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Gravity map of Hungary corrected for basin effect

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More than 70 % of Hungary is basin area covered by young sediments. The thickness of the sedimentary cover reaches 7000–8000 m in the deepest parts of the basins therefore the mass deficiency caused by the sediments has a considerable influence on the Bouguer anomaly map. Based on model calculations the authors determined the optimum procedure to calculate the 'distortion effect' of the sediments. The corrected gravity map presented in this paper reflects the effect of the density variations and the thickness of the crust. To emphasize the structural lines, a gravity lineaments map was constructed as well. Based on earlier seismic information, correlation studies were carried out between the depth to the Moho derived from seismic data and the corrected gravity anomalies. In possession of the correlation parameters the contours of the Moho could be determined.

Keywords: gravity survey maps, stripping, lineaments, Mohorovičić discountinuity, basin effect

1. Introduction

Some 70 % of the territory of Hungary is covered by young sediments. The thickness of the sedimentary cover reaches 7000–8000 m in the deepest parts of the basins. Due to the unconsolidated young sediments the Bouguer anomaly map is strongly influenced by the effect of the mass deficiency of the basins. To get information about the structure of the basement

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and of the crust the Bouguer anomaly map should be corrected for the basin effect.

A correction technique, the so-called stripping method, was proposed by HAMMER [1963] to eliminate the effect of known structures. In principle the gravity stripping technique extends the gravity interpretation to deeper horizons by calculating and subtracting the gravity effect of the overlying sedimentary cover whose structure and density relations are known in detail from former geophysical investigations and drilling activities. For areas of large extent the selection of the proper datum level of the correction is critical because of the inhomogeneity of information about the depth and density of the overlying layers. To eliminate this problem we have modified the stripping technique by selecting sea level as the datum level and calculating the gravity effect of the mass deficiency caused by the unconsolidated sediments between the sea level and the basement. This means that instead of stripping the known effects we calculated the effect of the missing masses; in other words, we substituted the young sediments by basement material. The effect obtained was added to the original Bouguer anomaly values.

The result is a version of the Bouguer anomaly map which does not reflect the effect of the young sediments but only the structure and density relations of the basement and the underlying crust. In this case the datum level is equivalent to that of the original Bouguer anomaly map.

In former years RENNER and STEGENA [1966], MESKÓ [1984], and BIELIK [1985] constructed a number of different stripped maps for Hungary but due to the lack of a proper contour map of the basement and adequate density data of the sediments at their disposal, their experiments can only be regarded as first approximations.

2. Principal factors for determining the basin effect

In order to determine the basin effect three principal factors are needed:

— Bouguer anomaly map
— contour map of the basement

— density relations of the sediments.

Thanks to the complemented gravity database of ELGI, the compilation of a basement countour map of Hungary, and the thorough investigation of the density relations of the Pannonian basin carried out in the last decade, the principal factors were at our disposal for calculating the basin effect.

Bouguer anomaly map

The Bouguer anomaly map was contoured on the basis of about 380000 gravity data. For Bouguer- and terrain corrections, elevation-dependent density values were applied, taking the highest value to be 2670 kg/m^3 (see separate paper in this volume). The accuracy of the map is more than adequate for a regional study on the structure of the crust.

Contour map of the basement

From the point of view of geophysical methods the basement of the young sediments is a first-order discordance originating from the contrast in the physical parameters of the sediments and basement rocks.

After all, it is not an easy task to contour the basement topography because integrated evaluation of many different data is needed which cannot be carried out without the close co-operation of scientists working in different branches of geological exploration. The basement contour map of Hungary [KILÉNYI, RUMPLER 1984] is based on borehole, seismic, geoelectric, and gravity data. The most reliable data come from borehole records but since the boreholes were drilled for mineral exploration purposes they are unevenly distributed. The oil-prospecting boreholes were drilled mainly on the elevated parts of the basement so in the deep basins the boreholes do not actually reach or penetrate the basement.

Since most of the geophysical measurements were carried out for mineral exploration, the geophysical coverage of different parts of the country differs. The most important regions for hydrocarbon exploration are: the Dráva basin, the Zala basin, the south-eastern part of the Danube–Tisza interfluve, and the southern part of the trans-Tisza region. In these regions the oil industry carried out detailed seismic reflection surveys and most of the boreholes were drilled in these parts of the country. The above-mentioned regions have the most detailed geophysical coverage but the different measurements are not all of the same quality. The depth range of the prospecting was determined by the specific purpose of the prospecting.

The Danube–Rába Lowland, the foreland of the Transdanubian Central Range, and the vicinity of the Mecsek–Villány mountains are in the second category.

The least explored regions at the time of the compilation of the map were: the region between Lake Balaton and the Mecsek Mts, the western part of the Danube–Tisza interfluve, and the Nyír region, where several thousand metre thick Neogene volcanic rocks and sediments cover the basement. The variable geophysical coverage means uneven reliability of the map.

Since geology does not conform with national boundaries the Pannonian Basin extends over the territory of neighbouring countries. In the second half of the 80s in co-operation with Austrian and Slovakian scientists Pre-Tertiary Basement Contour Map of the Carpathian Basin beneath Austria, Czechoslovakia and Hungary was prepared [KILÉNYI et al. 1991]. At present this is the most up-to-date basement contour map of the region. But because for the correction a larger area is needed, than is covered by the contour map, the latter was complemented by partly unpublished data (*Fig. 1*).

Density relations of the sediments

Up till now only sporadic density data have been published for the Hungarian part of the Pannonian basin [PINTÉR et al. 1964, KILÉNYI 1968, KOVÁCSVÖLGYI 1995]. More density information is available for the Slovakian part of the basin [ŠEFARA 1987]. Despite its incompleteness, for regional studies the above-mentioned data set was considered acceptable but nowadays, when detailed large-scale investigations are on the agenda, more accurate density data are needed for really meaningful geophysical interpretation.

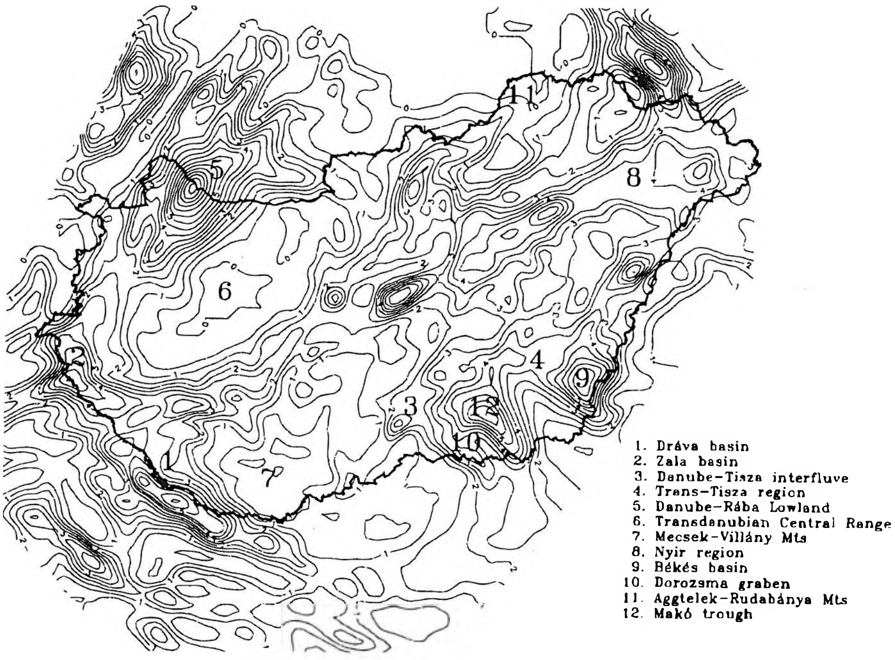

Fig. 1. Pre-Tertiary basement contours. Contour interval: 500 m

1. ábra. A neogén medence aljzatának szintvonalai. Szintvonalköz: 500 m

Rock densities can be determined indirectly from gravity data (Nettleton method) or directly either by laboratory measurements or by gamma-gamma density logs as was done by the authors (see separate paper in this volume).

To investigate the density contrast at the sediment–basement boundary we calculated the average density of the lowest 100 m density column of the sediment and that of the basement. The density values that we obtained confirmed the results given by the density functions derived from well-log data and laboratory measurements; in other words at about 3500 m depth the density of the sediments and the basement became very similar. This phenomenon calls our attention to the problems of basement contour determination from gravity data below 3500 m.

3. Preliminary model calculations

Before calculating the corrections we had carried out some preliminary investigations to sum up the limitations of the method. Because variations of the basement relief did not make it possible to approximate the sedimentary layers with infinite flat plates we divided the subsurface layers into 4000×4000×250 m blocks and calculated their gravity effect for each grid point (*Fig. 2*). The calculations were based on the method proposed by HAÁZ [1953]. In theory, the calculations should be extended over the whole surface of the Earth, but partly because of lack of data and partly to save computer time, we limited the calculations to a region of radius R.

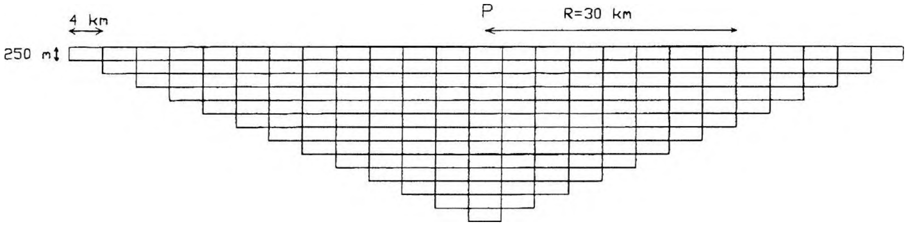

Fig. 2. Sketch of model calculations

2. ábra. A modellszámítások vázlata

To estimate R, i.e. the radius of the area to be taken into account in the correction, model calculations were carried out. Three basin areas were selected for the study where the basement depth was H=500, 2500 and 5000 m, respectively. For certain grid points the effect of mass deficiency of the basins was calculated by increasing R in 4 km steps. The effect belonging to R=42 km was taken as 100 % because the difference in the correction between the last consecutive steps was less than 0.28 % even in the case of a 5000 m deep basin. The effects belonging to different R values are expressed as a percentage of the total (R=42 km) effect (see *Table I*). It can be seen that the relative error is less than 1 % even in the worst case if we limit our calculations to R=30 km. That error in our case means less than

0.5 mGal regional uncertainty, which is negligible in regional interpretation.

R [km]	W_1	W_2	W_3
2	83.67	63.90	59.49
6	93.63	87.25	85.10
10	95.70	92.90	91.92
14	96.77	95.39	94.97
18	97.62	96.81	96.68
22	98.26	97.78	97.77
26	98.70	98.48	98.52
30	99.06	98.99	99.05
34	99.44	99.40	99.45
38	99.77	99.73	99.76
42	100.00	100.00	100.00

Table I. Relative gravity effect (W) as a function of R. W=percentage of total effect for a basin of 1 — H=500 m, 2 — H=2500 m, 3 — H=5000 m depth

I. táblázat. Relatív gravitációs hatás (W) R függvényében. W a teljes hatás százalékában van megadva, 1— H=500 m, 2 — H=2500 m, 3 — H=5000 m mély medencére

We were interested in what weight the 250 m thick layers of different depths have in the integrated mass deficiency. The calculations were carried out with three different density functions for the same H=500, 2500 and 5000 m deep basins as in the case of R determination. The results were very similiar: two of them are presented in *Tables II and III*.

It can be concluded that the effects of the near-surface layers dominate, and more than 90 % of the total effect originates from depths less than 2500 m. This means that the correction is sensitive to the density of the near-surface layers. Therefore the density determination of the relatively shallow geological formations requires special attention.

h [m]	$\sigma(h)$ [kg/m^3]	$\Delta\sigma(h)$ [kg/m^3]	W_1	W_2	W_3
0–250	2060	610	51.61	17.39	15.76
250–500	2110	560	46.99	15.85	14.35
500–750	2150	520	0.88	14.62	13.24
750–1000	2210	460	0.29	12.83	11.62
1000–1250	2270	400	0.13	11.07	10.02
1250–1500	2330	340	0.06	9.33	8.45
1500–1750	2390	280	0.04	7.56	6.91
1750–2000	2460	210	0.00	5.52	5.14
2000–2250	2510	160	0.00	3.51	3.86
2250–2500	2540	130	0.00	2.06	3.10
2500–2750	2570	100	0.00	0.19	2.35
2750–3000	2610	60	0.00	0.07	1.37
3000–3250	2620	50	0.00	0.00	1.09
3250–3500	2620	50	0.00	0.00	0.99
3500–3750	2630	40	0.00	0.00	0.64
3750–4000	2630	40	0.00	0.00	0.52
4000–4250	2640	30	0.00	0.00	0.24
4250–4500	2640	30	0.00	0.00	0.20
4500–4750	2650	20	0.00	0.00	0.07
4750–5000	2650	20	0.00	0.00	0.05
5000–5250	2660	10	0.00	0.00	0.02
5250–5500	2660	10	0.00	0.00	0.01
5500–5750	2670	0	0.00	0.00	0.00
5750–6000	2670	0	0.00	0.00	0.00

4. Gravity map of Hungary corrected for basin effect

Based on the above-mentioned model calculations R=30 km was accepted as the radius of the area involved in the correction. To improve the resolving power, the calculations were carried out for 1000×1000×250 m blocks instead of the 4000×4000×250 m blocks used in the model calculations. To make the procedure flexible, the effect of each block was calculated for each grid point with $\sigma=1000$ kg/m^3 density in order to reduce the further calculations to simple multiplications with the actual density and summation of the effects of different blocks. The following parameters were selected for the final calculations:

- density of the bedrock: 2670 kg/m^3
- R=30 km
- 3 different density functions, based on laboratory measurements and on gravity-derived and well log density data.

The correction factor was determined for each grid point and it was added to the mean Bouguer anomaly of the actual block. The corrected gravity values reflect that hypothetical situation as if all the young sediments were substituted by bedrock of $\sigma=2670$ kg/m^3 density. The contoured map indicates the density inhomogeneities of the basement and the undulation of the Moho. It has to be mentioned, however, that it is subject to all the uncertainties of the basement contours and the applied density relations. The corrected gravity map was prepared in three versions on the basis of the three density functions. They were compared with each other and it was concluded that they were very similar especially with regard to their anomaly pattern. The amplitudes of the respective anomalies differed by not more than 10 %, neglecting an additive constant, not influencing the anomaly pattern.

⇦

Table II. Relative weight of 250 m thick consecutive layers as a function of depth (h). Density function ($\sigma(h)$) from gamma-gamma logs. $\Delta\sigma(h)=2670-\sigma(h)$, W=percentage of total effect for a basin of 1—H=500 m, 2—H=2500 m, 3—H=5000 m depth

II. táblázat. A 250 m vastag rétegek relatív súlya (W) a mélység (h) függvényében. Sűrűségfüggvény ($\sigma(h)$) gamma-gamma karotázsból. $\Delta\sigma(h)=2670-\sigma(h)$, W a teljes hatás százalékában van megadva, 1—H=500 m, 2—H=2500 m, 3—H=5000 m mély medencére

h [m]	$\sigma(h)$ [kg/m^3]	$\Delta\sigma(h)$ [kg/m^3]	W_1	W_2	W_3
0–250	2050	620	54.44	21.13	19.01
250–500	2160	610	44.42	17.25	15.52
500–750	2250	520	0.74	14.10	12.68
750–1000	2320	450	0.23	11.66	10.48
1000–1250	2370	400	0.10	9.92	8.92
1250–1500	2420	350	0.05	8.19	7.37
1500–1750	2460	210	0.02	6.78	6.14
1750–2000	2500	170	0.00	5.33	4.93
2000–2250	2540	130	0.00	3.41	3.73
2250–2500	2570	100	0.00	1.87	2.83
2500–2750	2590	80	0.00	0.18	2.21
2750–3000	2610	60	0.00	0.08	1.63
3000–3250	2620	50	0.00	0.04	1.29
3250–3500	2620	50	0.00	0.03	1.18
3500–3750	2630	40	0.00	0.02	0.75
3750–4000	2630	40	0.00	0.01	0.62
4000–4250	2640	30	0.00	0.00	0.29
4250–4500	2640	30	0.00	0.00	0.25
4500–4750	2650	20	0.00	0.00	0.09
4750–5000	2650	20	0.00	0.00	0.05
5000–5250	2660	10	0.00	0.00	0.02
5250–5500	2660	10	0.00	0.00	0.01
5500–5750	2670	0	0.00	0.00	0.00
5750–6000	2670	0	0.00	0.00	0.00

The map in *Fig. 3* was based on the density function derived from well-log data (Table II). The main features of the corrected map are the conspicuous positive anomalies above the deepest sub-basins of the Pannonian basin. This phenomenon can be explained by the thinning of the crust and the upwelling of the dense mantle material. This supports the extensional origin of these basins.

A similar effect was reported by Canadian scientists [LOWE–DEHLER 1995] beneath the Queen Charlotte basin where up to 6 km marine and nonmarine sedimentary rocks with interbedded volcanic material were deposited on a Mesozoic basement. Another feature of the map worth mentioning is that the level of anomalies in the south-eastern part of Hungary is higher by about 15 mGal than in the other parts.

5. Gravity lineament map

To emphasise the structural lines reflected in the corrected gravity map, the maximum gradient method was applied for the anomalies interpolated to a 1 km grid network. The horizontal gradients were calculated for each grid point. Those grid points which have higher gradient values than a preselected limit (in our case 2.5 E), compared to the neighbouring grid points, are marked on the map (*Fig. 4*). Most of the markings form lineaments. If it is supposed that lateral density contrasts are related to structural features then most of the lineaments outlined in the map reflect tectonic lines. The exceptions are those erosional structures where the effect of tectonic processes is negligible.

Given that our initial assumptions and data are correct the lineaments reflect the structures of the crust including the basement.

⇦ *Table III.* Relative weight of 250 m thick consecutive layers as a function of depth (h). Density function ($\sigma(h)$) from laboratory measurements, W=percentage of total effect for a basin of 1 — H=500 m, 2 — H=2500 m, 3 — H=5000 m depth

III. táblázat. A 250 m vastag rétegek relatív súlya (W) a mélység (h) függvényében. Sűrűségfüggvény ($\sigma(h)$) laboratóriumi mérésekből. W a teljes hatás százalékában van megadva, 1 — H=500 m, 2 — H=2500 m, 3 — H=5000 m mély medencére

6. Contour map of the Moho based on gravity data

Correlation studies were carried out between the corrected gravity map and the Moho surface supposing that the corrected gravity map reflects mainly the undulations of the Moho, and that the effect of possible density inhomogeneities of the basement is negligible. The contours of the Hungarian part of the Moho are relatively well known. The seismic crustal investigations started in 1954. The first experimental measurements proved that the crust under the Pannonian basin is considerably thinner than the continental crust elsewhere [GÁLFI, STEGENA 1955]. Since that time many seismic profiles have been recorded to study the Moho; there is, however, variation in the quality of the sections mainly because of the long time span from the beginning. A synthesis of the deep seismic measurements was provided in 1991 by the publication of a map of the Mohorovičić discontinuity beneath Central Europe [POSGAY et al. 1991]. Our correlation studies were based partly on that contour map and partly on some new deep reflection seismic sections observed after the compilation of the map. The locations of the seismic profiles are presented as an insert in *Fig. 5*. The depth values and the corresponding gravity anomalies were read out from the two maps along seismic lines. The two data sets were correlated by linear regression. Having obtained the coefficients of the correlation function, the contours of Moho were determined from the gravity data. The resulting map is presented in Fig. 5.

It can be seen on the map that the depth of the Moho is between 23 and 32 km. The highest values are obtained in those regions where the basement is outcropping or lies at a shallow depth whereas the lowest values can be found over deep basins. This phenomenon indicates the striving for isostatic equilibrium. Generally speaking the south-eastern part of the country (the Great Hungarian Plain) — especially the Békés basin, the Dorozsma graben, the Danube–Rába Lowland and the Zala basin — is characterized by thin crust (< 30 km). The Mecsek Mts, the Transdanubian Central Range, and the Aggtelek–Rudabánya Hills have relatively thick crust (> 30 km). The highest discrepancies (5 km) between the seismic and gravity-derived maps can be found below the Mecsek Mts and the Dorozsma graben. It is interesting to note that in spite of the large depth of the

Makó trough, the crust below it is relatively thick suggesting a different structural evolution.

The Moho map derived from gravity data has many similarities with that derived from seismic data, but there are discrepancies as well. These originate from the essence of the two methods, viz. the better resolution but sparse net of the seismic profiles, and the smoothing effect of gravity. The main advantages of the latter are the good coverage and the elimination of local disturbing effects which are present in the seismic sections.

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Magyarország medencehatástól mentesített gravitációs térképe

SZABÓ Zoltán és PÁNCSICS Zoltán

Magyarország területének 70 %-át fiatal üledékek fedik. Az üledékek vastagsága elérheti a 7000–8000 métert, ennek következtében az üledékek okozta tömeghiány hatása nagymértékben befolyásolja a Bouguer-anomália térképet. Az üledékek "torzító" hatásának meghatározására a szerzők modellszámításokat végeztek. Az üledékhatás meghatározása után megszerkesztették a korrigált gravitációs térképet, amely már csak a kéregben levő sűrűséganomáliák és a kéregvastagság hatását tükrözik. A szerkezeti vonalak kihangsúlyozására a szerzők megszerkesztették a korrigált térkép gravitációs lineamens változatát is. Korábbi szeizmikus adatok felhasználásával korrelációs számításokat végeztek a szeizmikus adatokból meghatározott Moho mélységek és a korrigált gravitációs adatok között. A kapott korrelációs együtthatók segítségével meghatározták a Moho szintvonalas térképét.

ABOUT THE AUTHORS

Zoltán Szabó, for a photogprah and biography, see this issue, p. 27.

Zoltán Páncsics, for a photogprah and biography, see this issue, p. 27.