New 3D gravity modeling in the Carpathian–Pannonian basin region

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A b s t r a c t: New results related to the thickness of the sedimentary cover of the European platform and new study and analysis of the densities of the sediments in the Carpathian-Pannonian region result in the re-construction of the former density models. Based on these new models the 3D gravity effects of the sediments in the Pannonian Basin, the Carpathian Molassic Foredeep and the Outer Carpathian Flysch zone were calculated. The largest gravity effect (up to –85 mGal) comes from the sediments of Outer Carpathians Flysch and cover of the European platform. Maximum gravity effects of the Pannonian and Transylvanian basin sediments and Carpathian Molassic Foredeep are lower (up to –55 mGal). It was found out that the gravity effects of the sediments in the Eastern and Southern Carpathians still do not reach the amplitudes of the Carpathian gravity minimum. The results indicate that the Carpathian gravity minimum in these parts of Carpathians belt must be explained not only by gravity effect of low density sediments but also by additional gravity effects of some other deep-seated crustal (and/or uppermost part of the upper mantle?) density anomalous bodies. Contrary in the Eastern and Southern Carpathians, the amplitude of the Carpathian gravity minimum was

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exceeded by gravity effect of the sediments of the Outer Carpathian Flysch in the Western Carpathians and Eastern Carpathians junction.

Key words: 3D modeling, gravity, density, sediments, Carpathian-Pannonian region

1. Introduction

The process of the calculation of the stripped gravity map is based on the determination of 3D gravity effects of surface density inhomogeneities *(Hammer, 1963)*. In the inner part of the Carpathian-Pannonian region the sedimentary fills of the Pannonian Basin and Transylvanian Basin represent these surface density inhomogeneities. The resultant stripped gravity map is a result of subtraction of 3D gravity effects of the sedimentary fillings of both mentioned basins from the Bouguer gravity map. The first stripped gravity map in the inner part of the Carpathian region was calculated by *Bielik (1988)*.

In the papers of *Makarenko et al. (2002)* and *Bielik et al. (2004)* the calculations of the 3D gravity effects of the surface density inhomogeneities were extended into the Outer Carpathians. Based on these calculations the stripped gravity map for the whole Carpathian-Pannonian region has been published for the first time. This stripped gravity map brought very interesting preliminary results related to the deep-seated structures of the studied region. After publication of the stripped gravity map published in the paper of *Makarenko et al. (2002)*, *Rylko* and *Tomaš (2005)* constructed a new map of the thickness of the sedimentary cover of the European platform. Based on the comparison the new map with former one which was used in the papers of *Makarenko et al. (2002)* and *Bielik et al. (2004)* we found out large differences in the thickness of the sedimentary cover in the area of the Eastern Carpathian Flysch zone. In former map the maximum thickness of the sedimentary cover reached about 14 km while it was almost 20 km in the new map of *Rylko* and *Tomaš (2005)*.

At the same time in the study area we carried out a detailed study and analysis of densities of the rocks too. The obtained results improve the former density models. Taking into account these new data related

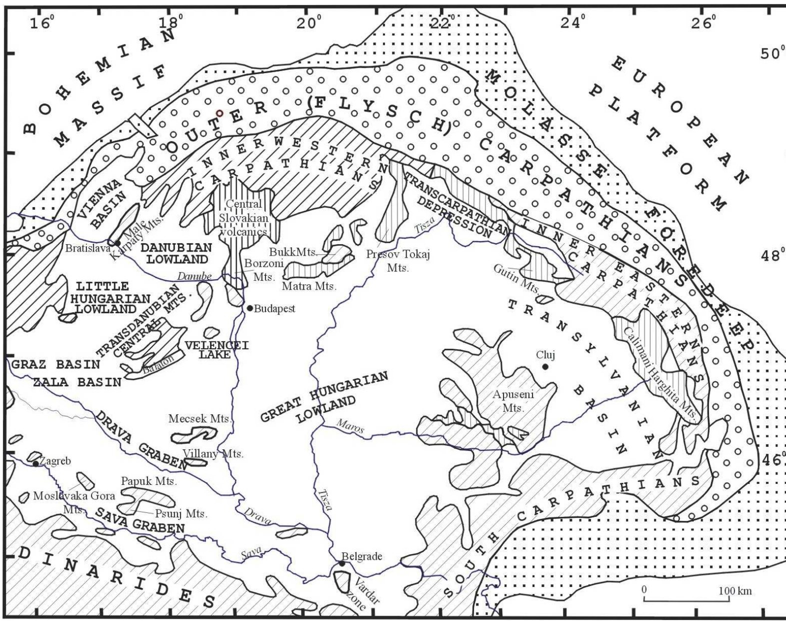

Fig. 1. Tectonic scheme of the Carpathian-Pannonian Basin region (modified after *Lillie et al., 1994*).

to geometry and density of the sediments we constructed the new density models for the Pannonian Basin, the Carpathian Molassic Foredeep and the Outer Carpathian Flysch zone (Fig. 1). The paper demonstrates the 3D gravity effects of these density models too.

2. 3D density models

New 3D density models were re-constructed for the tectonic sedimentary complexes of the Pannonian basin and the Transylvanian basin, the Carpathian Molassic Foredeep and the Outer Flysch Carpathians.

(a) *Pannonian basin and Transylvanian basin*
The thickness of the Neogene-Quaternally sediments in the Pannonian basin and Transylvanian basin was taken from the paper of *Makarenko*

et al. (2002) and *Bielik et al. (2004)*. The thickness of the sedimentary filing varies between 0 to 9 km, with average of 2.5–3.0 km. The filling of the basin mainly consists of sands, clays, shales, sandstones with isolated limestones and evaporites, and also clays and marls in the layers closest to the surface *(Bielik, 1988)*.

Tab. 1.

Depths [km]	Average values [gcm^{-3}]
0-1	2.142
1-2	2.314
2-3	2.457
3-4	2.535
4-5	2.580
5-6	2.625
6-7	2.670

Former density model of *Makarenko et al. (2002)* was completed by the density results obtained in the Ukrainian part of the Pannonian Basin and published by *Subbotin (1955), Borodatyj et al. (1965) and Khomenko (1971)*. Taking into consideration these results the mean density contrasts estimated by *Bielik (1988), Šefara et al. (1987), Szafián et al. (1997), Granser (1987), Bucha et al. (1994), Šefara and Szabó (1997)* were modified. Mean density contrasts for the sedimentary fill depth intervals used in this paper are shown in Tab. 1.

(b) *Carpathian Molassic Foredeep*

The thicknesses of the sedimentary fill were taken from *Makarenko et al. (2002)*. The map was compiled by using data published by *Poprawa and Nemčok (1989), Kováč (2000) and Matenco (1997)*. Density distributions in the Carpathian Molassic Foredeep were compiled by means of results published in *Ibrmajer et al. (1992); Królikowski and Petecki (2001); Subbotin (1955); Vysockij et al. (1963)*. Based on these results density model was divided into five parts (Fig. 3). The average density for the sediments of the Molassic Foredeep was determined on value of 2.435 gcm^{-3} in the Western Carpathians (Czech and Slovak part), 2.42 gcm^{-3} in the Poland territory, 2.42 gcm^{-3} in the Eastern Carpathians (Ukrainian area), 2.41 gcm^{-3} (Romanian territory) and 2.3 gcm^{-3} in the Southern Carpathians.

(c) *Outer Flysch Carpathians*

Based on the recent results published by *Rylko and Tomaš (2005)* the thickness model of the Outer Flysch Carpathians sediments compiled

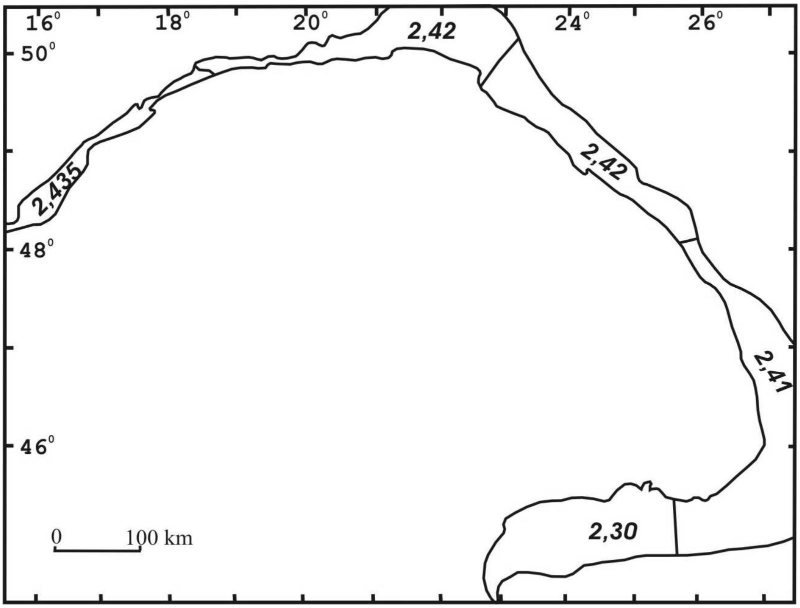

Fig. 2. Density model of the Carpathian Molassic Foredeep modified after *Ibrmajer et al. (1992); Królikowski and Petecki (2001); Subbotin (1955); Vysockij et al. (1963).*

by *Bielik et al. (2004)* using data of *Krejčí and Jurová (1997), Poprawa and Nemčok (1989), Mocanu and Radulescu (1994), Matenco (1997) and Kováč (2000)* was modified. The resultant thickness map is illustrated in Fig. 3. Note that the maximum thickness of sedimentary cover of the European platform lithosphere is greater by 5 km in comparison with the former results. The thickness of the cover varies from 0 to 12 km in the outer Western Carpathians, then it increases up to 20 km in the outer Eastern Carpathians and the Eastern and Southern Carpathians junction it attains 9 km. The improvement of the density model came out from the study and analysis of rock densities that build the Outer Flysch Carpathians. The determination of the average densities for different parts of this tectonic unit was based on the results published by *Tomek et al. (1979), Królikowski and Petecki (2001), Šefara et al. (1987), Ibrmajer Suk et al. (1992), Subbotin (1955), Bobrovnik (1973), Kultchickij (1966), Sovchik (1976), Gontovij (1961), Melnichuk et al. (1975).* The average densities used

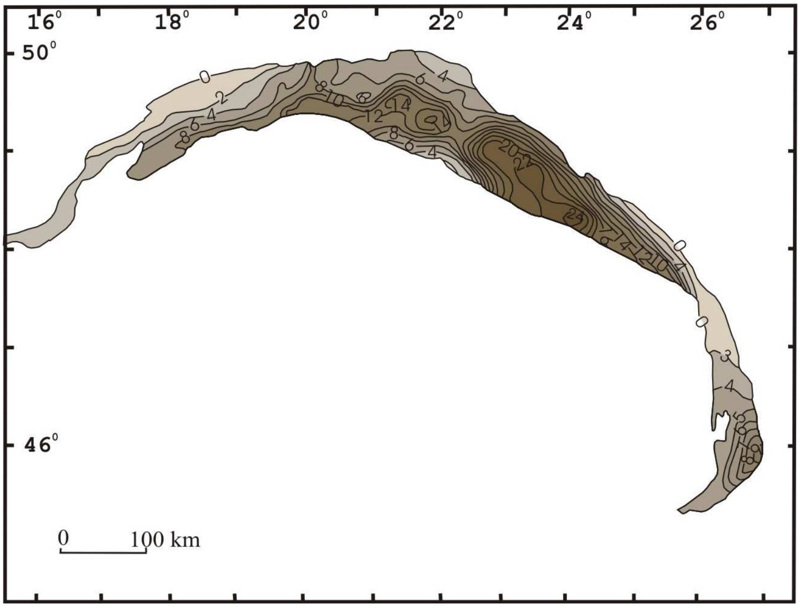

Fig. 3. The thickness model of the Outer Flysch Carpathian sediments compiled by using data published by *Rylko and Tomaš (2005), Bielik et al. (2004), Kováč (2000), Krejčí and Jurová (1997), Matenco (1997), Mocanu and Radulescu (1994),* and *Poprawa and Nemčok (1989).*

in our calculations are shown in Fig. 4. We can see that the Outer Flysch Western Carpathian sediments (Czech and Slovak territory), in which sandstones prevail, are divided into two parts with densities of 2.59 gcm^{-3} and 2.56 gcm^{-3}. For the whole territory the average density is 2.565 gcm^{-3}. The Western Carpathian Flysch in Poland has an average density of 2.49 gcm^{-3}. The average density in the Pieniny Klippen Belt zone was established as 2.56 gcm^{-3}. The average densities for the Ukrainian (Romanian) Eastern Carpathian Flysch is 2.57 gcm^{-3} (2.54 gcm^{-3}).

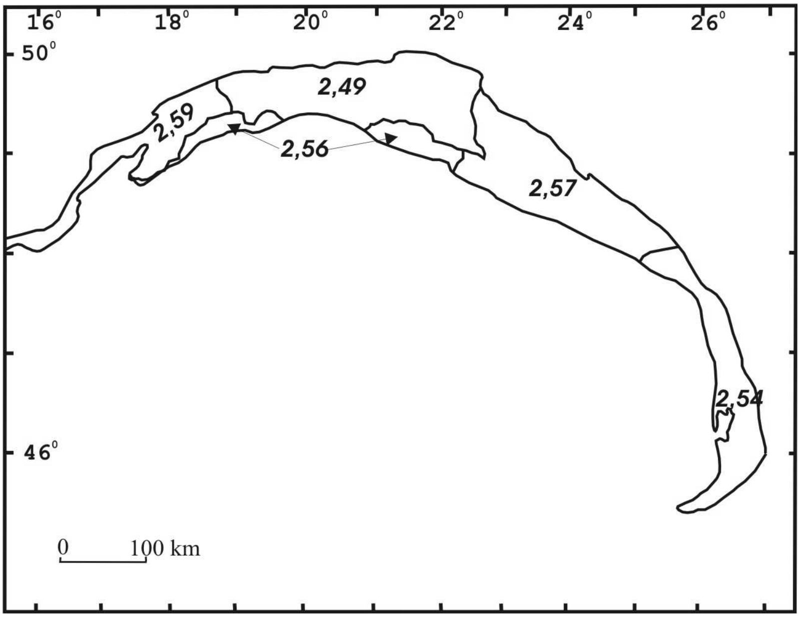

Fig. 4. Density model of the Outer Flysch Carpathians modified after *Tomek et al. (1979), Królikowski and Petecki (2001), Šefara et al. (1987), Ibrmajer et al. (1992), Subbotin (1955), Bobrovnik (1973), Kultchickij (1966), Sovtchik (1976), Gontovij (1961).*

3. 3D gravity effects

The 3D numerical gravity modeling is a very convenient method for interpretation of the gravity field. The gravity effects of density models have been calculated by means of the algorithm which was developed by *Starostenko et al. (1997)*. The main principle of this 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 inhomogeneous, arbitrarily truncated vertical rectangular prism. An automatization of input of initial graphic information (maps) by means of digitization is also very useful in the process of modeling *(Legostaeva, 2000)*. After this manner the input data are directly employed in field computation. The calculation have been made at the scale of 1:4 000 000 on the grid of 4x4 km (10x10 km). Such model field reflects all the main features of the regional geological structures.

(a) *Pannonian basin and Transylvanian basin*
The gravity effect of the sedimentary filling of the Pannonian basin (Fig. 5) varies from 0 to –50 mGal. The largest values of –55 mGal can be observed in the Danube basin. The maximum amplitude of –45 mGal characterizes the Békés basin, the Makó basin, the East Slovakian basin. The Vienna basin, Transylvania basin and Sáva and Dráva grabens are characterized by the gravity effect of –35 mGal. The Ukrainian part of the Transcarpathian basin is accompanied by the value of –25 mGal. The results are very similar to the former results published by *Makarenko et al. (2002)* and *Bielik et al. (2004).*

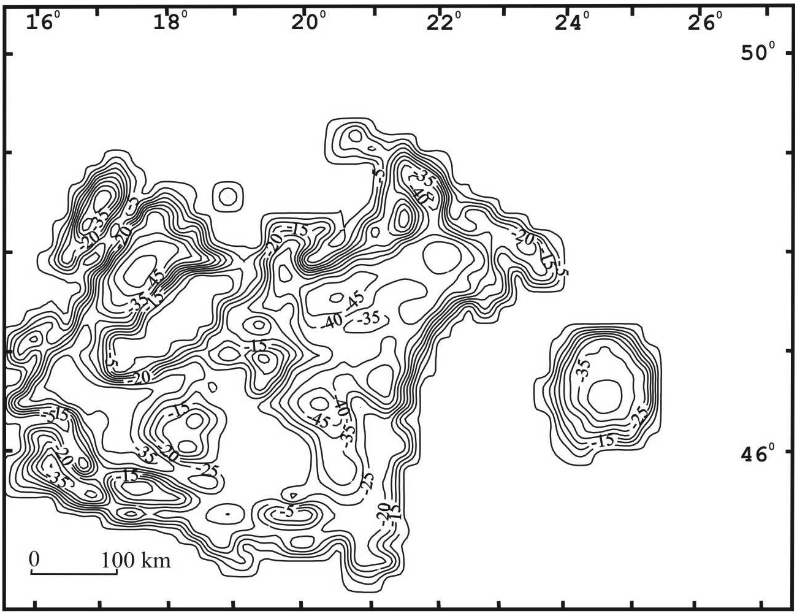

Fig. 5. Gravity effect of the Pannonian basin and the Transylvanian basin.

(b) *Carpathian Molassic Foredeep*
The gravity effect of the Carpathian Molassic Foredeep (Fig. 6) increases along the Carpathian belt. In the western part of the Western Carpathians it is very low (about –1 mGal), while in the eastern part the values reach –20 mGal. In the Ukrainian part of the East-

ern Carpathians –15 mGal maximum gravity effect can be observed. The largest thickness of the Foredeep in the Vrancea zone is characterized by the largest effect, which reaches –65 mGal. Towards the South Carpathians it decreases up to –40 mGal. In comparison with the former calculations *(Makarenko et al. 2002, Bielik et al. 2004)* the gravity effects are a little bit higher.

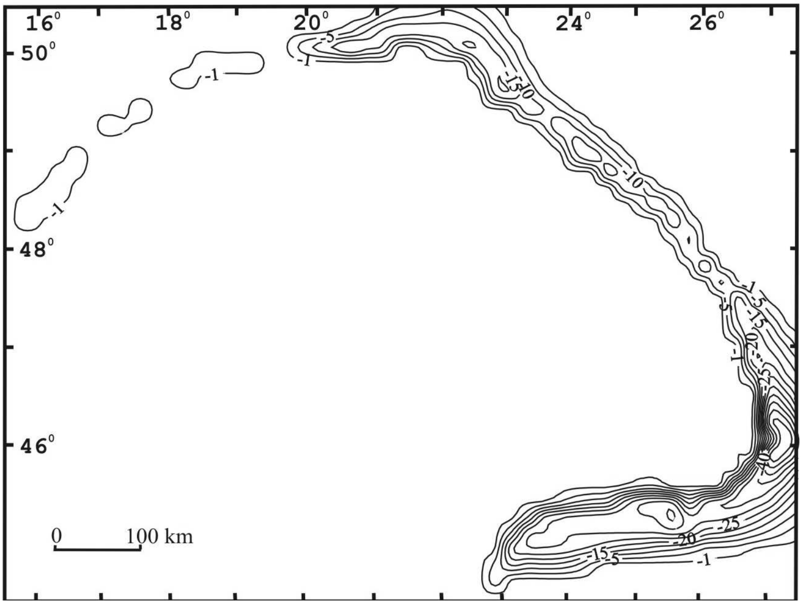

Fig. 6. Gravity effect of the Carpathian Molassic Foredeep.

(c) *Outer Flysch Carpathians*

The gravity effect of the Outer Flysch Carpathians (Fig. 7) was calculated for two variants of densities in the western part of the Western Carpathians. In the first variant we used different average densities for the sediments. It was 2.59 gcm^{-3} for the Czech part of the flysch zone and 2.56 gcm^{-3} for Slovak area of this tectonic zone. The average density of 2.565 gcm^{-3} was used in the second variant. In the paper we illustrate the results of the first variant only, because the differences between both calculations are very small and the results are very close. The largest effect can be observed in the Western and Eastern Carpathians junction (up to –80 mGal) and in the Eastern Carpathians (up to –65 mGal). In the Western Carpathians the gravity effect varies from 0 to –25 mGal in the western part and –65 in the eastern part. The Vrancea zone is characterized by maximum values of –30 mGal.

4. Conclusion and discussion

It is worth noting that the largest differences between the former and the present results of the gravity effects of the sedimentary basins in the Carpathian - Pannonian area can be observed just in the Outer Flysch Carpathians. It results from the largest changes in the determination of the thickness of the sedimentary filling in the Western and Eastern Carpathian junction. The thickness of the sedimentary cover in this region determined by *Rylko and Tomaš (2005)* indicates a 5 km greater thickness in comparison with the former model, which was compiled by *Bielik et al. (2004)*.

The total gravity effect of the sediments in the Outer and Inner Carpathians is illustrated in Fig. 8. The largest gravity effect (up to –85 mGal) comes from the sediments of Outer Carpathians Flysch and the cover of the European platform. Maximum gravity effects of the Pannonian and Transylvanian basin sediments and Carpathian Molassic Foredeep are lower (up to –55 mGal). The gravity effect of the sediments depends on the density and the thickness of the sedimentary units. We found out that the gravity effect of the Outer Carpathians Flysch and the cover of the European platform is larger than it was calculated in former papers of *Makarenko et al. (2002), Bielik et al. (2004)*. In spite of that the gravity effects of the sediments in the Eastern and Southern Carpathians still do not reach the amplitudes of the gravity minimum in this area *(Tomek et al., 1979)*. Therefore the results indicate that the Carpathian gravity minimum in these parts of the orogen must be explained not only by gravity effect of low density sediments but also by additional gravity effects of some other deep-seated crustal (and/or uppermost part of the upper mantle?) density anomalous bodies. Contrary in the Eastern and Southern Carpathians, the amplitude of the Carpathian gravity minimum was exceeded by gravity effect of the sediments of the Outer Carpathian Flysch in the Western Carpathians and Eastern Carpathians junction.

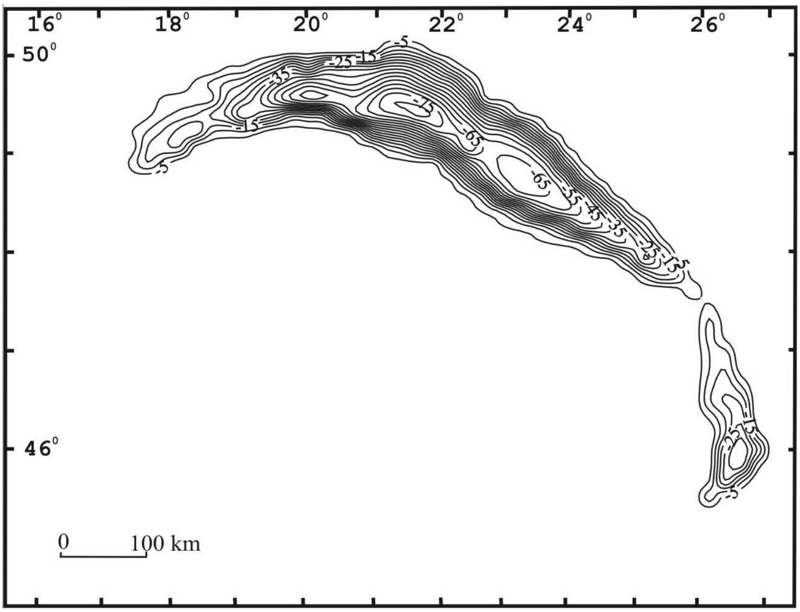

Fig. 7. Gravity effect of the Outer Flysch Carpathians.

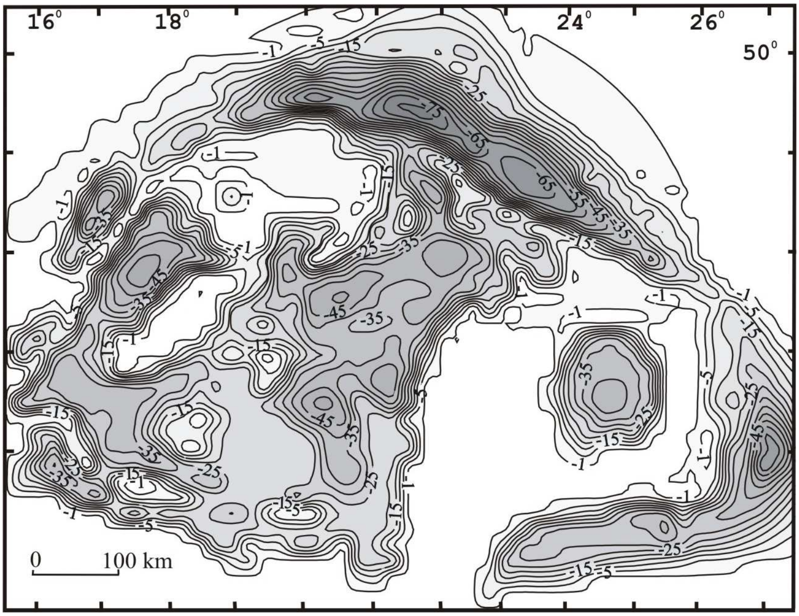

Fig. 8. Total gravity effect of the Carpathian-Pannonian Basin region.

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