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Bouguer anomaly map of Hungary corrected using variable density

Zoltán SZABÓ* and Zoltán PÁNCSICS*

Hungary's first steps towards a regional gravity survey were taken by Eötvös in 1901. The present work is based on the data of 380 000 gravity stations recorded in the gravity data base till the time of preparing this paper.

The Bouguer anomaly map presented here is based on the complete data set. It is no easy task to construct a unified Bouguer anomaly map for a region where the density of the surface rocks varies from 2000 to 2670 kg/m^3. If incorrect density values are used for Bouguer and terrain corrections they will lead to under or over corrections in the gravity map. On the other hand the application of region dependent density may cause fictive anomalies in the transition zones. To avoid creating such anomalies the authors constructed an elevation dependent density function for the Bouguer and terrain corrections.

Some of the main features of the map and the aspects of gravity interpretation are discussed. To facilitate structural interpretation of the gravity map a gravity lineament map based on the maximum gradient method was constructed.

Keywords: gravity surveys, Bouguer anomalies, maximum gradients, lineaments, density, Hungary

* Eötvös Loránd Geophysical Institute of Hungary, H-1145 Budapest, Kolumbusz u. 17–23.

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1. Introduction

Hungary's first steps towards a regional gravity survey were taken by Eötvös and his assistants on the frozen surface of Lake Balaton in 1901. The gravity measurements were carried out by torsion balances until the advent of gravimeters at the end of the 1930s. From the observed gradients the Δg values were also determined by integration, but the different survey regions could not be merged into a unified map because of the lack of a gravity base net. Since with gravimeters the relative value of gravity can only be measured between two points, the establishment of a gravity reference datum became a basic problem. The first gravity base network consisting of 168 points in the western part of the country (Transdanubia) was established by the Hungarian-American Oil Company (MAORT) between 1939 and 1940.

In the second half of the 1940s gravimeters gradually displaced torsion balances from gravity exploration so the establishment of a fundamental gravity base network for the whole territory of the country became a pressing necessity. The observations of the national gravity network had been carried out between 1950 and 1955. The network consisted of 16 first order and 493 second order points [FACSINAY and SZILÁRD 1956]. The national reference station of the survey was in the laboratory of the Department of Geodesy of the Technical University of Budapest. The reference point was tied to the absolute gravity point in Potsdam's Geodetic Institute, with relative pendulum measurements by K. Oltay in 1908 and 1915.

As a result of this connection the reference level of the first Hungarian gravity base network conformed with the Potsdam Gravity System, which is the reference point of the global gravity system as well. In later years the Hungarian Gravity Base Network was upgraded and updated so it is now converted to the absolute system [CSAPÓ 1996]. Since 1950 all gravity measurements carried out in this country have been tied to the national base network. The first regional gravity map series of Hungary was prepared in the 1960s. At that time a large part of the country was surveyed by torsion balance only so the isogams calculated from gradient values were converted into the gravity base net. The reconnaissance gravimeter survey of the country consisting of 120 000 points (1.2 point/km^2) was completed and stored in computer readable form (punched cards) at the end of the 1970s.

In later years the gravity data base was complemented by the data of detailed gravity surveys carried out partly by ELGI, partly by the oil industry. At present the gravity data base contains 380 000 points all in the same gravity system. During recent decades several national Bouguer anomaly maps based on different data bases were prepared but because of the confidential nature of gravity data they were not published.

2. The Bouguer anomaly map

'If the earth were a homogenous sphere at rest, gravity would be the same everywhere over the surface of the earth and would vary only radially, and the level surfaces would be spherical and concentric with the earth's surface. But the earth is not at rest; it is not a sphere, and its outer crust is in no way homogeneous' [BARTON 1929].

The rock bodies that make up the lithosphere are very irregular in size, density, and distribution consequently they produce varying anomalies of the gravity field. The magnitude of anomaly locally is at a maximum in the case of excess mass and at a minimum with deficiency of mass.

Those factors which affect the observed gravity are: the station elevation (because of the varying distances from the centre of the earth), irregularities of topographic form, the normal gravity field of the earth, and the density of the masses between the station and the reference elevation (generally sea level).

To make each observed gravity value comparable with every other one the effects of the above-mentioned factors have to be taken into account and the observed value should be reduced by them to a common datum, which considers not only the elevation, but also the Bouguer effect, the earth's normal gravity field, and the topography.

In order to calculate the Bouguer and terrain effects the density of the mass between the station and the elevation datum and the topography around the station have to be determined. In normal conditions the density determination is the crucial point of the reduction. The problem is even more important if the near-surface density has lateral variations between 2000 and 2670 kg/m^3 as in the case of Hungary. For an exact solution a three-dimensional density model would be required. Since density information is far from a three-dimensional model we had to restrict ourselves to estimates and approximations.

Direct determination of the density can be performed by laboratory methods measuring mass and volume of rock samples collected from outcrops or drilling cores. In gravity exploration an indirect density determination is possible by the method of Nettleton [NETTLETON 1939]. The hypothesis is based on the assumption that the Bouguer anomalies, if computed with correct density, do not correlate with the topography. The method can be applied for gravity profiles and area surveys as well. The Bouguer anomalies have to be calculated with different density values and then correlated with the topography. In other words, the correct density is where the calculated Bouguer anomalies have the least correlation with the topography.

Before constructing the Bouguer anomaly map we carried out density determinations with the Nettleton method for various hilly and mountainous regions of the country. From the results it could be concluded that the internationally accepted σ=2670 kg/m^3 density value can be regarded as a good approximation for all but one of the investigated regions. The exception is the neovolcanic area of the Zemplén Mts. where due to the predominantly tufaceous build up of the region, σ=2000 kg/m^3 was determined (*Fig. 1*).

The main problem in constructing a Bouguer anomaly map with variable density is the transition zone between geological structures with sharp density contrast. A sharp density difference in the Bouguer correction of neighbouring stations produces a high fictitious gradient in the Bouguer anomaly map which can lead to serious misinterpretations. To eliminate the distortion effect of density transitions we applied an elevation-dependent density function in the 100–435 m height interval:

$$\sigma_h = \sigma_0 + 0.01\frac{h - h_0}{5}$$

where σ_h: density in elevation h

σ_0: 2000 kg/m^3 density in h_0=100 m elevation

Fig. 1. Location map with the contours of the basement in km units
1. ábra. Helyszínrajz a medencealjzat km-es szintvonalaival

h: elevation of the point in m unit
$\sigma = 2000$ kg/m^3 if $h \leq 100$ m
$\sigma = 2670$ kg/m^3 if $h \geq 435$ m

Using these elevation-dependent density values for the Bouguer corrections one can ensure gradual transition in the Bouguer anomalies and the likelihood of fictitious anomalies arising could be prevented.

The Bouguer anomaly map presented here (*Fig. 2*) is based on 380 000 randomly distributed gravity data. The basic parameters of the map are given in the figure.

3. Some characteristics of the map

It can be seen on the Bouguer anomaly map that the deep basin areas have smooth anomalies with low gradients. In those parts of the country where the basement is on or near to the surface the anomalies become more disturbed and high gradients usually prevail.

The most characteristic features of the map are the elongated anomalies of NE–SW strike. This pattern of the anomalies served as one of the main clues to the nowadays generally accepted view of the basement topography and structure. It must be noted however that gravity anomalies reflect the effect of mass excess and mass deficiencies which may or may not be directly connected with different geological formations. It is worth mentioning that the highest anomalies are not in that region where the high-density basement (dolomite and crystalline limestone) is outcropping but in the lower middle part of the country where the basement is below sea level.

Another interesting feature of the map is the about 25–30 mGal difference between the anomalies of the deep basins of the SE part of the country (Békés basin, Makó trough) having the higher values and those of the W and NW part (Zala basin) having the lower values. This phenomenon can be regarded as originating from crustal sources, viz. from the isostatic effect of the Alps.

4. Aspects of gravity interpretation

Here, it is not our intention to interpret the Bouguer anomaly map, but to call attention to some basic characteristics that should be kept in mind when interpreting gravity maps.

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 of layers of horizontally uniform density, there would be no gravity anomalies even if vertical variation in density were to exist.

Since the Bouguer anomaly map reflects the integrated effect of subsurface masses the anomaly map is a complex pattern 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 speaking, sharp anomalies are caused by near-surface sources, broader anomalies by deep ones.

To illustrate the smoothing effect of the depth we present the gravity effect and its horizontal gradients of a vertical fault with 400 m throw at four different depths (*Fig. 3*). The density contrast between the hypothetical basement and the sediment was determined from the density function of

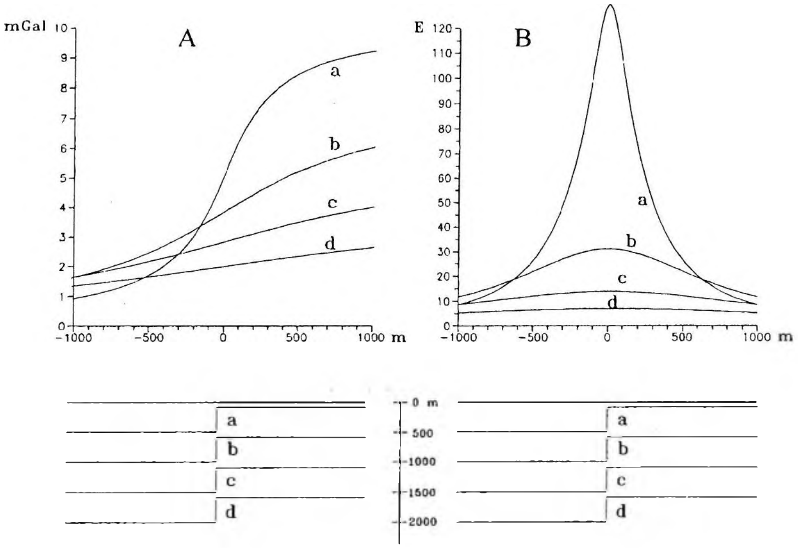

Fig. 3. Vertical fault: A – gravity effect; B – horizontal gradients

3. ábra. Függőleges vető: A – gravitációs hatása; B – horizontális gradiense

the sedimentary cover. The figure represents the masking effect of the sedimentary cover, i.e. in spite of the rugged topography of the basement the gravity contours are smooth and the corresponding gradients are low if the basement lies at a great depth.

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

For separating the different elements many procedures have been devised: 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 — which is equivalent to enhancing certain frequencies and suppressing 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 since it refers to broad anomalies with sources normally deeper than the target of prospecting. It is difficult to differentiate between residual and derivative maps, but it is important because residual maps reflect the gravity effect of local sources relatively near to the surface and derivative maps reflect the gradient of the gravity field. These latters 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 resolution 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 the prospecting: e.g. 'residual' has a completely different meaning in the case of ore prospecting and in the case of oil exploration.

According to PINTÉR and STOMFAI [1979] one possible way of characterizing map variations is by using the distribution of anomaly values. Maps with broad anomaly distribution curves can be regarded as residual ones, 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 one may reach wrong conclusions by interpreting a residual map as a derivative one or vice versa. Therefore it can be stated that there is no single or direct solution for eliminating regional effects and isolating 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 data (borehole data, seismic profiles, etc.).

As a conclusion, it has to be mentioned that Bouguer anomalies contain all information about the gravity field of a prospect area. The different transformations of the Bouguer anomaly map do not create new information but only emphasize certain elements or features of the original field to make it easier for the interpreting geologist to recognize such characteristics of the field which are not evident in the original Bouguer anomaly map.

5. Determination of lineaments based on maximum gradients of Bouguer anomalies

In basin areas, where the high-density basement is overlain by young, loose sediments, the topographical changes of the basement present themselves in a horizontal plane as density contrasts. The best way to detect a density contrast along a line is to analyse the horizontal gradient of the gravity field. The unit of the gradient is 1 E (Eötvös). Expressing this in a more practical way: 1E=0.1 mGal/km, i.e. gravity acceleration changes by 0.1 mGal within a distance of 1 km. In geological practice the gradient changes from 1–100 E. Above a fault where an abrupt density change exists, the horizontal gradient has a local maximum (Fig. 3). This phenomenon is utilized in determining structural lineaments.

As a first step, the Bouguer anomaly values were interpolated to a 1 km grid and from these interpolated values the horizontal gradients were calculated. A computer program had earlier been developed for the selection of local gradient maxima. The program's parameters can flexibly be varied depending on the radius of the neighbourhood to be studied and on the prescribed difference from the average to be selected. Moreover, the program can take into consideration the neighbouring gradients as well, when selecting the locations of gradient maxima. Since the gradients are perpendicular to the strike of the fault a new computer program has been developed to present the gravity lineaments reflecting the strikes of tectonic elements. In deep basins the Bouguer anomaly contours are smooth and have low relief because the main anomaly source, the basement, is deep and the density contrast between the sedimentary fill and the bedrock decreases with increasing depth. As a consequence the gradients of the gravity field are higher over areas where the bedrock is outcropping or is at a relatively shallow depth. In deeper basins, however, the gradients are low in spite of the possible rugged topography of the basement. This effect is illustrated in Fig. 3. It can be seen that the magnitude and the sharpness of the anomaly decrease considerably with increasing depth. To eliminate this distorting effect a depth dependent density correction was applied to the gradients. If we take the density of the near-surface sediments to be 2000 kg/m^3 and that of the basement to be 2670 kg/m^3, the near-surface density difference is 670 kg/m^3. By correction, the decreasing density difference with depth was normed to this 670 kg/m^3 value. The depths belonging to the gradients were taken from the pre-Tertiary basement topography map of Hungary [KILÉNYI et al. 1991], and the density values from the density versus depth function of Tertiary sediments [SZABÓ–PÁNCSICS 1999]. The correction enhanced the effect of deep-seated tectonic elements.

The gradient map is given in two different representations which complement each other (*Fig. 4, Fig. 5*). In Fig. 4. the lineaments are more characteristic but Fig. 5 is more expressive. Integrated study of the two maps helps one to understand the nature and importance of the different features, and to detect those structural lines taking part in the shaping of basement topography.

The gradient maps reflect the main structural lines of the country; most of them are more or less known from former studies. Here we would call attention only to the two lines marked ‘a’ and ‘b’ in Fig. 5. Line ‘a’ marks what is probably the eastern limit of the granitic belt of the basement extending from the western border of the country along the southern bank of Lake Balaton, its most eastern known manifestation is the granitic outcrop of the Velence Hills (No 5 in Fig. 1). Line ‘b’ offers an answer to the so far unresolved problem of the separation of the Mesozoic formations of the Transdanubian Central Range from the Triassic rocks of the Bükk mountains. We have stressed the importance of these two lines only, but further study of the maps — especially on a larger scale combined with geological information — will reveal more details about the geological structure of different regions. It is planned to deal with this topic in a future paper.

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Magyarország változó sűrűséggel korrigált Bouguer anomália térképe

SZABÓ Zoltán és PÁNCSICS Zoltán

Magyarországon az első gravitációs felmérést Eötvös végezte 1901-ben. A cikk írásának időpontjáig a gravitációs adatbnak kb. 380 000 gravitációs állomás adatait tartalmazta, mely átlagosan 4 pont/km állomássűrűségnek felel meg.

A bemutatott Bouguer anomália térkép a teljes adatkészlet felhasználásával készült. Egységes Bouguer anomália térkép szerkesztése egy olyan területen, ahol a felszínt alkotó kőzetek sűrűsége 2000–2670 kg/m^3 között változik meglehetősen nehéz feladat. Helytelen sűrűség alkalmazása a Bouguer- és terrén-korrekció meghatározásánál a gravitációs térkép alul-, vagy túlkompenzálását okozza. Területtől függő sűrűség alkalmazása következtében viszont fiktív anomáliák jelenhetnek meg az átmeneti zónákban. A szerzők, hogy elkerüljék fiktív anomáliák kialakulását egy magasságtól függő sűrűségfüggvényt alkottak és ezt alkalmazták a Bouguer- és terrén-korrekció meghatározásánál.

Tárgyalják a térkép néhány jellegzetes vonását és a gravitációs értelmezés lehetséges szempontjait. A maximális gradiens módszerével gravitációs lineamens térképet szerkesztettek, hogy megkönnyítsék a gravitációs térkép szerkezeti értelmezését.

ABOUT THE AUTHORS

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