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Gravity maps — border zone of Austria, Slovakia and Hungary

Ján ŠEFARA* and Zoltán SZABÓ**

New series of gravity maps have been constructed for the DANREG area.

After connecting the national gravity networks and establishing common databases of measurements a Bouguer anomaly map was constructed in an absolute gravity system. To calculate the normal field the WGS–80 system was used. The Adriatic sea level was taken as height datum, and a density of 2670 kg/m^3 was chosen for Bouguer and terrain corrections.

Although the Bouguer anomaly map reveals the large Neogene basins and the ridges in the basement surrounding or separating them the gravity values are not linearly proportional to the depth of the basins. To separate the effects of density inhomogeneities within the sediments and the basement from those of structural changes three different versions of filtered maps have been constructed as well as a stripped Bouguer anomaly and a lineament map. One of the most interesting anomalies having its source within the basement (anomaly at Kolárovo) was investigated by model calculations as well.

Keywords: gravity, Bouguer anomalies, stripped gravity map, density, lineament, DANREG

1. Bouguer anomaly map

One of the main topics of the DANREG project was the construction of a unified Bouguer anomaly map for the project area. Since the area forms a

* Comenius University, 84215 Bratislava, Mlynská dolina, pav. 6., Slovakia
** Eötvös Loránd Geophysical Institute of Hungary (ELGI),
H-1145 Budapest, Kolumbusz u. 17–23, Hungary

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part of three different countries, the first step was to review the state of the art of the respective gravity base networks and surveys.

The gravity values that are available can be regarded reliable since the early 1950s. Each country had some sort of a national Bouguer anomaly map, but as their parameters were different from each other the national maps did not match along the borders. Since the Bouguer anomalies referred to different datums and Bouguer- and terrain-corrections were calculated by means of different densities, we had to go back to the basic data and set up a common gravity data set containing the co-ordinates, elevations, observed gravity (converted to a common gravity system) and terrain correction of each gravity station.

We started by checking the national gravity base networks. At the time of the measurement of the first gravity networks it was standard procedure to link the national fundamental gravity station directly to Potsdam. In that time each national gravity network was based on one fundamental point, the possible distortions of the networks cannot be excluded. To improve the accuracy of the networks, interconnecting measurements were carried out between the gravity networks of the neighbouring countries.

These interconnecting observations between Slovakia and Hungary were carried out formerly in the framework of cooperation between the socialist countries. The gravity networks of the socialist countries were based on the corrected Potsdam gravity datum of 1971, later converted to an absolute system [Csapó et al. 1995]. Different was the case with Austria: although the Austrian network was based on the IGSN-71 system, using the same corrected Potsdam value and was converted recently to an absolute system, there were no interconnecting gravity measurements between the neighbouring countries, so they had to be carried out in the framework of the DANREG project [Csapó et al. 1993].

Though the interconnecting measurements between Austria and Hungary revealed a 40 μGal discrepancy between the datums of the two national gravity networks, this difference practically did not interfere with the construction of a unified Bouguer anomaly map. Similar measurements were carried out along the Austrian–Slovakian border.

A further problem was that a significant part of the Austrian gravity data, obtained by ÖMV, was observed in a local gravity network. These data had to be converted to the Austrian national gravity system. The conversion was done by B. Meurers.

The unification of the height systems meant no problem because the difference between the Adriatic system used by Austria and the Baltic one used by Hungary and Slovakia is a constant value:

$$H_{Adriatic} - H_{Baltic} = + 0.675 \text{ m}$$

The gravity experts of the three participating countries decided to use the following parameters for the unified Bouguer anomaly map:

Gravity system: absolute
Normal gravity: WGS-80
Height system: Adriatic
Density: 2670 kg/m^3

Contouring of the map was done by a computer program developed by ELGI. The randomly distributed anomaly data were interpolated to an 800 m grid by spline interpolation and this 800 × 800 m grid furnished the input for the contouring program. The final version of the Bouguer anomaly map is presented in a reduced scale in *Fig. 1*.

With regard to the accuracy of the Bouguer anomaly map the estimated error of ±0.35 mGal was determined for the Slovakian part by Molodensky's method [ŠEFARA 1978]. Since the accuracy of measurements and the determination of corrections are comparable in all three countries, the standard error of the map depends only on the density of measurements. Based on the actual station/km^2 point distribution the overall accuracy of the unified map is estimated to be ±0.8–1.0 mGal. This is the limit to be taken into account in model calculations.

The station coverage of the region is far from uniform. The density and distribution of gravity stations show gross variations in the project area, thus influencing the accuracy and quality of certain parts of the map.

The Bouguer anomaly map reflects the gravity effect of all subsurface geological bodies. The anomalies are sharper and variable and have high gradients on those parts of the area where the older rocks, forming the basement, are on or near the surface, i.e. in the western and eastern parts of the region. In the central part where the basement deepens to 7000–8000 m, the anomalies are flat and have low gradients due to the masking effect of the thick sedimentary cover.

2. Aspects of gravity interpretation

The objective of the interpretation of gravity maps is to deduce the geological build-up of the subsurface from the anomalies of the gravity field. All gravity anomalies originate from horizontal density variations. If the earth were built up by layers of horizontally uniform density, there would be no gravity anomalies even if vertical variation in density exists.

Since the Bouguer anomaly map reflects the integrated effect of subsurface masses, the anomaly map is a complex image of subsurface geology; however, in special cases single sources can be identified. This means that the interpretation can never provide an unambiguous answer to a given geological problem because there is no single mathematical solution to the determination of the sources of anomalies. Generally, sharp anomalies are caused by near-surface sources and broader anomalies by deep ones.

The crucial point of gravity interpretation is to separate the effects of different sources. This is a difficult task and needs the skill of the interpreter to choose the most convenient procedure and parameters.

In order to separate different elements, many procedures are known — from manual 'smoothing' to the more sophisticated computer-based filtering techniques. The common aim in all procedures is to emphasize certain elements and to suppress others, depending on the target of investigation.

As a result of anomaly separation we can speak about regional, residual and derivative maps. But the designation of 'regional' is also subjective, referring to broad anomalies with sources normally deeper than the target of prospecting. To differentiate between residual and derivative maps is also complicated, but important because the residual maps reflect the gravity effect of local sources relatively near to the surface and the derivative maps reflect the gradient of the gravity field. Residual anomaly maps reflect the gravity effect of near-surface bodies, whereas derivative maps enhance the zones of maximum gravity variations which in most cases indicate the existence of structural lines with density contrast across them.

The resolution of a gravity survey depends on the measurement spacing but decreases with increasing depth of source no matter how accurately we know the gravity field.

Filtering techniques are very sensitive to the size of the applied filter. With the combination of the matrix elements and the size of the filter, many map variations can be produced. The proper designation of the resulting maps, however, depends very much on the skill of the interpreter not to

mention the target of prospecting: 'residual' in the case of ore prospecting means something completely different than in the case of oil exploration.

According to PINTÉR and STOMFAI [1979] a possible characterization of map variations can be based on the distribution of anomaly values. Maps with broad anomaly distribution curves can be regarded as residual ones, and those with sharp distribution curves, as derivative ones.

To interpret a gravity map, the above-mentioned characteristics and limitations have to be kept in mind otherwise we can reach wrong conclusions by interpreting a residual map as a derivative one or vice versa. Therefore we can state that there is no single or direct solution to eliminate regional effects and isolate local anomalies. All methods have their merits and limitations but a combination of them can provide useful information on the geological sources of the different anomalies.

The practical ambiguity of the inverse gravimetric task is always smaller than the theoretical one and it depends on a variety of other information. As an example, there is the Kolárovo anomaly with an evident deep source, but because of the high gradient most probably due to sharp density contrast the anomaly is very distinct in the residual- and in the regional map as well.

Mathematical separation by convolution requires randomly distributed elementary bodies, without mutual dependence. In structural interpretation this requirement is not fulfilled because of highly different parameters [ŠEFARA 1986] tending to arrange the lithospheric masses in isostatic equilibrium, which is a natural trend of each system. As further shown in stripping (Fig. 8), such a system leads to mutual compensation of gravity effects of separate masses. In addition, the individual fields (Bouguer's) undergo coherence [ŠEFARA 1986] and the frequency content of the resulting field can be highly different from the frequency fields of the individual geologically defined inhomogeneities (see also Fig. 9 in NEMESI et al. [this volume]). In no case and by no convolution method can we separate the field into negative and positive anomalies, which in our case means separation into the gravity effect of sediments and that of the basement. The task of separation can be solved either by stripping, or by model calculations controlled by a priori information.

3. Filtered maps

Within the framework of the DANREG project, we have prepared several versions of regional, residual and derivative-like maps in order to separate the different components of the gravity field. All calculations were based on the original Bouguer anomaly values obtained as a result of the unification of the gravity data of the three interested countries. The randomly distributed data were gridded in an 800 × 800 m data set and these created the input for further transformations.

The calculations were based on the two-dimensional filtering technique and matrices defined by MESKÓ [1984a]. The weight functions of the applied filters are presented in *Fig. 2*. It can be seen that the κ parameter characterizes the sharpness of the filter, with increasing κ the weight of the local value

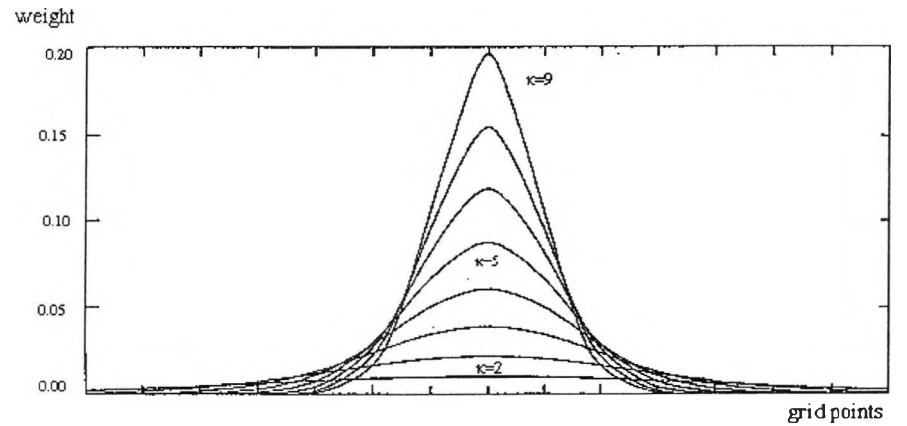

Fig. 2. Weight functions for the MESKÓ-filters
2. ábra. A MESKÓ-szűrők súlyfüggvényei

increases and vice versa. In other words, higher κ values mean higher amplification of local effects. From the transformed map versions we have presented one residual map (*Fig. 3*) with its corresponding regional pair (*Fig. 4*), and one derivative-like gravity map (*Fig. 5*). This third version is called derivative-like because it is only an approximation of a true mathematical representation. The gravity field is too complex to be described by an analytical expression. The derivative-like characteristics of the obtained map largely depend on the type of function being approximated, the region

involved in the calculations, the spacing of the gridded values and the complexity of the gravity field.

In the filtering procedure the parameters $\kappa = 2_{res}$ and $\kappa = 2_{reg}$ were applied to the presented residual and regional maps, respectively. The residual gravity map has the following characteristics: the local maxima and minima are indications of shallow geologic bodies, such as possible lateral density variations in the sedimentary complex, magmatic intrusions, or sharper undulations of the relief of the basement. While maxima and minima directly mark out the locations of the sources, their amplitudes depend on the applied procedure and on the complexity of the gravity field.

The regional anomaly map reflects the effects of all those sources not involved in the residual anomaly map (Fig. 4).

The presented derivative-like map was calculated by a narrow band-pass filter ($\kappa = 9$–8, Fig. 5). The reason for applying a band-pass filter was to exclude the high frequency noise of the gravity data attributed to observational and reduction errors which are always present.

In order to determine the characteristics of the maps, the anomaly values of each map variation were subjected to the test proposed by PINTÉR and STOMFAI [1979]. To demonstrate their characteristics, we present the anomaly distribution curves of the two maps (*Figs. 6* and *7*). It can be seen in the

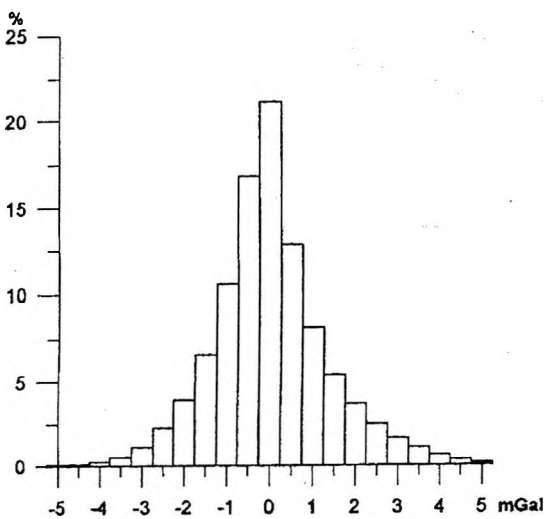

Fig. 6. Distribution curve for the map constructed with filter parameter $\kappa = 2$ (it suggests 'residual' character)

6. ábra. Maradék-jelleget sugalló eloszlási görbe a $\kappa = 2_{res}$ szűrővel készített térképre

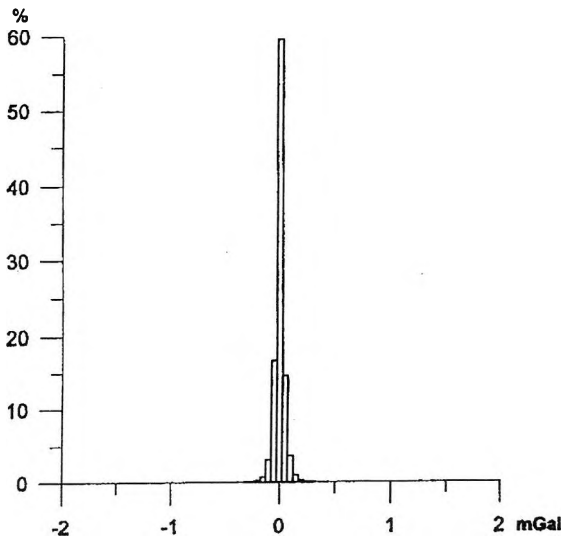

Fig. 7. Distribution curve for the map constructed with filter parameter $\kappa = 9\text{–}8$ (it suggests 'derivative' character)

7. ábra. Derivált jelleget sugalló eloszlási görbe a $\kappa = 9\text{–}8$ szűrővel készített térképre

figures that the map prepared with parameter $\kappa = 2_{res}$ has a broad distribution curve suggesting a residual nature. The $\kappa = 9\text{–}8$ map has a narrow distribution curve characteristic of derivative-like maps.

From derivative-like maps the effect of deep structures has been eliminated; however, shallow density variations may be indications of deep structural lines. In the case of derivative-like maps the zero contour lines deserve attention because they reflect the edges of the disturbing geological masses.

4. Stripped gravity map

Since in basin areas the density of the sedimentary layers is normally lower than the density of the underlying consolidated rocks forming the basement, in the Bouguer anomalies the effect of the basement topography dominates thereby masking the effects of intrabasement density anomalies. To get information from deeper sources, the effect of the sedimentary 'mass defect' has to be taken into consideration. Having information on the

topography of the basement and on subsurface density data we can produce a gravity map free of the effect of unconsolidated sedimentary layers.

As the central part of the DANREG project area coincides with the Danube–Rába basin where the thickness of sedimentary cover reaches 7000–8000 m, it seemed worthwhile to construct a gravity map corrected for sediment effect, thus enhancing the anomalies originating from deeper sources.

Before the beginning of the DANREG project, stripped gravity maps were prepared both for the Hungarian [MESKÓ 1984b] and for the Slovakian [ŠEFARA et al. 1987] part of the project area. In Hungary, MESKÓ based his calculations on the basement contour map of FÜLÖP, DANK [1987]. The density data were derived from the literature. An attempt was made to find a correlation between velocity and density data obtained from boreholes, but the result was not convincing. The gravity data were derived from a regional Bouguer anomaly map based on relatively few data. MESKÓ regarded the constructed map as a first attempt due to the incomplete data set available to him at that time.

In Slovakia, ŠEFARA and his team prepared a stripped gravity map [ŠEFARA et al. 1987]. The basic presumption was uniform density distribution of Tertiary sediments, i.e. $\sigma = F(x,y,z)$, subdivided into two functions $\sigma = f(h)+f_1(x,y)$. The first function is the dominant one in basins, the second gets significance in neovolcanic areas.

In the Danube–Rába- and Vienna basins functions $f(h)$ were determined according to density measurements on borehole samples (of 36 and 12 boreholes, respectively). Models in the form of polygonal prisms along basement contour lines were chosen (their gravity effects were calculated in the network of 1×1 km) (*Table I*).

height above sea level	density contrast (1000 kg/m^3)	
	Danube–Rába basin	Vienna basin
+150 — 0	-0.69	-0.69
0 — -100	-0.67	-0.67
-100 — -250	-0.65	-0.62
-250 — -500	-0.63	-0.52
-500 — -1000	-0.53	-0.47
-1000 — -1500	-0.45	-0.39
-1500 — -2000	-0.35	-0.33
-2000 — -2500	-0.24	-0.27
-2500 — -3000	-0.17	-0.19
-3000 — -3500	-0.10	-0.09
-4000 —	-0.05	-0.04

Table I. Density contrast given by ŠEFARA [ŠEFARA et al. 1987]
I. táblázat. ŠEFARA által közölt sűrűségkülömbségek [ŠEFARA et al. 1987]

The maximum depth in which observations of density were carried out was ca 3200 m in the Danube–Rába basin, ca 4200 m in the Vienna basin. For greater depths the density model was extrapolated. Former models of the basement relief were the results of the chosen input criteria (maximum possible depth of the source, inevitable smoothness of shapes of the stripped map). In the final form [KILÉNYI et al. 1991] the maximum depth of the Danube–Rába basin on the Slovakian side has dramatically changed: from 5600 m — according to seismic cross sections of low information content [FUSÁN 1987] — to depths of 7000–8000 m. Reprocessing of seismic profiles later confirmed this calculation. Corrections of the stripped map as to the lateral changes of density (functions $f_1(x,y)$) were calculated only in the northern part of the Danube–Rába basin where the basin fill is partly built up by sediments of older age producing higher compaction.

Accuracy of this part of the stripped map was assessed by standard deviation as ± 1.8 mGal. Later revision of the map within the frame of the DANREG project pointed to higher relative accuracy.

A stripped map was calculated [BIELIK 1991] using a similar technique in a net of 10×10 km and on the basis of less detailed Bouguer anomalies according to the model in the table. The accuracy of the map was not characterized; we assume it is considerably lower than that of other parts.

For preparing a stripped gravity map for the project area the following data were at our disposal:

a) The contour map of basement topography was prepared within the framework of the DANREG project by updating a formerly published map [KILÉNYI et al. 1991]. That map provided the geometry of the sedimentary complex.

b) In the absence of boreholes penetrating the deepest parts of the basin no direct density data were available for those parts of the area. The density function we have used was based on several thousands of laboratory measured density data [SZABÓ, PÁNCSICS 1994]. The measured drill cores originated from different parts of the Pannonian basin so the result can be regarded as an average density function approximating the sedimentary complex of the area.

In *Table II* below we present — besides the density contrast function used for our calculations — two more functions suggested by other authors [BIELIK 1991, BUCHA et al. 1994] for the same area.

depth (km)	density contrast (1000 kg/m^3)		
	DANREG	BUCHA et al.	BIELIK
0.0 — 0.5	-0.70	-0.57	-0.70
0.5 — 1.0	-0.50	-0.47	-0.55
1.0 — 1.5	-0.40	-0.42	-0.44
1.5 — 2.0	-0.30	-0.37	-0.44
2.0 — 3.0	-0.20	-0.22	-0.31
3.0 — 4.0	-0.15	-0.12	-0.17
>4.0	-0.10	-0.05	-0.10

Table II. Density contrast recommended for the project area by different authors
II. táblázat. Különböző szerzők által a területre javasolt sűrűségkülönbségek

The calculation of the gravity effect of the sedimentary complex was carried out in two steps:

1) To calculate the effect of the uppermost 4 km, a table was prepared containing the gravity effect of a 2×2 km sedimentary block for each 100 m depth interval and for each 2 km distance beginning from the center of the block to 20 km distance. The effect of blocks beyond 20 km from the actual grid point was neglected. The calculation was carried out by the MAGIX program (INTERPEX Co). The total effect was determined by summing, point by point, the data of the table corresponding to the actual geometry.

2) In the depth interval below 4 km the 2×2 km sedimentary blocks were substituted by vertical mass-lines and their gravity effects were calculated.

The effects for the two depth intervals were added to the Bouguer anomaly at each 2×2 km grid point.

The anomaly values obtained after the correction are free from the effect of mass defect due to the lower density of the sedimentary complex. Since the correction is based on the basement contour map and an average density function, the resultant map reflects their limitations. The total error, resulting from the errors of the density function, from approximating the basin fill by prisms and from taking into account only the 20 km neighbourhood of each point, can be estimated as not more than 10 mGals. This 10 mGal should be considered as the absolute error (i.e. a 10 mGal shift of the anomaly range), the relative error does not exceed 2 mGals. The biggest discrepancies between model and reality exist at the foot of the various surrounding hills (Sopron Hills, Transdanubian Central Range, etc.)

The most conspicuous feature of the stripped gravity anomaly map (*Fig. 8*) is the maximum range in the axis of the Danube–Rába basin, with values generally above 40 mGal, which turns eastward at the Kolárovo maximum. The source of this anomaly range is bordered on the south and south-east by the Rába–Hurbanovo line detected by both seismic and magnetotelluric data. Coinciding with the gravity anomalies, geomagnetic anomalies can be found as well.

It can be supposed that these anomalies of different physical phenomena can be attributed to a common source, namely to an elevation of the Mohorovičić discontinuity bounded by the Rába–Hurbanovo line. The northern and western borders of this elevation are unknown, the presumption of a continuous deepening or a deep fault seems to be plausible too.

The elevation of the Mohorovičić discontinuity cannot be detected by seismic data, partly because that part of section K-1 registered and processed till 12 s, stops just at the anomalous range and, partly, because at its easternmost part the Mohorovičić discontinuity reflections disappear, indicating a change in the deep structure.

The elevation of the Mohorovičić discontinuity under a deep basin cannot be regarded as a unique phenomenon, one can find several similar examples in the literature. Within the Pannonian Basin, in the Békés Basin, deep seismic sections of the last few years have revealed such an elevation involving even the asthenosphere. The respective gravity and geomagnetic anomalies are similar to those of the Danube–Rába basin.

A 10 mGal relative anomaly shows up against the maximum range of the corrected map at Kolárovo. It can be supposed that its source is in the basement. This area has an outstanding tectonic importance, as the SW–NE trend of the anomaly zone changes to a W–E trend at Kolárovo. The tectonic interpretation of this phenomenon has not yet been finally construed.

5. Gravity lineament map

Description of the procedure

This technique is designed for estimating the location of density contrasts using gridded Bouguer anomaly data. To obtain the regional geological features and to remove small and insignificant local effects of the gravity field, the primary grid of Bouguer anomalies was smoothed by a 9-point Hanning filter.

The smoothed grid of Bouguer anomalies was used as an input for calculating the magnitude and direction of the horizontal gradients using the gravity differences between grid points in the X and Y directions. The g_x- and g_y-components of the gradients were calculated by linear regression, applied to the smoothed Bouguer anomaly values in grid intersections. Differences were calculated for every grid intersection with reference to the central grid point. Linear regression was applied to all gravity differences within a radius of R=4.5 km to determine the g_x- and g_y-components of the horizontal gradient. Having obtained the gradient components from the linear regression, the magnitude and the direction of the gradient were calculated and stored.

The gravity lineaments were determined according to the method described by BLAKELY and SIMPSON [1986]. The values of horizontal gradient magnitude were compared with its eight nearest neighbours in four directions (along the row, column and both diagonals), to see if a maximum is present. This comparison test was applied to every direction if the gradient value of the central grid point was greater than that of its two neighbours. If this happened, a counter N was increased by 1. Counter N ranges from 0 to 4 and provides a measure of the quality of the maximum. The authors referred to parameter N as 'significance level' of the maximum. In the final step of the procedure, a small line, perpendicular to the direction of the horizontal gradient was drawn representing the gravity lineament at all grid points where parameter N was greater than 0.

Description of the lineament map

The above-described procedure was applied to the original Bouguer anomaly map without any modification. That is why the lineament map (*Fig. 9*) reflects all geological structures irrespective of their age and depth.

BLAKELY and SIMPSON's method approximates the edges of causative bodies as can be seen, for example, in the case of the Kolárovo anomaly. On the map (Fig. 9), besides the isometric shapes, at certain places linear patterns prevail, characterizing the tectonic elements of the region.

Based on the pattern of the lineaments, the area can be divided into four districts.

1. The central part is characterized by long and continuous lineaments — parallel with the Rába–Hurbanovo line — with subordinate, short transverse directions.
2. The area of the Transdanubian Central Range (the SE part of the map) can be characterized by a pattern of short and discontinuous lines of dominantly N–S direction, whereas in the eastern part it changes to the dominance of NW–SE directions.
3. The lineaments have a different character in the NW part of the map: in the Bruck–Stupava direction the Mur–Mürz line — the main, south-eastern tectonic line of the Vienna basin — is reflected, while in the Bratislava–Pezinok line the main tectonic directions of the Little Carpathians can be recognized. To the east of this latter, the N–S directions become dominant.

4. The Sopron–Bruck area (that of the Leitha Hills) is characterized again by short, discontinuous lineaments, such as that of the Transdanubian Central Range, reflecting the minor shallow structures.

Analysis of the lineament map is a useful tool for the tectonic interpretation of the region, especially in the deep basin areas.

6. The Kolárovo anomaly

From the point of view of interpretation, the Kolárovo maximum is a very characteristic and regular anomaly. Its position is closely related to the Rába–Hurbanovo line so the determination of its possible source can contribute to the understanding of the origin and nature of that tectonic element. The anomaly had already been interpreted by several authors [e.g. SITÁROVÁ et al. 1994] but because of its key position it seemed worth carrying out some new simple model calculations in order to get rid of possible preconceptions.

Since the gravity anomaly of a given geological structure depends directly on its dimensions and its density contrast, and an anomaly can be caused by an infinite number of possible geological structures we have to take certain limits concerning the size and density of the causative body to decrease the number of possible solutions. As for the dimensions of the source we accepted as its upper limit the depth of the basement from the map prepared in the framework of the present project. For the lower limit of the models we took the depth of the Mohorovičić discontinuity on the basis of the 'Contour Map of the Mohorovičić Discontinuity beneath Central Europe' published by ELGI [POSGAY et al. 1991]. For density contrast we took 350 kg/m^3 as a generally accepted value for the crust–mantle contact.

The calculations were carried out by 2.5-dimensional modelling. From the numerous possible solutions two models regarded as the most plausible are presented in *Figs. 10* and *11*:

a) In the first model, the source was approximated by a batholith-type intrusion of the upper mantle material into the crust (Fig. 10).

b) The second version is a combination of the thinning of the crust and a laccolith-type intrusion of the upper mantle material into the basement (Fig. 11).

Taking into account the dimensions of the two models, the laccolith-type solution seems to be more realistic. The problem, however, is open to

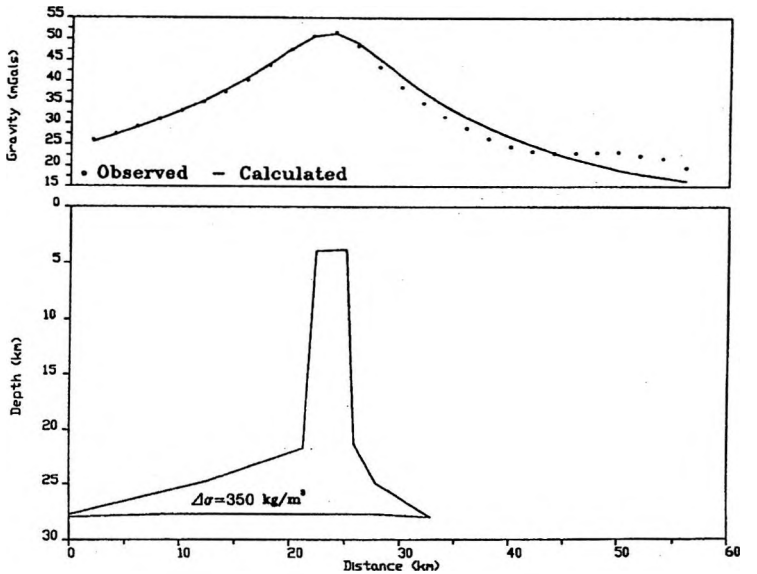

Fig. 10. Possible gravity model of the Kolárovo body (batholith)
10. ábra. A kolárovoi ható lehetséges batolitos gravitációs modellje

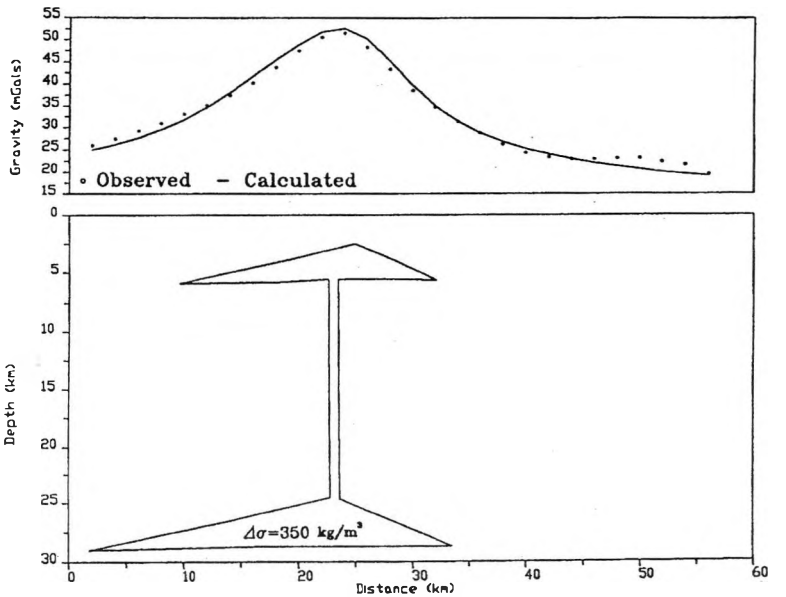

Fig. 11. Possible gravity model of the Kolárovo body (laccolith)
11. ábra. A kolárovoi ható lehetséges lakkolitos gravitációs modellje

discussion in connection with the origin and nature of the Rába–Hurbanovo line.

It has to be emphasized that the solutions can be regarded only as approximations. Their reliability depends not only on the inherent ambiguity of gravity interpretation but on the reliability of the sediment-corrected gravity anomaly map, as well.

7. Summarized geological interpretation of the gravity maps

In the foregoing we restricted ourselves mainly to presenting the procedure and the method of preparation of the various gravity maps and we mentioned only their main features.

By way of a summary, it can be concluded that the anomaly patterns of the Bouguer anomaly map characterize quite well with their smooth forms the deep basin areas and with their more varying forms those parts where the pre-Tertiary rocks are on or near the surface. In the contact zones of basement highs and deep basins the closely spaced, elongated isolines indicate fault lines such as the Mur–Mürz and Hurbanovo–Diósjenő lines.

We would call attention to two significant features of the Bouguer anomaly map: the first is that the Vienna basin in spite of its shallower nature is characterized by higher negative anomalies than the deeper Danube–Rába basin. The second main feature of the map is that the Kolárovo gravity maximum lies in the intersection of the Rába and Hurbanovo–Diósjenő lines. It is our conviction that the Kolárovo anomaly plays a key role in the understanding of the geological structure and history of the region.

These characteristics inspired us to prepare different versions of gravity maps to emphasize local, regional and directional features of the original Bouguer anomaly map.

It is clear, however, that gravity itself with its inherent ambiguity does not give clear-cut answers to our geological problems but due to the dense gravity survey over the whole region, gravity data represent a continuous information system.

By integrating the gravity data with the results of other geophysical methods (geomagnetic, geoelectric, seismic) and with the geological information available for the area, our knowledge of the geological build-up from the surface to the Mohorovičić discontinuity will increase.

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Gavitációs térképek — Ausztria, Szlovákia és Magyarország közös határterületein

Ján ŠEFARA és SZABÓ Zoltán

1. A Bouguer-anomália térkép

A geofizikai program egyik fő feladata a Bouguer-anomália térkép megszerkesztése volt. A három ország szakembereiből álló gravitációs munkacsoport először felmérte a kutatások helyzetét. Úgy döntöttek, hogy az 1950-es évek elejétől végzett graviméter mérések tekinthetők megbízhatónak és ezekből mindhárom országban készültek is Bouguer-anomália térképek. Ezek azonban az országhatárokon nem voltak illeszthetők, mert a Bouguer- és terephatás-korrekciókat más sűrűséggel számították, más-más gravitációs rendszereket, más normálértéket (Helmert, Cassinis), más magassági rendszert (baltit és adriait) használtak, és a nemzeti bázishálózatok csak Szlovákia és Magyarország között voltak összekötve.

A munka egy közös adatbázis létrehozásával kezdődött. Megállapodtak abban, hogy:

— „abszolút" gravitációs rendszerben fognak dolgozni,
— a normálértéknek az Európában már széles körben alkalmazott WGS–80-at fogadják el,
— az adriai magassági rendszert használják,
— a Bouguer- és a topografikus-korrekció számításához 2670 kg/m^3 sűrűséget választanak,
— valamint összemérik a szlovák–osztrák és az osztrák–magyar bázishálót.

A rendezetlen eloszlású és változó állomássűrűségű adatokból számolt anomália adatokból spline interpolációval 800×800 m-es hálózatot hoztak létre, majd az eredetileg 1:200 000 méretarányú szintvonalas térképet az ELGI-ben kifejlesztett számítógépes programmal szerkesztették meg. (*1. ábra*). A térkép hibáját Molodensky eljárásával ŠEFARA vizsgálta. Úgy találta, hogy az ±0,8 – 1,0 mGal-ra becsülhető, de pontosságát a mérési sűrűség jelentősen befolyásolja.

2. A gravitációs értelmezés szempontjai

A Bouguer-anomália térkép a felszín alatti tömegek integrált hatását mutatja, a geológiai értelmezés kritikus feladata azonban a különböző mélységű, kiterjedésű testek hatásainak szétválasztása. Ennek elterjedt módszere a szűrés. A klasszikus értelmezés szerint a Bouguer-anomália térkép a nagysűrűségű aljzat topográfiájával mutat hasonlóságot, a regionális (felülvágó szűrés eredményeként született) anomália térkép a mélybeli, a maradékanomália térképek (az alulvágó szűrések eredményeiként) a felszínközeli hatókat, a derivált térképek pedig a gravitációs tér horizontális gradienseit emelik ki. A szűrési eljárások azonban nagyon érzékenyek az állo-

mássűrűség mellett az alkalmazott szűrő paraméterére is. A mátrixelemek és a szűrőméret kombinálásával sokféle térképváltozat készíthető, amelyek megválasztása jelentősen függ az értelmező geofizikus tapasztalataitól.

3. A szűrt térképek

A szűrt térképek számítása a MESKÓ [1984a] által definiált kétdimenziós szűrési eljáráson és mátrixokon alapult. Az alkalmazott szűrők súlyfüggvényeit a *2. ábra* mutatja. A κ paraméter a szűrők szélességét jellemzi. Minél nagyobb ez az érték, annál jobban kiemeli a szűrő a kis, helyi anomáliákat. A szűrt térképváltozatok közül a *3. ábra* egy maradék-anomália térkép, a *4. ábra* ennek regionális párja, az *5. ábra* a derivált jellegű térkép. Ez utóbbit egy keskeny sávátereszto szűrővel kaptuk (κ=9–8), hogy a gravitációs adatok mérési hibáit (nagyfrekvenciás zaját) is kiszűrjük.

A térképek jellegének meghatározására minden térképváltozatot alávetettük a PINTÉR és STOMFAI [1979] által javasolt vizsgálatnak. Ennek értelmében a κ=2 paraméterrel készített térkép eloszlási görbéje (*6. ábra*) széles, azaz maradék jellegre utal. A *7. ábrán* látható κ=9–8 térkép eloszlási görbéje keskeny, ami a derivált jelleg bizonyítéka.

4. Az üledékhatással korrigált gravitációs térkép

Több geofizikai módszer eredményeire épülő komplex értelmezési törekvéseink megkívánták, hogy a pre-tercier aljzat belső inhomogenitásait is vizsgáljuk. Ennek egyik gravitációs módja, hogy a 7–8 km vastagságot is elérő neogén korú üledék okozta tömeghiányt kompenzáljuk. Kutatási területünk különböző részeiről már 1984-ben MESKÓ és 1987-ben ŠEFARA is szerkesztett ilyen térképet, azonban mindkét ilyen megoldás csak az akkor létező ismeretekre (például aljzat-mélység térképre és sűrűség-adatokra) épülhetett. Az azóta eltelt idő alatt a neogén medence aljzatáról a szeizmikus újrafeldolgozások és újabb geofizikai mérések kapcsán a korábbiaknál megbízhatóbb (a későbbiekben e kiadványban is bemutatott) térképet szerkeszthettünk. A mélység (vastagság) adatokat ebből vettük. A sűrűségekre egy mélységintervallumoktól függő váltózó értéksort vettünk fel. Táblázatunk létrehozásához felhasználtuk a mélyfúrásokban (magokból és geofizikai mérésekből) meghatározott sűrűség adatokat, amelyek a Pozsony-Győr közötti „Duna-Rába" medencében maximum 3200 m-es mélységből, a Bécsi-medencében maximum 4200 m-es mélységből származtak. Ez utóbbi adatrendszert láthatjuk az *I. táblázatban*, ahol az aljzat-sűrűséghez viszonyított relatív értékek láthatók. Az itt bemutatott „üledékhatástól megtisztított" térképünk (*8. ábra*) szerkesztéséhez azonban a *II. táblázatban* látható, kerekített értékekkel számoltunk, amelyhez még felhasználtuk SZABÓ és PÁNCSICS [1994] több ezer fúrómagon végzett és karotázs mérésekre alapozott sűrűség vizsgálati eredményét, amelyek a Pannon-medence különböző részeiről származnak. (Ebben a táblázatban közöljük még BUCHA, BLIŽKOVSKY és BIELEK hasonló mélységintervallumokra publikált adatait is.)

Az üledékes összlet gravitációs hatásának számítása két lépésben történt.

— A felső 4 km hatásának számításánál 2×2 km-es horizontális kiterjedésű, 100 m vastag blokkokat választottunk. Ezeknek a blokkoknak a gravitációs hatását kiszámoltuk mind a kérdéses felszíni pontunk alatti hasábokra, mind a maximum 20 km-es felszíni távolságra található hasábokra és ezeket összegeztük.

— A 4 km-nél mélyebb 2×2 km-es üledékes blokkokat függőleges vonalszerű tömegekkel helyettesítettük és ezek gravitációs hatását számítottuk.

A két mélység-intervallum hatásait hozzáadtuk a Bouguer-anomáliákhoz minden 2 km-es rácshálózati pontjában.

A számítások az INTERPEX Co. MAGIX programjával történtek.

A 8. ábrán látható korrigált térkép legszembetűnőbb vonása a Duna-Rába síkság tengelyében kifli alakban hajló 40 mGal feletti anomália, amelynek lefutása és elhelyezkedése a mágneses térképpel, D–DK-i pereme a Rába–Hurbanovo vonal lefutásával mutat sok hasonlóságot. Mint erre a későbbiekben még visszatérünk, ez az anomália kéreg kivékonyodással, köpeny-kiemelkedéssel magyarázható.

5. A gravitációs lineamens térkép szerkesztése és értelmezése

Bármelyik gravitációs térképünkön láthatunk olyan párhuzamos izovonal-kötegeket, amelyek ismert törésvonalaknál tűnnek fel. Ezeknek a jelenségeknek a korrekt matematikai kiemelését láthatjuk a lineamens térképen, vagy más néven a sűrűséghatárok térképén. (*9. ábra*).

A térképet R. J. BLAKELY és R.W. SIMPSON [1986] módszerével szerkesztettük, a GEOCOMPLEX-ben, illetve a Bratislavai Egyetem Geofizikai Tanszékén. A térkép úgy készült, hogy kiszámítottulk a Bouguer-anomália térkép minden egyes rácspontjában az É–D és K–Ny irányú deriváltakat, amelyek alapján egy 4,5 km sugarú körön belül lineáris regresszió számítással a vízszintes gradiens nagyságát és irányát meghatároztuk. A gradiens nagyságát összehasonlítottuk a nyolc szomszédos ponthoz (É–D, K–Ny irányban, valamint ezek szögfelezőiben) tartozó értékkel és megnéztük, hogy a központi rácspont értéke nagyobb-e, mint szomszédai. Ha igen, akkor a 0 és 4 között változó úgynevezett *N* paraméter értékét növeltük 1-gyel. Végül kijelöltük az összes olyan rácspontot, ahol *N* értéke 0-nál nagyobb volt. Ezeken a pontokon a gradiens irányára merőlegesen egy rövid vonalkát helyeztünk el.

A lineamens térkép anomáliáit vizsgálva a 20 000 km^2-nyi területet négy nagyobb körzetre oszthatjuk.

1.) A terület középső részén, nagyjából az üledékhatástól megtisztított térkép nagy anomáliájának területén az említett anomália csapásában, a Rába-vonallal és a Hurbanovo-vonallal párhuzamosan a hosszú és folytonos sűrűséghatárok jellemzők.

2.) A Dunántúli-középhegységben (a térkép DK-i részén) a rövid és nem folytonos határok jellemzőek. A Budapest-Esztergom vonaltól Ny-ra az É–D irányok, a vonaltól K-re pedig az ÉNy–DK irányok a jellemzők.

3.) Az ÉNy-i részen más a lineamensek jellege; a Bruck–Stupava vonal a Bécsi-medence nagy törésvonalának, a Mur–Mürz vonalnak irányát követi, a Pozsony–Pezinok vonalban viszont a Kis Kárpátok uralkodó tektonikai irányai ismerhetők fel. Ettől K-re viszont az É–D irány a jellemző.

4.) A Sopron–Bruck térség a Lajta-hegység körzetében a kismélységű aljzat apró szerkezeteit sejteti.

6. A kolárovoi gravitációs anomáliáról

Bármelyik eddig tárgyalt gravitációs térképen az egyik legszembetűnőbb a Kolárovo melletti gravitációs anomália, amelynek helyzete szorosan kapcsolódik a Rába-vonalhoz is. A ható nyilvánvalóan mélyen (a pre-tercier aljzatban) van, de minden bizonnyal éles sűrűségkontraszt választja el környezetétől. Mégis a priori ismeretek nélkül semmiféle módszerrel nem tudjuk elkülöníteni az üledékekben vagy az aljzatban lévő sűrűség inhomogenitások hatását.

Itt most feltételezzük, hogy a ható teteje legfeljebb a pre-tercier aljzat mélységében és legalább a Mohorovičić diszkontinuitás felületén van. Sűrűség-kontrasztként 350 kg/m^3-t vettünk. A számításokat 2,5 dimenziós modellezéssel végeztük. A számos megoldás közül a két legvalószínűbbet a *10.* és *11. ábrán* láthatjuk. A 10. ábra egy olyan lehetőséget mutat, ami a köpeny anyagának a kéregbe történő behatolásával magyarázható. A 11. ábra egy kéregkivékonyodásnak és egy lakkolit-szerű benyomulásnak felel meg.

7. A gravitációs térképek földtani értelmezésének összefoglalása

A DANREG programban eredetileg elképzelt egyetlen gravitációs (Bouguer-anomália) térkép gravitációs maximumai és minimumai alapjában véve, a klasszikus értelmezésnek megfelelően, kvalitatíve jelzik a 20 000 km^2-es terület harmadkori medencealjzatának mélységviszonyait és bizonyos szerkezeti elemeit is. Mégis feltűnő, hogy a mélyfúrásokból és kvantitatív geofizikai módszerekből megismert Bécsi-medence aljzatmélysége kisebb, mint a Duna-Rába medencéé, holott a Bouguer-értékeik alapján ennek fordítva kellene lennie. A térkép egyik legszembeötlőbb (kolárovoi) anomáliája a Rába- és a Hurbanovo–Diósjenő vonal kereszteződésénél fekszik, de hatóját nem lehet egyértelműen meghatározni. Ezért többféle gravitációs térkép készült a lokális, a regionális és irány szerinti jellegzetességek kiemelésére. A sűrű gravitációs mérés folytonos információ rendszert alkot, de értelmezésük csak egyéb geofizikai és földtani adatok bevonásával lehetséges. Így viszont a Mohorovičić diszkontinuitásig kaphatunk képet a földtani felépítésről.