryski, 1977) and included a Palaeozoic collision and de-

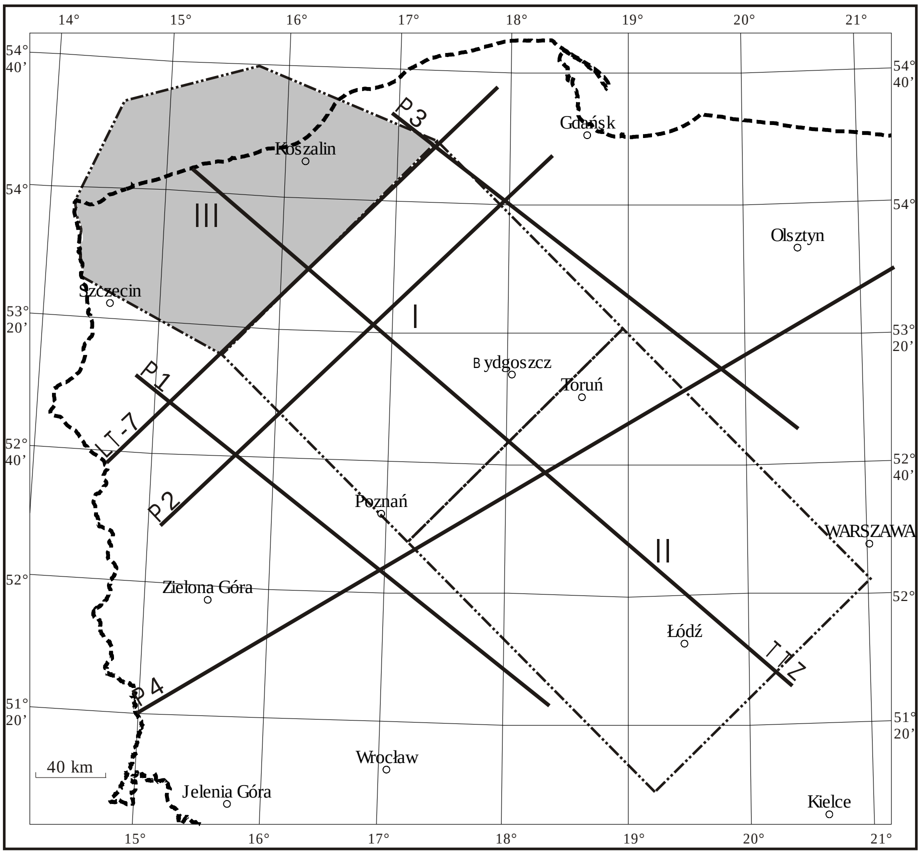

Fig. 1. Location of the research areas and DSS profiles

I and II — areas of previous studies, III — area under study; P1, P2, P3, P4, LT-7 and TTZ — DSS (deep seismic soundings) profiles

formation of terranes docked at the borders of Baltica during the formation of Pangea (e.g. Pharaoh, 1996). In the Late Carboniferous-Permian, the area was subjected to extension, manifested by volcanics. The area subsided during the Permian and Mesozoic, resulting in the formation of the Mid-Polish Trough (Dadlez *et al.*, 1995). This basin was inverted during the Cretaceous and Tertiary. It is now filled with Permian and Mesozoic successions, up to 5–7 km thick. The study area covers the following tectonic units (Dadlez ed., 1998; Znosko, 1998): Szczecin Trough, Pomeranian Swell and Pomeranian Trough, together with their prolongations into the area of the Baltic Sea.

The analysis of potential field anomalies (Grabowska *et al.*, 1991; Królikowski and Petecki, 1995, 1997, 1999; Królikowski *et al.*, 1996, 1999) shows the presence of a number of fault zones in the TESZ, identified as deep crustal fractures, interpreted as boundaries of crustal blocks, which are considered as representing structural units of the crystalline crust. Their parallel trend along the edge of the platform may reflect dynamic processes of collision and accretion of protocontinents (terranes). The TESZ is also transected by transverse fault zones — crustal fractures, resulting in the occurrence of a number of segments that show different structural and petrological features.

The latest seismic investigations (Guterch *et al.*, 1994; Grad *et al.*, 1999; Jensen *et al.*, 1999; Środa *et al.*, 1999) indicate that thickness of the Earth’s crust ranges from 32 km in the Palaeozoic platform to 36 km along the TESZ, and up to 42 km in EEC. The upper crust of the Palaeozoic platform is composed of Palaeozoic and Mesozoic sequences, 6–7 km thick, and a metamorphic complex reaching to below 20 km. Similar thickness relations occur in the TESZ, whereas in the marginal zone of EEC, the sedimentary complex is 5–7 km thick, and is underlain by Precambrian rocks.

DENSITY MAPS OF THE ZMC COMPLEX

The density distribution is based on data from the interpretation of well logs as well as the results of laboratory measurements. Where such determinations were unavailable, and there were boreholes of known lithostratigraphical sections, average densities were estimated (Królikowski ed., 1988). The first method is considered to be the most reliable because the data have been obtained from a complete depth-converted profile and scaled basing on laboratory measurements of core samples. Density determinations of rocks were made from well log data for a total of 21 boreholes, drilled on the onshore portion of the study area. These data were used for a construction of density maps of the following stratigraphical units: Zechstein, Lower and Upper Triassic, Lower and Middle Jurassic, Upper Jurassic, Cretaceous and Cenozoic.

In order to construct density maps onshore, already existing density and thickness data were used. For offshore areas, data from the onshore were extrapolated, with additional use of an interpreted seismoacoustic image. The vertical gradient of gravity maps, map of percentage contribution of tills in Quaternary deposits and map of brown coal deposits and their occurrence in Poland (Ciuk and Piwocki, 1990) were also used for the whole area studied.

STRUCTURAL-DENSITY MODEL OF THE ZMC COMPLEX AND ITS GRAVITY EFFECTS

A three-dimensional structural model of the ZMC complex is based on structural and thickness maps, constructed by a team led by Prof. Ryszard Dadlez within the framework of a research project financed by the State Committee for Scientific Research (Dadlez *et al*., 2000). Because of interpretational requirements, the mapped area has been enlarged by 20 km wide belts along its margins, using data from Mojski ed. (1995) and Dadlez ed. (1998).

The structural-density model was created as a digital database, after digitizing of structural, thickness and density maps. The model was helpful at the first stage of investigation to control the accuracy of structural and thickness maps. The maps were verified by summing up the successive stratigraphical units from the surface down to the base of the Zechstein, comparing the obtained sum with the structural map of the base of Zechstein, and introducing corrections on maps, if necessary. The next stage of verification of the structural and density model was the analysis of gravity effects, originating from the ZMC complex, as well as anomalies caused by the sub-Zechstein basement.

The gravity effect from the ZMC complex was subtracted from the observed Bouguer anomaly field (Fig. 2), giving the gravity anomalies caused by the sub-Zechstein basement, the so-called "stripped" anomalies. They were calculated using a Bouguer correction with varying density, in order to eliminate the effect of density variations in rocks lying above sea level (Królikowski and Twarogowski, 1991).

The first version of the "stripped" gravity anomaly map revealed local disturbances of the field, which were not removed in the process of initial verification of the structural and density model. In order to remove these disturbances, we used software that enabled introduction of corrections into the database, and calculations of gravity effects from the verified ZMX complex.

The "stripped" gravity anomalies, obtained after verification of the structural-density model, were smoothed to eliminate anomalies related to small errors in the model. The "stripped" gravity anomaly map, constructed in this way (Fig. 3), is the basis of further interpretation.

"STRIPPED" GRAVITY ANOMALIES CAUSED BY THE SUB-ZECHSTEIN BASEMENT

For comparative purposes, the Bouguer anomalies with variable density of reduced horizontal slab (Królikowski and Petecki, 1995), interpolated onto a 2 x 2 km grid, are shown in Figure 2 against the background of major tectonic units of the ZMC complex (Dadlez, 1987; Dadlez *et al*., 2000). A significant role in the formation of these anomalies is played by Zechstein-Mesozoic structures.

One of the most important features of the "stripped" anomaly field (Fig. 3) is the presence of a vast gravity high trending NW–SE across the entire study area. Its location corresponds approximately to the Pomeranian gravity high on the Bouguer anomaly map (Królikowski and Petecki, 1995). However, considerable differences, when compared with the Bouguer anomaly map, can be observed both in the trend of gradient zones, which bound the gravity high to the NE and SW, and in its inner structure. This gravity high becomes wider, mainly towards the NE, covering the NE part of the Pomeranian Swell. The gradient zone, bounding the gravity high from the SW, is not so distinct and linear as on the Bouguer anomaly image. Significant changes occur in the internal variability of the gravity high. Anomalies, which had not been seen on the Bouguer anomaly map, are observed here. The highest amplitude is recorded for the anomaly located in the center of the study area, near the Ślepce 3 borehole (S in Fig. 3). Worth noting is its meridional strike. At its northern end there is a similar but smaller anomaly near the Dobrzyca 2 borehole (D in Fig. 3). It trends NW–SE and is situated east of Kołobrzeg. This anomaly, and a strong gradient zone adjoining from the NE, is not observed on the Bouguer anomaly map. The positive anomaly, visible near the Czaplinek IG 2 borehole (C in Fig. 3), has also undergone considerable modification.

Many changes can also be observed in the Baltic Sea area. Prominent anomalies and gradient zones, associated with the Trzebiatów and Wisełka synclines, and Kołobrzeg and Kamień Pomorski anticlines, have been almost completely eliminated.

In the SW part of the study area, generally covering the Szczecin Trough, a prominent anomaly can be observed in the vicinity of Szczecin. The anomaly is separated from the Pomeranian high by a narrow, NW–SE trending anomaly located NW of Nowogard. This anomaly cannot be observed on the Bouguer anomaly map, either. The negative anomaly situated in the Szczecin Trough becomes considerably weaker.

This brief description of the "stripped" gravity anomalies image points to some essential elements of both the geological structures of the sub-Zechstein basement and of deeper crustal zones which are not recorded in the Bouguer anomaly image.

FILTERED "STRIPPED" GRAVITY MAPS

The filtered versions of the "stripped" gravity map have been used to enhance the regional and local features of the TESZ and the surrounding basement domains. Generally, long-wavelength gravity anomalies are attributed to deep sources in the crust and the upper mantle, whereas short-wavelength anomalies are related to shallow sources in the upper crust. In addition, maxima in the horizontal gradient of the filtered gravity data were identified (Blakely and Simpson, 1986). The gradient maxima are represented on the filtered maps by points of sizes proportional to the gradient

magnitude. Plots of these maxima were used to locate the edges of gravity sources and to trace tectonic and lithological discontinuities (Cordell and Grauch, 1985; Grauch and Cordell, 1987; Thurston and Brown, 1994).

REGIONAL "STRIPPED" GRAVITY ANOMALIES

Regional anomalies, associated with deep-seated sources, were defined by upward continuation of the "stripped" gravity field by 20 km (Fig. 4). This transformation was performed in the wavenumber domain using the Geosoft MAGMAP software.

The most prominent and best-documented element is the Pomeranian high, extending across the study area. The presence of this element in regional "stripped" gravity anomaly map (Fig. 4) shows that it is sourced in deeply rooted structures. The considerable length of the anomaly and its high values indicate that there is a large crustal block of high density. It appears to have very deep foundations associated with density changes in the lower crust and upper mantle, as well as with the Moho discontinuity. In this map the Pomeranian high is bounded to the NE by a wide high gradient zone, crossing the whole area analysed. It suggests the occurrence of a deep fracture which, in the LT-7 profile, corresponds approximately to the fracture assumed to represent the edge of the EEC (Guterch *et al*., 1994).

NE of the Pomeranian high there is an area showing lower values of the field. Two regional anomalies, bounded by prominent gradient zones, are observed here. In the study area they can be traced only partly. A narrow zone of higher values of the field separates these anomalies. This is the boundary between the Baltic and Pomeranian high (Królikowski and Petecki, 1995; Królikowski *et al*., 1996) probably representing a lithological discontinuity separating the Pomeranian granite-gneiss massif from heavier metamorphic or intrusive rocks of the Baltic area (Kubicki and Ryka, 1982).

In the area adjoining the Pomeranian high to the south-west, an interesting positive anomaly is observed, located in the vicinity of Szczecin but traced only as fragments (Fig. 3). It may have a similar origin to the East Elbe Massif gravity anomalies. The Szczecin Block was distinguished within the sub-Zechstein basement by Pożaryski (1987) who suggested connections of the study area with this massif.

LOCAL "STRIPPED" GRAVITY ANOMALIES

In order to obtain local anomalies, whose sources are associated with shallower structures located in the upper crust, upward-continued anomalies (Fig. 4) were subtracted from "stripped" gravity anomalies (Fig. 3).

In the local "stripped" gravity anomaly map (Fig. 5), where the effects of deep crustal structures and the Moho are filtered out, anomalies resulting from density differentiation of the immediate sub-Zechstein basement in the Pomeranian Trough are evident. Their distribution and trend of gradient zones indicate that, in the area located SW of the Precambrian Platform, the sub-Zechstein basement shows a block structure, determined by deep tectonic lineaments. Three prominent anomalies (C, D and S in Fig. 5) indicate the occurrence of additional rock masses in the upper crust, most probably intrusive bodies with dominantly basic rocks.

The northeastern boundary of the Pomeranian high corresponds over a long distance to the Biesiekierz Fault Zone (Dadlez and Marek, 1997). Many other faults, observed in the Zechstein-Mesozoic complex of the area (e.g. Rzeczenica, Sianów-Polanów), correspond to gravity gradient zones. The SW part of the Pomeranian high shows a more complicated structure. It is bounded by a few prominent gradient zones (Fig. 5) which occur at the border of the Pomeranian Swell (Fig. 2). It is probable that they mark fault zones of the sub-Zechstein basement, which show a relationship with the tectonics of the overlying complex.

Off the Polish coast, the local anomaly pattern is less variable (Fig. 5). Only the NE boundary of the Kołobrzeg Block (Fig. 2) manifests itself strongly in the form of horizontal gradient maxima. The Trzebiatów Fault Zone (Fig. 2) is less distinct. The difference between offshore and onshore local anomaly images (Fig. 5) can be associated with the occurrence of lower density Upper Carboniferous deposits in the sub-Permian basement of the Gryfice and Kołobrzeg blocks, as compared with the central part of the Pomeranian Swell (Fig. 2), where the sub-Permian base is underlain by higher density Lower Carboniferous and Devonian deposits (Dadlez, 1987).

THREE-DIMENSIONAL (3D) INVERSION OF THE "ŚLEPCE" GRAVITY ANOMALY

The "Ślepce" local positive gravity anomaly is located in the central part of the area (S in Fig. 5). The enlarged image of the anomaly is shown in Figure 6a. It was interpreted with the use of the 3D inversion method, assuming that an intrusive body causes this anomaly. It enabled determination of the approximate depth of occurrence, thickness and density contrast of the body. A depth to its top was determined using the power spectrum method (Spector and Grant, 1970). The depth obtained (approximately 9 km) shows that the top of the anomalous body occurs within the upper crust, which, according to the LT-7 profile (Guterch *et al*., 1994) and TTZ profile data (Grad *et al*., 1999), is characterised by relatively low seismic velocities $V_p < 6.0$ km/s (compare Fig. 7). A high velocity body has been interpreted at a similar depth in the TTZ profile in the Pomeranian segment of the TESZ, SW of the intersection with the LT-7 profile.

The "Ślepce" anomaly (Fig. 6a) was modelled using a 3D gravity inversion modelling program (Petecki, 2000). The modelled body is assumed to have a flat bottom. The model constructed with the power spectrum depth control is shown in Figures 6b and c. The results of the analysis indicate that the "Ślepce" positive "stripped" gravity anomaly may be caused by a source located at a depth of about 9 km, and it has a maximum thickness of approximately 7 km. A considerable density contrast (0.22 g/cm^3) suggests that the source is an intrusion of lower crustal and/or upper mantle origin. The modelling results show that the final model fit the observed data to a satisfactory degree (Fig. 6d) and can be used to provide constraints on deep density structure.

Fig. 4. Map of the “stripped” gravity anomalies continued upwards to 20 km

Other explanations as in Figs. 2 and 3

Fig. 5. Map of the local “stripped” gravity anomalies

Positive anomalies C, D and S are discussed in the text; other explanations as in Figs. 2 and 3

Fig. 6. 3D inversion of the "Ślepce" local "stripped" anomaly

a — "Ślepce" local "stripped" anomaly, **b** — depth of the source body in km, **c** — source body thickness in km, **d** — gravity effect from source body

The other two positive anomalies, "Dobrzyca" and "Czaplinek" (D and C in Fig. 5), presumably of similar origin, have not been analysed using the above-described methods due to either unfavourable position with respect to other anomalies or their incomplete record. The source of the "Dobrzyca" anomaly, located north of the "Ślepce" anomaly, is seated probably at shallower depths. The "Czaplinek" anomaly, situated in the southeastern border of the area, is probably caused by a source of similar parameters as the "Ślepce" anomaly.

TWO-DIMENSIONAL (2D) MODELLING OF THE "STRIPPED" GRAVITY DATA

The purpose of the gravity modelling was to study the crust and upper mantle structure across the contact zone of the Palaeozoic platform and EEC in the study area. Deep seismic surveys, performed in Poland (Guterch *et al*., 1994, 1999; Grad *et al*., 1999; Jensen *et al*., 1999; Środa *et al*., 1999; Janik *et al*., 2000), revealed that this region is characterised by anomalous geological structure of the Earth's crust and upper mantle. Gravity forward modelling was performed along profile A, crossing the analysed area nearly perpendicular to the major gravity anomalies (Fig. 3). Gravity profile A coincides with part of the refraction and wide-angle reflection profile LT-7 (Guterch *et al*., 1994). The modelling was carried out using the GM-SYS™ software that allows calculation of 2D gravity effects originating from bodies perpendicular or oblique to the profile's strike. The bodies are assigned a finite strike length.

Gravity modelling is based on the 2D seismic velocity model along the LT-7 profile (Guterch *et al*., 1994) shown in Figure 7. Seismic data indicate that, beneath the Palaeozoic platform and in the TESZ, the upper crust has anomalously low velocities (below 6.0 km/s) down to a depth of approximately 20 km. The thinner lower crust (10–15 km) is composed of two layers, showing velocities of 6.5 and 7.15–7.25 km/s. Its greatest thickness is observed in the TESZ, and the velocity below the Moho is 8.26 km/s. In the EEC, the crystalline crust consists of three layers with velocities of 6.2–6.3, 6.5–6.6 and 7.0–7.15 km/s, respectively, and the depth to the Moho is about 42 km. Seismic velocities beneath the Moho increase to 8.33 km/s.

Velocities for individual crustal blocks and the Earth's mantle were averaged and converted into densities using the density/velocity relation of Christensen and Mooney (1995). The calculated gravity effect from the density model that corresponds to the velocity model described above differs considerably from the observed curve. Comparison of the modelled and "stripped" gravity effects reveals a major discrepancy of 70 mGal around the TESZ (Fig. 7). The lower gravity values computed from the velocity model demostrate a mass deficiency in the initial interpretation. It indicates of the occurrence of high-density sources, which have not been recorded in the velocity model. The analysis of gravity anomalies from the sub-Zechstein basement in the Pomeranian segment of the TESZ (Królikowski and Petecki, 1997) shows two causes of the observed discrepancy: the increased density of the upper mantle in the TTZ and the occurrence of basic rock intrusions (of high density) in the upper crust. These conclusions, recently confirmed by a seismic survey performed along the TTZ profile (Grad *et al*., 1999), were taken into consideration during the gravity modelling. Results of interpretation of seismic profiles, carried out within the POLONAISE'97 project (Fig. 1) (Guterch *et al*., 1994; Jensen *et al*., 1999; Środa *et al*., 1999; Janik *et al*., 2000), have also been employed. They have provided more detailed data on the geological structure of the lithosphere in the vicinity of the study area.

An important result of the gravity modelling (Fig. 8) was the confirmation of the occurrence of a high-density (~ 2.90 g/cm^3) intrusive body in the upper crust of the TTZ area. The presence of basic rock intrusions in the upper crust of the Pomeranian segment of the TESZ was earlier postulated on the basis of interpretation of gravity anomalies from the sub-Zechstein basement (Królikowski and Petecki, 1997). Seismic data along the LT-7 profile do not indicate the occurrence of any intrusion, maybe due to its relatively small dimensions. In the Pomeranian segment of the TESZ on the TTZ profile, however, a high-velocity body has recently been indicated at a depth of about 10 km (Grad *et al*., 1999).

The lower crust of the TESZ also has a complex structure. The gravity modelling indicates the occurrence of a transitional zone between the crust and upper mantle. Its formation can be related to penetration of mantle matter into the lower crust. The maximum depth of the Moho discontinuity (approximately 48 km) presumably occurs beneath the outer edge of the EEC crust. The contact of this complex transitional zone with the crystalline crust of the Palaeozoic platform dips northeastwards, and may represent a southeastern continuation of the Trans-European Fault (TEF) (Królikowski *et al*., 1999).

The density model of the crystalline crust of the EEC along the profile analysed shows a relatively simple, three-layered structure, not altered significantly by gravity data modelling in relation to the seismic model.

Density variability within the upper mantle is necessary to explain long-wavelength gravity anomalies. The latest interpretations of deep seismic experiments also indicate much velocity variability within the upper mantle (Środa *et al*., 1999; Grad *et al*., 1999; Jensen *et al*., 1999).

DISCUSSION

Based on the 3D structural-density model of the ZMC complex in the Baltic segment of the TESZ in NW Poland, the gravity anomalies caused by the structures below the Zechstein were calculated. The "stripped" gravity image (Fig. 3) shows a significant positive anomaly in the central part of the study area, the NW–SE trending Pomeranian gravity high. According to the model presented here, the regional component of this gravity high (Fig. 4) is caused by dense lower crust and upper mantle in the TESZ. The high-density lower crustal zone that extends beneath the cratonic edge (Fig. 8) is interpreted as being composed of mafic material that may have resulted from underplating of mantle material. This process could play an important role in the evolution of the Mid-Polish Trough (Dadlez *et al*., 1995).

The contact of the crystalline crust of the TESZ with the crystalline crust of the Palaeozoic platform dips to the NE (Fig. 8), and may represent a southeastern continuation of the TEF (Królikowski *et al*., 1999). On the basis of gravity and magnetic modelling along the LT-7 profile Petecki (2002) pointed out that it may indicate a suture formed due to the Caledonian collision of Eastern Avalonia and Baltica with the presumed participation of an additional crustal block of unclear provenance.

The laterally heterogeneous upper mantle (Fig. 8) with an anomalously high density (3.42 g/cm^3) zone beneath the TESZ is difficult to explain. However, the gravity modelling of large positive anomalies above Dnieper-Donets Basin also revealed increased density in the upper mantle beneath the basin (Lobkovsky *et al*., 1996). Lobkovsky *et al*. (1996) presented a quantitative model of the Dnieper-Donets Basin evolution based on a subsidence of a heavy eclogite lens in the asthenosphere. The model fits well the tectonic subsidence data. It may be speculated that increased density in the uppermost mantle of the study area is caused by metamorphic transformation of mafic rocks to eclogite.

Fig. 7. P-wave velocity model of profile A (after Guterch *et al*., 1994) (bottom) and the comparison between the calculated and "stripped" gravity anomalies along profile A (top)

Fig. 8. Gravity modelling along profile A

Explanations as in Fig. 7

The local "stripped" gravity map (Fig. 5) indicates the complex tectonic pattern of the pre-Zechstein basement. The strong local positive anomalies (C, D and S in Fig. 5) clearly indicate the presence of high-density sources in the upper crust. The power spectrum analysis, 3D inversion and 2D modelling of gravity data show that the depth to the top of these bodies is about 9 km and their thicknesses reach 5–6 km. These high-density (2.90–2.92 g/cm^3) sources may be intrusive bodies (2.90–2.92 g/cm^3) with dominant basic rocks. Their presence may be linked to the development of the Mid-Polish Trough.

CONCLUSIONS

1. The image of the "stripped" gravity anomalies in the Baltic segment of the TESZ is characterised by the occurrence of a vast positive anomaly that corresponds to the gravity unit of the Pomeranian high.

2. The images of the regional and local components of the "stripped" gravity anomalies of the Pomeranian high show that the anomalies are controlled by both deep and shallower (sub-Zechstein) sources.

3. The long-wavelength positive anomaly located within the TESZ is caused by sources situated in the lower crust and upper mantle. 2D modelling of gravity data indicates increased densities of the lower crust and upper mantle within the TESZ and a complex structure of the lower crust (transitional zone). The boundary between this transitional zone and the upper mantle descends to a maximum depth of approximately 48 km near the marginal zone of the EEC. This high-density lower crustal zone may be caused by magmatic underplating.

4. The increased density of the uppermost mantle beneath the TESZ may be caused by metamorphic transformation of mafic rocks to eclogite.

5. The contact of the crystalline crust of the TESZ with the crystalline crust of the Palaeozoic platform appears to dip north-eastwards and may be a southeastern continuation of the TEF. It may represent a suture formed during the Caledonian collision of Eastern Avalonia and Baltica.

6. Local positive "stripped" gravity anomalies can be associated with intrusions of dense basic rocks from the lower crust and/or upper mantle; 3D inversion analysis shows that the depth to the top of these bodies is about 9 km and their thicknesses reach 5–6 km; gravity modelling indicates that these may be high-density intrusive bodies (2.90–2.92 g/cm^3) with dominantly basic rocks. Their presence may be linked to extensional and coeval magmatic events during the Mid-Polish Trough formation and evolution.

Acknowledgements. The authors express their cordial thanks to Prof. Ryszard Dadlez for valuable cooperation in both the last research project (Baltic segment) and previous projects covering the Pomeranian and Kujawy regions. Without structural and thickness maps of the Zechstein-Mesozoic complex, compiled by a team of specialists under the leadership of him, it would have been impossible to study the geological structure of the sub-Zechstein basement using the 3D gravity stripping method. Careful reviews by Z. Fajklewicz and R. Stephenson helped to improve the paper. Editorial review by M. Narkiewicz is also appreciated.

REFERENCES

BLAKELY R. J. and SIMPSON R. W. (1986) — Approximating edges of source bodies from magnetic or gravity anomalies. Geophysics, **51**: 1491–1498.

BOJDYS G. and LEMBERGER M. (1986) — Three-dimensional gravity modelling of Earth's crust and upper mantle in the Polish Carpathians. Ann. Soc. Geol. Pol., **56** (3–4): 349–373.

CHRISTENSEN N. I. and MOONEY W. D. (1995) — Seismic velocity structure and composition of the continental crust: a global view. J. Geophys. Res., **100**: 9761–9788.

CIUK E. and PIWOCKI M. (1990) — Map of brown coal deposits and prospect areas in Poland, 1:500 000. Państw. Inst. Geol. Warszawa.

CORDELL L. and GRAUCH V. J. S. (1985) — Mapping basement magnetization zones from aeromagnetic data in the San Juan Basin, New Mexico. In: The Utility of Regional Gravity and Magnetic Anomaly Maps (ed. W. J. Hinze): 181–197. SEG.

DADLEZ R. (1974) — Tectonic position of Western Pomerania (northwestern Poland) prior to the Upper Permian. Biul. Inst. Geol., **274**: 49–88.

DADLEZ R. (1987) — Tectonics. Zechstein-Mesozoic complex. In: Geological structure of the Pomeranian Swell and its basement (ed. A. Raczyńska). Pr. Inst. Geol., **119**: 186–195.

DADLEZ R. ed. (1998) — Tectonic Map of the Zechstein-Mesozoic complex in the Polish Lowlands, 1:500 000, II ed. Państw. Inst. Geol. Warszawa.

DADLEZ R., KASIŃSKI J. and SZYMAŃSKI B. (2000) — Wewnętrzna geometria pokrywy osadowej w strefie T–T, segment bałtycki. Projekt badawczy KBN nr 9 T12B 019 14. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

DADLEZ R. and MAREK S. (1997) — Tektonika kompleksu permsko-mezozoicznego. In: The epicontinental Permian and Mesozoic in Poland (in Polish with English summary) (eds. S. Marek and M. Pajchlowa). Pr. Państw. Inst. Geol., **153**: 410–415.

DADLEZ R., NARKIEWICZ M., STEPHENSON R. A., VISSER M. T. M. and VAN WEES J.-D. (1995) — Tectonic evolution of the Mid-Polish Trough: modelling implications and significance for central European geology. Tectonophysics, **252** (1–4): 179–195.

GRABOWSKA T., KOBLAŃSKI A. and DOLNICKI J. (1991) — Deep structure of the Earth's crust in the Teisseyre-Tornquist Zone (TTZ) in Poland, based on gravity and magnetic studies. Publ. Inst. Geophys. Pol. Acad. Sci., **A-20** (255): 81–89.

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.

GRAUCH V. J. S. and CORDELL L. (1987) — Limitations of determining density or magnetic boundaries from the horizontal gradient of gravity or pseudogravity data. Geophysics, **52**: 118–121.

GROBELNY A. and KRÓLIKOWSKI C. (1988) — Gravimetric anomalies caused by sub-Permian sediments in northwestern Poland (in Polish with English summary). Kwart. Geol., **32** (3–4): 611–634.

GUTERCH A., GRAD M., JANIK T., MATERZOK R., LUOSTO U., YLINIEMI J., LÜCK E., SCHULTZE A. and FÖRSTE K. (1994) — Crustal structure of the transition zone between Precambrian and Variscan Europe from new seismic data along LT-7 profile (NW Poland and eastern Germany). Geophysique/Geophysics, C. R. Acad. Sci. Paris, **319** (2): 1489–1496.

GUTERCH A., GRAD M., THYBO H., KELLER R. and POLONAISE WORKING GROUP (1999) — POLONAISE'97 — International seismic experiment between Precambrian and Variscan Europe in Poland. Tectonophysics, **314**: 101–121.

HAMMER S. (1963) — Deep gravity interpretation by stripping. Geophysics, **3**: 369–378.

HERMES H. J. (1986) — Calculation of pre-Zechstein Bouguer anomaly in northwest Germany. First Break, **4** (11): 13–22.

JANIK T., YLINIEMI J., GRAD M., THYBO H., TIIRA T. and POLONAISE P2 WORKING GROUP (2000) — Crustal differentiation across TESZ along POLONAISE '97 seismic profile P2 in NW Poland. In: Joint Meeting of EUROPROBE (TESZ) and PACE Projects. Zakopane/Holy Cross Mts., Poland, Sept. 16–23, 2000. Abstracts. Warsaw.

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

KRÓLIKOWSKI C. ed. (1988) — The distribution of the density of Cainozoic and Permian-Mesozoic rocks in north-western Poland (in Polish with English summary). Pr. Inst. Geol., **124**.

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

KRÓLIKOWSKI C. and PETECKI Z. (1997) — Crustal structure at the Trans-European Suture Zone in northwest Poland based on the gravity data. Geol. Mag., **134** (5): 661–667.

KRÓLIKOWSKI C. and PETECKI Z. (1999) — The Earth's crust structure in the Pomeranian and Kujavian segments of the TESZ based on the gravity data. Abstracts of the "7th Eurobridge Workshop 26–30 May 1999, Szelment, Poland".

KRÓLIKOWSKI C., PETECKI Z. and DADLEZ R. (1996) — Vertical discontinuities of the Earth's crust of the TESZ in Poland — gravity data. Geol. Quart., **40** (2): 155–168.

KRÓLIKOWSKI C., PETECKI Z., SZCZYPA S., TWAROGOWSKI J. and ŻÓŁTOWSKI Z. (2001) — Badanie struktury podłoża podcechsztyńskiego w obszarze nadbałtyckim strefy TESZ z wykorzystaniem metody 3-wymiarowego modelowania grawimetrycznego. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

KRÓLIKOWSKI C., PETECKI Z. and ŻÓŁTOWSKI Z. (1999) — Main structural units in the Polish part of the East-European Platform in the light of gravimetric data (in Polish with English summary). Biul. Państw. Inst. Geol., **386**: 5–58.

KRÓLIKOWSKI C. and TWAROGOWSKI J. (1991) — The map of the density of rocks existing above sea level in Poland (in Polish with English summary). Kwart. Geol., **35** (3): 371–382.

KUBICKI S. and RYKA W. eds. (1982) — Geological Atlas of Crystalline Basement in Polish Part of the East-European Platform. Inst. Geol. Warszawa.

LOBKOVSKY L. I., ISMAIL-ZADEH A. T., KRASOVSKY S. S., KUPRENKO P. Ya. and CLOETINGH S. (1996) — Gravity anomalies and possible formation mechanism of the Dniepr-Donets Basin. Tectonophysics, **268**: 281–292.

MOJSKI J. E. (ed.) (1995) — Geological Atlas of the Southern Baltic (in Polish). Państw. Inst. Geol. Warszawa.

PETECKI Z. (2000) — Processing and interpretation of potential field data at the Kujavian segment of the Teisseyre-Tornquist Zone and the western part of the Precambrian Platform (in Polish with English summary). Biul. Państw. Inst. Geol., **392**: 75–120.

PHARAOH T. and TESZ COLLEAGUES (1996) — Trans-European Suture Zone — Phanerozoic accretion and the evolution of contrasting continental lithosphere. In: EUROPROBE 1996 — Lithosphere Dynamics: Origin and Evolution of Continents (eds. D. G. Gee and H. J. Zeyen): 41–54. EUROPROBE. Uppsala.

PILKINGTON A., ABDOH A. and COVAN D. R. (1995) — Pre-Mesozoic structure of the Inner Moray Firth Basin: constraints from gravity and magnetic data. First Break, **13** (7): 291–300.

POŻARYSKI W. (1977) — The Caledonian Epoch in the Epi-Gothian Platform and its border zone. In: Geology of Poland, **4** — Tectonics: 175–206.

POŻARYSKI W. (1987) — Tektonika. Paleozoik podpermski. In: Budowa geologiczna wału pomorskiego i jego podłoża (ed. A. Raczyńska). Pr. Inst. Geol., **119**: 174–194.

SPECTOR A. and GRANT F. S. (1970) — Statistical models for interpreting aeromagnetic data. Geophysics, **35**: 293–302.

ŚRODA P. and POLONAISE 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.

THURSTON J. B. and BROWN R. J. (1994) — Automated source-edge location with a new variable pass-band horizontal-gradient operator. Geophysics, **59**: 546–554.

YEGOROVA T. P. and STAROSTENKO V. I. (1999) — Large-scale three-dimensional gravity analysis of the lithosphere below the transition zone from Western Europe to the East European Platform. Tectonophysics, **314**: 83–100.

ZNOSKO J. ed. (1998) — Atlas tektoniczny Polski. Państw. Inst. Geol. Warszawa.