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Results of the gravity field interpretation in the Turčianska Kotlina Basin

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Abstract: The paper deals with the quantitative interpretation of the gravity field in the Turčianska Kotlina Basin. The interpretation was done by means of the application of the 2D density modelling method using the GM-SYS software. Geophysical constraints of the density models are represented by the existing geophysical measurements and interpretations. The Turčianska Kotlina Basin in the picture of the regional gravity field is characterized by the local gravity low with amplitude of about 12 mGal. The source of this gravity low is low density Tertiary sediments, which fill the basin. From the Tertiary sediments the Neogene sediments play dominant role in observed gravity, because their gravity effects are considerably larger in comparison with the gravity effects of the Paleogene sediments. The contacts between the Malá Fatra and Veľká Fatra Mts., and the Turčianska Kotlina Basin are characterized by the significant gravity gradients. They reflect tectonic contact between the basin and crystalline core mountains. In the Turčianska gravity low we can see along the Profile TK-AL three local gravity lows. The highest local gravity low is explained by the largest thickness of the Tertiary sediments. Another two local gravity lows are also characterised by thicker layers of the Tertiary sediments. Density models assume that the eastern (western) part of the basin basement is built by the Mesozoic (crystalline) rocks. In the central part of the Profile TK-BL the thick Paleogene sedimentary filling (more than 1 km) compensates the deepest part of the Pretertiary basement. Density model along the Profile TK-BL does not suggest a presence of the Paleogene sediments in the basin filling. It is also indicated that the Mesozoic rocks underlie the Tertiary sediments. The Pretertiary basement was interpreted in the depths from 0 km up to the 2 km. Note that all geological structures (blocks) are sliding from the East to the West. The dipping of the Malá Fatra Mts. is steeper than in a case of the Veľká Fatra Mts. The anomalous bodies observed on the western part of the basin result from the alluvial and detrital cones. Their presence and gravity effect can be observed mainly on the eastern slope of the Malá Fatra Mts.

Key words: gravity, geophysics, geology, density modelling, interpretation, Turčianska Kotlina Basin

1. Introduction

Turčianska Kotlina Basin (TKB) is one of the most typical intramontane Neogene depression of the Western Carpathians. The TKB is situated in northern part of Slovakia, elongated in NNE–SSW direction with the sharp (fault) contact with the Pretertiary surroundings. Geological structure of the Pretertiary basement and surroundings of depression is characterised by crystalline schists and Mesozoic rocks belonging to the Tatricum subautochthonous tectonic unit (Fig. 1), and autochthonous Mesozoic sedimentary complexes of the Fatricum and Hronicum tectonic units.

The Mesozoic sequences are discordantly overlaid by the Tertiary sediments. Paleogene sediments of the Central Carpathian Paleogene Basin are situated in northern part of the depression. Late Miocene sediments of the Rakša Formation (Egenburgian) are preserved only in remnants in southernmost part.

Significant portion of sedimentary fill belongs to the Middle and Late Miocene sediments. From the Middle Miocene the TKB was isolated depression with sedimentation under the freshwater conditions. Therefore the thickness of the sediments is variable. Two main depocenters are localised in TKB. Northern depocentre is situated in Martin vicinity. In the ZGT-3 borehole (south margin of Martin) the thickness of the Miocene sediment reaches 1025 m *(Gašparik et al., 1995; Fendek et al., 1990)*. Correlative horizons of the Middle to Late Miocene sediments were drilled in BJ-2 borehole (NW margin of Martin). The thickness is 909 m and borehole did not reach the Pretertiary basement. Another depocenter is located in the southernmost part of the TKB (Mútne depression). Middle to Late Miocene sediments including a volcanoclastics sequences achieve the thickness of 908.7 m in the GHŠ–1 borehole *(Gašparik et al., 1974)*.

The extent of Tertiary sediments is distinctive, separated from the Pretertiary rocks sequences by long-living normal faults. The main role during tectonic evolution was played by NNE – SSW oriented faults. The intra-basin faults are arranged in NW–SE direction and separate the TKB into two different parts with specific lithology and distribution of Tertiary sediments.

The normal faults situated on western margin of the depression controlled subsidence of the TKB. Western margin of TKB flanked occurrence of large

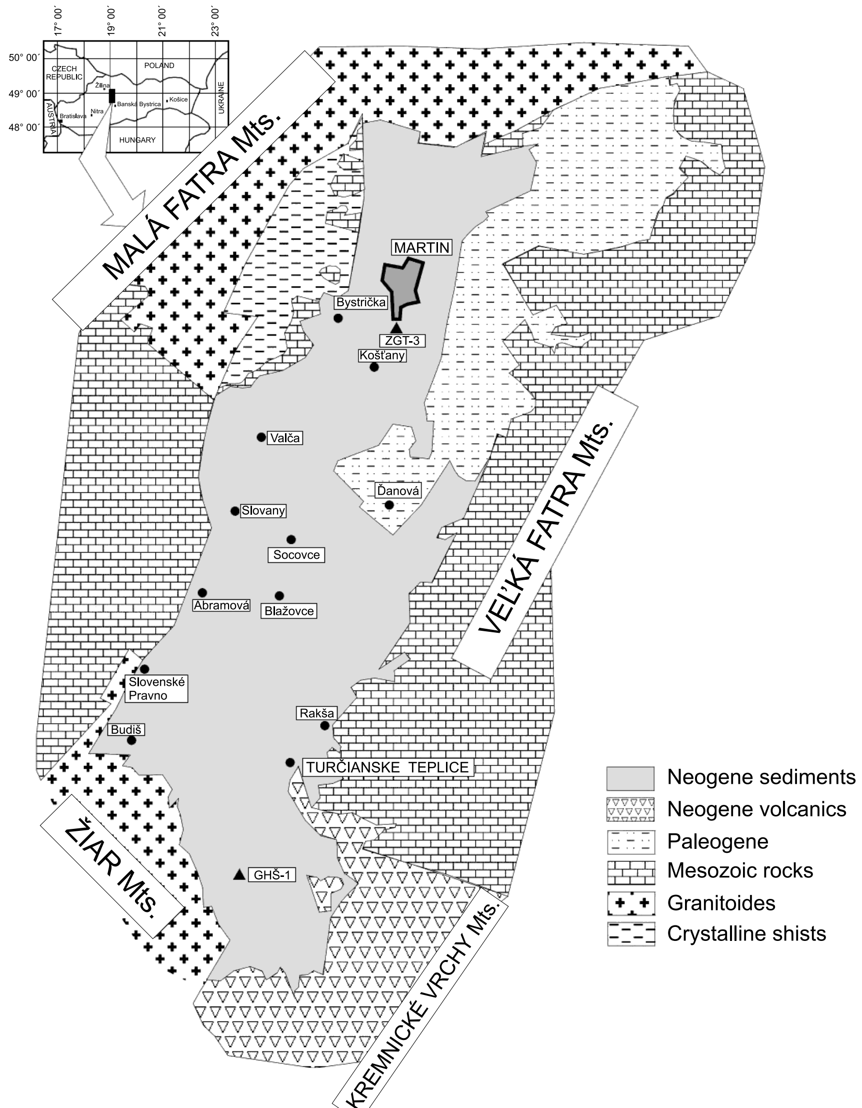

Fig. 1. Simplified geological structure of the TKB and its surroundings (modified after *Gašparik et al., 1995*).

alluvial fans indicating a significant denivelization of paleorelief during subsidence. The tectonic evolution of the TKB is most probably connected with dextral transtension regime of the Central Slovakia fault system operated during Middle to Late Miocene *(Kováč and Hók, 1993; Hók et al., 2000).*

The geophysical surveys of the regional characters have been performed approximately from the 60-ies of the 20th century. The gravimetric measurements on the scale of the 1:200 000 *(Ibrmajer, 1963)* were realised as first geophysical work in the TKB. Consequently, the seismic, gravimetric, magnetic, geoelectrical, thermal and petrophysical measurements have been done, here.

The goal of the paper is to study the geological structure of the TKB by means of the density modelling method. The density modelling is based on the existing geophysical and geological constraints (e.g., seismic, gravimetric and geoelectrical). The results of the seismic interpretation played the most important role in the construction of the input density models. The results obtained would help us to improve our knowledge, which related to the geological structure and tectonic position of the sedimentary Tertiary filling compared with the Pretertiary basement basin relief. The results (e.g., in the sense of Šujan in *Bielik et al., 2009; Mikita et al., 2009; Putiška et al., 2005*) would also help in the effective exploitation and rational usage of natural sources, protection of the environment and land planning of the Turiec region.

2. Geophysical constraints

Gravity measurements in the scale 1:200 000 have been performed as the first geophysical works in the TKB *(Ibrmajer, 1963).* The map of the total Bouguer gravity anomalies on the same scale and its qualitative interpretation were the main results of these measurements.

The Profile K-III *(Hrdlička et al., 1983)* is the only one from the deep seismic refraction profiles, which crosses the TKB. Based on these seismic results, the TKB is characterized by the zone of higher effective velocities. The upper crust is represented by the velocities of 5800–6000 m/s. The refraction horizon in the depth of about 2–3 km indicates the gentle depression. The source of this horizon is not clear. It is suggested that it could reflect the boundary between Mesozoic and crystalline basement. The Moho in the basin was interpreted at the 35 km depth.

The further seismic survey went on by the reflection measurements, which used the common point method. These measurements have been performed along the regional Profiles 4HR/86, 4AHR/86 and 519/87 (Tomek in *Blížkovský et al., 1990*). The seismic results brought out the first knowledge about the thickness of the Neogene and Paleogene sedimentary filling, Mesozoic rocks and the Pretertiary basement.

More detailed gravity measurements in the TKB and its surrounding mountains *(Zbořil et al., 1975; Szalaiová and Stránska, 1977, 1978)* have been performed in the scale 1:25 000. The results showed that the TKB represents asymmetric gravity depression, which belongs to the Western Carpathian minimum. Based on these measurements quantitative parameters of the basin faults were estimated.

The TKB is covered by the geoelectrical measurements very sporadically *(Zbořil et al., 1982, 1985)*. These works contributed mostly to the interpretation of three morphostructural Pretertiary basement sub-depressions with thick accumulation of Tertiary sediments. The interpretation assumes the carbonatic rocks beneath these sediments.

From geothermal point of view *(Fendek et al., 1990)* the basin presents the zone of higher temperatures in comparison with the outside regions. At the depth between 900–1200 m it is assumed the temperature values take about 50 °C. In the borehole GHŠ-1 the temperature of 35 °C was measured at 500 m depth, 49 °C at 1000 m depth, 64 °C at 1500 m depth. The temperature of 78 – 80 °C is expected at 2000 m depth.

The geophysical measurements of the TKB have been summarized in the book by *Šefara et al. (1987)*. The last geophysical measurements have been performed and interpreted in the period 1989–1991 *(Panáček et al., 1991)*. The results consist of the physical properties of the rocks, additional geoelectrical profiling and vertical electrical sounding, and geological–geophysical interpretation of the geological structure in the TKB.

3. Gravity field of the TKB

The most interesting feature of the TKB gravity field is the existence of the gravity low with the significant gravity gradients on its margins (Fig. 2). The gravity gradient is higher on the western part of the basin in contrast of the eastern one. The gravity field can be distinguished into three gravity sub-regions (Martin gravity low (MGL), Slovenské Pravno gravity low (SPGL)

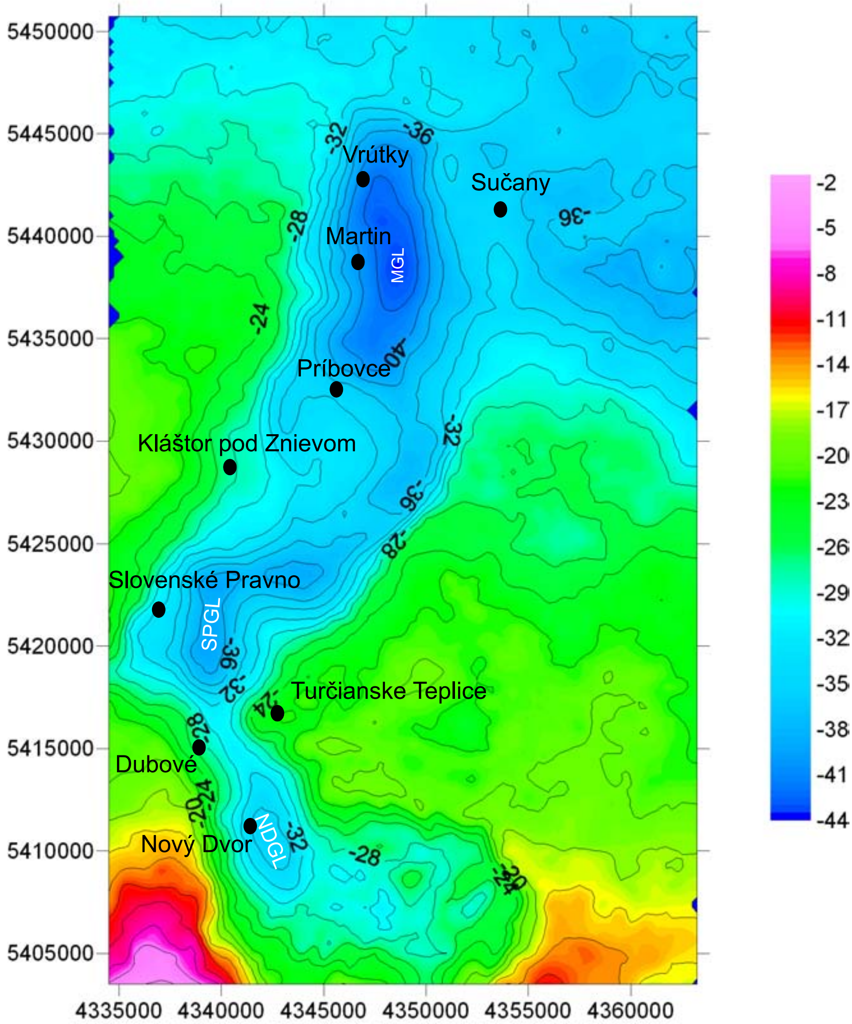

Fig. 2. Total Bouguer gravity anomaly map (after Kučera and Michalík in *Bielik et al., 2007*).

and Nový Dvor gravity (low NDGL)). The regions are separated by the relative gravity highs. The first (second) one can be observed East of Kláštor pod Znievom (between Dubová and Turčianske Teplice). Southeast of the Turčianske Teplice, where the neovolcanic complex outcrops, the gravity field has a scattered feature. In the region, which is covered by Paleogene (northeastern from Sučany), the gravity field decreases by only about 2–3 mGal and consists of local lows and highs (Kučera and Michalík in *Bielik et al., 2007*). Except of these gravity anomalies the significant decrease of the gravity field towards north can be observed. Different gravity decrease in the Veľká Fatra Mts. compared with the Malá Fatra Mts. reflects probably different structure of the crust beneath both mountains *(Šefara, 1989)*. This idea is also supported by the existence of the Central Western Carpathian gravity low.

4. Methodology

The methodical part of our work can be divided into two phases: preparatory and interpretative. In the first phase the selection of the interpretation profile locations have been done. The fact that two regional seismic reflection Profiles 4HR/86 and 4AHR/86 (Tomek in *Blížkovský et al., 1990; Vozár and Šantavý, 1999*) are going through the TKB was the most important for the location of the representative interpretative regional Profile TK-AR and Profile TK-BR (Fig. 3). In the basin their locations are almost identical with the locations of both seismic reflection profiles.

The Profile TK-AR is in SW-NE direction and its start is in the Danube Basin. Then, it goes on via the margin of the Tríbeč Mts., Hornonitrianska Kotlina Basin, Malá Fatra Mts., TKB, Oravská vrchovina Mts., Klippen Belt, Oravské Beskydy Mts., Oravská Kotlina Basin and ends in the Polish Beskydy Mts. The Profile TK-BR has NW-SE direction and it starts in the Moravskoslezské Beskydy Mts. and continues through the Javorníky Mts., Žilinská Kotlina Basin, Malá Fatra Mts., TKB, Veľká Fatra Mts., Poľana Mts., Stolické vrchy Mts. Finally, it ends in the South Slovak Basin. Both profiles cross near Príbovce and they are 200 km long.

The second phase includes the interpretation of the gravity field. For the quantitative interpretation we applied the 2D density modelling method.

The density models were solved by application of the software GM-SYS (Gravity and Magnetics Modelling System – *GM-SYS^{TM}, 1992*). The program is capable of interactive gravity and magnetic interpretations. The calculations of the gravity effects of the geological bodies are based on the formulae defined by *Talwani et al. (1959)*.

The aim of the regional interpretation was to find the gravity and tectonic position of the TKB compared with the surrounding Western Carpathian tectonic units as well as to determine "real" regional component of the observed gravity field. The regional gravity component consists of the superposition of the gravity effects of the upper-lower crustal boundary, Moho discontinuity and lithosphere-asthenosphere boundary. The regional grav-

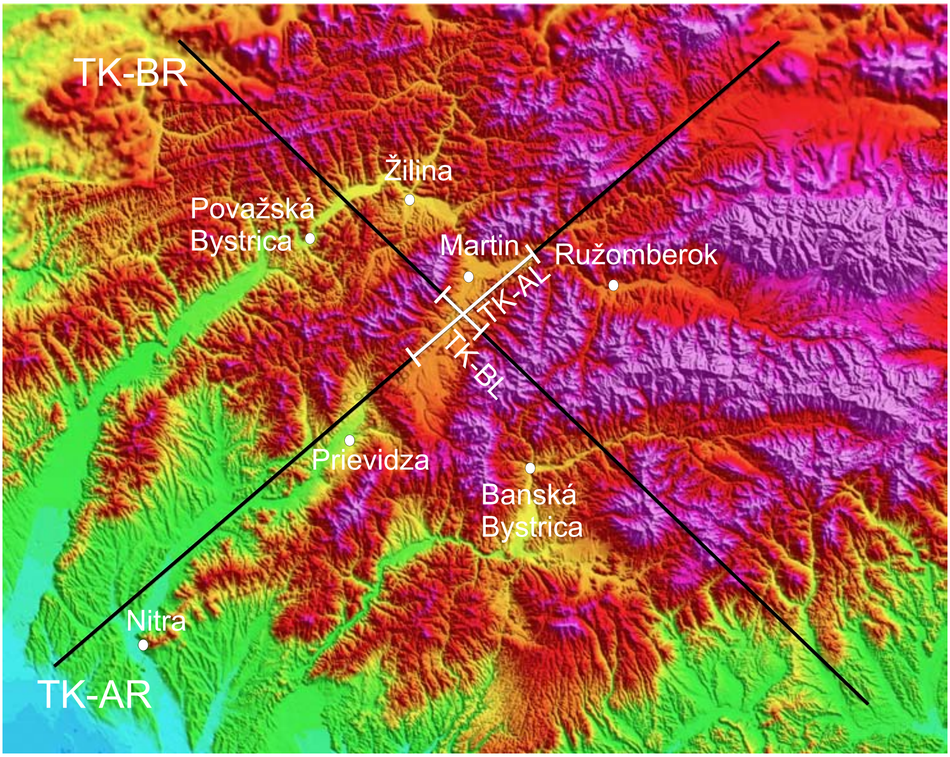

Fig. 3. Location of the interpretation profiles TK-AR, TK-BR, TK-AL and TK-BL.

ity values have been used for the definition of the local (residual) gravity anomalies in the TKB. The residual gravity anomalies have been applied for the density modelling in the TKB along the local density Profile TK-AL and Profile TK-BL.

5. Input data

Profile observed gravity values along the Profiles TK-AR and TK-BR have been taken from the total Bouguer gravity anomalies of Slovakia map *(Szalaiová and Šantavý 1996).* The gravity values outside Slovakia have been supplemented by the data from the unified map of the total Bouguer gravity anomalies of the states Poland, Hungary, Austria Czech Republic and Slovak Republic *(Bielik et al., 2006).* The total Bouguer gravity anomalies were calculated with reduction density equal 2670 kg/m^3. For the definition of the residual gravity anomalies we used the total Bouguer gravity anomalies calculated by Kučera and Michalík in *Bielik et al., 2007*).

The topography was defined based on the map of topography in Slovak Republic (EQUIS 2008).

Based on the interpretations of the seismic reflection measurements along the Profiles KIII/75, 4HR/86, 4AHR/86 and 519/87, the input density models have been constructed. The constraints for these models consist of the information about the sedimentary filling structure, Paleogene/Neogene boundary and Pretertiary basement basin relief.

From the geological data we took into account mostly the results from the existing boreholes. The surface outcrops of the geological units were defined by the geological map *(Lexa et al., 2000).*

The Moho discontinuity relief and the lithosphere-asthenosphere boundary have been defined from the published maps in the papers of *Bielik et al. (2004), Dérerová et al. (2006)* and *Zeyen et al. (2002)*, respectively.

Based on the papers by *Zbořil et al. (1985), Panáček et al. (1991), Eliáš and Uhmann (1968), Šefara et al. (1987), Bielik (1995)* and *Tašárová et al. (2009)*, the density average values for the geological structures and physical discontinuities have been defined (Table 1).

Table 1. Average densities of the geological structures and physical discontinuities

Geological units and physical discontinuities	density kg/m^3	density kg/m^3		density kg/m^3
Lithosphere-Astenosphere boundary	3247			
Moho	3250			
Lower Crust	2950	2970		
Upper Crust	2750	2770		
Profile TK-AR			**Profile TK-BR**	
Danube Basin	2400		Javorníky Mts.	2550
Tríbeč Mts.	2670		Klippen Belt	2700
Hornonitrianska kotlina basin Neogene	2400		Malá Fatra Mts.	2680
Hornonitrianska kotlina basin Paleogene	2540		TKB Neogene	2370
Malá Fatra Mts.	2680		TKB Paleogene	2560
TKB Neogene	2370		Veľká Fatra Mts.	2680
TKB paleogene	2560		Zvolenská kotlina basin	2550
Oravská vrchovina Mts.	2670	2690	Slovenské Rudohorie Mts.	2670
Klippen Belt	2700		South Slovak basin	2400
Polish Beskydy Mts.	2550			

6. Density modelling results

Regional density models

The regional density models of the Profile TK-AR and Profile TK-BR consist of the density inhomogeneities from the topography up to the lithosphere-asthenosphere boundary. For better illustration of the density anomalous bodies the models were divided into two depth parts (types). The first type of the models shows the models from real topography up to the 8 km depth (Figs. 4a,b). The second type of the models illustrates the density model from 0 km up to 140 km. In the last models the surface and subsurface anomalous bodies were not taken into account for determination of the regional gravity effects (Figs. 5a,b). Here, except of the observed gravity fields, the regional gravity effects are also illustrated.

The TKB in the picture of the Profile TK-AR regional gravity field (Figs. 4a and 5a) appears as in significant local gravity low (12 mGal amplitude) with regional trend decreasing from SW to NE direction. The local gravity low is separated into three sub-parts. The first two parts of the

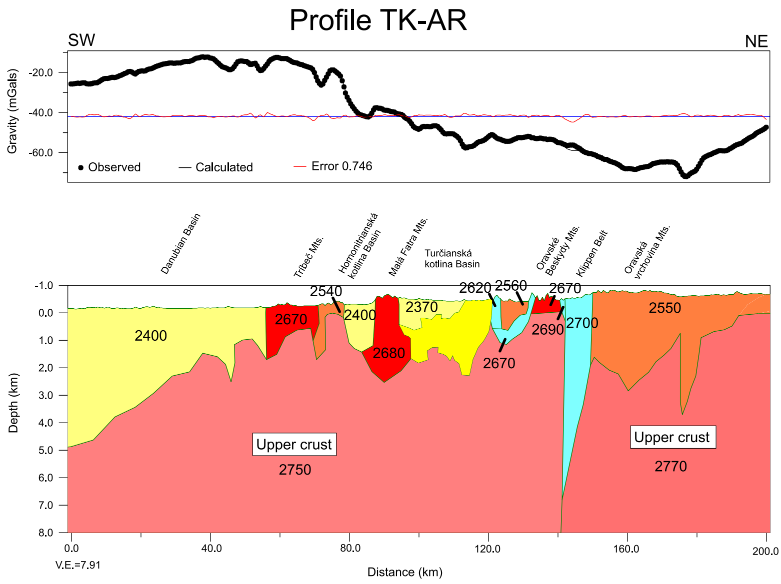

Fig. 4a. The upper part of the density model along of the Profile TK-AR.

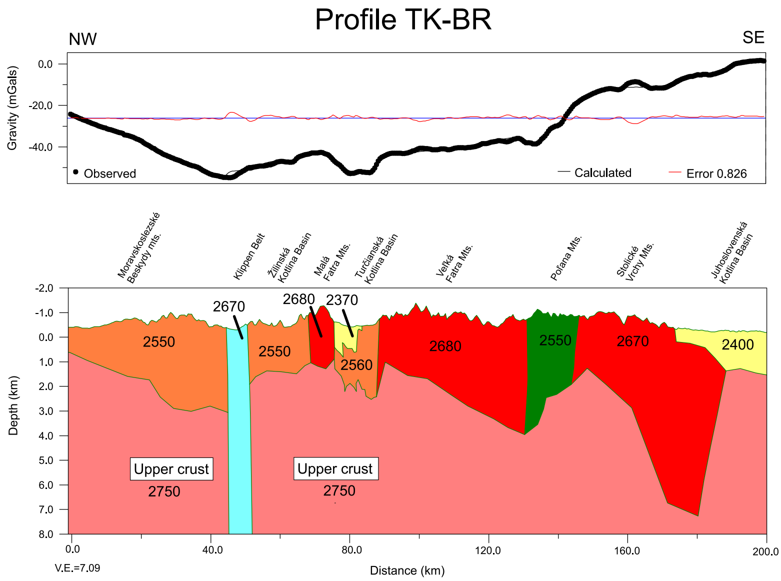

Fig. 4b. The upper part of the density model along of the Profile TK-BR.

gravity low are separated by local gravity elevation (between km 95–110). The third part of the gravity low can be observed over the region, which is covered by the Paleogene sediments (the centre on the 130 km). The local gravity low due to the TKB on the regional Profile TK-BR (Figs. 4b and 5b) is considerably sharper and clearer against the former profile. The local gravity low has similar maximum values (about of 12 mGal). The margins of the basin against the Malá Fatra Mts. and Veľká Fatra Mts. are followed by the significant horizontal gravity gradients in both profiles.

Local density models

Profile TK-AL is 35 km long (Fig. 3). It has SW-NE direction and starts on the 95 km and ends on 130 km of the regional Profile TK-AR. From geological point of view the profile starts in the crystalline core of the Malá Fatra Mts., goes on through the Tertiary filling of the TKB and ends at the Mesozoic cover sequence of the Veľká Fatra Mts. The length of the Profile TK-BL is 15 km and it has NW–SE direction (Fig. 3). It starts on 75 km and on 90 km of the regional Profile TK-BR. It runs through of the crystalline core of the Malá Fatra Mts., via the Tertiary filling of the TKB to the Mesozoic of the Veľká Fatra Mts. The residual gravity anomalies for the Profile TK-AL and Profile TK-BL were calculated by subtracting of the regional gravity components from the values of the total Bouguer gravity anomalies (Fig. 5a,b).

The Profile TK-AL residual gravity anomaly shows variability. Generally, the TKB is characterized by the gravity low, in which the relative gravity high can be seen (121 km of the profile). The relative gravity high is in agreement with the surface outcrop of the Mesozoic of the Malá Fatra Mts. The Mesozoic is built here by the rocks of the Krížna nappe. In the Turčianska gravity low we can see three local gravity lows (on about 99.5 km, 113 km and 125 km). The first two lows are separated by the relative gravity high. The second gravity low is larger. From this gravity low the values increase toward to NE, except in the third gravity low region. The last local gravity low correlates very well with the existence of the Paleogene sedimentary basin filling. Residual gravity anomaly of the Profile TK-BL is characterised by the significant local gravity low too. The maximum amplitude is about 10 mGal. In the center of the gravity low a bit higher gravity values can be observed. The residual gravity values increase

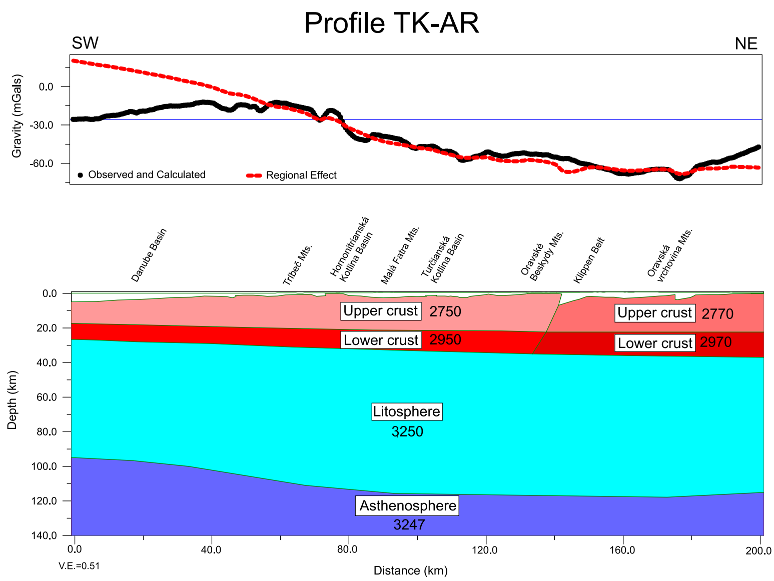

Fig. 5a. The lower part of the Profile TK-AR with the showing of the calculated regional component of the observed gravity.

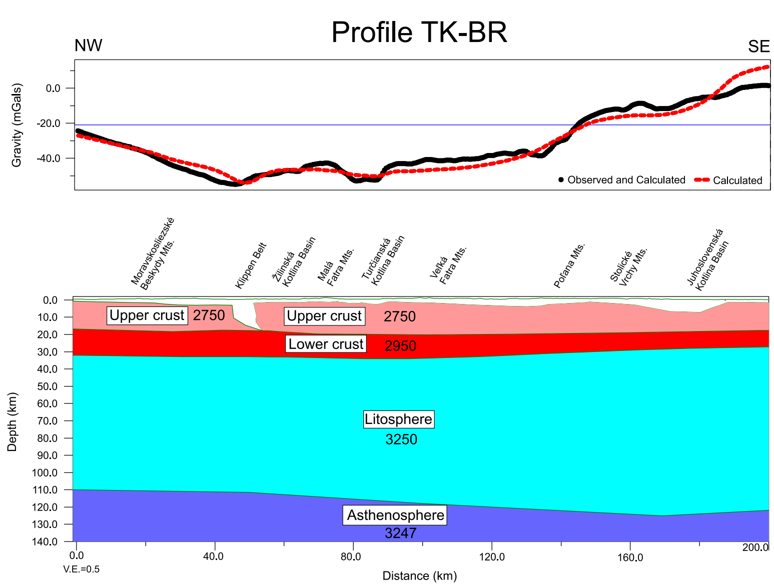

Fig. 5b. The lower part of the Profile TK-BR with the showing of the calculated regional component of the observed gravity.

very steeply on the northwestern and southeastern sides of the profiles.

The sufficient fit between the residual anomalies and the gravity effects of the density models has been reached by means of the interactive density modelling. In this process the geometry and density parameters of the geological structures have been adjusted until the good fit has been attained. The results of density modelling are illustrated in Fig. 6a,b.

7. Conclusions

Based on the density modelling it was found out that the Turčianska Kotlina gravity low (Fig. 6a,b) is a result of low density Tertiary sediments, which fill the basin. From gravity point of view the Neogene sediments play dominant role in observed gravity, because their gravity effects are considerably larger in comparison with the gravity effects of the Paleogene sediments.

On the Profile TK-AL the largest local gravity low (113 km) was explained by the largest thickness of the Tertiary sediments. Another two local gravity lows are also due to thicker layers of the Tertiary sediments. Density model assumed that the eastern (western) part of the basin basement is built by the Mesozoic (crystalline) rocks. In the central part of the Profile TK-BL the thick Paleogene basin filling (more than 1 km) compensates the largest depth of the Pretertiary basement. Taking into account the borehole data the model does not suggest a presence of the Paleogene sediments in this part of the basin.

Both density models suggest that the Mesozoic rocks underlie the Tertiary sediments. The Pretertiary basement was interpreted in the depths from 0 km up to 2 km. Note that all geological structures (blocks) are sliding from the East to the West. The dipping of the Malá Fatra Mts. is steeper than in the case of Veľká Fatra Mts. Interesting density anomalous bodies were modelled in the western part of the basin. It is suggested that the bodies represent the presence of the alluvial and detrital cones (CNS – coarsegrained neogene sediments). They can be observed mainly on the eastern slope of the Malá Fatra Mts. The contact between the Malá Fatra and Veľká Fatra Mts., and the TKB is characterized by the significant gravity gradients. They reflect tectonic contact of the basin with crystalline core mountains.

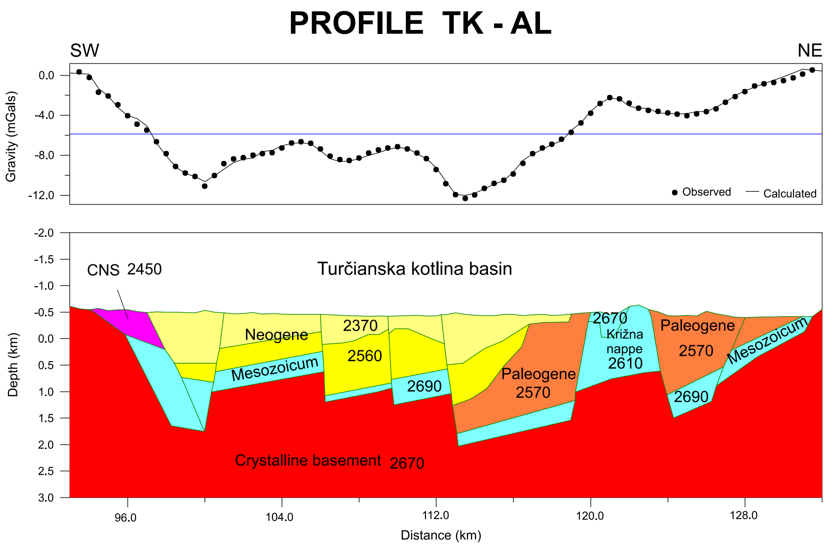

Fig. 6a. Density model along the TK-AL. Densities are in kg/m^3.

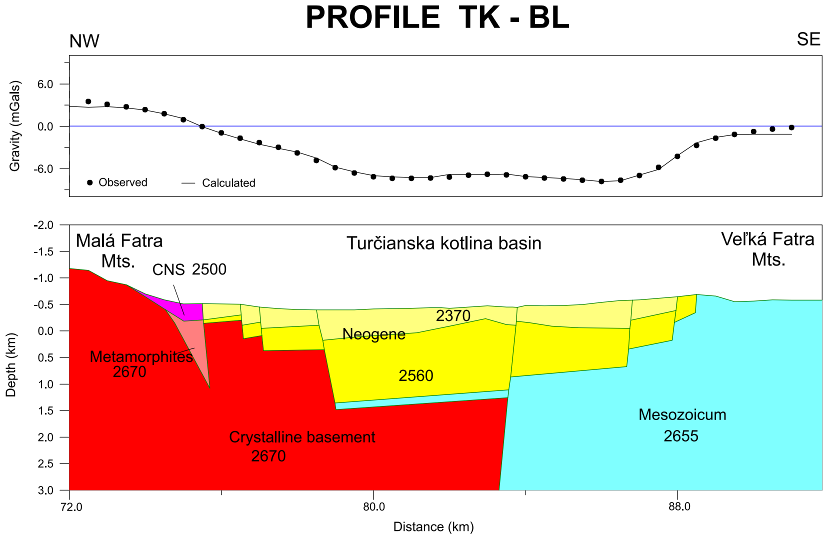

Fig. 6b. Density model along the TK-BL. Densities are in kg/m^3.

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