Crustal structure at the Trans-European Suture Zone in northwest Poland based on gravity data

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(*Received* 15 May 1996; *accepted* 17 March 1997)

Abstract – A new gravity model of the crustal structure of the Trans-European Suture Zone in the northwestern Poland has been constructed. The Bouguer anomaly map, obtained after stripping off the three-dimensional gravity effect of the sedimentary cover down to the Zechstein formations, is characterized by a 50 mGal gravity anomaly. We have assumed that the short-wavelength components derive from upper crustal intrusions and the long-wavelength components reflect crustal thickness and lateral heterogeneity which are strongly supported by the new seismic data along the LT-7 geotraverse. Quantitative modelling of gravity data along three profiles crossing the area indicate the presence of anomalous masses within the Lower Palaeozoic sequence, mainly along the Teisseyre-Tornquist Zone. Two of the profiles crossing the long-wavelength 'stripped' gravity high suggest the existence of a zone of 35 km crust above a dense upper mantle along the Teisseyre-Tornquist Zone. The extent of the zone can be determined based on the Bouguer anomalies interpretation.

1. Introduction

The study area (Fig. 1) is located in northwestern Poland. It comprises the part of the Trans-European Suture Zone (TESZ) with the tectonic Teisseyre-Tornquist Zone (TTZ) of increased crustal thickness and part of the European mobile Variscan zone on the southwest side, and the East European Craton on the northeast side (Guterch *et al.* 1983, 1986). The TTZ outlines the northeast border of the TESZ (Berthelsen, 1993) and is marked by a notable thickening of the crust from the Phanerozoic Europe's thin crust of 32–34 km to the cratonic crust with thickness of 42–44 km. According to the seismic data, the Moho depth in the TTZ varies from 35 km at the LT-7 profile (Guterch *et al.* 1994) to 50 km at the VII profile (Guterch *et al.* 1986).

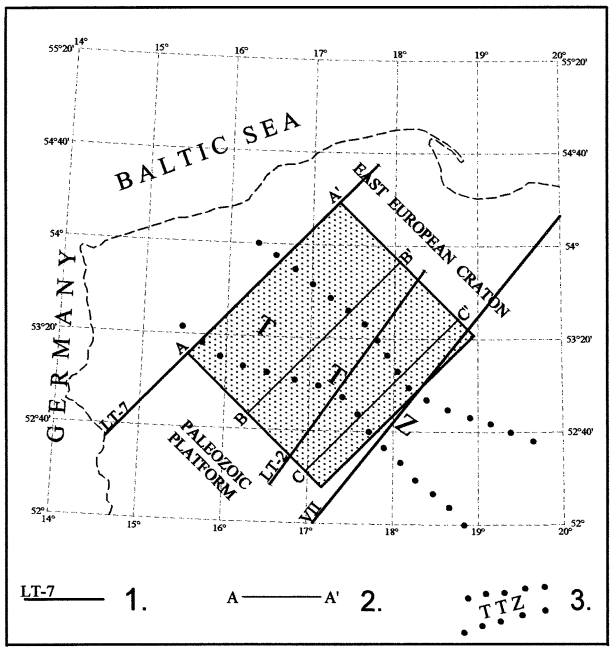


Figure 1. Location map of the study area with major tectonic units. 1 – deep seismic profile, 2 – gravity profile, 3 – steps in Moho.

Most of the area is covered by thick (locally up to 11 km) sequences of Palaeozoic, Mesozoic and Cenozoic sediments. The Middle Polish Basin has been created by the Permian–Mesozoic complex. The structural style in most of the study area was affected by the strong salt tectonics and late Cretaceous–early Tertiary inversion of the central part of the Basin. In northwestern and central Poland the Caledonian basement is largely concealed by the thick Permian to Mesozoic fill. Thick Zechstein salt has hampered successful seismic reflection imaging of pre-Zechstein basement.

2. Determination of the pre-Zechstein anomalies

The relatively good definition of the Zechstein–Mesozoic–Cenozoic structure based on seismic exploration and drilling has permitted the application of the 3-D stripping method prior to 2.5-D gravity modelling (Hermes, 1986; Królikowski & Grobelny, 1991; Pilkington, Abdoh & Covan, 1995). The 3-D structure model was constructed using the structural and thickness maps of successive stratigraphical members. The study of the density distribution was based on the results of laboratory measurements of rock samples and log interpretation. Every structural and density map was digitized in grid at a 2.5 km interval, and the structural-density data base was formed.

The gravity effects of geological formations from the surface to the base of the Zechstein were calculated against a density of 2.67 g/cm^3 for the pre-Zechstein rocks. The total gravity effects of the sediments range from about –66 mGal to –15 mGal. The result of subtracting the calculated effects from the Bouguer anomalies (Fig. 2) with variable density reduction (Królikowski & Petecki, 1995) has provided 'stripped' anomalies (Fig. 3) which should originate from the pre-Zechstein bedrock.

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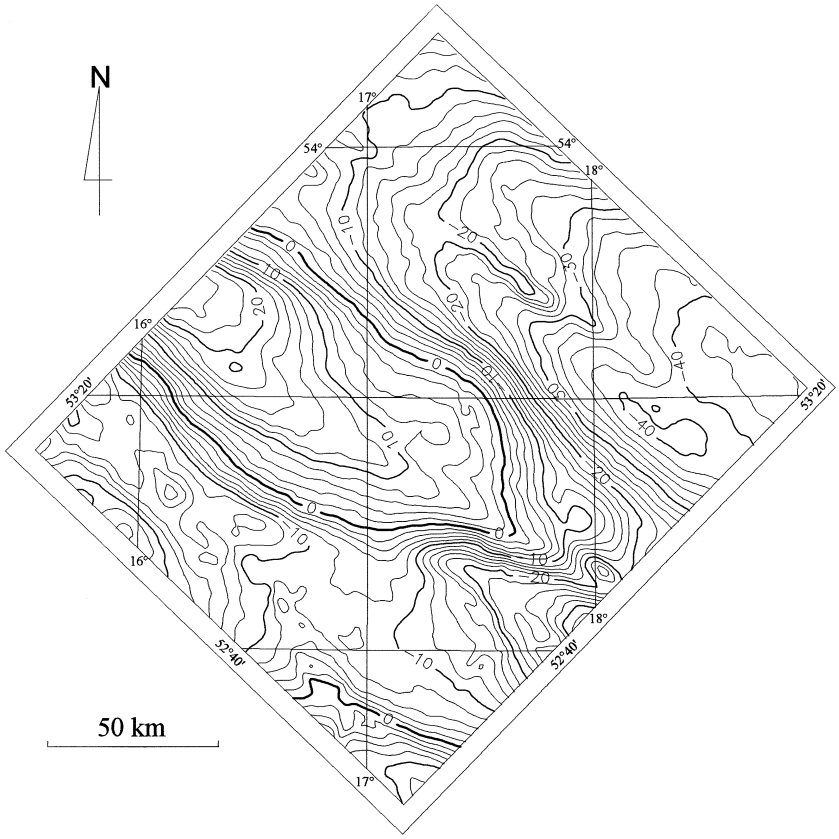


Figure 2. Bouguer anomalies in the study area. Isarithms in mGal.

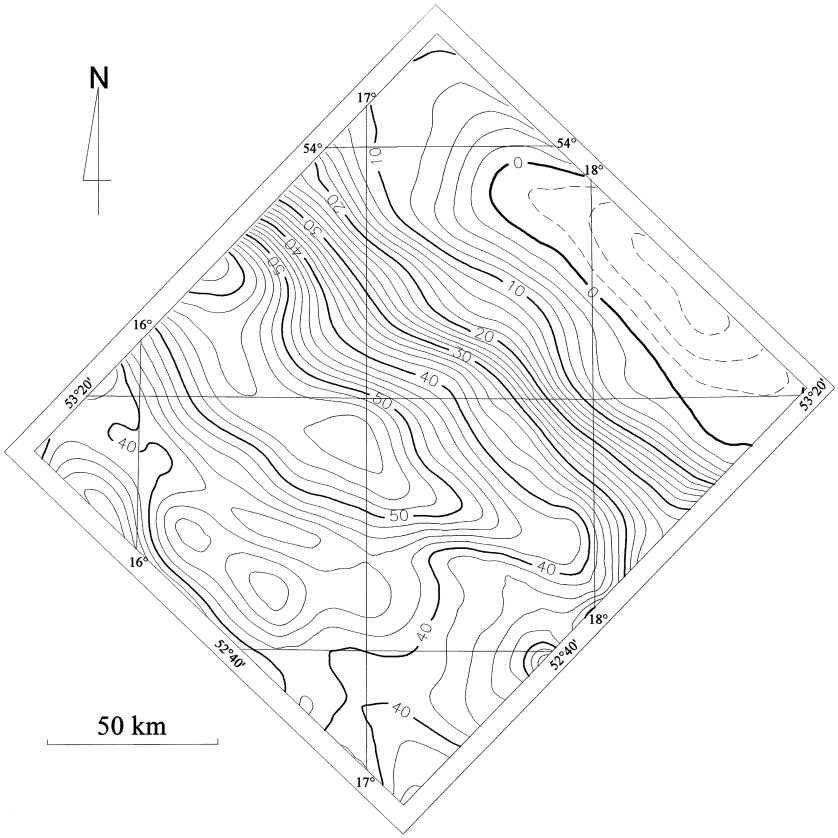


Figure 3. Pre-Zechstein Bouguer anomalies which are referred to as 'stripped' anomalies. Units as in Figure 2.

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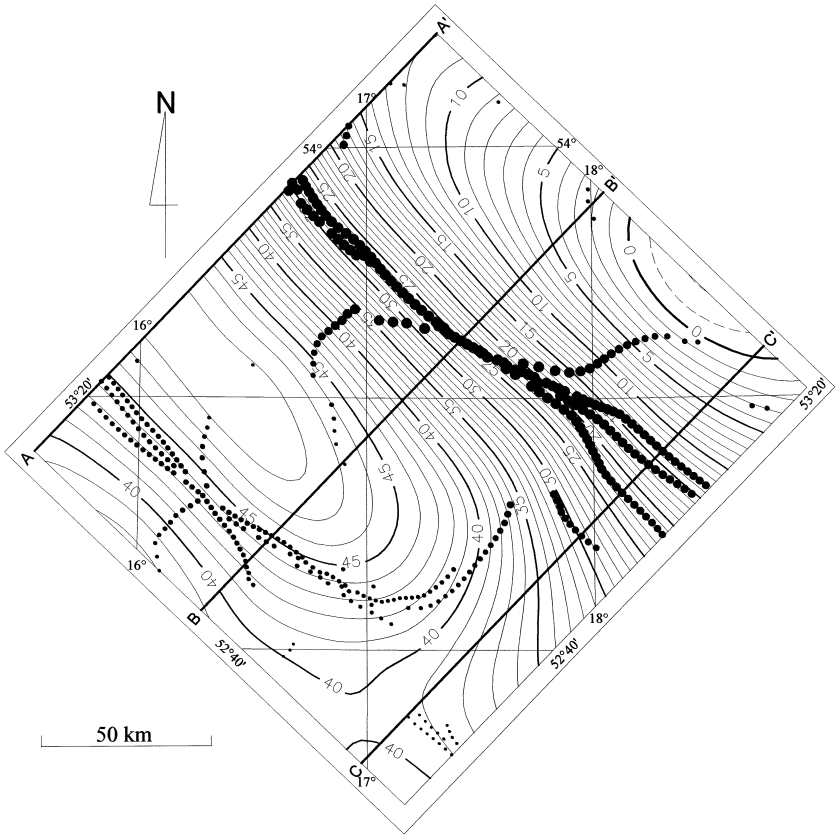


Figure 4. Long-wavelength components of the 'stripped' anomalies. They are referred to as regional anomalies. Maxima of the horizontal gradient are denoted as solid circles. For other explanations see Figure 1 and Figure 2.

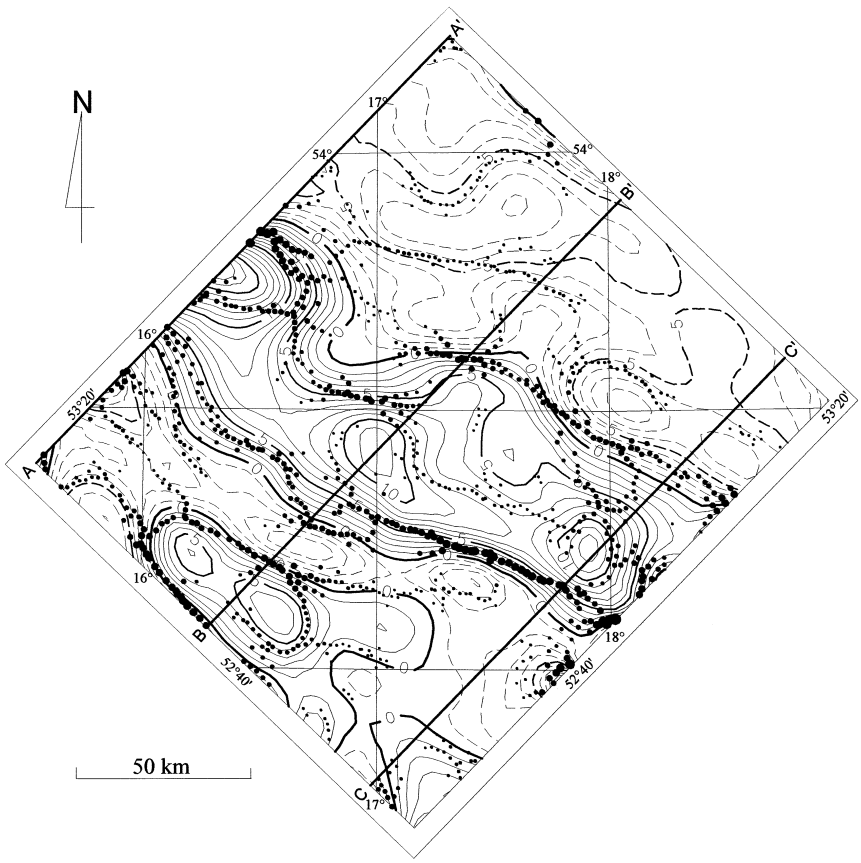


Figure 5. Short-wavelength components of the 'stripped' anomalies. They are referred to as residual anomalies. Maxima of the horizontal gradient are denoted as solid circles. For other explanations see Figure 1 and Figure 2.

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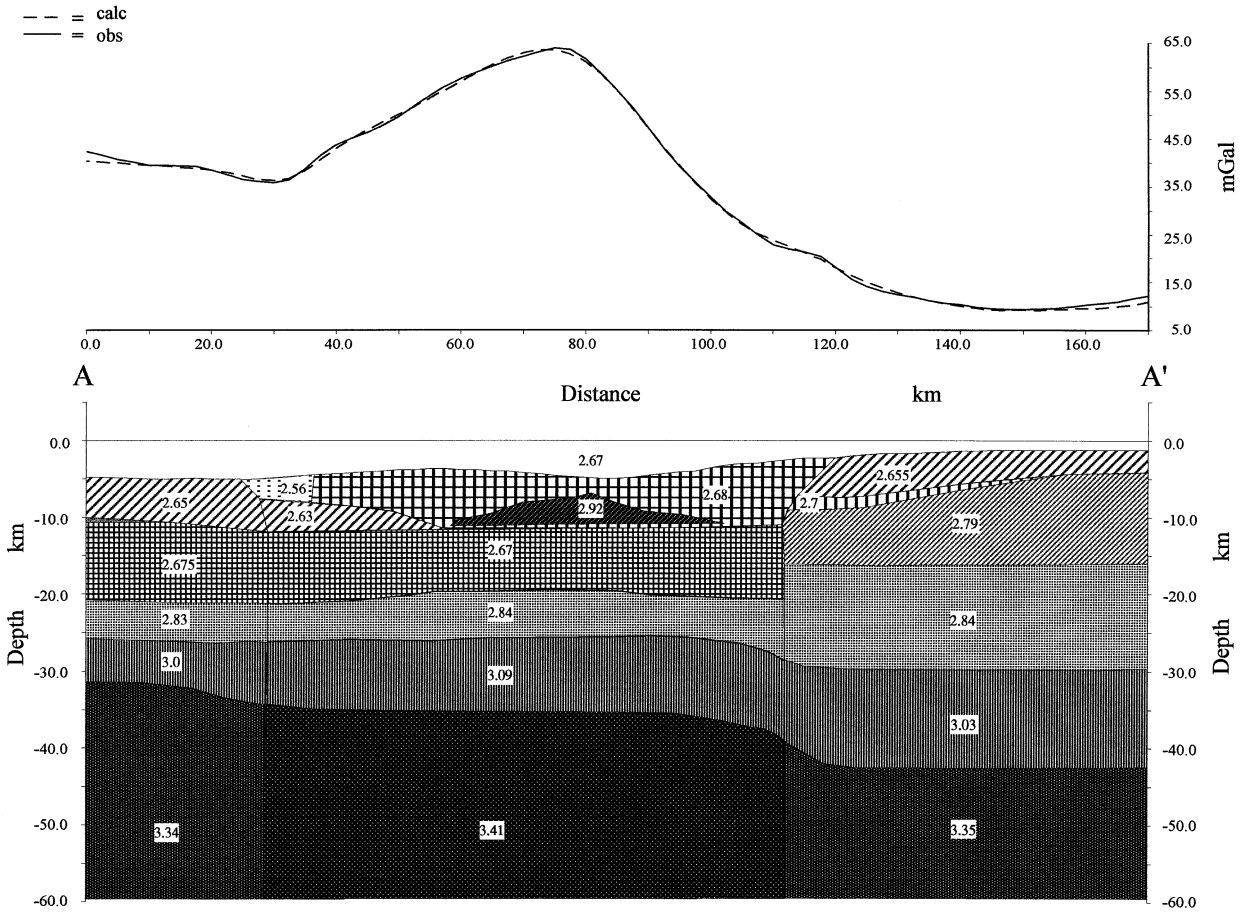


Figure 6. Interpretation of 'stripped' anomalies across the TESZ along profile A–A'. For profile locations see Figure 4. Densities are in Mg m^{-3}.

3. Interpretation of the pre-Zechstein anomalies

After the removal of the gravity effects of the Zechstein–Mesozoic structure the 'stripped' anomalies map (Fig. 3):

(a) does not show any slight anomalies from the shallow sources;

(b) comprises the major regional anomalies of slightly changed shape, that is, the Pomerania high in the central part of the area and the Pomerania low in the northeastern part. The amplitude difference for both the anomalies is the same as for the Bouguer anomalies, indicating the pre-Zechstein origin of the anomalies;

(c) reveals the significant positive anomaly in the southwestern part of the area.

To investigate the deep seated sources of the 'stripped' anomalies the gravity data were smoothed to enhance long-wavelength features. After some tests, an averaging method within a circle of radius of 37.5 km was used. The regional (smoothed) and residual anomalies are shown in Figure 4 and Figure 5. The former reflect structures below the depth interval 10–15 km, where the heterogeneities are mainly related to the Moho topography; the latter reflect anomalous densities above this interval. The locations of the maxima of the horizontal gradient of the regional and residual fields (Blakely & Simpson, 1986) are also presented (solid circles) in these figures. The size of the circles is proportional to the magnitude of the gradient.

The regional gravity field is characterized by an elongated northwest–southeast large positive anomaly with the steeper northeastern gradient and a gentler southwestern one. This anomaly was assumed to be due to crustal thinning within the TTZ which is strongly supported by seismic data along the LT-7 profile. The strong gradient zone running northwest–southeast across the area (Fig. 4) is the most important feature of the anomalies pattern. Its source may be attributed to a deep fracture. The location of the fracture, outlined by the horizontal gradient maxima, conforms to the seismically determined margin of the East European Craton (profiles LT-7 and LT-2). We therefore assumed that these maxima delineate the border of the craton. Figure 4 shows a less significant gradient axis in the southwestern part of the area. It can be treated as a continuation of the Trans-European Fault (Grosse *et al.* 1990). The axis changes its direction from oblong to transverse in the vicinity of the LT-2 profile.

The depth to the Moho changes by about 15 km over a distance of 110 km between the profiles LT-7 and LT-2. Therefore, the question arises: what does the change look like? Is the change gradual, monotonous or abrupt? The detailed analysis of the gravity field in the TESZ

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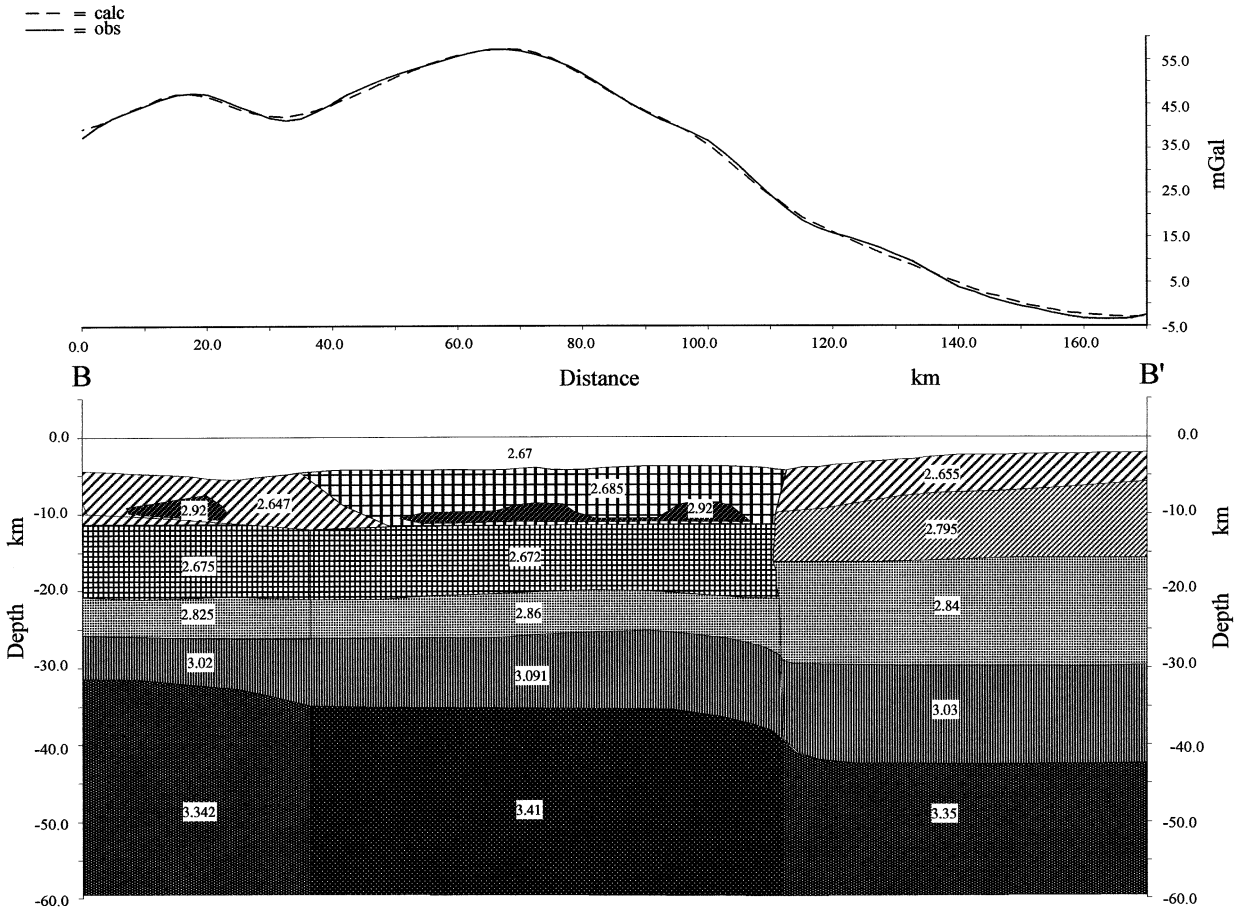


Figure 7. Interpretation of 'stripped' anomalies across the TESZ along profile B–B'. For profile locations see Figure 4. Densities are in Mg m^{-3}.

(Królikowski, Petecki & Dadlez, 1996) suggests an occurrence of a transverse fault zone near the LT-2 profile. This seems to be confirmed by the regional anomalies pattern after stripping (Fig. 4). We think that the upper mantle elevation would terminate near the southeast border of the study area, where an occurrence of deep and wide fracture, transverse or oblique to strike of the major structures, is possible.

On the residual anomalies map (Fig. 5) a positive anomaly with three maxima of amplitude of about 15 mGal occurs along the TTZ. The anomaly may be caused by disturbed masses in the upper crust, with high densities and igneous origin. The other anomaly of smaller size and amplitude, located in the southwestern part of the area, may have a similar origin.

4. Modelling

Quantitative modelling of gravity data obtained after stripping off the 3-D gravity effects of the sedimentary cover down to the Zechstein layer has been used to test our assumptions about crustal structure. Three profiles crossing the area approximately perpendicular to the anomaly contours have been interpreted using the BGS GRAVMAG program (Pedley, Busby & Dabek, 1994). For two profiles, A–A' and C–C', the initial crustal models were constrained by seismic refraction data. Using the relationship between velocity and density and taking into account the pressure and temperature conditions (Krasovsky, 1989), a range of suitable densities were assigned to each layer of the models. Modelling was first carried out on profile A–A', part of the LT-7 geotraverse, because of good seismic control on depth to the Moho and P-wave velocities distribution for the crust and upper mantle.

4.a. Profile A–A'

Profile A–A' (Fig. 6) crosses the TTZ along the northwestern border of the area. Two-dimensional seismic modelling of the crust and upper mantle velocity structure indicates that thickness of the Earth's crust changes along profile A–A' from 31 km on the Palaeozoic Platform, to about 35 km in the TTZ and to 43 km on the East European Craton. The boundary velocity beneath the Moho is 8.22 km/s, 8.26 km/s and 8.33 km/s, respectively. Below consolidated basement characterized by velocity 5.8–5.9 km/s, crustal velocities down to 20 km depth are lower than 6.0 km/s. The lower crust, between 20 and 31 km for the Palaeozoic Platform and 35 km for the TTZ, consists of two layers: the first with velocity of 6.52 km/s and the second with velocity of 7.15–7.25 km/s. The crust of the East European Craton is characterized by three

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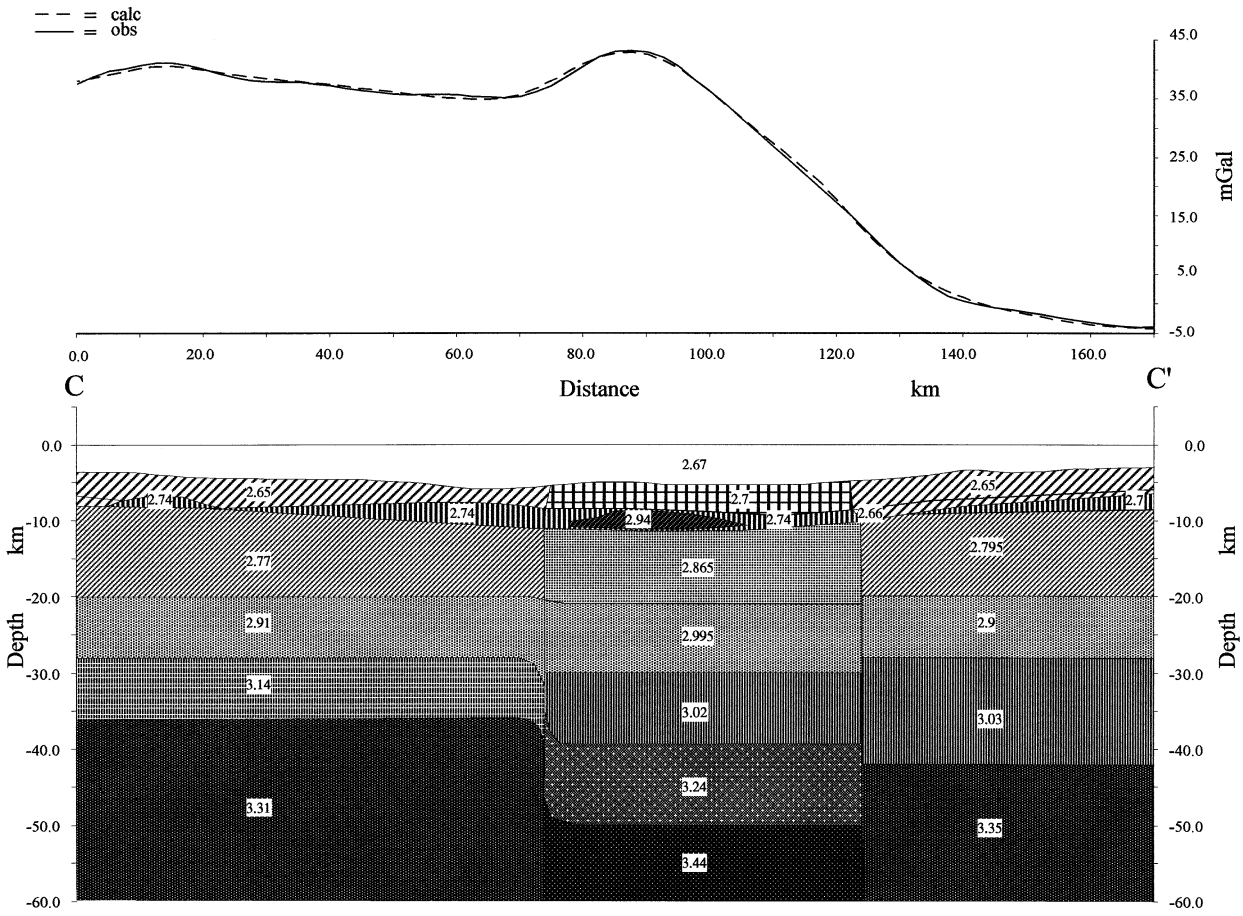


Figure 8. Interpretation of 'stripped' anomalies across the TESZ along profile C–C'. For profile locations see Figure 4. Densities are in Mg m^{-3}.

crystalline layers: an upper crust between 4–8 and 16 km depth with velocity 6.2–6.3 km/s, a middle crust between 16 and 30 km depth with velocity 6.5–6.6 km, and a lower crust at a depth from 30 to 43 km with velocity 7.0–7.15 km/s.

The long-wavelength anomalies over the TTZ have been modelled in terms of lateral heterogeneity within the crust and upper mantle. A contribution to the observed gravity high is also provided by the interpreted relatively shallow Moho depth (35 km) in this zone. In order to achieve the match between the observed and calculated gravity fields, therefore, it was necessary to assume denser upper mantle beneath the TTZ. The short-wavelength positive anomaly is due to dense mass (2.92 Mg/m^3) placed most likely within the Lower Palaeozoic sequence. The model curve obtained with densities shown in Figure 6 for the crust and the mantle, fits well with 'stripped' gravity anomaly and is consistent with the seismic data.

4.b. Profile B–B'

This profile (Fig. 7) is about 65 km southeast of profile A–A'. As on profile A–A', the long-wavelength anomaly can be explained by Moho depths and density heterogeneity within the crust and upper mantle. The thickness of the crust in the TTZ is 35 km increasing to up to 42 km on the East European Craton. The residual gravity anomalies at the southwestern and central parts of the profile are assumed to be due to igneous intrusions with density of about 2.92 Mg/m^3. This model displays a similar density and deep crustal structure to the previous one.

4.c. Profile C–C'

Profile C–C' (Fig. 8) crosses the area near its southeastern border. The initial model was constructed using the depth and velocity information obtained from refraction results on profile VII (Fig. 1). One-dimensional crustal models along this line show that the crustal structure of the Palaeozoic Platform and the TTZ differs from that on the LT-7 profile. The thickness of the Earth's crust changes from 35 km on the Palaeozoic Platform to about 50 km in the TTZ and to 42 km on the East European Craton. The boundary velocities beneath the Moho are 8.0 km/s, 8.4 km/s and 8.1 km/s, respectively. The upper crust of the Palaeozoic Platform, with velocity 5.9–6.4 km/s, is situated at depth from 8 to 20 km. The lower crust, between 20 and 36 km, consists of two layers: the first one with the thickness of 8 km and velocity of 6.5–6.7 km/s, the second with velocity 7.3–7.5 km/s.

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For the crystalline complex of the crust within the TTZ the velocity increases from 6.3 to 6.8 km/s in the depth range from 12 to 40 km. In the lower part of the crust, there is a 10 km thick transition layer with a large velocity of 7.6–7.75 km/s.

The cratonic crust in the vicinity of the TTZ is composed of two layers. The velocity in the upper layer increases from 6.2 km/s at a depth of 8 km to 6.5 km/s at 28 km depth. The lower layer in the depth interval 28–42 km is characterized by velocity changes from 6.8 to 7.0 km/s. The thickness of the crust increases to 45 km in the northeastern part of the profile and in the depth interval 38–45 km a high-velocity layer (7.3 –7.4 km/s) is also displayed.

Profile C–C' shows a broad positive anomaly of a lower amplitude than on profiles A–A' and B–B'. This anomaly decrease is assumed to be due to thickening of the crust within the TTZ, revealed by seismic profile VII. The gravity model depicts the depth to the Moho as about 50 km in this zone. The density–depth model shown in Figure 8 is consistent with the velocity–depth model along profile VII. The residual gravity anomaly over the TTZ was modelled as an igneous intrusion with high density (2.94 Mg/m^3).

5. Conclusions

As a result of gravity data interpretation a considerably changed model of the crustal structure of the TESZ in northwestern Poland has been proposed. It indicates a very complex tectonic and igneous evolution of the area.

The main features of the model are as follows:

(1) The high-gravity anomaly pattern (the regional component) of the area can be modelled in terms of density inhomogeneities of the crust and upper mantle. Two profiles (A–A' and B–B' in Figs 6 and 7, respectively) crossing this gravity high suggest the gravity influence of the shallow Moho depth (35 km) and dense upper mantle along the TTZ. The TTZ borders are outlined by the maxima of the horizontal gradient (Fig. 4).

(2) An abrupt change of the crustal thickness from 35 to about 50 km occurs near the LT-2 profile, on its southeastern side. Lateral heterogeneity along the TTZ is also apparent from the gravity models constrained by seismic refraction data.

(3) The positive residual anomalies may be caused by intrusive basic rocks of high density. Their existence so far has not been confirmed by seismic data, probably because of their relatively small sizes. The intrusive masses occur mainly in the central part of the Polish Basin, within the TTZ. An appearance of such intrusions of limited masses is also possible outside of the TTZ, as indicated by the B–B' profile.

(4) Due to non-uniqueness of the potential fields interpretation, the location of the intrusive bodies in the older Palaeozoic formations is only one of probable variants.

Acknowledgements. This is EUROPROBE publication no. 136.



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