The first stripped gravity map of the Turčianska Kotlina Basin

Martin KRAJŇÁK[1], Miroslav BIELIK[1,3], Irina MAKARENKO[2], Olga LEGOSTAEVA[2], Vitaly I. STAROSTENKO[2], Marián BOŠANSKÝ[1]

[1] Faculty of Natural Sciences, Department of Applied and Environmental Geophysics
Comenius University, Mlynská dolina, pav. G, 842 48 Bratislava, Slovak Republic
e-mail: krajnak@fns.uniba.sk, bielik@fns.uniba.sk, bosansky@fns.uniba.sk

[2] Institute of Geophysics, National Academy of Sciences of Ukraine
Palladin, av. 32, Kiev, 03680, Ukraine
e-mail: irinam@igph.kiev.ua, olgal@igph.kiev.ua, vstar@igph.kiev.ua

[3] Geophysical Institute of the Slovak Academy of Sciences
Dúbravská cesta 9, 845 28 Bratislava, Slovak Republic, e-mail: geofmiro@savba.sk

Abstract: During the last years, many new results related to the thickness of the sedimentary fill and other geophysical and geological constrains on the structure of the Turčianska Kotlina Basin have been obtained. It allowed us to calculate the first, original stripped gravity map in this basin. To obtain this map the 3D gravity effect of the basin sedimentary fill had to be calculated. The gravity effect of the sediments was determined for two different density conditions. Firstly, the average density of the sediments was constant (2.45 $\mathrm{g\,cm^{-3}}$). Secondly, we supposed that the density of sediments varies exponentially from 2.00 $\mathrm{g\,cm^{-3}}$ on the surface up to 2.67 $\mathrm{g\,cm^{-3}}$ on the pre-Tertiary basement. On the maps of the calculated gravity effects it can be observed that the maximum amplitudes reach about -12 mGal. The gravity effect is larger in the case when the densities of the sedimentary fill vary exponentially. After subtraction of the gravity effects from the map of complete Bouguer gravity map, the resultant stripped gravity maps were defined. The detailed analysis of these maps indicates that the northern part of the pre-Tertiary basement of the basin could be built mostly by the Mesozoic rocks, which belong to the Hronic and Fatric units. The structure of the basement in the southern part of the basin seems to be more complicated. This feature probably reflects a presence of Neogene volcanites in the basin basement belonging to the Kremnické vrchy Mts. The picture of the gravity field in the stripped gravity map predicts that the Paleogene sediments probably do not build the sedimentary fill in the southern part of the basin. Finally, taking into account the differences in the size of the gravity gradients along the basin margins it could be suggested that the dipping of the Veľká Fatra Mts. beneath the Turčianska Kotlina basin is gentle in comparison with the Lučanská Malá Fatra.

Key words: applied geophysics, gravity, 3D gravity modelling, stripped gravity map, Western Carpathians, Turčianska Kotlina Basin

1. Introduction

The Turčianska Kotlina Basin (TKB) belongs to the region of the Western Carpathians (Figs. 1, 2) with relative good coverage of geophysical data. In former time, the seismic, gravity, geoelectric and thermal measurements have been performed on different scales (e.i., *Ibrmajer, 1963; Hrdlička et al., 1983; Tomek, 1990; Zbořil et al., 1975, 1982, 1985; Szalaiová and Stránska, 1977, 1978*). Deep seismic profile K-III *(Hrdlička et al., 1983)* (Fig. 3) has shown that the TKB is a zone with higher effective velocities, where velocities 5800–6000 ms^{-1} occur in depth of 9 km. According to K-III the depth of Moho discontinuity was set to 35 km with a SSE dip. Regional seismic profiles 4HR/86, 4AHR/86 a 519/87 *(Tomek, 1990)* (Fig. 3) acquired information about the geological structure, structure of Tertiary sedimentary fill and its relation to the crystalline basement in the TKB. The basin is covered with gravity measurements in a scale of 1:50 000 *(Zbořil et al., 1975; Szalaiová and Stránska 1977, 1978).* The main acquisition of the geoelectrical survey *(Zbořil et al., 1982, 1985)* was defining a relief of the pre-Tertiary basement and thick accumulations of the Tertiary sediments. The density of these measurements is higher in the southern part of the basin than in the northern one. The geothermal characteristic is also well known in TKB. The basin represents an area of higher temperatures compared to the surrounding region. The results from borehole GHŠ-1, in the southern part of the basin, are showing temperature of 35 °C in 500 m depth, 49 °C in 1000 m depth and 64 °C in 1500 m depth *(Fendek et al., 1990).*

The aim of the paper is the 3D gravity modelling and interpretation of the observed gravity data in the TKB. Based on the 3D gravity modelling the original stripped gravity map in the TKB was carried out for the first time. The resultant stripped gravity maps were calculated by means of the GMT-AUTO software *(Starostenko et al., 1997; Starostenko and Legostaeva, 1998, 2006).* The paper provides also the preliminary geophysical interpretation of these new and original gravity maps.

2. Geology

The TKB is the northernmost intermountain depression of the Central Western Carpathians filled by the Paleogene, Neogene and Quaternary deposits

(Fig. 2). From the north it is bounded by the Krivánska Malá Fatra Mts. and from the south by the Žiar Mts. predominantly composed of the Tatric unit crystalline basement rocks of the Variscan age. Volcanics of the Kremnické vrchy Mts. restrict the basin to the southeast. Lučanská Malá Fatra Mts. create the western and Veľká Fatra Mts. eastern flank of the TKB. Both these are composed of the crystalline basement rocks of the Tatric unit and Mesozoic Fatric or Hronic nappes. The TKB is westward dipping halfgraben with two main depocenters, one in the northern and second in the southern part *(Kováč et al., 2011)*. The pre-Neogene basement in the southern part consists of the upper Paleozoic and Mesozoic of the Fatric and Hronic tectonic units *(Fusán et al., 1987* in *Vass, 2002)*, and also Paleogene post-nappe sedimentary cover in its northern part.

The Paleogene and Early Miocene deposits cropping out on the eastern and north-eastern margin as well as in the basement of Miocene basin fill. They represent basal formation containing coarse-grained deposit to clays, claystones, sandstones and deposits of turbidity flows lying directly on the Mesozoic basement. The Lower Miocene paleostress field had no effect on the opening and formation of the TKB. The Upper Badenian initial rifting caused by transtensional to extensional tectonic regimes led to subsidence in the southern part of TKB, where the volcano-sedimentary andesite complex of the Turček Formation was deposited. Late Miocene clockwise rotation of principal compressional ais to a NNE–SSW led to the Pannonian subsidence of the TKB and synrift sedimentation of the principal fill of TKB – Martin Formation deposited in closed basin surrounded by uplifted mountains. Pelitic grey clay is dominant lithological type but also clay with coal pigment, thin lignite coal seams, sand and sandstone are present. The uniform dip of the sedimentary sequence points to the long-term activity of faults near the western margin of the depression *(Hók et al., 1998)*, which played a dominant role during basin evolution. In the time from the latest Pannonian to Pontian the coarse-grained alluvial fans of the Abramová and Balážovce members were deposited on the margin on uplifted central part of the Lučanská Fatra Mts. They were deposited on the pre-Neogen basement nad Middle Miocene pelitic sediments. Towards the basin, the marginal coarse-grained subaerical sediments are interfingering with fine-grained lacoustrine deposits. In some places they partly intercalate with clays of the Martin Formation. During the Pontian and Early Pliocene, the change of

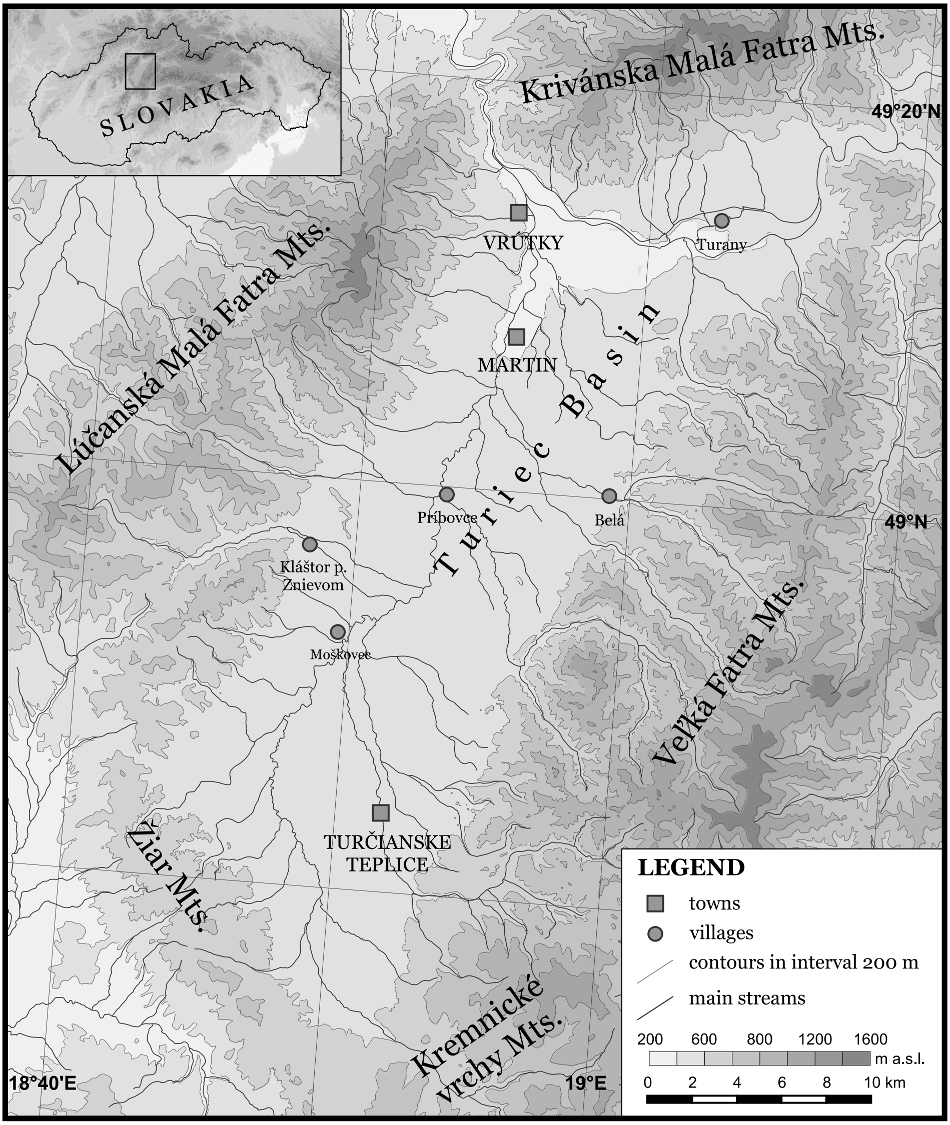

Fig. 1. Geographical position of the TKB (modified after *Kováč et al., 2011*).

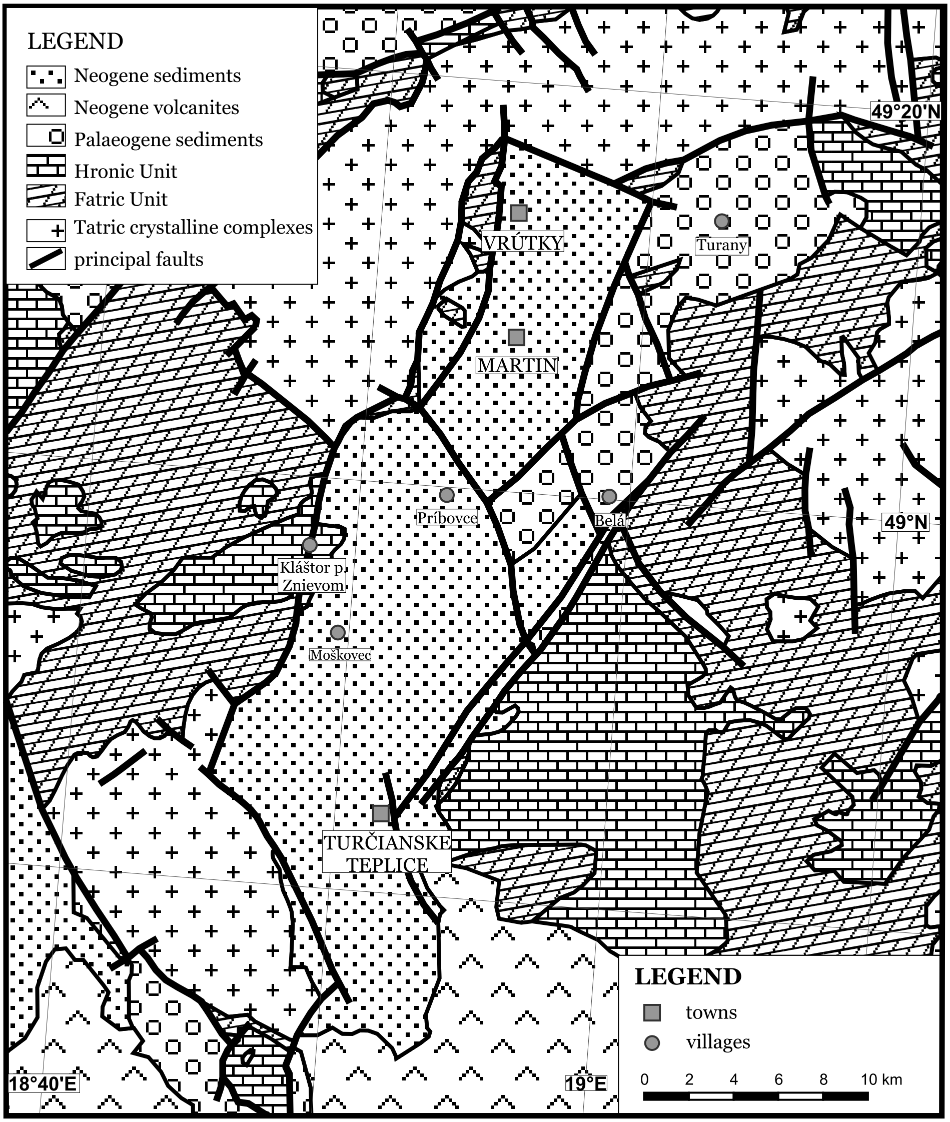

Fig. 2. Schematic geological map of the TKB and its surroundings (modified after *Kováč et al., 2011* and *Grinč et al., 2010*).

tectonic regime led to the end of subsidence and end of deposition followed by the uplift of the whole TKB catchment *(Kováč et al., 2011)*. A rapid uplift of the crystalline basement of the Krivánska Malá Fatra Mts. is documented by the Late Pliocene Bystrička member and the Pleistocene alluvial fans of the Podstráne member, containing material derived only from the Malá Fatra Mts. Tatric rocks.

3. Three-dimensional gravity modelling

The method of the 3D gravity modelling was applied for the stripped gravity map calculation. It is well-known that this approach is very useful for the study of the basement and deep seated structure in different sedimentary basins *(Bielik, 1988; Bielik et al., 2005; Alasonati et al., 2008; 2009)*. The 3D gravity effect of the sedimentary fill of the TKB was determined by the GMT-AUTO software package *(Starostenko et al., 1997; Starostenko and Legostaeva, 1998; 2006)*. The principle of the method is that the geological structures are divided into horizontally stratified medium with an arbitrary density distribution in each layer. The geological structure is approximated by an inhomogeneous, arbitrarily truncated vertical rectangular prism. An automatization of input of initial graphic information (maps) by digitization is also very useful in the process of modelling *(Legostaeva, 2000)*. The gravity effect of 3D bodies can be determined not only with constant densities, but also with different densities on the upper and lower limits having a linear or exponential vertical transition. After the gravity effect calculation of the Tertiary and Quaternary fill of the TKB (Figs. 6 and 7) the resultant stripped gravity maps (Figs. 8 and 9) were calculated by subtraction of these effects from the complete Bouguer anomaly map.

3.1. Geophysical input data

The basic input data for the calculation of the stripped gravity map is represented by the complete Bouguer anomalies (Fig. 3), which was compiled by Michalík and Kučera and published in *Bielik et al. (2007, 2008)* and *Grinč et al. (2010)*. The gravity field of the TKB is characterized by the relative local gravity low (maximum -42 mGal) with the significant gravity

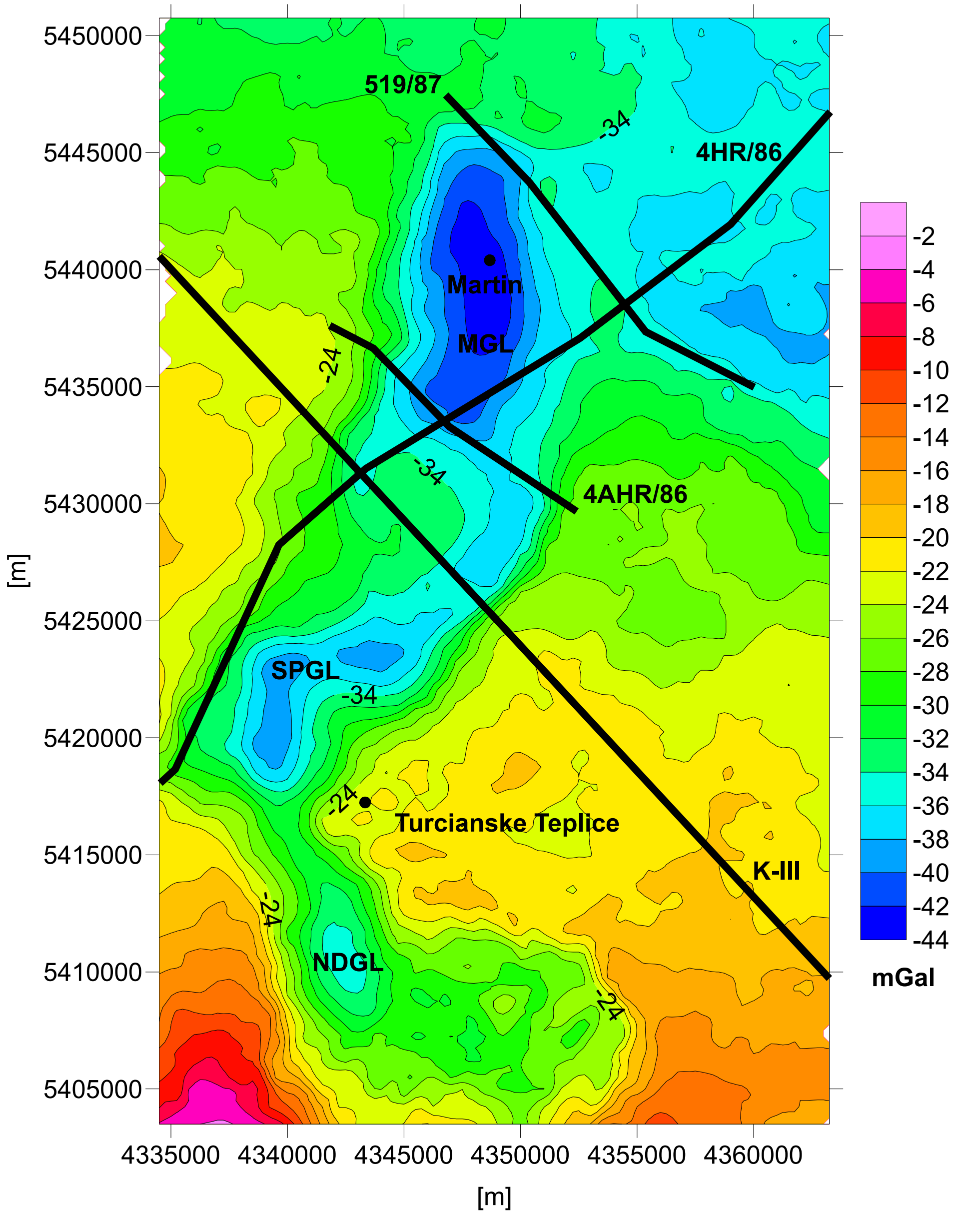

Fig. 3. Complete Bouguer gravity anomaly map (after Kučera and Michalík in *Bielik et al., 2007*) with seismic profiles of Turčianska Kotlina Basin.

gradients on its margins. The relative amplitude of this gravity low is about 12–14 mGal. This relative local gravity low can be divided into the three gravity sub-lows *(Grinč et al., 2010)*: Martin gravity low (MGL), Slovenské Právno gravity low (SPGL) and Nový Dvor gravity low (NDGL) (Fig. 3). From regional gravity field point of view it can be observed that the negative gravity-field gradual increases from the south to the north.

The next input data is the thickness of the TKB sediments. The first 3D map of this type has been calculated by Kučera and Michalik (in *Bielik, 2007, 2008; Fig. 4*). This was solved as a 3D inverse gravimetric problem based on Pohanka's formula, which allows to calculate the gravitational effect of a polyhedral prism with a linear density transition with depth *(Pohánka, 1988* in *Bielik et al., 2008)*. Barry's algorithm (1991) was used for the own 3D model construction. Here, the three main sub-basins can be distinguished: the Martin sub-basin (MS), the Slovenské Právno sub-basin (SPS) and the Nový Dvor sub-basin (NDS) (Fig. 4). Note that the gravity field (Fig. 3) correlates expressly with this map. It can be seen clearly that the largest thicknesses of the sedimentary fill are reflected by the largest relative gravity sub-lows in the complete Bouguer gravity map. The SPS and NDS are the deepest depressions (more than -3000 m a.s.l.) in the TKB (Fig. 4). In the MS the pre-Tertiary basement depression with several lows with depths exceeding to -2000 m a.s.l. can be found. The SPS and NDS are separated from the MS by the central basin elevation clearly visible in the area of Kláštor pod Znievom and Moškovec, which reaches up to 500 m a.s.l. Another remarkable feature of the pre-Tertiary basement is located in the vicinity of Turany, in the north-eastern part of TKB. In this area the relief of the pre-Tertiary basement is formed by a plateau with an altitude around 350 m a.s.l. The boundary between the basin and the surrounding mountain ranges is appearing about 500 m depth a.s.l.

For calculation of the gravity effect of the Tertiary sediments we suggested two different possibilities related to density of the sedimentary fill. Firstly, the average constant density 2.45 $\mathrm{gcm^{-3}}$ (2450 $\mathrm{kg\,m^{-3}}$) of the Tertiary and Quaternary sediments has been taken from the paper by *Grinč et al. (2009)*. Secondly, based on the analysis of published sedimentary densities we suppose that the density of these sediments varies exponentially from 2.00 $\mathrm{gcm^{-3}}$ on the surface up to 2.67 $\mathrm{gcm^{-3}}$ on the pre-Tertiary basement.

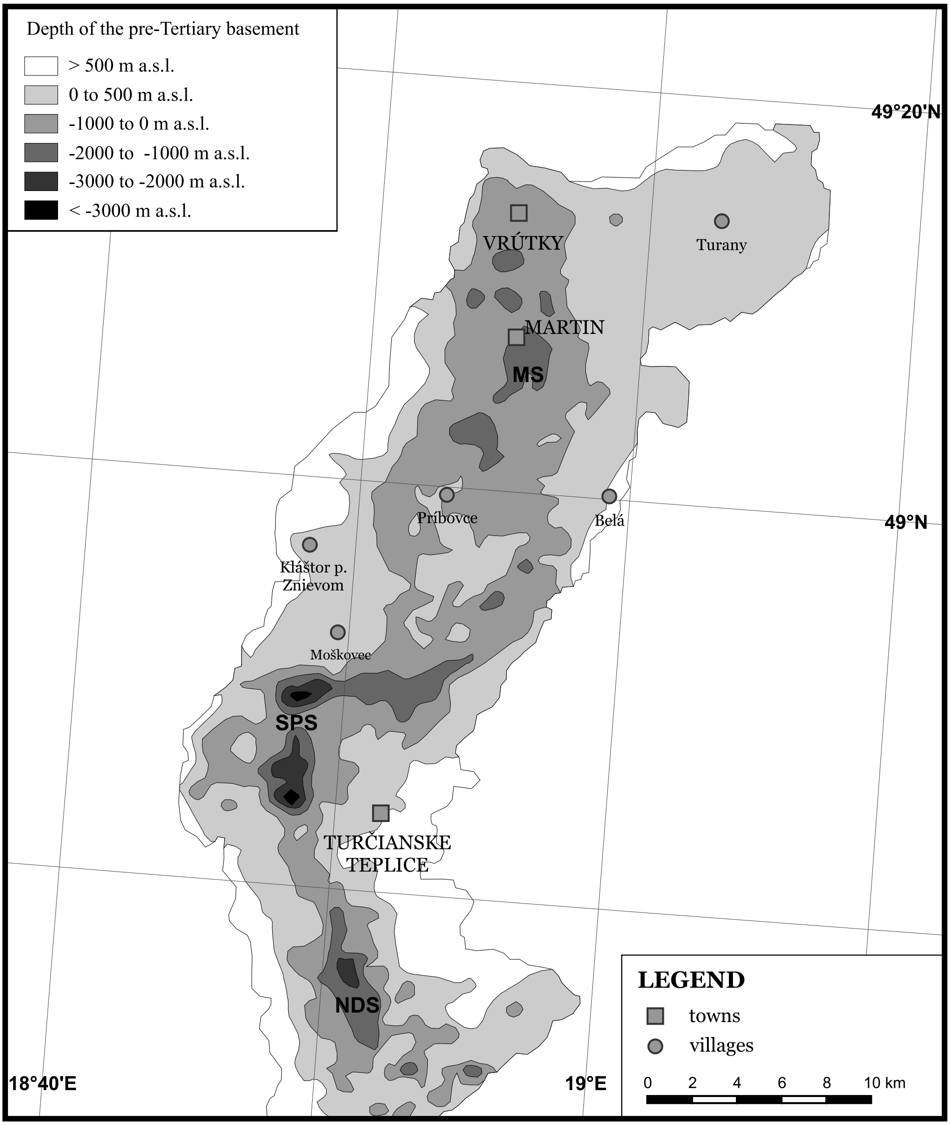

Fig. 4. Map of the pre-Tertiary basement *(Bielik et al., 2008)*.

The maps of the complete Bouguer gravity anomaly and the Tertiary sediment thickness were digitized by the GMT-AUTO software *(Starostenko et al., 1997; Starostenko et al., 2011)* for the calculation of the final stripped gravity maps. The digitized map of the complete Bouguer gravity anomaly is illustrated in Fig. 5.

4. Results

On the maps of the gravity effects of the sediments (Figs. 6 and 7) it can be observed that the amplitude of the gravity field (maximum up to -12 mGal) is larger in the case, when the densities of the sedimentary fill varies exponentially. For the average constant density of the sediments (2.45 gcm^{-3}), the maximum amplitude was only -7 mGal in the MGL. Generally, the courses of the gravity effects are similar. They are largest over the thickest parts of the sedimentary fill (MS, SPS and NDS). In both maps the largest gravity effects were determined in the MS.

The resultant stripped gravity maps of the TKB were calculated by the subtraction (removing) of the gravity effects of the sediments from the map of the complete Bouguer anomalies. The stripped gravity map, which is based on the calculation of the gravity effect when average density of the sediments was constant, is illustrated in Fig. 8. The second stripped gravity map (density of the sediments varies exponentially) is shown in Fig. 9.

Both resultant stripped gravity maps in the TKB show that the relative local gravity lows MGL, SPGL and NDGL lost the position of dominant features in the gravity field of the basin. The detailed analysis indicates that the northern part of the pre-Tertiary basement of the basin could be built mostly by the Mesozoic rocks, which belong to the Hronic and Fatric units. In the central part of the basin around the Kláštor pod Znievom and Moškovce the basement is probably also composed by the Mesozoic rocks. The structure of the basement in the southern part seems to be more complicate. This feature probably reflects a presence of Neogene volcanites in the basin basement belonging to the Kremnické vrchy Mts.

Looking in more detail at the gravity field we could predict that the Paleogene sediments would not build the basin sedimentary fill in its southern part. and The boundary between the northern and southern basin parts

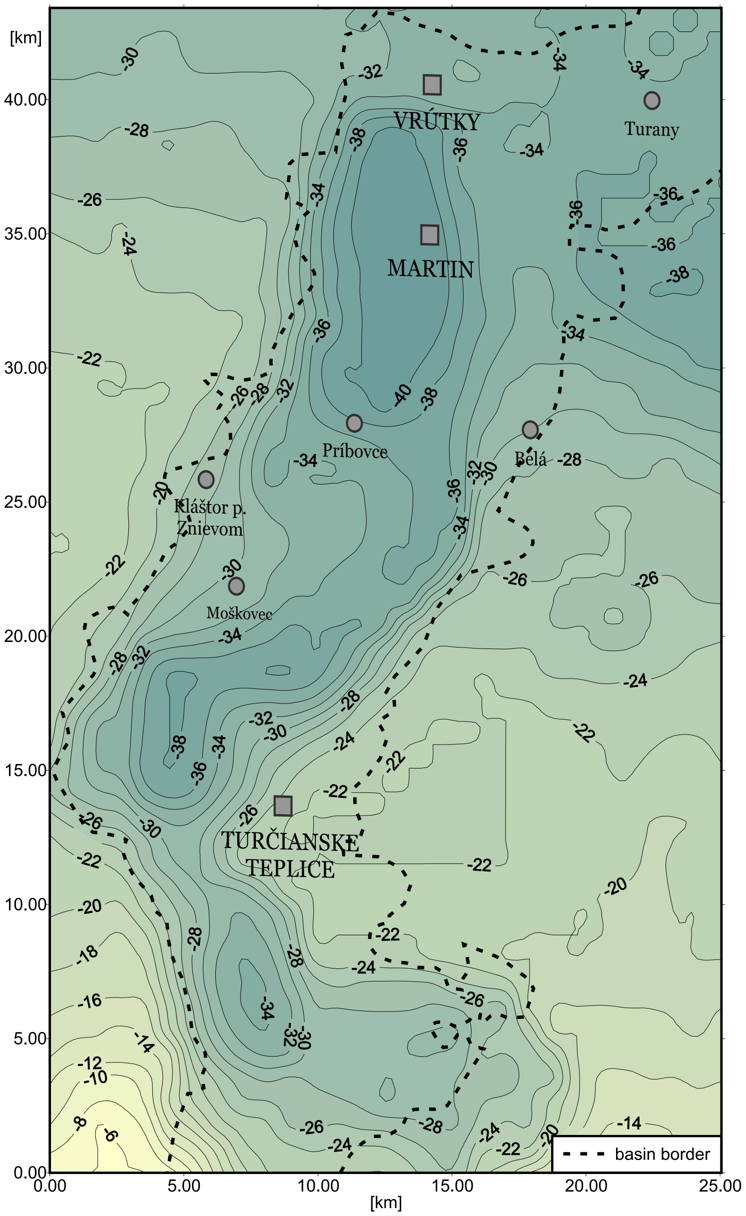

Fig. 5. Digitized complete Bouguer gravity map.

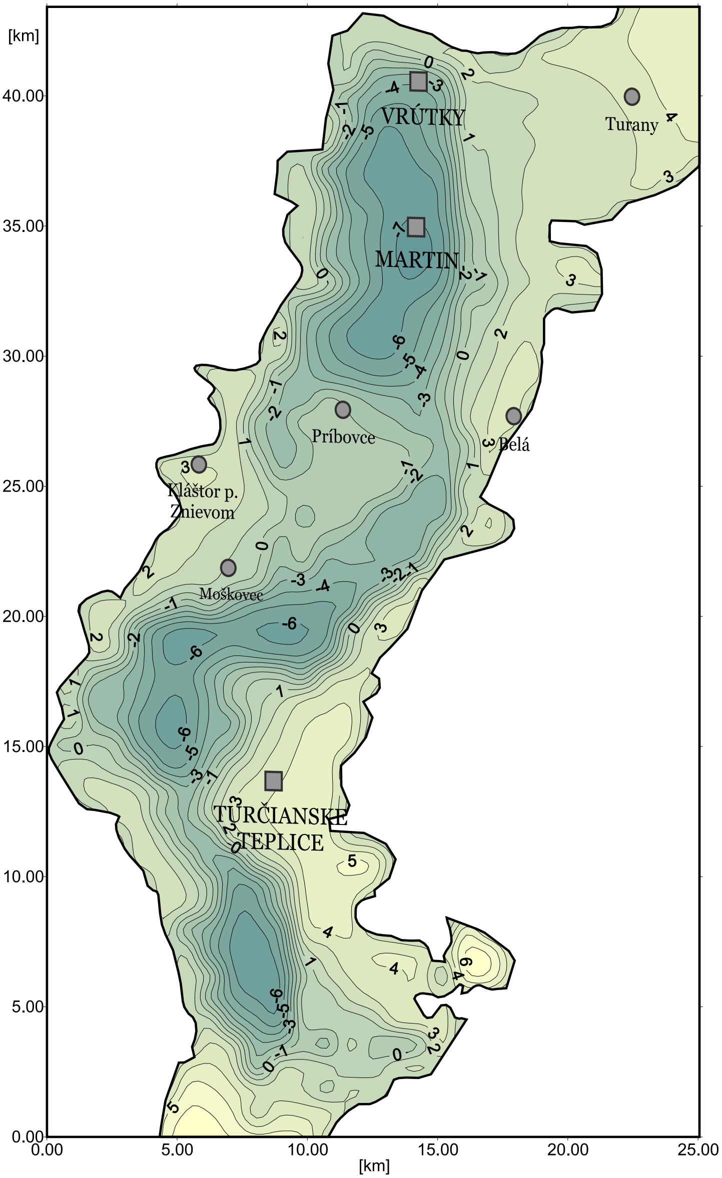

Fig. 6. Gravity effect of the sedimentary fill of the TKB. The average density of the sediments is 2.45 gcm^{-3} and the reference density is 2.67 gcm^{-3}. The values of the gravity are in mGal.

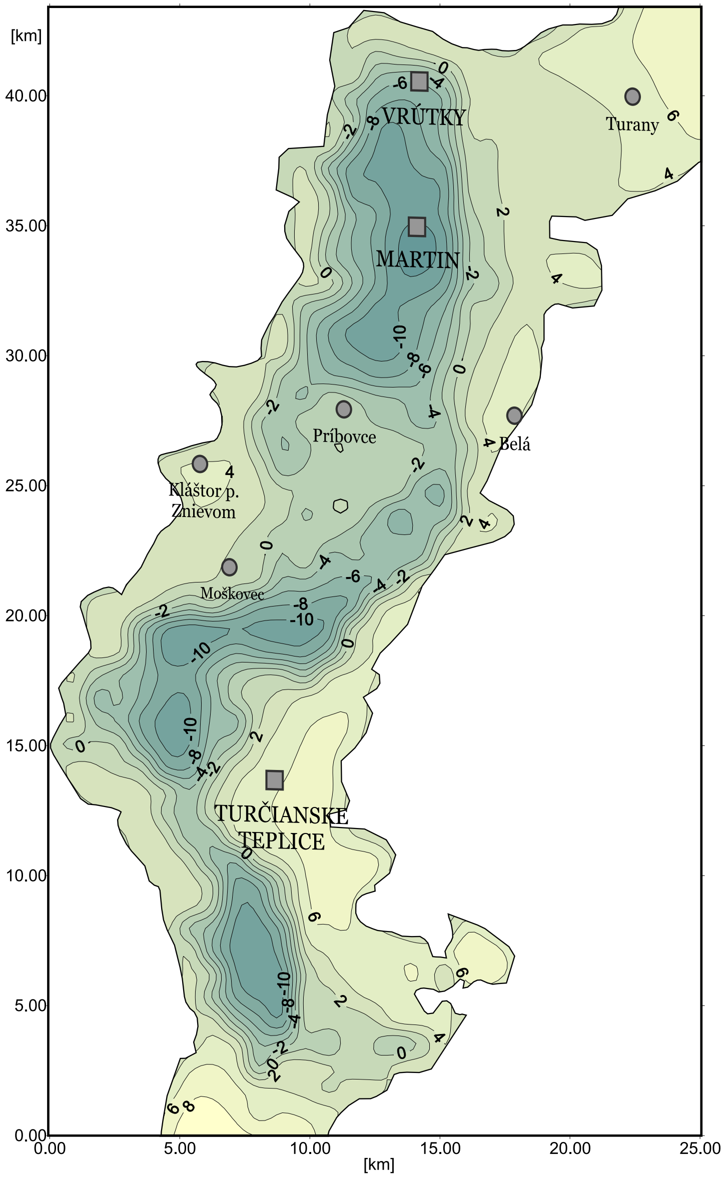

Fig. 7. Gravity effect of the sedimentary fill of the TKB. The density of the sediments varies exponentially from 2.00 gcm^{-3} on the surface up to 2.67 gcm^{-3} on the pre-Tertiary basement. The values of the gravity are in mGal.

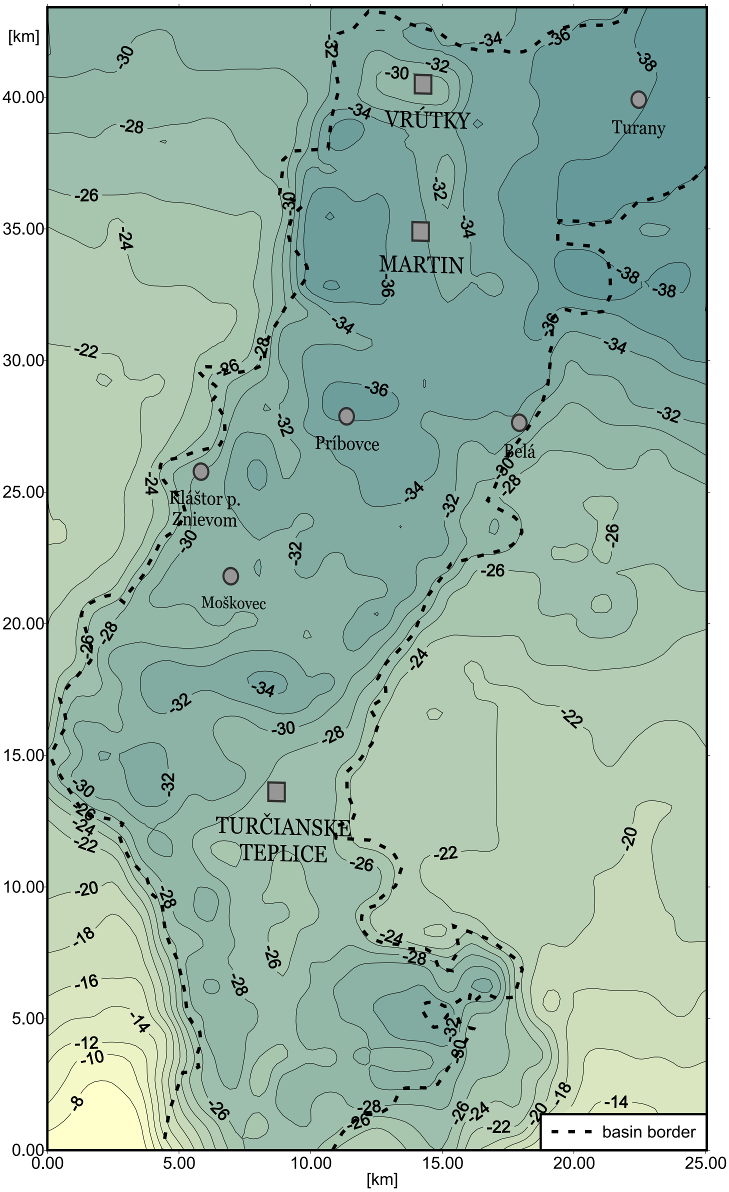

Fig. 8. Stripped gravity map of the TKB calculated by the subtraction of the sediment gravity effect with the average density 2.45 gcm^{-3}. The values of the gravity are in mGal.

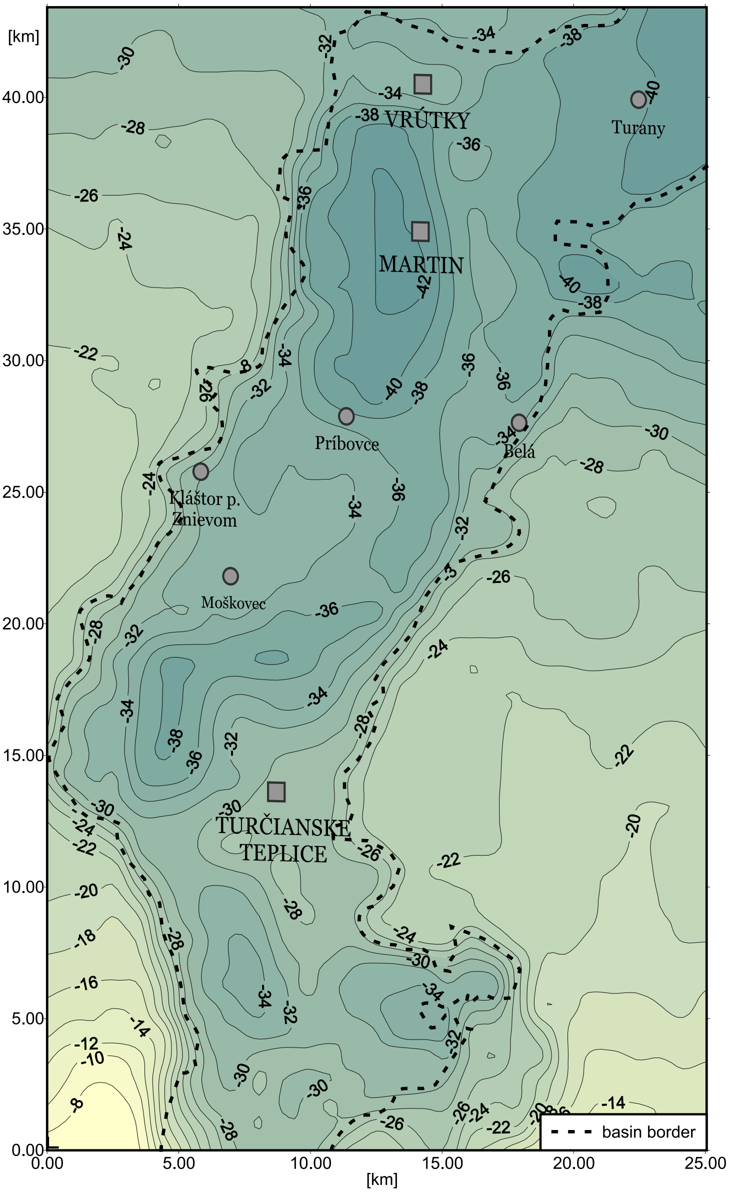

Fig. 9. Stripped gravity map of the TKB calculated by the subtraction of the sediment gravity effect with the density varies exponentially. The values of the gravity are in mGal.

could be located southern from Moškovce.

The surrounding regions of the TKB the Lučanská Malá Fatra and Veľká Fatra Mts. are characterized by relatively flat gravity field decreasing gradually from their southern parts to the northern ones. The flat gravity field does not reflect more complicated geological structure of both these mountain ranges, which are built by the Tatric crystalline and Mesozoic complexes. Is it questionable if it is due to in significant density contrast between the rocks of these two main tectonic units? The Žiar Mts. are characterized by significant gravity elevation of -8 mGal.

Taking into account the differences in the gravity gradient along the basin margins we could propose that the dipping of the Veľká Fatra Mts. is gentle in comparison with the Lučanská Malá Fatra. This result is also supported by the 2D density modelling in the TKB, which has been done by *Grinč et al. (2010)*. For verification of this hypothesis and to study in more detail the tectonic contact between the crystalline mountains and the detailed geoelectric, electrical resistivity tomography, microgravity and radon measurements (e.i., *Putiška et al., 2012; Mojzeš et al., 2006; Kušnirák et al., 2011*). These measurements could help also to interpret the areas of planation surfaces and alluvial deposits of the TKB *(Kováč et al., 2011; Vojtko et al., 2011; Petrýdesová et al., 2011; Kušnirák et al., 2011)*.

5. Discussion

In both resultant stripped gravity maps it seems that over the largest pre-Tertiary sub-basins of the TKB the weak gravity lows are still observed. This feature is stronger in the stripped gravity maps in which the sediment density varies exponentially. This characteristic could be explained by two different ways. In the first case it could come from not taking into account the real topography for calculation of the 3D gravity effects of the sedimentary filling, where thickness of sedimentary fill would increase by 400–600 m. In the second case, when the first explanation would have shown as implausible, then it could result from the underestimated the real average constant density of the sedimentary fill and/or the thickness of the sedimentary basin fill. But we also cannot exclude that the results reflect the real structure. To answer this question correctly, it would be necessary, in future, to consider in the calculations also the real topography.

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