GEOLOGICA CARPATHICA, 49, 2, BRATISLAVA, APRIL 1998
75–83

ANALYSIS OF THE GRAVITY FIELD IN THE WESTERN AND EASTERN CARPATHIAN JUNCTION AREA: DENSITY MODELLING

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(Manuscript received February 24, 1997; accepted in revised form December 11, 1997)

Abstract: An analysis of the gravity field in the Western and Eastern Carpathian junction area is based on local isostasy and forward density modelling. For the first time the lithosphere/asthenosphere boundary was taken into account for density modelling of long-wavelength gravity anomalies in this region. The gravity effects of the main geological structures within the lithosphere were estimated. To give a better view of the present lithosphere structure in this region, density cross sections were calculated along the profile KP-X. The results demonstrate a slab-like structure under the mountain range. The slope of the underthrusted lower European Platform is very steep. Modelled slab dips from about 60^o to 80^o. Density modelling shows that the southern margin of the European basement bends down to the soutwest into the Carpathian subduction system. The East Slovak Basin is characterized by thinning of the crust and lithosphere. The extension process is accompained by the existence of lower crustal high-density mass.

Key words: Western and Eastern Carpathian junction zone, gravity field, density modelling, lithosphere, asthenosphere.

Introduction

The Carpathian arc and the Pannonian back-arc basin are interrelated components of the Mediterranean arc-basin complex (Royden 1988). Royden & Horváth (1988), Csontos et al. (1992), Horváth (1993) and Ratschbacher et al. (1991a,b) have developed the extrusion hypothesis, explaining the escape of the Eastern Alps into the Carpathian area during Neogene subduction. The formation of the Central European Alpides was influenced by complex processes such as riftogenesis, crustal thinning, convergence, lateral displacement, rotational movements, collisional suturing, accreation, transpression-transtension (Soták 1992). The shape of the Carpathian arc was apparently dictated by the Mesozoic geometry of an embayment in the European passive margin (Tomek et al. 1996).

Szafián et al. (1997) proposed that in accord with active transpressional orogens, a strong strain partitioning occurred within the Carpathian arc, due to the oblique convergence between the escaping units of the Western Carpathians (North-Pannonian units in the sense of Csontos et al. (1992), Tari et al. (1992) and Horváth (1993)) towards the northeastern and European margin areas. The process was combined with extension in the hinterland. The latest stage of development of the Western Carpathian arc and the Pannonian Basin was characterized by a lithospheric desintegration which occurred as a consequence of a transition from a transpressional to an extensional regime (Kováč et al. 1995; Fodor 1995). Most of the transpressional deformations were associated with uplift and erosion, but the final step was connected to the earliest Miocene sedimentation (Fodor 1995). The Western Carpathian (North-Pannonian) units were involved in a Late Oligocene-Early Miocene episode of eastward-directed, large-scale continental escape, followed by extensional collapse of the overthickened and gravitationally unstable crustal wedge (Ratschbacher et al. 1991a,b; Tari et al. 1992; Horváth 1993). The Intra-Carpathian area was made up of a set of tensional and transtensional basins. A mechanism of extension varied with depth-dependent rheology (Horváth 1993). Their initial subsidence and extension took place mostly during the 17 and 13 Ma interval, synchronously with the deformation of the external parts of the Carpathians (Royden 1988; Szafián et al. 1997). It was accompanied by both crustal thinning and, what is more important, by thinning of the lithosphere which was associated with an uplift of asthenospheric and partly molten masses (Ádám 1989, 1990; Praus et al. 1990; Stegena et al. 1975; Babuška et al. 1987, 1990; Beránek & Zátopek 1981; Pospíšil & Vass 1983; Horváth 1993; Kováč et al. 1995). The mantle xenoliths transported to the surface by the youngest alkaline basalts support this suggestion (Konečný et al. 1995; Šefara et al. 1996)

Investigation of the geodynamic evolution of the Western Carpathians was concentrated mainly on a study of deep-seated crustal and lithospheric structures in its western and central segments. For an integrated study not only of the Western Carpathians but also the whole Carpathians it is also very important to investigate their junction zone. For this purpose it is useful to study the gravity field (besides other geophysical fields) in this region. In the present study the gravity field was analyzed. The analysis was performed by means of modelling in local isostatic equilibrium using not only gravity and topographic data but also the thickness of sediments, crust and lithosphere. This paper also utilizes gravity modelling for determining a preliminary density model of the lithosphere along the profile KP-X (Fig. 1). Several density models have been constructed in the Western Carpathians (e.g. Fusán et al. 1971; Pospíšil & Filo 1980; Pospíšil & Vass 1983; Šefara et al. 1987; Bielik et al. 1990, 1991; Vyskočil et al. 1992; Škorvanek & Biela 1993; Lillie et al. 1994, etc.). New maps of the gravity field in Poland (Królikowski &

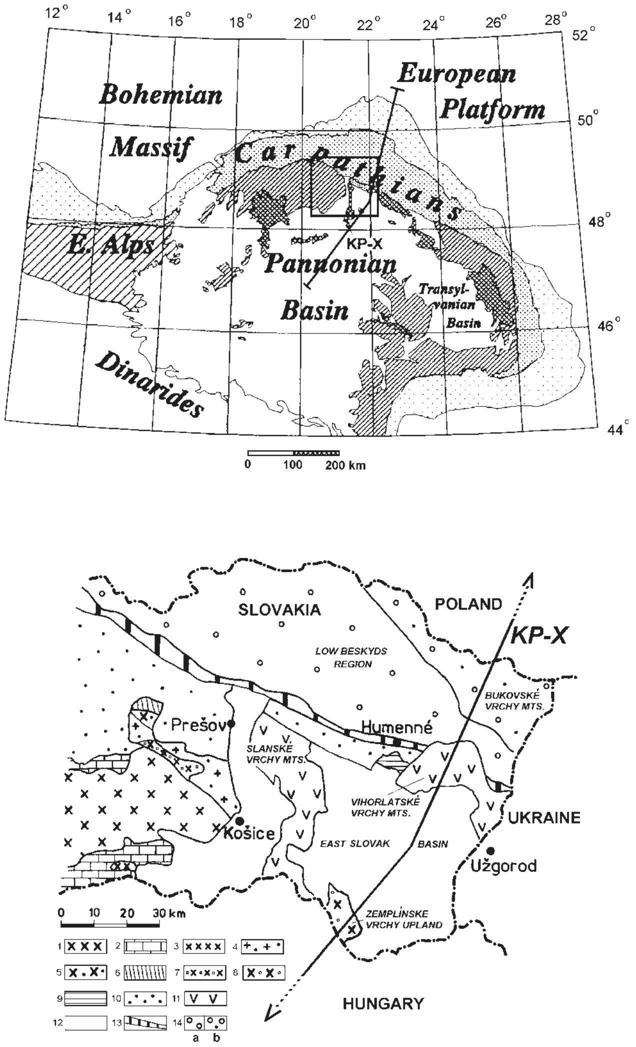

Fig. 1. Tectonic sketch of the eastern part of Slovakia after Biely et al. (1996). Thick line shows the location of the sector of the profile KP-X. Legend: 1 — Gemeric Superunit, 2 — Silicic Supernit, 3 — Turnaic Superunit, 4 — Veporic Cover Superunit, 5 — Tatric Superunit basement, 6 — Tatric Cover Superunit, 7 — Veporic basement, 8 — Zemplinic Cover Superunit, 9 — Fatric Superunit of the Humenské vrchy Upland, 10 — Inner Carpathian Paleogene, 11 — Neogene volcanics, 12 — Neogene basins, 13 — Pieniny Klippen Belt, 14 — Carpathian Flysch Belt [a) Magura Zone, b) Krosno Zone].

Petecki 1995) and in Central Europe (Szafián et al. 1997), new detailed maps of the crustal and lithosphere thicknesses (Horváth 1993; Šefara et al. 1996), coupled with maps of the thickness of Neogene sediments (Kilényi & Šefara 1989) and the Carpathian Flysch Belt and Mollasse Foredeep (Rylko & Tomas 1995) enable improvement of the density model in the Western and Eastern Carpathian junction zone. The results contribute to a more complete picture of the lithospheric structure, slab evolution, collision and extension in the Carpathian mountain arc. This is the first time the lithosphere-asthenosphere boundary was taken into account for density modelling of long-wavelength gravity anomalies in this region.

The gravity field

Former studies of the Bouguer gravity anomalies (Fig. 2) in eastern Slovakia were published, for example, in the papers of Blížkovský (1961), Ibrmajer (1981), Matoušek & Odstrčil (1975), Pospíšil (1977, 1980), Šutor & Čekan (1965), Škorvanek & Biela (1993). The first synthesis of gravity measurements and their interpretation was done by Pospíšil (1980). These studies provided the first information about crustal structure.

The gravity field can be devided into two zones. The first zone is characterized by positive anomalies. It correlates very well with the area, which includes the whole East Slovak Basin, Zemplínske vrchy Upland, Vihorlatské vrchy Mts. This positive zone extends far towards the Pannonian and Transcarpathian basins. The maximum amplitude of the gravity field in the Zemplínske vrchy Upland reaches the values of about +35 mGal (+350 μms^{-2}). The Humenské vrchy Upland and the Vihorlatské vrchy Mts. are accompanied by a local gravity high with the maximum amplitude of about +25 mGal. It is interesting to note that in spite of the East Slovak Basin representing an expressionless relative gravity low between the Zemplínske vrchy Upland and Vihorlatské vrchy Mts., it is accompanied by positive gravity values (about +10 mGal). In general, extensional basins which are filled by low-density sediments should be characterized by negative observed gravity anomalies. On the basis of the stripped gravity map (Bielik 1988) it is well known that this is not valid for subbasins of the Pannonian Basin (e.g. for the Danubian Basin, the Little Hungarian Basin, the Great Hungarian Basin). This map showed significant gravity highs over the deepest subbasins. Pospíšil (1980) and Bodnár & Pospíšil (1981) were first to discover this phenomenon in the East and South Slovak basins, respectively.

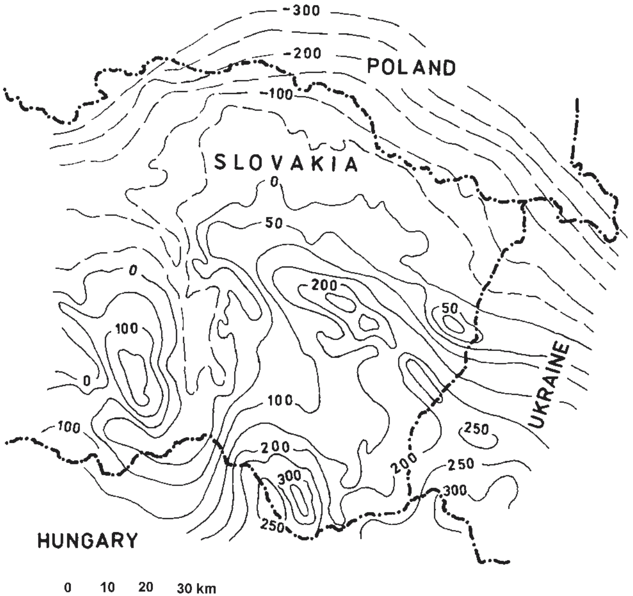

Fig. 2. Bouguer gravity anomaly map of the eastern part of the Western Carpathians (after Ibrmajer 1981 and Šefara 1987). Contour interval 50 μms^{-2} (5 mGal).

The second zone is characterized by negative values of the Bouguer gravity anomalies. It covers in the northern and northeastern parts of eastern Slovakia and includes the Low Beskyds region and the Bukovské vrchy Mts. In the region of eastern Slovakia the amplitude of the gravity low is only about -10 mGal. But this negative gravity zone represents only a part of the third segment large Carpathian gravity minimum (Tomek 1988). Most of the third part of the Carpathian gravity minimum is located in Poland and mainly in Ukraine. The anomaly runs southeast for more than 500 km along the Eastern Carpathians. The Carpathian gravity minimum reaches about -100 mGal in Ukraine. According to Tomek et al. (1979) and Pospíšil & Filo (1980) the source of this third segment of the Carpathian gravity minimum can be explained by the gravity effect of a large accumulation of flysch sediments and autochthonous molasse.

The stripped gravity map in the East Slovak Basin, which has been constructed by Pospíšil in Šefara et al. (1987) shows that eastern Slovakia is covered only by a zone of positive gravity anomalies. The reason for that is removal of the negative gravity effect of basin fill and the gravity effect of higher-density inhomogeneities of the crust (beneath the pre-Tertiary basement), which extends outwards from the East Slovak Basin to well within the whole of eastern Slovakia.

The Western and Eastern Carpathian junction zone and its wider surroundings is characterized by the long-wavelength positive-negative gravity anomaly couple (Królikowski & Petecki 1995; Ibrmajer 1981; Szafián et al. 1997). It is known that this fact is valid for the whole Carpathian belt (Royden 1993; Bielik 1995; Krzywiec & Jochym 1997) and the Alps, Apennines and Appalachians, too (Karner & Watts 1983; Royden 1993). This gravity anomaly couple was interpreted as evidence for flexure of the continental lithosphere by surface and subsurface loading (Royden 1993; Bielik 1995; Krzywiec & Jochym 1997).

Density modelling in local isostatic equilibrium

Calculation of a simple density model in local isostatic equilibrium taking into account topography, gravity and density data together with published maps of thicknesses of sedimentary fill, crust and lithosphere provides a clue to analysis of observed gravity field. The aim of density modelling in local isostatic equilibrium is to offer and show the contributions of the main anomalous zones to the free-air and Bouguer anomalies.

Topography was available from the topographic map of Slovakia (SÚGK 1976). In Poland these data were taken from

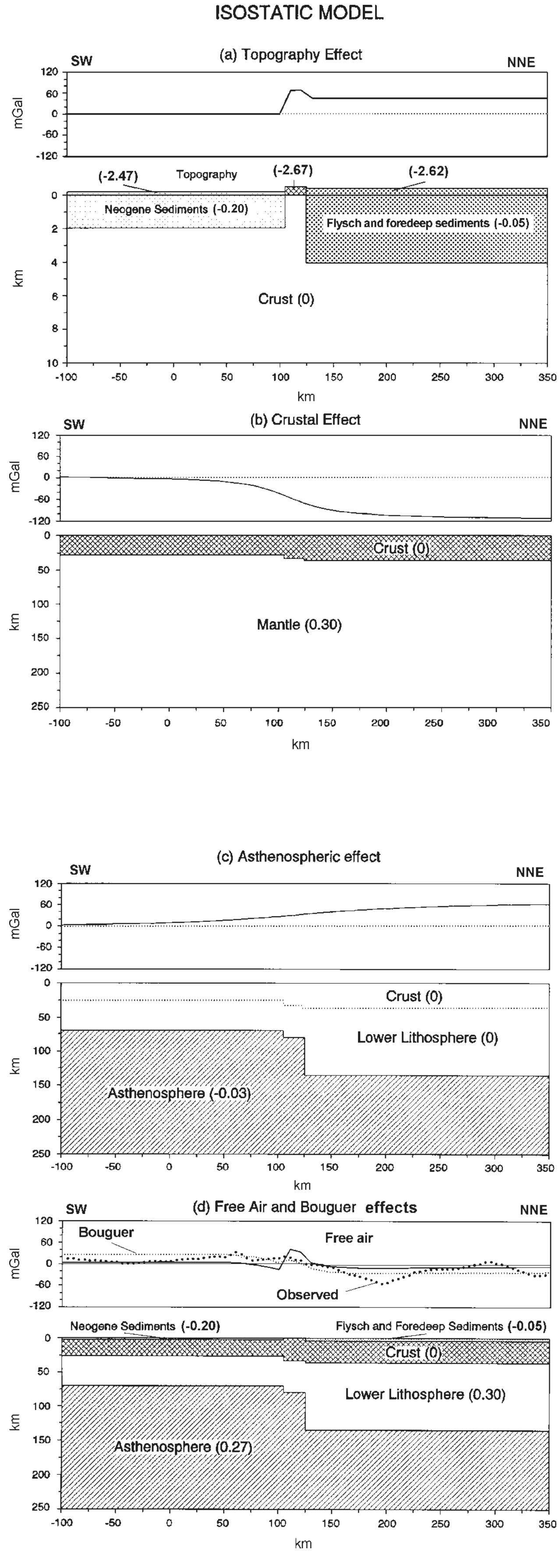

Fig. 3. Local isostatic model showing gravity contributions from different levels. The depth of compensation is 250 km. Density contrasts are in gcm^{-3}. The anomaly due to the topography (a), the Moho (b) and the lithosphere (c). Free-air gravity effect (d) calculated by summing the three components. For this model a Bouguer reduction densities of -2.67 gcm^{-3} for crust, -2.47 gcm^{-3} for Neogene sediments, -2.62 gcm^{-3} for outer flysch and molasse sediments remove the effect of topography, resulting in a Bouguer anomaly which is similar to the observed Bouguer anomaly in the studied area.

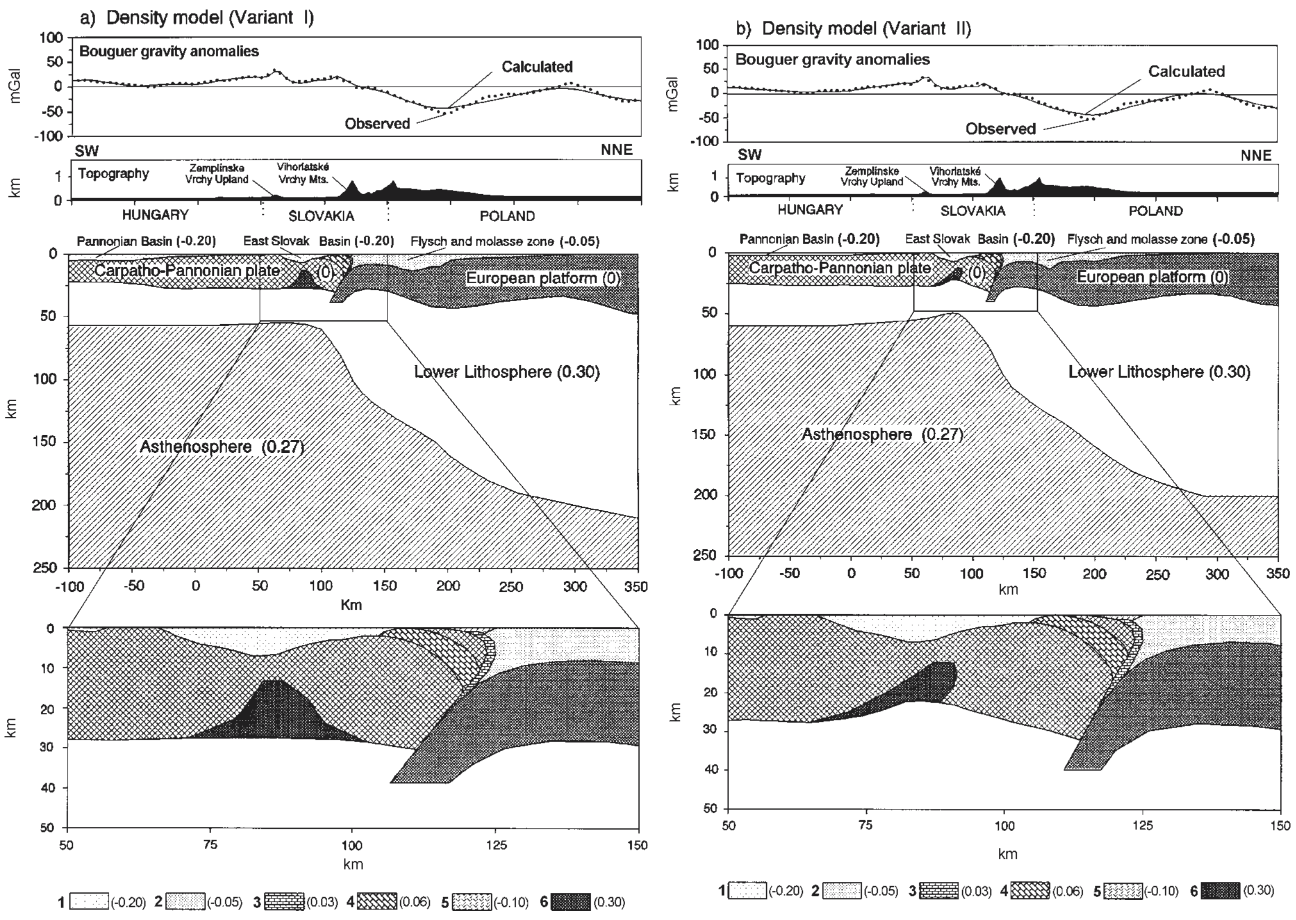

Fig. 4 . Two-dimensional density models of the lithosphere along profile KP-X. Density contrasts are in gcm^{-3}. Density models: variant I **(a)**, II **(b)** and III **(c)**. Legend: 1 — Neogene sediments, 2 — Carpathian Flysch Belt and Molasse Foredeep sediments, 3 — Pieniny Klippen Belt, 4 — Mesozoic of the Humenské vrchy Upland, 5 — Neogene volcanics, 6 — high-density anomalous body.

the Atlas of average topography in Europe (Geodätischen Dienste 1979). The thicknesses of Neogene sedimentary fill of the East Slovak Basin and Pannonian Basin were modified after Kilényi & Šefara (1989). Depths of the Outer Carpathian Flysch Belt and Molasse Foredeep basement in Poland were available from the results of Rylko & Tomas (1995). In Slovakia, they were extrapolated on the basis of Polish data. Input data on crustal thickness were taken from the map of Moho depths in Slovakia (Beránek & Zátopek 1981; Mayerová et al. 1985; Šefara et al. 1996), in Hungary (Horváth 1993) and in Poland (Guterch et al. 1986; Bojdys & Lemberger 1986). For the thickness of the lithoshere were adopted the depths published by Horváth (1993) and Šefara et al. (1996). These authors constructed a lithospheric thickness map for the Pannonian Basin and surrounding territories on the basis of seismological (Babuška et al. 1987, 1990; Spakman 1990), geothermal (Čermák et al. 1991) and magnetotelluric (Praus et al. 1990; Ádám et al. 1989, 1990) data. Bouguer anomalies were taken and modified from the gravity maps published by Ibrmajer (1981), Szafián et al. (1997) and Królikowski & Petecki (1995).

For analysis of relatively long-wavelength gravity anomalies it is useful to simplify density models into anomalous zones characterizing major density contrasts (Lillie et al. 1994). In the paper density contrasts are relative to typical crustal materials. The study prefers density contrasts to absolute densities. This approach has the effect of approximating normal density increases with depth. Density contrast for sediments is relative to upper crustal materials, while the lower lithosphere and asthenosphere are relative to the lower crust. The mean densities for the upper (2.75 gcm^{-3} = 2750 kgm^{-3}) and the lower crust (2.95 gcm^{-3}), the lower lithosphere (3.25 gcm^{-3}) and asthenosphere (3.22 gcm^{-3}) are estimated by using formulae published by (Rybach & Bunterbarth 1984; Lachenbruch & Morgan 1990). The mean densities of the anomalous bodies in the upper crust were defined after Eliáš & Uhmann (1968), Pospíšil (1980), Šefara et al. (1987), Bielik et al. (1990, 1991), Vyskočil et al. (1992). In spite of knowledge that the density of Neogene sediments increases with depth (Plančár in Biela 1978; Šefara et al. 1987; Bielik 1988; Meskó 1988; Kovácsvölgyi 1994) for our purpose it is sufficient to suggest mean densities for both Neogene sediments of the East Slovak Basin and the Pannonian Basin and the Outer Carpathian Flysch Belt and Molasse Foredeep.

In this study the following anomalous zones and their density contrasts are considered:

(1) Neogene sediments filling the East Slovak Basin and the Pannonian Basin (−0.20 gcm^{-3}).

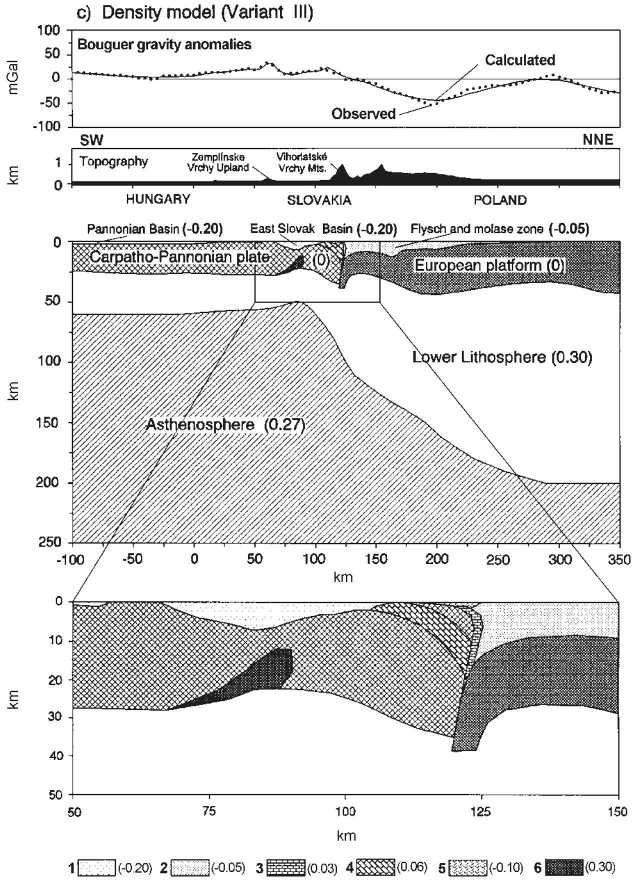

Fig. 4c.

(2) Flysch and molasse sediments of the Outer Carpathians (-0.05 gcm^{-3}).

(3) Mantle part of the lithosphere ($+0.30$ gcm^{-3}).

(4) Asthenosphere ($+0.27$ gcm^{-3}, i.e. -0.03 gcm^{-3} density contrast with the lower lithosphere).

The elements assigned zero density contrasts include crustal rocks. In local isostatic modelling density contrasts are for topographic relief relative to air (-2.67 gcm^{-3} for crust; -2.47 gcm^{-3} for Neogene sediments; -2.62 gcm^{-3} for outer flysch and molasse sediments).

The three average topographic data are:

a) 0.2 km for the region of the East Slovak Basin and the Pannonian Basin;

b) 0.6 km for the collision region;

c) 0.4 km for the region of the Outer Carpathian Flysch Belt and molasse Foredeep.

The density contrast between crust and upper mantle ($+0.30$ gcm^{-3}) and lower lithosphere and asthenosphere (-0.03 gcm^{-3}) results in isostatic equilibrium (Fig. 3d) for an approximately 10 km deeping of Moho discontinuity (Fig. 3b) and about 70 km deeping of the lithosphere/asthenosphere boundary from the Pannonian Basin to the European Platform (Fig. 3c). The maximum gravity contribution of Moho to the free-air gravity effect is about -105 mGal (Fig. 3c). This effect is not fully compensated by the gravity effect of topography (Fig. 3a). The compensation in the Outer Carpathians is about half (+50 mGal). In the collision region it is a little bit more (about +70 mGal). For the second part of compensation is also necessary to consider the gravity effect of the lithosphere/asthenosphere boundary. Its gravity effect on the free-air gravity effect is about +50 mGal (Fig. 3c). The total of all anomalous zones gives free-air gravity effects (Fig. 3d), which are positive over the Pannonian Basin and the East Slovak Basin and negative over the Outer Carpathians. In spite of rough approximation of crustal and lithospheric geometry the calculated Bouguer anomaly correlates relatively well with the observed gravity effect.

Lithosphere density cross section

To obtain a better view of the present lithosphere structure in the Western and Eastern Carpathian junction zone a density cross section was calculated along the profile KP-X (Fig. 4). The line of profile KP-X (Fig. 1) starts in the Pannonian Basin 150 km southwest of the Slovak-Hungarian border. In a northeastern direction the profile runs across the Zemplínske vrchy Upland and through the East Slovak Basin. Then it enters the Vihorlatské vrchy Mts. and passes the Outer Carpathian Flysch Belt and Molasse Foredeep and terminates in the European Platform (200 km from the Slovak-Polish border). The Fig. 4 shows a sector of the interpretation profile with a length of 450 km. The GMSYS software package, which was used for calculation of density models, enables avoidance of the marginal effects and to use the lithosphere/asthenosphere boundary for density modelling by prolonging both ends of the profile by several hundred kilometers.

The method of density modelling, like every geophysical method of interpretation, is ambiguous from the mathematical point of view. Even the best correlation between observed and calculated gravity anomalies does not guaranty that the density model reflects real geological structure. It is only one possibility from many solutions. On the other hand additional geophysical data bind the modelling due to ambiguity of the gravity field. Taking into account these facts three "most optimal" solutions corresponding most with current geophysical and geological knowledge are presented.

Density models are based on consideration of the four anomalous zones mentioned above. Moreover, the models include and interpret other crustal anomalous bodies, of which the sizes and density contrasts effect observed gravity anomalies more than about ±5 mGal (e.g. Mesozoic of the Humenské vrchy Upland together with the Pieniny Klippen Belt). A significant anomalous body of high-density mass beneath the East Slovak Basin basement is also a result of density modelling. To give a better image of the influence of anomalous zones and bodies (density inhomogeneities) upon the total gravity field some chosen gravity effects are shown in Fig. 5. The picture illustrates that the largest contribution to the Bouguer anomalies comes from the Moho discontinuity. The differences between gravity effects of the Moho and lithosphere/asthenosphere boundary from the Pannonian Basin to the European Platform are about -200 mGal and $+130$ mGals, re-

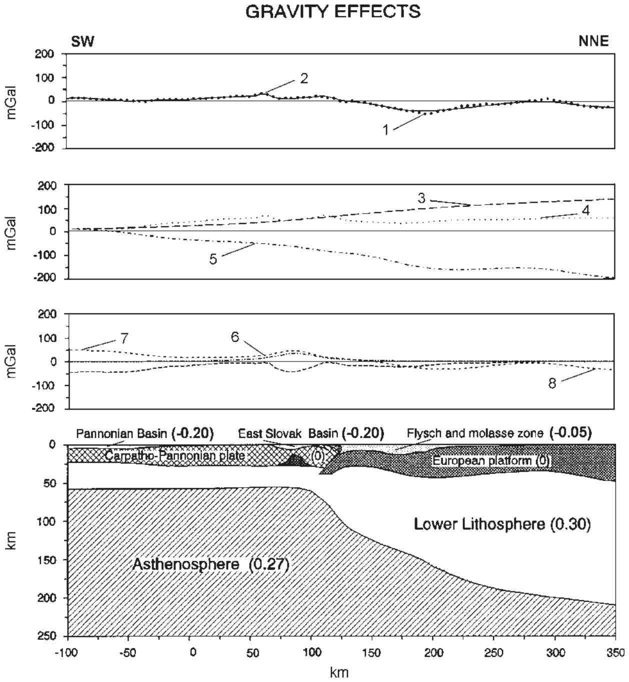

Fig. 5. Illustrating contributions to gravity from different density inhomogeneities for density model (variant I) along profile KP-X. Legend: 1 — observed Bouguer anomaly, 2 — calculated Bouguer anomaly, 3 — gravity effect of the lithosphere/asthenosphere boundary, 4 — crustal gravity contribution, 5 — gravity effect of the Moho, 6 — gravity anomaly due to high-density anomalous body, 7 — stripped gravity anomaly (the Bouguer gravity anomaly corrected by gravity effect of sedimentary fill), 8 — gravity contributions of Neogene sedimentary fill of the East Slovak Basin and the Pannonian Basin and Carpathian Flysch Belt and Molasse Foredeep.

spectively. The Carpathian Flysch Belt and Molasse Foredeep give a maximum gravity effect of about −30 mgal. The gravity effects of the Neogene sediments in the Pannonian Basin and East Slovak Basin vary from about 0 to −42 mGal.

The results of density modelling (Fig. 4) demonstrate that, a slab-like structure appears to be required under the mountain range with dipping to the southwest to obtain a good fit between the calculated and observed gravity anomalies. The slope of the underthrusted lower European Platform is very steep. The modelled slab dips from about 60° (Fig. 4a,b) to 80° (Fig. 4c). Density modelling shows that the southern margin of the European basement bends down to the southwest into the Carpathian subduction system. The bending is in accord with the seismic results obtained in the Western Carpathians (Tomek et al. 1989, 1996) and with density modelling results obtained by Szafián et al. (1997) and Bielik & Mocanu (1998) in the Eastern and Southern Carpathians. For the Carpathian system Royden (1993) suggests that the crustal slab dips about 60°.

Under the East Slovak Basin region it was necessary to interpret a striking high-density anomalous body (density contrast +0.30 gcm^{-3}). It is located within the lower crust (gravity effect is about +37 mGal) and it compensates for the isostatically low-density basin fill (−42 mGal). The geometry of the anomalous body was interpreted by two approaches. In the first case the body has an almost symmetrical shape (Fig. 4a), while in the second case it has a elonqated shape with a slope toward southwestern (Fig. 4b,c). The upper boundary of the anomalous body is at a depth of 12–14 km. This study confirmed the results obtained by Pospíšil (1980).

Starting cross sections showed varying degrees of agreement between observed and calculated gravity anomalies. For the Western Carpathian and the Pannonian Basin region (Lillie et al. 1994) it was found that most of the disagreement could be corrected simply by adjusting Moho depths. Existing maps of crustal thickness (e.g. Beránek & Zátopek 1981; Mayerová et al. 1985; Guterch 1986; Čekunov et al. 1988) were mainly constructed by seismic refraction experiments. While these maps are useful in showing general changes in crustal thickness (e.g. crustal thinning from the European Platform to the Pannonian Basin), they do not adequately portray shorter-wavelength changes in Moho depth. These shorter-wavelength changes are important in presenting geometries that can be interpreted in terms of tectonic evolution (Lillie et al. 1994). Therefore the disagreement was partly corrected by adjusting the Moho configuration. This approach is significant supported by the fact that in the eastern part of Slovakia the published Moho depths were only extrapolated. Seismic refraction and reflection data are not available. Moreover, discrete points at which the Moho depths were determined from industrial explosions do not exist either (Mayerová et al. 1985). Density modelling shows that the adjusted Moho correlates, in general, with published Moho maps (Beránek & Zátopek 1981; Čekunov et al. 1988; Horváth 1993; Šefara et al. 1996). It means that the thickness of the crust increases gradually in the direction from the Pannonian Basin (26 km) to the European Platform (35–50 km). A sharp thickness contrast is interpreted between the colliding plates. The results of the modelling also demonstrate that the relief of the Moho under the outer flysch and molasse zone has a rolling character.

Investigation of the lithospheric structure in the junction of the Western and Eastern Carpathians by means of density modelling is only the first step in complex geophysical and geological interpretation. Unfortunately, the presented interpretation cannot be supported by available seismic refraction and reflection profiling observations or seismic tomography, because they are missing here.

Discussion and conclusions

The view of the current structure of the lithosphere obtained by density modelling in the junction of the Western and Eastern Carpathians appears to be compatible with lithosphere geometry in the thrust belts formed at retreating subduction boundaries which were defined by Royden (1993). At retreating plate boundaries the rate of overall plate convergence is slower than the rate of subduction. Linzer (1996) has estimated between the stable East European and Moesian plates and the Carpathian nappe systems that the hanging-wall plate is convergence rate of 2 cm/yr is less than the subduction rate of the foot-wall plate. These orogenic systems (e.g. the Apeninnes, the Carpathians and the

Hellenides — Royden 1993) are evidenced by significant back arc extension contemporaneous with subduction. Presented lithospheric cross sections show clearly the presence of regional extension both beneath the East Slovak Basin and the Pannonian Basin within the overriding plate.

Interpretation of the gravity field also suggests the existence of a slab-like structure in an area of colliding plates with dipping under the overthrusted plate. The existence of the subducted slab is also assumed, for example, by Giese & Morelli (1977), Royden (1993) and proved by Linzer (1996). Similar results were also obtained by Száfian et al. (1997) and Bielik & Mocanu (1996) in the Eastern and Southern Carpathians. In this study the crustal slab was modelled as the anomalous body which is submerged at a depth of about 40 km. This depth was required to obtain good agreement between the observed and calculated Bouguer anomalies. It is very probably that during initial stage of subduction the slab submerged into the deeper parts of the lower lithosphere and asthenosphere. During subduction the slab in oceanic form resulted in melting of andesite magma at a depth of about 100 km (Tomek — personally communication). It is speculated that modelled crustal slab is only a remnant after breaking and submerging of the subducted plate. Using implications for the crustal structure variation along the Carpathian arc (Szafián et al. 1997) it could be assumed that the subducted slab has detached and sunk into the deeper asthenosphere or has been heated up and largely assimilated to the surrounding asthenosphere. In the Vrancea region the dipping of rigid subducted plate goes on, probably, into large depths (170) km and it is still active (Oncescu 1984, 1987). It is documented and accompanied by recent strong intermediate earthquakes. The latter are limitted to the Vrancea area and are distributed along a vertical plane. These intermediate earthquakes are not observed in the Western and Eastern Carpathian junction zone (Kárnik 1968). Underthrusting of the Vrancea plate beneath the Eastern Carpathians is almost vertical (Oncescu 1984, 1987; Tomek et al. 1996).

It is also assumed that the current shape of the crustal slab and its slope results from considerable rollback effect (Balla 1981; Tomek et al. 1996) which is connected with Krosno-Menilite subduction (Tomek et al. 1989). It means that the dip of the slab could be flatter at the beginning of subduction. The existence of the rollback process along the Carpathians was clearly shown by Linser (1996). The andesic volcanism started in the Western Carpathians and the Apuseni Mts. during the Middle Miocene (16 Ma) and migrated continuosly to the east, ending in the Eastern Carpathians at 0.2 Ma (Vass et al. 1988; Kaličiak & Pospíšil 1990; Szakács & Seghedi 1995). Therefore, the rollback process of the ratreating slab occurred between 16 Ma and the Holocene over a distance of 600 km, indicating an average displacement velocity of 3.75 cm/yr and the width of the rollback area about 50 km (Linzer 1996).

It seems that the collision process in the Western and Eastern Carpathian junction zone has finished or is coming to its end (Vass et al. 1988), even though in this region and its surroundings shallow crustal earthquakes can be observed (Zsiros et al. 1988; Labák & Brouček 1996). There is evidence that the Upper Miocene and Pliocene collision (11.0–1.8 Ma) of the European Platform and the Carpathian-Pannonian plate in the region investigated is older than in the Vrancea area of the Eastern Carpathians. The established K-Ar dates of the Carpathian volcanic rocks show decreasing age toward the southeast (Szakács & Seghedi 1995). The orogenic activity of the Alpine-Carpathian chain is also characterized by a continuous eastward progression of deformation along the leading thrust systems (Linzer 1996). The present east-south and east-directed convergence in the easternmost part of the Carpathians, the Vrancea area (Schmitt et al. 1990), probably marks the final stage of retreating subduction. This convergence is accompanied by recent earthquakes of crustal and intermediate depth (Linzer 1996). Tomek et al. (1996) also speculates that the Vrancea seismic zone is related to a more-or-less detached lithospheric slab, perhaps the final expression of Carpathian subduction along the European margin.

Two-dimensional density models of the lithosphere structure presented in the paper indicate that the Western and Eastern Carpathian junction zone is a very complicated area in which interaction of compression, strike-slip and extension can be observed. This interplay led to the formation of the East Slovak Basin (Kaličiak & Pospíšil 1990; Soták 1992; Soták et al. 1995; Kováč et al. 1995). The basin cross section is characterized by a larger thickness of sediments, both crustal and lithospheric thinning. The extensional process is accompanied by the existence of high-density (upper mantle?, eclogical?) mass within the lower crust. Pospíšil (1980) suggested that the high-density anomalous body can be explained by a suture associated with basic and ultrabasic rocks and/or a diapiric intrusion of upper mantle material into the thin crust along the axis of the East Slovak Basin. It is also possible (Soták — personal communication) that the anomalous body could also represent a detached part of an older and shallower dipping of the subducted plate, when its higher crustal position is a result of the tectonic exhumation and extensional unroofing, which culminated in the formation of the East Slovak Basin. Similar tectonics are suggested by Tomek et al. (1997) for the Danube Basin. All extensional movements have been placed on older Alpine-Carpathian thrust faults and have made the tectonic exhumanation of the Kolárovo enigmatic lower crustal body possible.

Acknowledgements: Author is thank Prof. Ján Šefara, Dr. Čestmír Tomek, Dr. Vladimír Bezák, Dr. Adrián Panáček and anonymous reviewer for their critical comments, valuable suggestions and fruitful discussion which helped to improve the quality of the manuscript. This research (Grant No. 95/5305/418) was supported by the Scientific Grant Agency (VEGA) of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences.

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