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Statistical study of ground geophysical potential field data from areas of East Hungary

Sándor KOVÁCSVÖLGYI*

Results are presented of new statistical studies that follow the method of our earlier Transdanubian (West Hungary) studies, but now data are used from areas in East Hungary. In the latter, the geophysical image is much more complex than that experienced in Transdanubia. In particular, a new element is the anomalously high conductance of certain Pannonian sediments and the gravity step running roughly along the Middle Hungarian Line. A gravity anomaly map reduced with the average curve characterizing the Transdanubian basement depth—Bouguer anomaly connection was constructed for the whole territory of the country based on which certain megastructural blocks can be delineated. Results of statistical studies may well be of support in the interpretation work of applied geophysics.

Keywords: statistics, tellurics, cluster analysis, potential field, East Hungary

1. Introduction

With the completion of East Hungary's telluric database and the area's telluric conductance map (Enclosure 1) it is now possible to carry out an integrated statistical study of the geophysical potential field results from the regions covered by measurements. This work is a continuation of an earlier analysis carried out on the Transdanubian area [KOVÁCSVÖLGYI, OCSENÁS 2000], and it pursues a similar methodology.

2. Basic data, methods of study

Three geophysical data systems (Bouguer anomaly, geomagnetic anomaly, telluric conductance) are available from the area, and there is a map of the pre-Tertiary basement's surface. Because the density and reliability of the individual data differ, the various peculiarities of the data sets are briefly reviewed.

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—The map of the surface of the pre-Tertiary basement [KILÉNYI, ŠEFARA 1991] was fundamentally constructed from borehole and seismic data, and in areas without such data by taking into account telluric and gravity anomalies. The map's reliability is variable because it depends on the existence of real data concerning the depth to the basement in the given area; it indicates the wells used in the course of construction and characterizing certain areas.

—The basis of the gravity data set is the national gravimetric database [KOVÁCSVÖLGYI 1994, MILÁNKOVICH 1995]. In a considerable part of the area surveying took place along roads typically 2–3 km apart, with a station separation of 500 m. In some earlier hydrocarbon investigation areas, measurements were performed in a grid of 500×500 m, and in the Bükk and Mátra mountains in a quasi-grid with a density of 8–16 station/km^2. The estimated accuracy of Bouguer anomaly values is 0.1 mGal. This data network permits construction of a reliable interpolated 2×2 km grid (see Enclosure 1).

—The basis of the geomagnetic data system is the national geomagnetic database [MILÁNKOVICH 1995]. This consists of the stations of countrywide reconnaissance ground ΔZ measurements performed and uniformly processed in the 1950s and 1960s. During the course of processing the map constructed was published on a scale of 1:500 000 [HAÁZ, KOMÁROMY 1966]; it is now presented on a scale of 1:1 000 000 as part of Enclosure 1 of the present publication. The measurement stations form a quasi-grid of 1.5×1.5 km. The estimated accuracy of the observations is 5 nT. The anomaly values determined for the measurement stations were interpolated in a grid of 2×2 km.

—The telluric database includes data of measurements performed in different exploration projects. The density of measurement stations is different in the individual sub-areas; there are absolutely no measurements in the areas of basement outcrops, but several large connected areas without data can be found in the basin areas as well.

Thus, we were able to construct a reliable 2×2 km grid for the whole area for three of the four different data systems. Therefore, the concrete survey area was put into shape bearing in mind the absence of telluric data. Because statistical processing does not require connected polygons formed by the subareas that were studied, the following method was chosen: only those 2×2 km squares were involved in the statistical study in the area of which at least one telluric measuring station can be found.

Theoretically the Bouguer anomaly and the telluric conductance are closely connected with the depth to the pre-Tertiary basement. Because the density and electric resistivity of the basement are higher than those of the overlying sediments, by increasing the basement depth a decrease in the Bouguer anomaly values and an increase in telluric conductance can be expected. The aim of statistical processing is, on the one hand, to check where and under what kind of circumstances the above statement is valid and, on the other hand, to delineate those areas where the connection between the above three parameters can be considered identical.

Judging from our earlier correlation studies [KOVÁCSVÖLGYI 1999] it cannot be expected on a countrywide scale that a connection exists between the magnetic anomalies and the three other parameters. At the same time, it cannot be excluded that such a connection exists locally (e.g. when the source of the magnetic anomaly can be found at the surface of the pre-Tertiary basement), therefore magnetic anomalies were also taken into account in the study.

Similarly to the Transdanubian studies [KOVÁCSVÖLGYI, OCSENÁS 2000] at first the overall area was divided into several large regions and in these the statistical connections between the depth to the basement and the Bouguer anomalies and, on the other hand, the telluric conductance were separately studied, then cluster analysis was carried out over the regions, and the connections between the parameters were separately examined within the area of the individual clusters.

To investigate the connections between the depth to the basement and the geophysical parameter values for 500 m wide intervals of the basement depths the average of the basement depths and of geophysical parameters belonging to the points of the given data set falling into the given interval were calculated, and plotted as curves. To increase the statistical data number and to smooth the random fluctuations the 500 m wide interval was shifted on and on by 250 m (half width) to obtain the next interval. Those points at the edges of the curves where averaging is unreliable due to the low data number were not taken into consideration and are not plotted in the curves.

A central non-hierarchic cluster analysis was applied. This procedure considers the standard values of *n* parameters as coordinates of an *n* dimensional space. Initial core centre coordinates were randomly ordered to each cluster after which data were compartmentalized to that cluster to whose core centre they lie closest. After determining the real centre of the division developing in this way classification into clusters is repeated. The procedure is reiterated until the classification no longer changes (i.e. all points remain in the cluster they reached in the previous iteration step).

For the regions, cluster analysis was carried out with four parameters (complete data systems), and with three parameters (without the magnetic anomalies). Each four-parameter experiment showed that the magnetically anomalous points were arranged in a separate cluster, i.e. involvement of magnetic anomaly values in the study did not lead to new information: instead, it decreased the efficiency because this parameter influences the position of the core centres in the 'non-magnetic' clusters as well.

The optimum number of clusters was experimentally determined. In the case of each region the four-cluster division proved to be the most informative; application of 5–6 clusters provided excess information only in the case of division into preliminary (incorrect) regions (see later).

2.1. Delineation of regions

Statistical studies do not take into account the geological–geophysical content of the applied data. Thus, the smaller the site we work on the more efficient the study because the smaller the site the more likely it is that the geological–geophysical conditions do not change essentially, or we experience only one or two statistically detectable essential changes. At the same time the smaller the site the lower the data number, this worsens the possibilities for statistical processing. In that the investigated site represents almost half of our country's territory; it seemed to be a prerequisite to separate the regions about which it is known in advance that they essentially differ from each other. Because the two geophysical parameters primarily depend on the depth to the basement, separation according to the basin structure seemed to be plausible. According to the delineation shown in *Fig. 1*, region 1 falls within the Northern Middle Ranges. Because there were no telluric measurements in the outcrop areas, the area that was actually studied includes only the edges of the mountain ranges and the smaller inner basins. Region 2 is a deep graben, 4 is an area crossed by deep grabens and elevations, while region 3 is a featureless, relatively shallow (about 2 km deep) basin lying between 2 and 4. The strike of the lines separating the regions coincides with the area's main tectonic, ENE–WSW, direction.

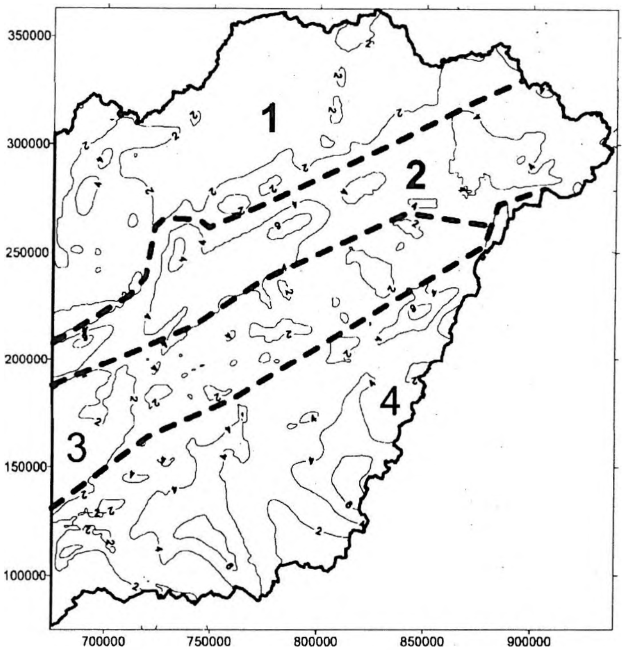


Fig. 1. Location of preliminary regions

1. ábra. Elsődleges régiók elhelyezkedése

Figure 2 shows the statistical connection between the depth to the basement and the Bouguer anomaly values for the four regions. It can be said that the curves of regions 1 and 2, and 3 and 4, respectively, run very close to each other; there is, however, a 6 mGal difference between the two groups: the two northern regions are at a much lower anomaly level. A similar phenomenon is experienced in *Fig. 3* that shows the statistical connection between the basement depth and telluric conductance. The four curves — at least from

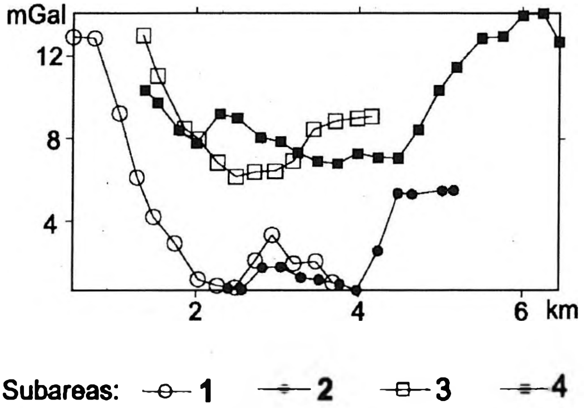
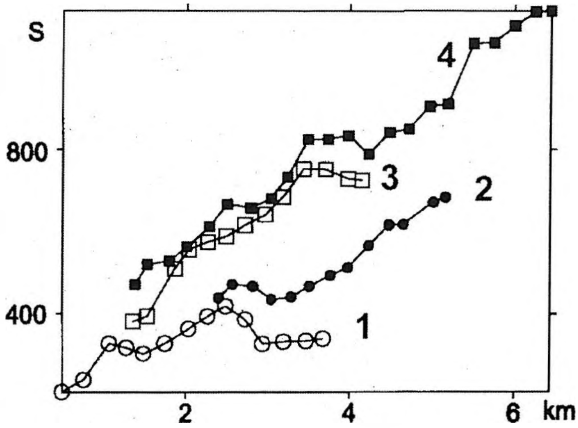


Fig. 2. Dependence of Bouguer anomalies on depth to the basement surface

2.ábra. A Bouguer-anomáliák függése az aljzatfelszín mélységétől a basement depth of 1.5 km — form two groups: the curves of the two northern regions 1 and 2 show a level of 200–300 S lower than the curves of the southern regions 3 and 4. These findings demonstrate that our initial division was not correct because it seems that the parameters do not form four, but only two groups. At the same time a simple contraction of groups is not a necessarily correct solution because it is not definitely known whether the boundary between the 'northern' and 'southern' types runs at the edge of the Middle Hungarian Graben. For the sake of a more accurate grouping average curves were constructed for both connections and the points were classified according their position, i.e. the corresponding parameter pairs were located above or below the average curve. The above grouping based on the Bouguer anomaly—basement depth and telluric conductance—basement depth connections led to similar results; finally, delineation of regions was performed on the basis of the Bouguer anomaly—basement depth connection because the regions' diversity and similarity here definitely present themselves throughout the whole depth interval (see Figs. 2 and 3).



3.ábra. A tellurikus vezetőképesség függése az aljzatfelszín mélységétől

Fig. 3. Dependence of telluric conductance on depth to the basement surface

Figure 4 shows the locations of the 'northern' and 'southern' type points. Finally, three regions were marked out: classification of the Nyírség (this is a larger region than the geographical territory) as an independent region is justified by the fact that the two types occur on areas of approximately equal extent, but the 'northern' type points can be found in the southern part of the region, while the 'southern' type ones in the northern part. At the same time geological information is also the most deficient here: in the absence of real data the applied basement depth map is in large measure based upon telluric and gravity data; in other words, the statistical connection, i.e. the basis for division, possibly might also partly be a consequence of the map construction procedure.

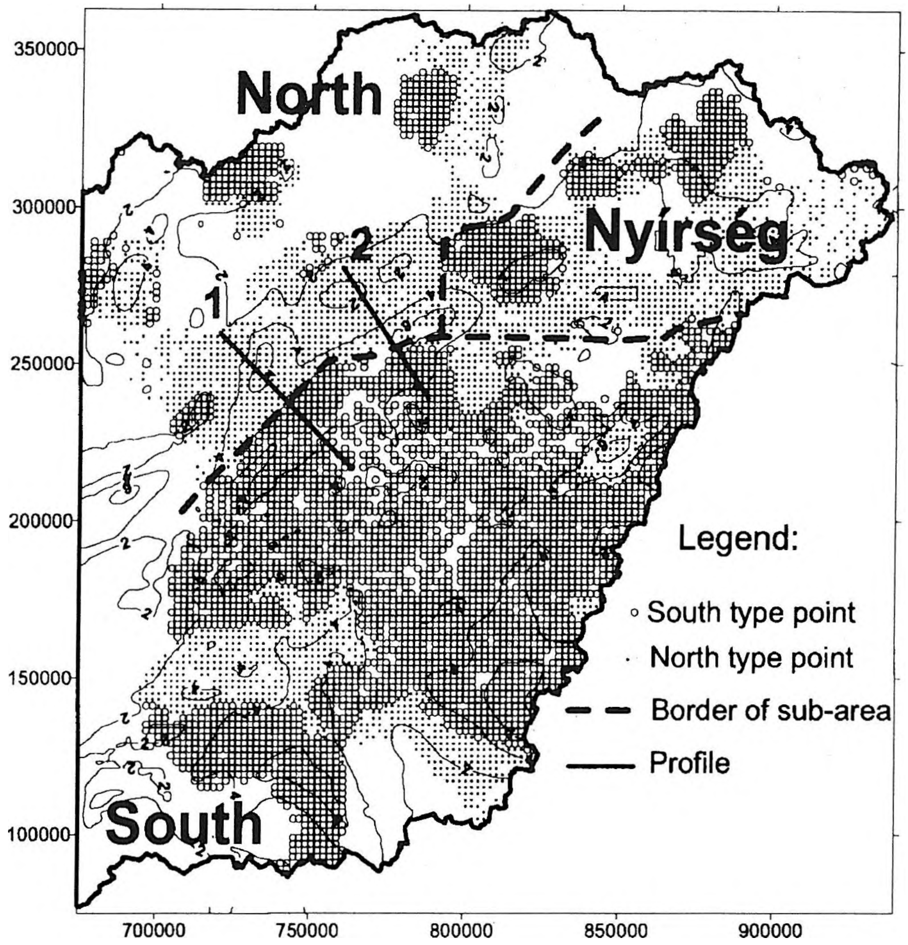


Fig. 4. Location of final regions

4. ábra. Végleges régiók elhelyezkedése

The boundary between the northern and southern regions runs roughly along the axis line of the Middle Hungarian Graben. Because here we were concerned with a division of statistical character, it was practical to check its reality along the profiles (lines: Fig. 4, 1, 2).

Profile 1 crosses the widening, branching part of the graben. The line of Bouguer anomalies (*Fig. 5*) is 'abnormal' along the total length of the profile. In the 0 km–15 km section, over the gradually deepening basement, slightly ascending Bouguer anomalies are experienced. The Bouguer anomalies go up ever more steeply from here, and they reach a maximum at

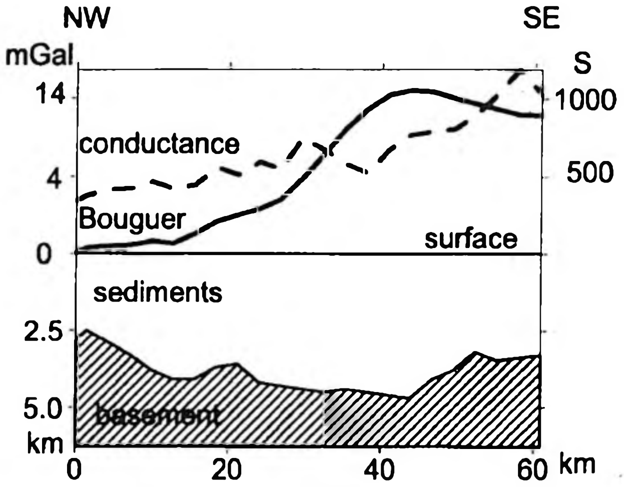


Fig. 5. Profile 1
5. ábra. 1. szelvény

42 km, over the basin's deepest point. From here a moderate decrease in Bouguer anomaly values accompanies the rise in the basement. Based on the anomaly image two effects, independent of basin structure, can be detected as well. A pronounced maximum accompanies the deep basin, as was already successfully demonstrated locally in several parts of the Pannonian Basin [POSGAY et al. 1995, KOVÁCSVÖLGYI 1999, KOVÁCSVÖLGYI, OCSENÁS 2000]. In addition, a step-like effect prevails as well that can be detected along the whole profile, as a result of this –5 mGal belongs to a basement depth of about 3 km at the NW end of the profile, while at the SE end 12 mGal to a similar basement depth; i.e. the change is 17 mGal. It seems that this step is responsible for the existence of 'northern' and 'southern' type connections. The previous effect, which is associated with the deep basin and prevails primarily in the 30 km–55 km section of the profile, is independent of this (at least in the geophysical sense).

The telluric conductance curve shows a rise — although loaded with fluctuations of varying size — roughly proportionally with the increase in sediment thickness till 30 km. In the 30–38 km section moderate deepening of the basin is associated with decreasing telluric conductance. In the 38–58 km section increasing telluric conductance belongs to the decreasing sediment thickness, i.e. the curve also shows an effect independent of basin structure.

Profile 2 runs over a typically wide part of the graben. The line of Bouguer anomalies (*Fig. 6*) is 'normal' in the 0 km–10 km section; it increases proportionally with the rising of the basement. In the 10 km–20 km section the values of Bouguer anomalies remain practically

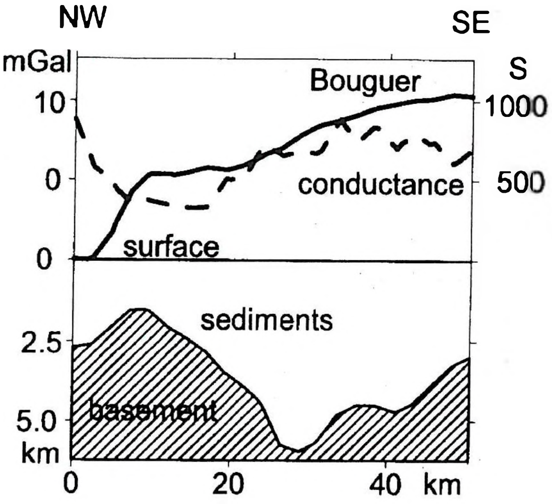


Fig. 6. Profile 2
6. ábra. 2. szelvény

at the same level over the rapidly deepening basement; a regional positive effect compensates the negative effect of the increasing sediment thickness. It should be noted that until 18 km the depth to the basement does not reach 2500 m. In such a relatively shallow case, however, results both of the Transdanubian studies [KOVÁCS-VÖLGYI, OCSENÁS 2000], and of the present work (see later) everywhere demonstrated statistically the decrease in Bouguer anomalies with increasing basement depth in agreement with the results of density studies [SZABÓ, PÁNCSICS 1999]. All these suggest that in fact a regional effect causes the peculiarity of this section of the profile. From 20 km the Bouguer anomaly's line shows a rising tendency independent of the changes in basement depth, and at the profile's SE end it practically sets in the 10 mGal level. Thus, the step effect experienced in profile 1 can be rendered likely from 10 km to the SE end of the profile; the extra maximum associated with the deep basin, however, cannot be observed. The step's magnitude is 20 mGal, –10 mGal belongs to the 3 km basement depth at the NW end ('normal' section), whereas +10 mGal to the SE end.

The NW part of the telluric conductance curve up to the graben's axis shows — on the whole — changes proportional to the sediment thickness. Southeastwards from here, however, it practically sets in at about the 700 S value; the observed fluctuations of various sizes are independent of the otherwise rapid changes in sediment thickness.

Summarizing what was found from the profiles, the following can be stated:

—The line of Bouguer anomalies suggests a density step as a result of which the Bouguer values belonging to the same basement depth are about 20 mGal higher at the southeastern end of the profiles than at the northwestern one. Other effects make determination of the step's exact place difficult, but it can be assumed that it runs in the deep graben's neighbourhood. This step's presence causes the gravitational discrepancy between the detected 'northern' and 'southern' types. The step's effect can be detected in a 40–50 km wide zone.

—Independently of the density step a Bouguer maximum may appear over the deep basins.

—The behaviour of the telluric conductance changes on crossing the graben's axis. NW of the graben telluric conductance increases together with the sediment thickness, while SE of it it changes independently of that.

—Based on the two parameters' study it is realistic to draw the boundary of 'northern' and 'southern' types' extension in the graben's axis.

2.2. General connections between the geophysical parameters and the depth to the basement

Figures 7 and *8* present the statistical connections between the parameters in the regions obtained by the final division. Our Transdanubian studies [KOVÁCSVÖLGYI, OCSENÁS 2000] showed that the Bouguer anomaly—basement depth curves of those regions, especially in the 2–5 km depth interval, run very close to each other. Therefore we determined the

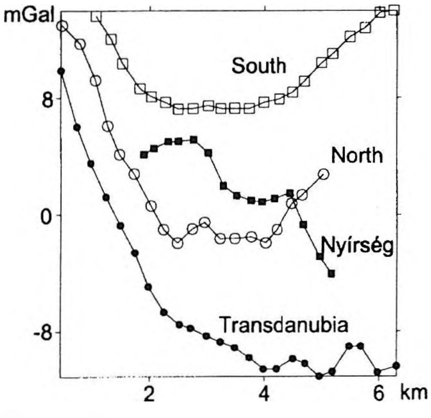


Fig. 7. Dependence of Bouguer anomalies on depth to the basement surface

7. ábra. A Bouguer-anomáliák függése az aljzatfelszín melységétől

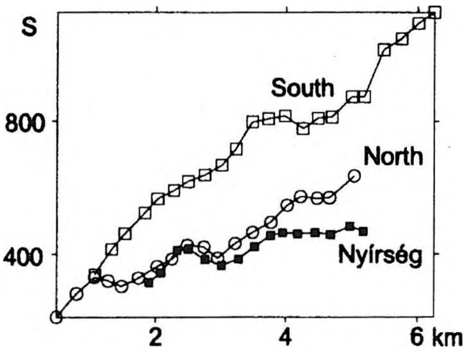


Fig. 8. Dependence of telluric conductance on depth to the basement surface

8. ábra. A tellurikus vezetőképesség függése az aljzatfelszín mélységétől average curve for the whole Transdanubian material (see Fig. 7). In the case of telluric conductance this method could not be used because the curves of the individual Transdanubian regions showed remarkable differences, thus the average for the whole region is not interpretable. It is noted, however, that it was a peculiarity of the Transdanubian regions' curves that the rise of telluric conductance stops somewhere between 2 km and 3.5 km basement depth and from here the conductance remained practically at the same level. One of the differences between the individual regions was the precise depth that belongs to this level setting and the conductance level itself.

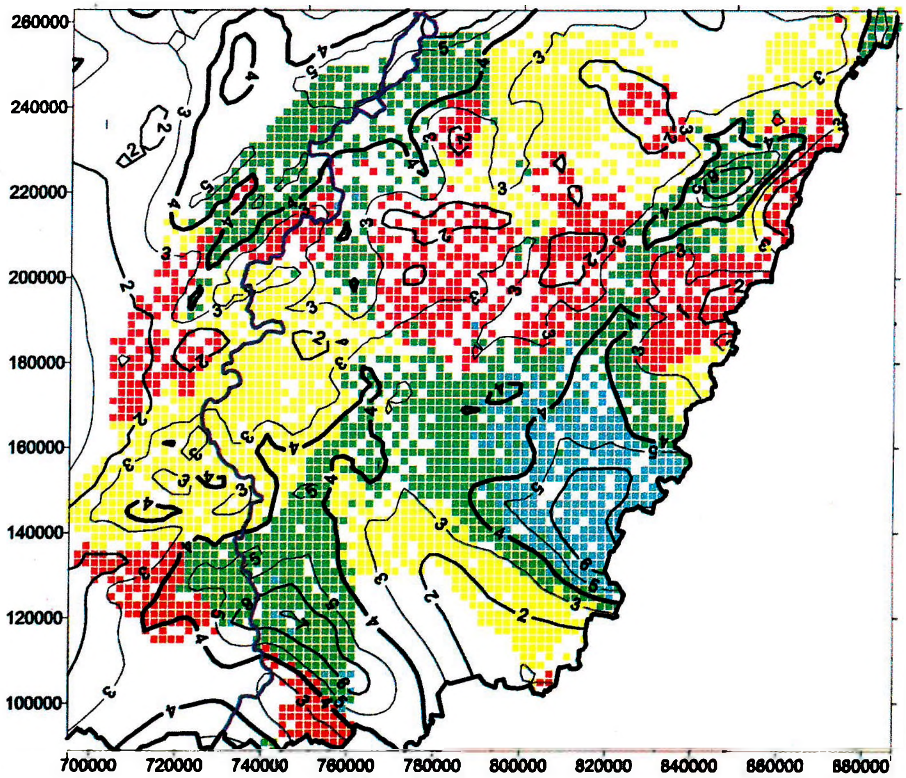
According to Fig. 7 the 'northern' and 'southern' type curves, apart from the different levels, are very similar. Down to a basement depth of 2.5 km, we experience a rapid decrease, then from 2.5 km down to 4 km the curves remain practically at the same level; at basement depths greater than 4 km the Bouguer anomaly values increase with basement depth. Compared with the Transdanubian reference curve it is a significant difference that the Bouguer values further decrease there in the 2.5 km–4 km depth interval although the extent of this decrease is significantly smaller than in the upper 2 km. In addition the Transdanubian curve does not show a monotonic rise below a basement depth of 4 km but a fluctuation of values. In the course of our earlier studies [KOVÁCSVÖLGYI, OCSENÁS 2000] we revealed that the reason for this is that from the area's deep basins the elevated position of deep structural elements (lower crust, mantle) can be found below the Little Hungarian Plain, while not below some parts of the Drava Basin.

In the depth interval of 2.5 km–4 km the level difference between the 'northern' and 'southern' type curves is 10 mGal. This is not in contradiction with the step of 17–20 mGal detected in the course of the two profiles' study because there definite profiles were studied in contrast to the statistical average of large areas (Fig. 7). In connection with the profiles we found that the change in level takes place gradually in an about 40–50 km wide zone, thus this transition zone can draw considerably closer the two curves in spatial average. The difference between the 'southern' curve and the Transdanubian reference curve studied at 4 km basement depth is already 18 mGal. Bearing in mind that Transdanubia supposedly lies outside the transition zone the 18 mGal can be considered a realistic difference and it agrees with what was experienced from the profiles.

To explain the higher Bouguer level of the 'southern' area it would be reasonable to consider the difference in density of formations that can be found near to the basement surface. Geological data, however, do not support this assumption; in addition, if this were to be correct, at small basement depths a larger difference should be obtained between the curves because in this case the density contrast is closer to the surface. According to Fig. 7, however, the situation is the opposite: at 1 km basement depth the 'southern' curve is by 5 mGal above the 'northern' and by 12 mGal above the Transdanubian curve, as opposed to the 10 and 18 mGal mentioned at larger depths. Consequently, the reason for this phenomenon could be linked with the morphological peculiarity, probably with the density conditions of deep structural elements (lower crust, mantle). Unfortunately, at present up-to-date seismic material suitable to study this question is not available. In the near future, however, results of the seismic lithospheric investigations carried out in the framework of the CELEBRATION 2000 project [BODOKY et al. 2001] will be processed and published, and thus it is worth returning to this question. It should be noted that a relatively small elevation of the mentioned deep structural elements can already generate the seemingly significant gravity effect. Because both at the Mohorovičić surface and at the lower crust—upper crust boundary an about 300 kg/m^3 jump in density can be expected: calculating with an infinite Bouguer plate the effect of 18 mGal corresponds to a 1400 m elevation in one of the mentioned horizons. If the two horizons' morphology is similar (i.e. both show elevation at the same place) a hardly 700 m change in level can cause the experienced gravity step.

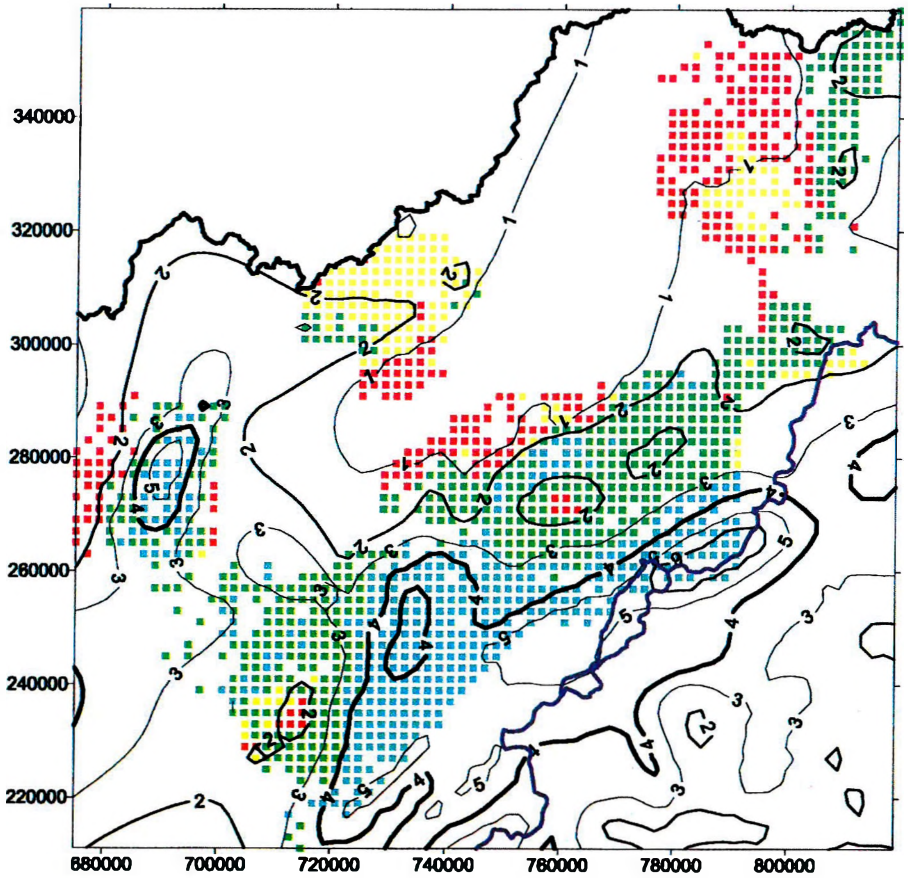
The curve of Nyírség significantly differs from the others. In the 2 km–3 km interval it shows a moderate rise (and its level is closer to that of the 'southern' curve); starting from 3 km at first a large decrease then a settling is experienced, as a consequence the curve gets closer to the 'northern' type. From 5 km the curve abruptly decreases.

Figure 8 shows the statistical change in telluric conductance as a function of the depth to the basement surface. It can be stated that the level setting experienced at large depths in the Transdanubian area can be detected neither on the 'northern' nor on the 'southern' curve. A possible reason for this may partly be that good conductors may also appear in the deep basins among the basement formations. At the same time it is known that the resistivity of the Pannonian sediment in the Békés Basin is extremely low (2–5 Ωm), i.e. the local changes in the sediment's conductance



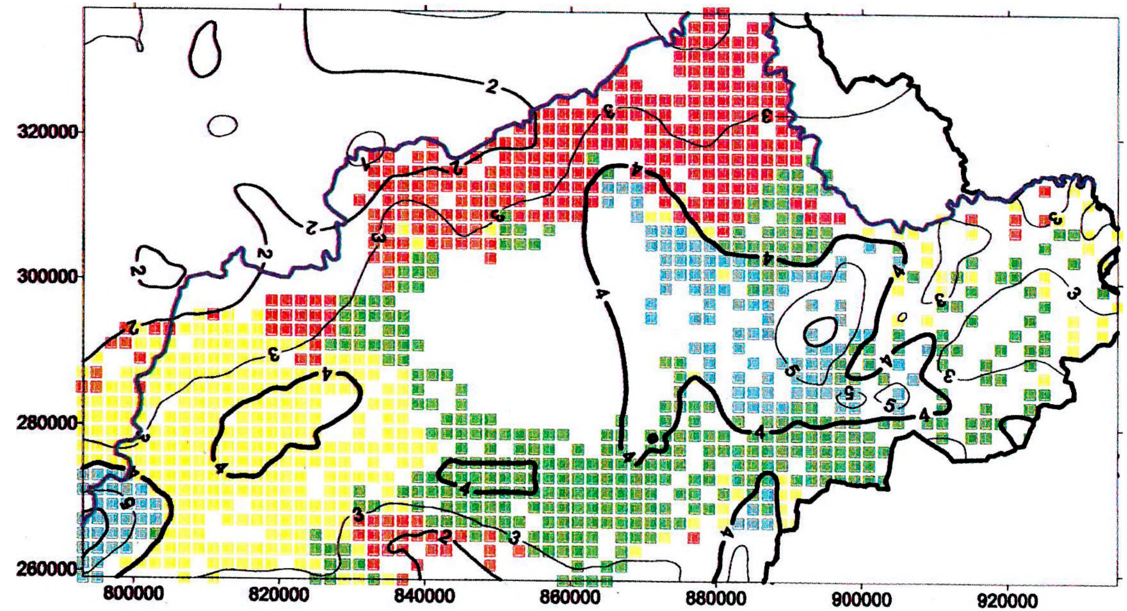
9. ábra. A déli terület klasztertérképe

Fig. 9. Cluster map of the Southern area



10. ábra. Az északi terület klasztertérképe

Fig. 10. Cluster map of the Northern area



11. ábra. A Nyírség klasztertérképe

Fig. 11. Cluster map of the Nyírség area

also influence the statistical results. The 'southern' curve rises more steeply in the interval shallower than 2.5 km (Pannonian sediments of the Békés Basin!) than the 'northern' one; from here, however, a difference of about 200 S becomes stabilized. The curve of Nyírség practically coincides with the 'northern' one in the interval shallower than 3.5 km; from here, however, it runs further horizontally.

3. Results of cluster analysis

Results of cluster analysis are plotted in cluster maps (*Figs. 9–11*), where dissimilar colours mark the different clusters. The colours correspond to the clusters' average basement depth: red marks the shallowest cluster, then yellow, green and pale blue mark the clusters with increasing depth. In the figures (*Figs. 12–17*) presenting the connection between the geophysical parameters and the depth to the basement, digit 1 corresponds to the cluster marked with red in the maps, 2 to the yellow, 3 to the green, and 4 to the blue clusters.

In Figs. 9–11 the country border and the Tisza river are marked to facilitate orientation, and with contour lines the simplified version of the KILÉNYI–ŠEFARA [1991] map as well.

3.1. 'Southern' area

The cluster map of the area is Fig. 9. Figure 12 presents the Bouguer anomalies' dependence on basement depth, and Fig. 13 the telluric conductance's dependence on basement depth.

It can be seen in Figs. 12 and 13 that clusters 1 and 2, and 3 and 4 pair-wise cover basically the same depth interval. In the case of the two shallow clusters the telluric conductance curves also follow a similar line (Fig. 13, 1, 2); the difference between their levels is little as well. The reason for classification into a

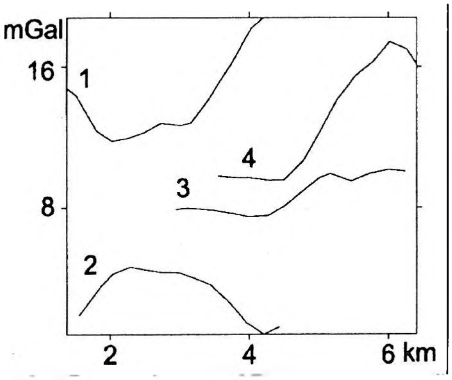


Fig. 12. Dependence of Bouguer anomalies on depth to the basement surface in clusters of the 'southern' sub-area

12. ábra. A Bouguer-anomáliák függése az aljzatfelszín mélységétől a déli terület klasztereiben

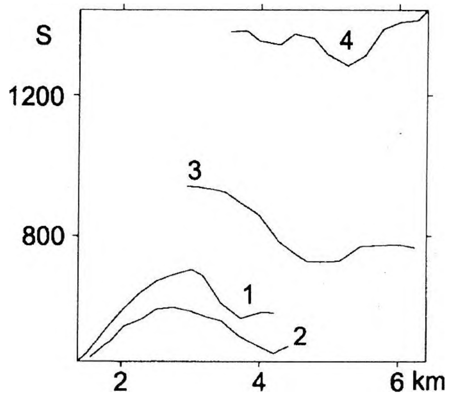


Fig. 13. Dependence of telluric conductance on depth to the basement surface in the clusters of the 'southern' subarea

13.ábra. A tellurikus vezetőképesség függése az aljzatfelszín mélységétől a déli terület klasztereiben

separate cluster is the differing behaviour of Bouguer anomalies (Fig. 12, 1, 2). Considering the curve's shape in cluster 1 it is similar to the average curve of the 'southern' area (Fig. 7): down to a depth of 2 km decreasing tendency, considerable increase from 3.5 km. Its level is, however, higher by about 4 mGal. The curve of cluster 2 (Fig. 12, 2), on the other hand, shows peculiarities differing from the 'southern' average curve (Fig. 7): down to 2 km it increases, then from 3.5 km it rapidly decreases, it takes place by 4–8 mGal below the 'southern' average curve. Considering the spatial locations of the points in cluster 2 (Fig. 9, yellow points), which can be regarded as anomalous behaviour, it can be stated that they concentrate at the edges of the 'southern' area where the area's boundaries were drawn on an ad hoc basis because of the absence of data. As a consequence it can be assumed that this cluster's points are not uniform from the geological, crust structural viewpoint, those shallow areas acquired here the gravity behaviour which differs from that of the 'southern' areas' typical points.

The Bouguer curves of the two clusters for deep basins (Fig. 12, 3, 4) are similar, but cluster 4 shows a more rapid rise at greater depths than 5 km in contrast to cluster 3. The tendency in the telluric conductance curves is similar (Fig. 13, 3, 4: decrease down to a depth of 4–4.5 km, and increase from there), but the level significantly differs, the curve of cluster 4 is by about 500 S higher. In Fig. 9 it can be seen that the points of cluster 4 (blue) form a structural unit (Békés Basin). Its gravity (and magnetic) anomalies were earlier interpreted on the basis of seismic profiles from lithosphere investigations [POSGAY et al. 1995], and it was found that they are caused by the elevated position of the lower crust and the mantle. Our present studies complete this with the anomalous high value of telluric conductance here: but this is caused partly by the known anomalously low resistivity of Pannonian sediments and partly by the appearance of low resistivity Late Cretaceous formations in the basement.

3.2. 'Northern' area

The cluster map of the area is Fig. 10; Fig. 14 presents the dependence of the Bouguer anomalies on basement depth, Fig. 15 the dependence of the telluric conductance on basement depth.

Based on Figs. 14–15, clusters 1 and 2 fall on roughly similar areas of shallow, less than 2 km deep basins, cluster 3 corresponds to a medium (1.5–3.5 km) depth, while cluster 4 to a deeper (2.5–5 km) zone that partly overlaps the zone of cluster 3. In the case of the two shallow clusters the Bouguer curves (Fig. 14, 1, 2) are very similar to each other; the level of telluric conductance, however, significantly differs (Fig. 15, 1, 2): in the case of cluster 1 this is 150–200 S, while in the case of cluster 2 this is 500–600 S. It should be noted that the telluric curves of these two clusters do not show the unambiguously increasing tendency previously observed in the shallow position throughout the country (Transdanubia, and 'southern' areas of the present study). Judging from Fig. 10, the points of the two shallow clusters appear in many cases intermingled with each other. The points of cluster 2 (yellow) that can be characterized by anomalously high telluric conductance form two relatively large connected areas: the western patch along the country's border falls on the area of very young, Pleisto-

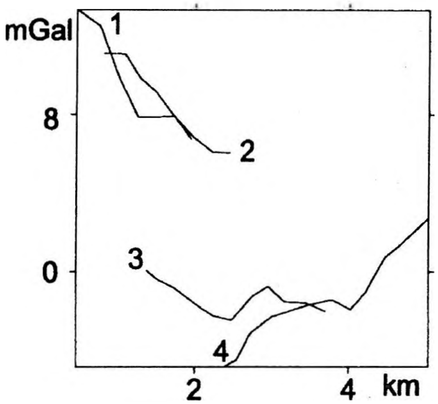


Fig. 14. Dependence of Bouguer anomalies on depth to the basement surface in clusters of the 'northern' sub-area

14. ábra A Bouguer-anomáliák függése az aljzatfelszín mélységétől az északi terület klasztereiben

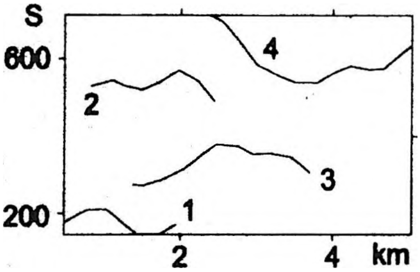


Fig. 15. Dependence of telluric conductance on depth to the basement surface in clusters of the 'northern' sub-area

15. ábra. A tellurikus vezetőképesség függése az aljzatfelszín mélységétől az északi terület klasztereiben cene volcanism, the appearance of good conductors may possibly be related to this volcanism. The eastern patch is a smaller subbasin, there are no well data about its real depth, moreover its exact extent is not known.

The Bouguer curve of medium depth cluster 3 (Fig. 14, 3) shows a characteristic feature of the whole area studied: a decrease down to 2.5 km, then a small amplitude fluctuation down to 3.5 km, at the anomaly level corresponding to the 'northern' area. The telluric curve (Fig. 15, 3) rises down to 2.5 km, and then shows a moderate decrease. The Bouguer curve (Fig. 14, 4) of the deep basins (cluster 4) runs close to the curve of cluster 3 in the overlapping interval and the rising tendency continues toward the larger depths. The telluric curve (Fig. 15, 4) shows a decreasing tendency in the overlapping interval, but at significantly higher conductance values than the curve of cluster 3, and at depths larger than 3.5 km it increases.

On the whole the Bouguer curves of the four clusters deviate only slightly from the corresponding interval of the 'northern' curve (Fig. 7); a noteworthy difference exists only in the overlapping interval of clusters 2 and 3 (1–2.5 km), where the curve of cluster 2 is by about 8 mGal above the curve of cluster 3. In Fig. 10 it can be seen that points of cluster 2 (yellow) appear mostly at the edge of even shallower (possibly outcrop) areas, thus a side effect of nearby basement elevations may (also) cause the high Bouguer values.

From the telluric curves of the four clusters, roughly the whole interval of clusters 1 and 3, and the deeper than 3 km part of cluster 4 show the peculiarities of the 'northern' curve (Fig. 8). According to these the whole bulk of cluster 2 (see above) and shallower points of cluster 4 (Fig. 10, blue points) are characterized by anomalously high conductance. Basin areas shallower than 3 km of cluster 4 (see Fig. 10) are typically located near to points of cluster 2 (yellow points), and presumably they show, together with these, extension areas of individual good conductors within the basement.

3.3. Nyírség

The cluster map of the area is Fig. 11; Fig. 16 presents the Bouguer anomalies' dependence on basement depth, and Fig. 17 the telluric conductance's dependence on basement depth.

According to Figs. 16–17 clusters 1–3 correspond to a depth of 2–4 km, while basins deeper than 4 km got into cluster 4. The geophysical parameters of clusters 1–3 do not show a tendency to change as a function of basement depth. Relatively high Bouguer values (4–8 mGal) characterize clusters 1 and 2 (Fig. 16, 1, 2) in the Bouguer curves, whereas negative values characterize cluster 3 (Fig. 16, 3). In the case of telluric curves the independence of the parameter of basement depth within the clusters is even more conspicuous: conductance is about 300 S in cluster 1 (Fig. 17, 1), in cluster 2 (Fig. 17, 2) it is about 600 S, in cluster 3 (Fig. 17, 3) it is about 400 S. The moderate decrease observable in clusters 2 and 3 lags far behind the difference between the average level of the clusters. A simple explanation for the observed phenomena could be that areas showing completely different geological–geophysical peculiarities got into the individual clusters due to the random-like similarity of parameter values, and the otherwise causal dependence of parameters on basement depth therefore disappeared in the course of averaging. A contradiction of this assumption, however, is that the points belonging to the individual clusters were spatially separate from each other. In Fig. 11 it can be seen that points of cluster 1 (red) concentrate in the area's NW part, the bulk of the points of cluster 2 (yellow) fall on the area's western part; the points of cluster 3 (green) surround the deep basin that can be found in the middle of the area. Thus, it is more likely that clustering marked out blocks whose geological

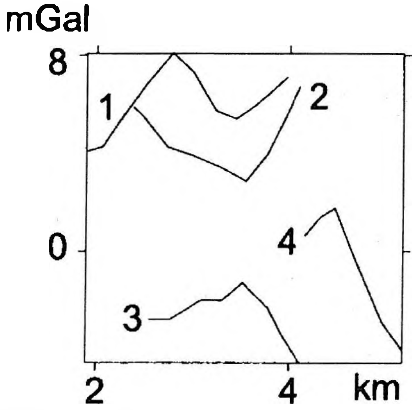


Fig. 16. Dependence of Bouguer anomalies on depth to the basement surface in clusters of the Nyírség sub-area

16. ábra. A Bouguer-anomáliák függése az aljzatfelszín mélységétől a nyírségi terület klasztereiben

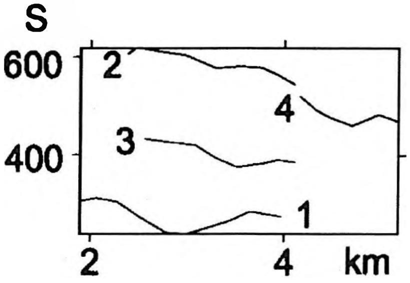


Fig. 17. Dependence of telluric conductance on depth to the basement surface in clusters of the Nyírség sub-area

17. ábra. A tellurikus vezetőképesség függése az aljzatfelszín mélységétől a nyírségi terület klasztereiben structure really differs. From the 'northern' gravity average curve in Fig. 7, it is evident that it is independent of basement depth just in the depth interval of the Nyírség clusters 1–3. Although in Fig. 8 the 'northern' telluric average curve shows a generally increasing trend to its end, a short decreasing section breaks it in the 2.5–3 km interval, demonstrating that within the regional trend there may be significant local differences. Thus, based on the above observations it is possible in the depth interval of clusters 1–3 that the investigated parameters are independent of basement depth, and the different value levels reflect local peculiarities of geological structure.

Based on the level of Bouguer anomalies clusters 1 and 2 are of 'southern' type (high values), whereas cluster 3 is of 'northern' type. Based on the level of telluric conductance cluster 2 is of 'southern' type, while cluster 1 shows an anomalously poor conductor environment; in this cluster the conductance is even lower than in the 'northern' type. In the area under review (Fig. 11, red points) it is known that there is a large volume of Miocene volcanites in the level of sediments, these may cause the anomalously poor conductance. Magnetic checking of these formations cannot be carried out with certainty; although sources of the magnetic anomalies in this area are presumably volcanic—subvolcanic formations, such formations are, however, known in anomaly-free areas as well. In addition, the most significant magnetic anomalies fall just on parts excluded from the study due to the lack of telluric data, therefore the utilization of magnetic data in the statistical studies did not provide additional information.

The conductance level of cluster 3 is of 'northern' type.

In practice, basins deeper than 4 km belong to cluster 4. As indicated in Fig. 11 three basins probably of different geological environment are concerned: in the west the ending of the Middle Hungarian Graben, in the south the northern ending of a graben of smaller extent and of N–S strike are found, while significant part of the points belonging to this cluster concentrate in the middle of the area. It would be worthwhile to separately study the dependence of geophysical parameters on basement depth in the three basins, but the lack of sufficient data does not render this possible. Moreover, it is true that the real depth conditions of the middle larger basin are very poorly known. It is a fact, on the other hand, that it is a really deep basin in which the thickness of the volcanic sequence may be as much as

3 km, and the sedimentary cover of the volcanic sequence is thicker than in the area of cluster 1.

If one summarizes the results of cluster analysis one obtains the following image of the Nyírség area:

—From the crust structural viewpoint the whole area is of 'southern' type (presumably with lower crust and/or mantle in a somewhat elevated position).

—The volume, position and physical properties of volcanites influence the appearance of characteristics of the 'southern' type, thus in some cases value levels corresponding to the 'northern' type may appear as well (but without the curve lines characterizing the investigated areas).

—The level of Bouguer anomalies is of 'southern' type in the area of clusters 1–2; however, volcanites lying close to the surface influence the line — especially in the area of cluster 1.

—The value of telluric conductance shows 'southern' characteristics only in the area of cluster 2; in the area of cluster 1 the conductance is anomalously low due to the high resistivity of near-surface volcanites.

—Volcanic activity was the most intensive in the central deep basin. In the area of clusters 3–4 the effect of volcanites penetrating the basement whose density is lower than that of the basement formations reduces the level of Bouguer anomalies. The conductance reducing effect of volcanites strongly depends on the depth to their surface, thus the conductance ever increases in the area of clusters 3 and 4 which can be characterized by the gradual deepening of the surface of volcanites compared to cluster 1.

4. Practical consequences of the results of East Hungarian statistical studies

—The level of Bouguer anomalies deviates in the investigated regions both from each other and the relatively uniform image detected in Transdanubia. Thus in the course of gravity interpretation the effect of the actual step should be taken into account in the about 50 km wide zone bordering the individual areas.

—Downward from a 2.5 km basement depth the Bouguer anomalies do not decrease further, thus a two-layer (basement + sedimentary cover) interpretation is acceptable only in basins shallower than this.

—In each basin, excluding the Nyírség, deeper than 4 km it can be detected that the Bouguer anomalies increase with increasing basement depth (deep structural effects, i.e. beneath the deep basins, the lower crust and/or mantle are in elevated position).

—Appearance of volcanites in large volume in the Nyírség leads to a decrease in Bouguer anomalies.

—The telluric image is significantly more complex than the Transdanubian one, at the sediment level anomalously good conductor formations (Békés Basin), and anomalously high resistivity formations (certain volcanites) equally appear.

—Intensive volcanism lowers telluric conductance in the Nyírség, its measure significantly depends on the depth to the surface of the volcanites.

5. Hungary's regional gravity anomalies

Our studies on East Hungary showed that the behaviour and the level of Bouguer anomalies significantly differ from the picture in Transdanubia that seemed to be relatively uniform there even after division into regions. Since we have no telluric date for an approximately 50–70 km wide zone between Transdanubia and the study area the procedure applied in the two areas cannot be extended to this intrafluvial area. At the same time it is of interest from the viewpoint of deep structural investigations and of applied gravity interpretation that it is within this zone that the boundary effectively separating the area types runs. In order to study this, a country-wide gravity anomaly map was constructed in which the gravity anomaly value belonging to the given basement depth in the Transdanubian average curve (Fig. 7) is subtracted in the grid points from the Bouguer values deduced from measurements. The reduced map obtained in this way is *Fig. 18.* Taking it into consideration that the curve used for reduction is of statistical character, the '0' level of the reduced map cannot easily be interpreted from the geological–geophysical viewpoint; it does not support our further studies. Therefore in the map the areas between –5 and +5 mGal (i.e. areas showing values close to the Transdanubian average) were left blank; on the other hand, larger differences either in positive or negative direction, were emphasized by colouring. The area that can be characterized by basin depths less than 500 m and more than 3 km are marked either with horizontal or vertical lines [see KILÉNYI, ŠEFARA 1991]. In the

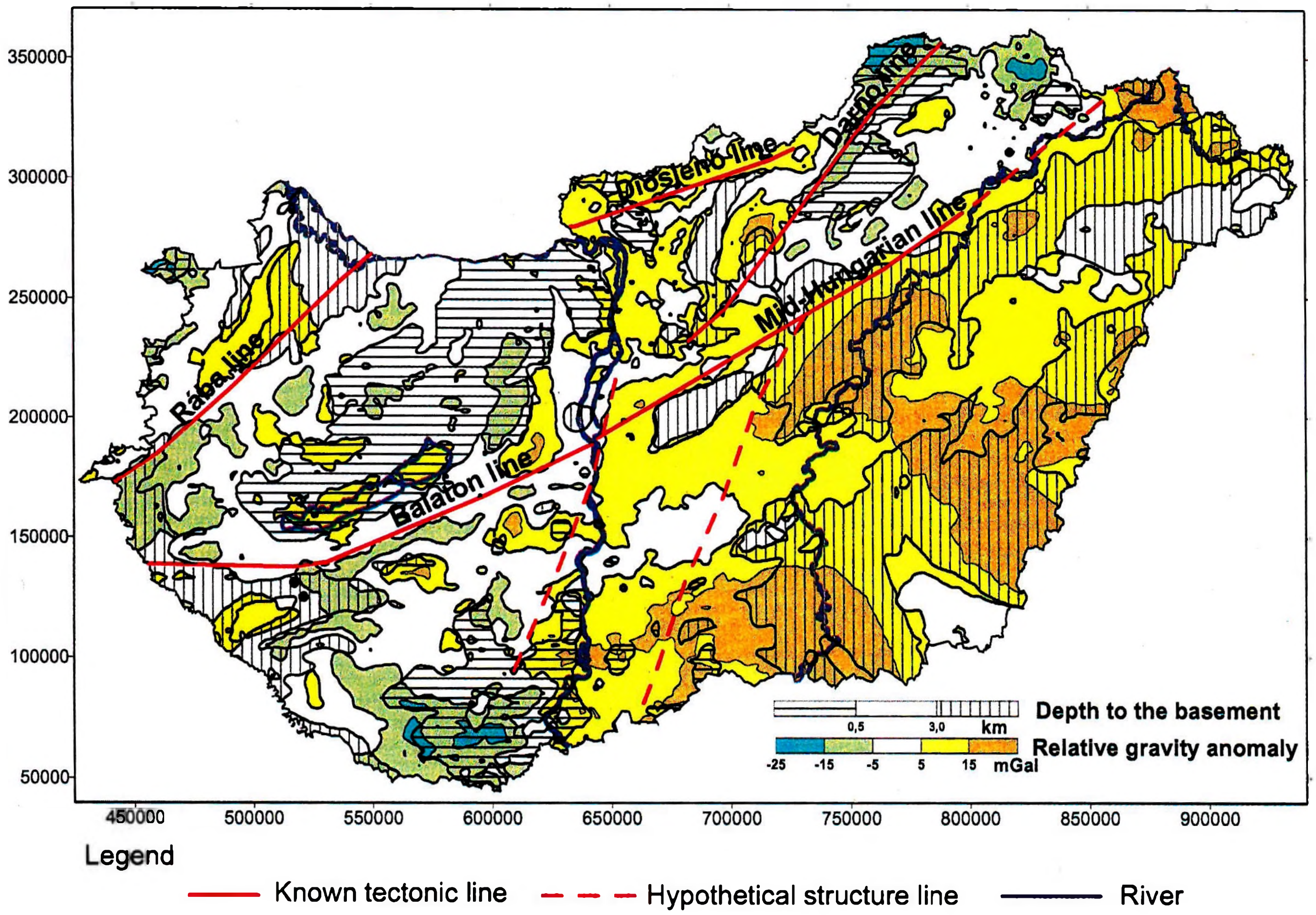


Fig. 18. Gravity anomaly map corrected with the Transdanubian average curve

18. ábra. Dunántúli átlaggörbével korrigált gravitációs anomáliatérkép case of basement depths less than 500 m the local density of basement formations occurring on the surface or near to the surface can more heavily influence the Bouguer anomalies and, in addition, the effect of differences between the 2×2 km basin model and reality may be more significant as well in near-surface situations. Below a 3 km basement depth, the decrease in Bouguer anomalies with increasing basement depth everywhere ceases in the studied sub-areas, thus it doubtlessly plays an important role in comparing the two parameters.

On the map (Fig. 18) we have also indicated several known megastructural lines of Hungary, after VETŐ-ÁKOS [1999]. It can be observed that in many cases these border blocks of regional gravity anomalies show differing characteristics as well.

The maximum that can be seen on the NW side of Rába line is the effect of the elevated lower crust and mantle detected beneath the deep basin of the Little Hungarian Plain [NEMESI et al. 1994, NEMESI et al. 1999].

A large subvolcanic body causes the single, larger (positive) anomaly (that is, at the same time, the magnetic anomaly) of the Transdanubian area between the Balaton line and the Rába line characterized by basement depths deeper than 500 m [POSGAY 1966].

South of the Balaton line runs an array of maxima. Their westernmost element is presumably connected with the elevation of the lower crust and/or mantle that can be found beneath the deep basin. In connection with the area of the two other maxima (and of the minimum lying between them and the Balaton line) our earlier studies [KOVÁCSVÖLGYI, OCSENÁS 2000] demonstrated that the basement map is wrong here, thus these anomaly elements are not real ones.

In the course of our earlier study [KOVÁCSVÖLGYI, OCSENÁS 2000] we associated the minimum area that can be found in the southern part of Transdanubia with the thickening of the lower crust (deepening of mantle).

The Middle Hungarian Line separates from each other the ‘northern’ and ‘southern’ areas of our present study. Based on the results in the Nyírség this line can be continued in the NE direction up to the country’s border; it runs roughly along the +5 mGal line.

In a large part of the area between the Middle Hungarian Line and the Darnó line the relative values are around 0, i.e. a Transdanubian-type crust structure can be assumed. No light was thrown on this peculiarity in the course of the Middle Hungarian studies because, due to the lack of telluric data, a large part of the area dropped out from the scope of studies. The northern minimum is a consequence of the more than 2000 m thick, low density pyroclastics that outcrop to the surface in the Tokaj Mountains.

The area between the Darnó and Diósjenő lines shows a variegated image: one of its characteristics is that in the deeper basins the values are around 0 while the shallower areas mostly fall into the zone between 5–15 mGal. A possible explanation for this is that a Bouguer anomaly level by 5–15 mGal higher than the Transdanubian curve characterizes generally the whole area, but Bouguer anomalies do not set in a level in the deep basins (nor do they start to rise below a certain depth but moderately further decrease — i.e. there is no local lower crust and/or mantle elevation beneath these basins). The western boundary of this unit runs somewhere near to the Danube. The basement is in a surface–near-surface position west of the river, this makes its more accurate determination more difficult, and thus the mentioned uncertainties should be taken into account as well.

According to our earlier studies [SCHÖNVISZKY, KOVÁCSVÖLGYI 1993] the minimum detected in the northernmost part of the area is a consequence of the northward (beyond the country's border, too) ever more thickening Earth crust.

North of the Diósjenő line we are unambiguously in a positive zone. In this zone crystalline formations build up the basement (Vepor unit) whose density exceeds the density of the Mesozoic basement formations located south of the Diósjenő line. Thus, the source of the positive anomaly is not of deep structure, but of basement origin.

The area south of the Middle Hungarian Line is our present studies' 'southern' and Nyírség areas. In Fig. 18 it can be seen that the area between the Danube and Tisza rivers is here unambiguously in the positive zone. It seems that the zone's western boundary is a line of NNE–SSW strike that runs in the main in Transdanubia. Recent geological maps do not indicate such a tectonic line, thus it is possible that this structural line is not of tectonic nature: elevation of the lower crust and/or mantle gradually takes place, and we see it as a 'line' when the phenomenon's gravity effect reaches a certain (subjective) limit.

The area's gravity anomaly image is not uniform (Fig. 18). A line can be marked out that is nearly parallel with the assumed boundary terminating the unit from the west, and runs about 50 km SE of the boundary; typical values of the western side are 5–10 mGal whereas its eastern side values typically exceed 15 mGal. In the eastern block the highest values are connected with the deep basins, in these places the effect of local lower crust and/or mantle elevation beneath the basins is superimposed on the effect of the regional gravity step. This phenomenon is missing here only in some parts of Nyírség, the reason for which was analysed above. At the same time relative values higher than 15 mGal uniformly characterize the southern part of the eastern block, also where the depth to the basement decreases down to about 500 m. It is remarkable that a semicircular zone surrounds this area in question where the relative values mostly decrease below 5 mGal. This may suggest that this southern part forms a separate unit from the crust structural viewpoint. Because this southern unit's boundaries are uncertain using this particular method, they are not indicated in Fig. 18.

A noteworthy element of the western block (the area between the two lines of NNE–SSW strike and marked as assumed structural lines in Fig. 18) is the deep basin located close to the Middle Hungarian Line, where the relative gravity anomaly values show a decrease, similarly to the deep basins between the Middle Hungarian Line and the Diósjenő Line. It can be assumed that the reason for this phenomenon is similar too: there is no lower crust and/or mantle elevation beneath the deep basin and the decrease in Bouguer anomaly values does not stop at the usual 2.5–3.5 km depth.

In short the following can be stated:

- —From the viewpoint of the connection between the Bouguer anomalies and the depth to the basement of the pre-Tertiary basin the 'Transdanubian' type can be considered 'normal' in the country's territory. Its area of extension is the area between the Middle Hungarian Line and the Darnó Line, and almost the whole area of Transdanubia. Within these areas thickening of crust generates the high negative relative anomalies while the positive anomalies are connected with the local deep structural elevations below the deep basins. Only the large subvolcanic body detected north of the Balaton line and characterized by magnetic anomaly as well shows a deviation from this scheme as a local feature (positive relative anomaly).
- —The whole other area of the country shows anomalous behaviour, the value of Bouguer anomalies is typically by at least 5–15 mGal higher than that which would be justified by the basin structure and the Transdanubian type crust structure. This phenomenon is brought into connection with the regionally elevated position of the lower crust

and/or mantle. According to our calculations the measure of this elevation does not necessarily exceed 0.5–1.5 km.

—Out of the anomalous areas the parts south of the Middle Hungarian Line and east of the eastern structural line in Fig. 18 represent separate units. Here the gravity effect of the local lower crust and/or mantle elevations beneath the deep basins is superimposed on the regional effect, thus the value of relative anomalies is typically over 15 mGal in these areas, and may reach 30 mGal. The deep basins of Nyírség represent the exception within this unit due to the thick volcanic sequence's density that is lower than in its surroundings. It is possible that the area's southern part also separates due to the crust being regionally even thinner independently of the deep basins; its demonstration is, however, beyond the possibilities of the applied method.

—The higher than average density of crystalline basement formations causes the relative anomaly in the area north of the Diósjenő line, it has presumably no crust structural relationship.

The 5–15 mGal relative anomaly is the common feature of the anomalous areas not detailed up to now, and the deep basins cause local minima here. Thus, beneath these basins there is no lower crust and/or mantle elevation, and the Bouguer anomaly values decrease down to a larger basement depth than in the case of other deep basins.

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Kelet-magyarországi területek felszíni erőtér-geofizikai adatainak statisztikai vizsgálata

KOVÁCSVÖLGYI Sándor

Kelet-Magyarország tellurikus adatbázisának és a terület tellurikus vezetőképesség-térképének (1. sz. melléklet) elkészülte lehetővé tette a mérések által lefedett részek erőtérgeofizikai eredményeinek komplex statisztikai vizságlatát. A munka a Dunántúl területére elvégzett elemzés [KOVÁCSVÖLGYI, OCSENÁS 2000] folytatása, ahhoz hasonló módszertant követ. A vizsgálatok az OTKA T 026515 téma keretében készültek, e publikáció megjelentetését szintén az OTKA támogatta.

ABOUT THE AUTHOR

Sándor Kovácsvölgyi (1956) graduated in geophysics from Moscow Geological University in 1979. Up till 2000 he was with the Eötvös Loránd Geophysical Institute of Hungary; since then he has been working for the MOL Hungarian Oil and Gas Co. In the 1980s he dealt with geoelectric methods, ore prospecting, and with gravity and geomagnetic measurements. He constructed the Bouguer anomaly map of Hungary on a scale of 1:500 000; the map is based on about half a million measuring points. He played a significant role in interpreting gravity and geomagnetic maps concerning the crust and mantle anomalies.

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Telluric Map of East Hungary

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The telluric map (see Enclosure 1), an absolute conductance map, came into being based on the results of three Hungarian institutions — the Geophysics Department of Miskolc University, the Geophysical Exploration Company of the Hungarian oil industry (OKGT), and the Eötvös Loránd Geophysical Institute of Hungary (ELGI). These results — quasi-grid measurements — were obtained from observations using oscillations of 25 s period time. The relative telluric measurement results were transformed into absolute values by means of magnetotelluric soundings.

Interpretation of the now presented map was carried out after geoelectric checking — deep direct current soundings and magnetotelluric measurements — primarily by comparing it with gravity Bouguer anomaly and magnetic ΔZ anomaly maps and a pre-Tertiary basement map. It is stated that

— The telluric map shows a very good image about the 5–8 km deep sedimentary basins, their depth and structural elements as opposed to the gravity or magnetic maps; their anomalies in eastern Hungary can be explained first of all by mantle plumes. This fact clearly justifies the importance of the method's application in hydrocarbon exploration, after the gravity and magnetic measurements, in the exploration stage prior to the seismic measurements.

— If a significant amount of (Miocene) volcanic material is also present in the Neogene basin, then in these areas the telluric image is not proportional to the depth to the pre-Tertiary basement because the volcanites' resistivity is commeasurable with that of the basement formation. In such an area in northeast Hungary (region of Nyírség) the telluric anomaly image is more or less similar to the magnetic anomaly image.

— Since the 1980s, the development of measuring and computer processing techniques allows anisotropy ellipses to be plotted as well. This, in addition to the conductance anomalies, also enhances the detection of remarkable structural lines, e.g. between the Tisza unit and the Pelso unit, and the Pelso unit and the Western Carpathian unit.

— In the northern intra-mountain basins low resistivity formations, e.g. graphitic shales, frequently occur in the pre-Tertiary basement. This phenomenon is often the source of significant anomalies in addition to the changes in conductance due to the changes in thickness of Tertiary sediments.

The main benefit of the telluric map and other such maps (gravity and magnetic) is that they give different images of certain areas, the factual geological reasons behind this are frequently not known. These differences call one's attention to geological curiosities, perhaps to the existence of up-to-now undiscovered raw material

Keywords: tellurics, geophysical maps, Hungary, conductance

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1. Introduction

Telluric surveys in Hungary started with the construction of measuring instruments and field measurement experiments more than a half century ago. Later, from 1960 to 1994 (with some interruptions) systematic and routine investigations were carried out in a quasi-grid. As a result of these investigations map parts, frequently not fitted to each other, came into being covering 80–85% of the basin areas. Because we see no chance of providing the missing parts under the changed circumstances, we decided to publish the West part of Hungary's telluric map, published in 2000 [NEMESI et al. 2000]. Both parts made use of the same calculation and construction method and used the same colour code.

Support obtained from the Hungarian Scientific Research Fund (OTKA, project N° T 026515) made possible the practical realization. This enabled us to publish the Telluric conductance map of East Hungary on a scale of 1:50 000. In addition, the gravity and magnetic maps can also be seen, for comparison purposes (see Enclosure 1).

It is pointed out that when a geophysical map covering almost the whole country has come into being it is worth recollecting briefly the reasoning and the basic objectives associated with the method's introduction and application, and the likely results:

— In utilizing telluric currents for geological investigations Hungarian-born Géza Kunetz, who lived in France and worked for the Schlumberger company, played a decisive role. With Kunetz's experience as well as his direct assistance Károly Kántás, geophysics professor at the University of Sopron, could launch the development, then inaugurate routine prospecting in Hungary. The professor's colleagues, Ernő Takács and Pál Egerszegi, carried out the first successful field measurement in 1952 [EGERSZEGI 1954].

— Károly Kántás formulated the basic objective of telluric measurements in his inauguration address at the Hungarian Academy of Sciences in 1954. He pointed out that first of all the depth to the basement of sedimentary basins and lateral changes in the sediment's average resistivity can be investigated with tellurics, and this is of primary interest from the viewpoint of hydrocarbon exploration. He stated: *'compared with the classical exploration methods the place of telluric prospecting can be placed between gravimetry and seismic exploration'* [KÁNTÁS 1954].

Both the Hungarian oil industry (National Oil and Gas Trust, OKGT) and the Central Geological Office (KFH) that managed the national government-financed explorations accepted (although sometimes queried) the above statement. These two organizations have financed telluric measurements in Hungary for about 40 years.

Four Hungarian institutions carried out the exploration work: the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (MTA GGKI), the Geophysics Department of Miskolc University, the oil industry's Geophysical Exploration Company (OKGT GKV) and the Eötvös Loránd Geophysical Institute of Hungary (ELGI). The last three institutions performed the measurements in the above mentioned eastern Hungarian region. As a final result measurements were carried out at 16 509 stations throughout the country, in a quasi-grid of 1.5–2 km^2, and from among the basin areas only the region of about 10 000 km^2 between the Danube and Tisza rivers remained uncovered (*Fig. 1*).

Reports were generally compiled only for clients on areas of 500–1500 km^2 that were covered annually with measurements, although the results obtained by ELGI between 1965 and 1990 can be found in ELGI's annual reports [see References], as partial maps related to the

Fig. 1. Map of telluric coverage
1. ábra. Tellurikus megkutatottsági térkép

relevant telluric base station. The first map uniting a larger area, of about 30 000 km^2, was published in 1981: 'The telluric isoarea map of the Tisza region and the area east of Tisza, scale 1:500 00' [NEMESI et al. 1981]. In addition to the telluric map the relative isoohm map of the sedimentary sequence and the map of depth to the high resistivity formations can be seen as well on the same scale.

The Telluric map of Transdanubia (West Hungary) was published in 2000 [NEMESI et al. 2000].

In the present study our aim is to present and to offer an interpretation of the results that can be seen in the East Hungary map (Enclosure 1), and to indicate that if one juxtaposes the classical (field) maps it more than adequately demonstrates the correctness of Kántás's exploration principle: It is of paramount importance to select the appropriate order of methods for integrated prospecting. Despite the fact that telluric surveys added up to hardly 1–2% of seismic exploration costs, in significant parts of East Hungary these provided a completely different image from those of gravity and magnetics. Tellurics provided the correct image of the sediment thickness and basement structure in the deep basins promising from the viewpoint of hydrocarbon extraction.

2. Brief history of the explorations in East Hungary

ELGI's staff commenced measuring the first experimental profiles in East Hungary in 1956 under the direction of András ERKEL [1965]. Based on the results along the lines connecting known wells that reached the basement, in 1960 OKGT commissioned ELGI and the Geophysics Department of the University (that had moved from Sopron to Miskolc) to carry out quasi-grid measurements. The Geophysics Department performed its measurements for a four-year-period in the northern part of the Great Hungarian Plain, in the zone of the Tisza river, in the region of Eger–Mezőkeresztes–Mezőcsát–Polgár–Tiszavasvári–Nagyhalász–Kisvárda [CSÓKÁS 1964], but later the university's directorate did not allow the already routine investigations to continue.

Influenced by the favourable results OKGT established its own geoelectric department under the guidance of Zoltán Nagy in 1963. Routine telluric measurements started between 1965 and 1967 in the northern part of the Great Hungarian Plain, on the right bank of the Tisza, in the region of the Zagyva river (in the area of Jászberény–Heves–Tiszabura), essentially joining to the areas of Miskolc University's Geophysics Department and ELGI. Later, in 1967–68, OKGT's geoelectric department carried out telluric measurements in the southern Plain as well, in the area of Szeged–Hódmezővásárhely–Makó [LANTOS et al. 1966, NAGY 2002].

ELGI's measurements, in several stages, covered the largest area.

The quasi-grid survey started with measurements commissioned by OKGT in Hortobágy in 1960. In 1964 the Central Office of Geology (KFH) launched our country's uniform reconnaissance exploration programme in the middle of the Great Plain, financed by the state budget. At that time all geophysical methods began their measurement on the 1:100 000 scale Szolnok map sheet. In addition to gravity and magnetic measurements, seismic and geoelectric surveys started as well. Moreover telluric measurements and the routine application of deep direct current dipole equatorial array (DE) soundings also started then. The main objective was to determine the resistivity and thickness of the sedimentary sequence. In other words, with this kind of measurement performed in a grid one order of magnitude less than that of telluric measurements it was possible to determine that the source of the telluric anomaly is a change in basement structure — significant from the viewpoint of hydrocarbon exploration (e.g. an anticline) — or a lateral change in the conductance of the sedimentary sequence; otherwise the anomaly's source should perhaps be looked for in basement formations [SZABADVÁRY 1965].

Later, magnetotelluric measurements took over the role of direct current soundings [CSÓKÁS, TAKÁCS 1965], and the use of this principle (i.e. checking the telluric anomaly with direct current or magnetotelluric sounding) allowed interpretation of telluric results from the very beginning to the last measurements.

In the integrated geological–geophysical exploration programme launched in 1964 (that had been planned for several decades) bore results in 1966 when the oil field in the southern Plain near Szeged (Algyő) was discovered; in view of this the oil industry itself wanted to explore the southern Plain, though ELGI was commissioned to carry out a significant part of the geoelectric measurements.

After 1967 the Plain's northeastern part became the integrated (including all geophysical methods) survey area for ELGI, where again the exploration methods were not applied in a logical order. Here also, all methods appeared. On the other hand, from the viewpoint of telluric explorations this survey programme spatially jumping to and fro resulted in relative conductance maps covering areas of 1000–1500 km^2. In the second half of the 1970s even telluric measurements were interrupted, but by that time a connected area of 30 000 km^2 in East Hungary had been covered with measurements. Then ELGI carried out large scale base-station-connecting measurements as a consequence of which the monograph entitled '*Geoelectric investigation of the deep structure in the Tisza region and east of Tisza*' could be published [NEMESI, HOBOT 1981], in which the relative conductance map ('isoarea map') referred to the Plain's principal base station can be found as well.

In the 1980's subsequent investigations in several regions were linked with the area presented here [NEMESI et al. 1984].

Similarly, in the above mentioned period surveying also took place in the majority of northern Hungarian basins, but in these cases map portions mostly referred to the local bases came into being [GYÖRGY et al. 1986, NEMESI et al. 1990].

ELGI carried out the last telluric measurement in East Hungary in the Ózd basin in 1989 [MADARASI 1990].

Researchers who took part in the survey work of the East Hungary area, in the processing and interpretation of measurements, and in the development and construction of instruments included: Ernő Takács, Ferenc Béldi, János Csókás, Pál Egerszegi, Mihály Hartner, Béla Ruzsa, Ferenc Steiner. (In field observations and in geodetic work other staff of Miskolc University's Mining Engineering Faculty and of the Physics Department of Sopron University gave a hand as well.)

Included in the oil industry's Geophysical Exploration Company were Zoltán Nagy, Adorján Divéki, Miklós Lantos, Gyula Lux, István Nemes, Béla Péterfai, Pál Simon, István Zimányi. In addition to the geophysicists the work relied on the valuable input of many other technical and non-technical staff. Among ELGI's staff one might mention:

András Erkel, Károly Sebestyén, Sándor Lakatos, József Hobot, Judit Varga, Gyula Fábián, László Nemesi, András Simon, Géza Rezessy, Imre Fejes, Géza Varga, Pál Draskovits, József Csörgei, Gábor Széles, András Borsányi, Sándor Galambos, Zoltán Süslecz, András Milánkovich, András Madarasi. These experts were similarly to the oil industry, supported by the highly constructive work of technical and non-technical personnel.

3. Most significant geological aspects from the viewpoint of planning and interpreting telluric surveys, and regarding the physical parameters of formations

During the half century of telluric surveys geological knowledge on the Carpathian Basin has continuously widened. Several thousand wells reached the basement, and in a significant part of our plains the separation between the lines of seismic exploration — that was repeated several times with ever more up-to-date devices and processing methods — is as little as only a few hundred meters. If we want to evaluate the telluric results in the mirror of present knowledge, these facts should be taken into account as well.

A summary is given of the development of those geological aspects of the Carpathian Basin revealed during the half century of telluric exploration [NEMESI et al. 2000]. From these the most important ones from the viewpoint of planning and interpretation of telluric measurements are the following:

A.) Hungary's geological set-up reflects events of three main geological eras

- — the development stage before the Alpian: this is connected to the Precambrian–Palaeozoic history of Central-Europe, but it is difficult to reconstruct it.
- — the Alpian stage, including Late Palaeozoic. Mesozoic and Palaeogene evolution of Thetys, with orogenic events, that showed itself in nappe-like, folded tectonics, and large-scale side-slips.
- — the Pannonian (Neo-Alpian) evolution stage: viz. from Early Miocene to the present and onwards. Evolution of small pull-apart basins, then development of the Pannonian basin characterizes this stage, with large amplitude depression. These young basins — that fundamentally determine the present geological set-up and the recent geographical image — are dominantly filled with fine-grain terrestrial sediments, but these were deposited in the brine of an inland sea, and in some places with thick magmatic rocks.

B.) Formations older than Tertiary are rocks of generally high resistivity, high density and high seismic velocity.

In our survey area the resistivity of Palaeozoic granites and crystalline shales is generally 80–100 Ωm, that of Mesozoic carbonate rocks is 200–500 Ωm. Properties deviating from these in some subareas — and experienced later — represent nowadays an essential physical basis for interpretation. Sediments — frequently flysch-type — older than Tertiary–Late Cretaceous, mean such an overall known deviation, these are less metamorphosed and besides their relatively high seismic velocity and high density their resistivity is low (about 10 Ωm), which is similar to that of sedimentary sequences. In these subareas the geoelectric basement can be placed to the boundary between the Lower and Upper Cretaceous. Because the Austrian orogenic movements took place at that time, György Szénás, the late chief geologist of ELGI — and an outstanding authority on geological–geophysical interpretation — called the geoelectric basement 'Pre-Austrian'.

On the basis of the development mode of basement formations older than Tertiary, Hungary's territory can be divided into three primal mega structural units: **the Tisza unit, the Pelso unit and the Western Carpathian unit** (*Fig. 2*). Tectonic lines of great importance separate these mega-structural units from each other and, for example, significant volcanism was associated with them as well. There are also essential dif-

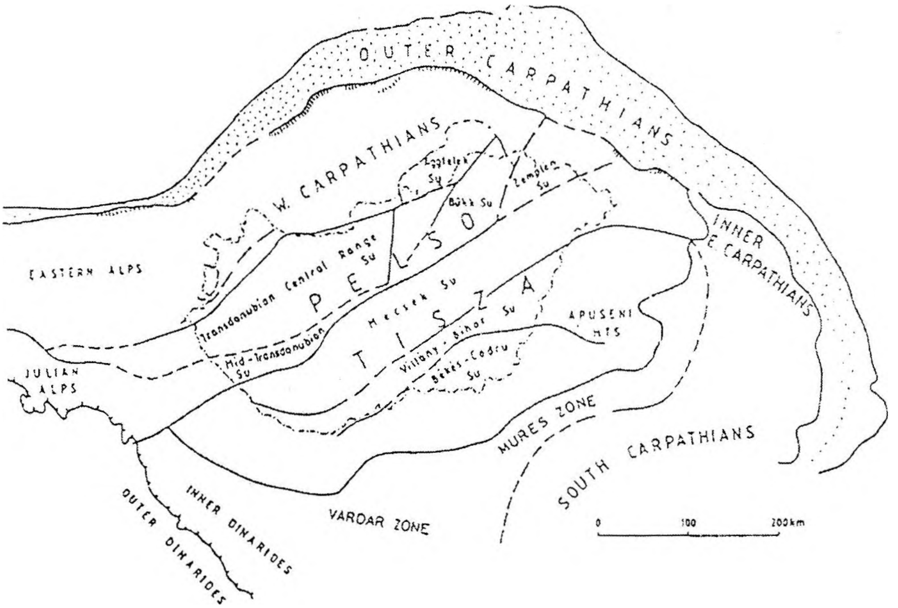

Fig. 2. Schematic geological map of the Carpathian region [after HAAS]

2. ábra. A Kárpátok vidékének áttekintő geológiai térképe HAAS nyomán ferences between the depression evolution histories of individual units; for example, in the area of the eastern Hungarian Pelso unit Palaeogene — mainly Oligocene — sediment of significant thickness (1–2 km) has accumulated whereas such sediment is unknown in the area of the Tisza unit. Here relatively little Miocene and even 3–5 km thick Pliocene sediment settled. The sediment's resistivity, however, is significantly lower between 5 and 10 Ωm in both areas. At the beginning of telluric surveys practically no counter-example was known.

C.) Depth to the basement of the Tertiary basin according to our present knowledge

A pre-Tertiary basement contour map of the Carpathian basin was constructed primarily using drilling and seismic survey results [KILÉNYI et al. 1991] for details, see *Fig. 3*. With regard to this map there are two aspects of major interest.

— The first is whether the first researchers correctly gave the frequency range of telluric measuring serving the purpose of basement investigation.

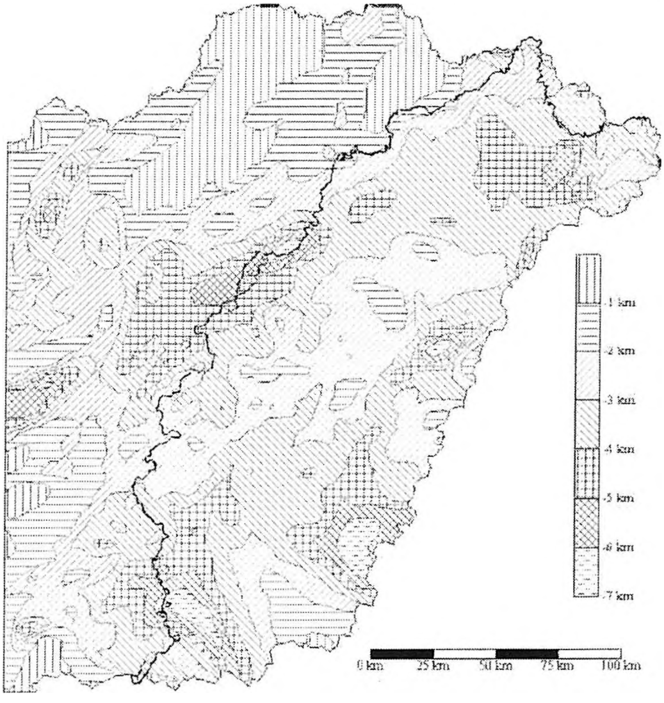

Fig. 3. Contour map of the pre-Tertiary basement

3. ábra. A pre-tercier aljzat mélységtérképe

In Fig. 3, according to the basement depth map of Tertiary formations, maximum values of 6.5–7.5 km can be found. This is roughly twice as much as expected at the beginning of exploration. Had the original assumption (the maximum basin depth of 3–3.5 km) proved true, the electromagnetic waves of 20–30 s period time most frequently occurring in nature — in the case of 5–10 Ωm average sedimentary sequence resistivity that proved true later as well — would have penetrated everywhere down to the basement according to the rules of skin effect. This, however, was not the case in the deepest parts of the basin.

— The other aspect is the question of interpretation. Comparison of the results of the individual methods — gravity, magnetics, tellurics, seismics, and well data — gives an answer to the basic questions. Such could be, for example,

- Do the gravity, magnetic, telluric maps reflect the depth and structural element of basins?
- If the above is not the case, did we comply with the logical, economically also reasonable order in exploration?
- On considering Enclosure 1 it can be realized that the gravity, magnetic and telluric maps show fairly different images. With our present knowledge, the most interesting areas are those where the maps bear absolutely no resemblance to each other, because clarification of the reasons for deviations leads to new geological information.

4. Measurement and processing

In the telluric paper published in 2000 details were given of the instruments used in the measurements and the processing methods [NEMESI et al. 2000]. Concerning these instruments all three institutions worked in East Hungary occasionally with their own home-made instruments from the beginning up to 1980, but they tended rather to work with the well known analogue photorecorders of types T–9 and T–14 manufactured by the Factory of Geophysical Measuring Instruments and exported into many countries all over the world. The Piccard type galvanometers of 10^{-9} A/mm/m sensitivity represented their most important component part.

Initially all three institutions processed the measurements with the relative ellipse method, but later they applied other methods as well, among them primarily Kunetz's total ellipse method. In fact from the middle of the 1960s up to the 1980s ELGI exclusively used the total method, taking advantage of Takács's total mechanical integrator and nomograms [TAKÁCS 1960]. GKV preferred Nemesi's straight line method [NEMESI 1963]. It should emphasized, however, that independently of the processing methods the results are equivalent from the viewpoint of reliability [NEMESI 1963].

Since the beginning of the 1980s only ELGI has carried out telluric measurements, but already with the TEM–80 digital equipment [BORSÁNYI et al. 1980] that was able to perform quasi-real-time processing as well. This equipment also solved calculation of total values, digitally, and then using the values recorded in the data tape processing was completed with desktop computers. Since then the intermittent absolute ellipses were also plotted at the measuring stations in the isoarea maps. Our aim was to prove that these latter — by virtue of the applied procedure — can practically be considered anisotropy ellipses that can be interpreted as dip-strike directions, based on the E and H polarizations [NEMESI et al. 2000].

5. Telluric map of East Hungary

5.1. Conversion of relative conductance maps referred to different base stations to a common level and to absolute conductance

By virtue of our West Hungary map winning OTKA tenders, funding was ensured for performing magnetotelluric soundings at each one-time telluric base. We determined the summarized conductance — from oscillations of 25 s. This is the centre of the period range most frequently — in about 90% of cases — used in telluric measurements. Starting from these, we converted the relative conductance of all telluric stations to absolute values.

Because in constructing our present map we had no possibility to carry out new measurements, we had to content ourselves with the results of relative base network measurements performed in earlier decades, and with a lower number of magnetotelluric soundings than in the western part of the country. These soundings were carried out earlier partly at telluric base stations, partly on some anomalies, thereby enabling us to convert the relative values to absolute values.

The base network in the Plain means about 30 telluric bases. The network took shape gradually by enlarging the covered area (*Fig. 4*).

The principal base is the station marked GEAB–I, located near to the well Túrkeve–7. The relative conductances at the other stations have been converted to this station. The base connecting measurements for the con-

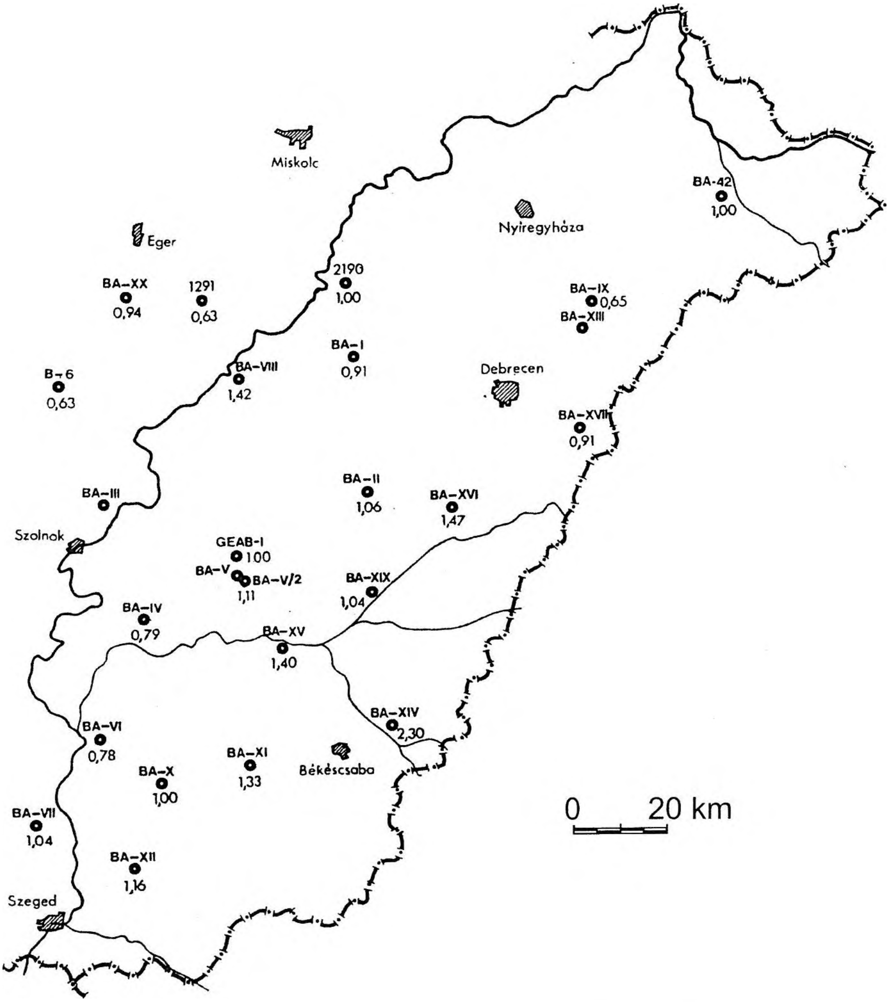

Fig. 4. The telluric base network in the Plain, with the relative conductance values referred to the GEAB–I principal base station

4. ábra. Az alföldi tellurikus bázisháló, a GEAB–I főbázisra vonatkoztatott relatív vezetőképesség értékekkel version were always carried out in a triangular network. The instruments were set up at the nearest stations and simultaneous recording was maintained for days, during the maxima of pulsation activity forecast by the observatories [VERŐ 1968]. The processed amount of pulsations was as much as 20–30 times more than in normal telluric processing; as a consequence of this the measurement and processing error became less than 2%. This turned out from the closing error of the measurements in a triangular network because, for example in the case of base stations A–B–C forming a triangle from the relative values determined between the stations A and B, and A and C, respectively, follow the relative values between B and C as well. Because the conversion value between B and C was measured as well, this rates as excess measurement and it was suitable for error calculation.

Even after the first successful base connecting measurements in a triangular network we just the same planned to adjust the base network. Later, however, we experienced that in some areas, in connecting measurements from measurements of pulsations with different dominant period time and in spite of the good closing error we obtained results with deviations of 5–10% between certain base stations. It turned out that the reason for this is that the conductance is frequency-dependent even in the range of 20–30 s at some stations. Under such circumstances there was no sense in making rigorous adjustments. We thus tried to determine the relative values referred to the GEAB–I for telluric bases further from GEAB–I by averaging conversions obtained along different paths and omitting the outlying values.

We have changed to the absolute conductance values by means of the conductance value 520 S determined from waves of 25 s period time that falls into the 'S' interval of the reliable, up-to-date magnetotelluric sounding measured at GEAB–I (*Fig. 5*).

The bases in Northern Hungary have never been connected with the network in the Plain. Here the conversion to absolute values took place using magnetotelluric soundings measured partly at the bases, partly on certain anomalies of the telluric map.

5.2. Global evaluation of the telluric map (Enclosure 1)

The map's colour code is the same as that of the West Hungary one. Blue-green colours mark the high conductances, yellowish and brownish

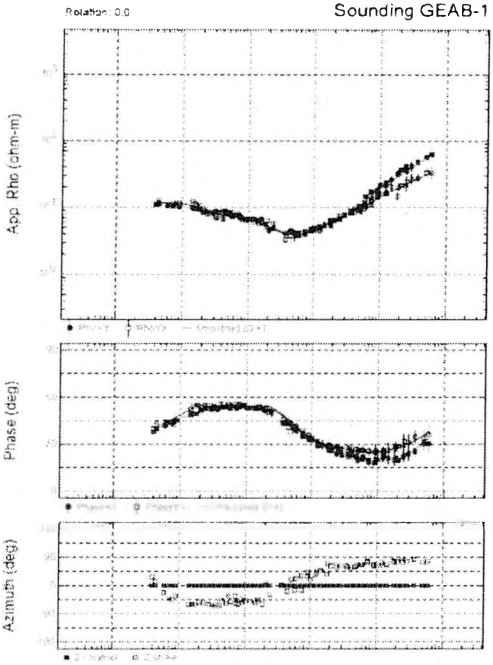

Fig. 5. Magnetotelluric sounding curves of the principal telluric base marked GEAB–I

5. ábra. A GEAB–I jelű tellurikus főbázis magnetotellurikus szondázási görbéi

colours the low ones. In doing this, our intention was to mark basement elevations and depressions with colours usual in surface topographic maps. The buried mountains are brown; the basins are blue-green. (Colouration of the gravity Bouguer anomaly map and the contour map of the basement is based on similar principles as well.) Therefore when we speak about a telluric maximum it means low conductance, while high conductance values characterize the telluric minima and as a first approximation they are interpreted as depressions, or basins.

The first striking thing in comparison with the West Hungary telluric map is that the average electric conductance in the basin's eastern Hungarian part is significantly higher than in the western parts. We can immediately state that the significant difference is not in the basin depth, but the resistivity of the sedimentary sequence is lower in the eastern part, in the Plain. From this viewpoint the Békés basin at the southeastern edge of the map is especially striking.

If we compare our map with the Bouguer anomaly map the most striking thing is that while in the country's western part the two maps seemed to be visually basically similar [NEMESI et al. 2000], this cannot be said about the maps that can be seen here (see Enclosure 1). At first glance it might seem that one of the maps had been wrongly coloured. It is characteristic in a notable part of the investigated area that, for example, a maximum in the telluric map that suggests a basement elevation (yellowish and brownish) is a minimum indicating a basement depression in the Bouguer anomaly map (green and bluish).

When the telluric map is compared with the magnetic map that also can be seen in Enclosure 1 little similarity can be observed at first glance. The northeastern subbasin represents an exception, where correlation seems to exist between the magnetic anomalies and the telluric highs.

When the gravity and magnetic maps shown in Enclosure 1 are compared over the basin areas covered by tellurics as well, it might be appropriate to emphasize three items:

a) Northeast–southwest directionality can be observed in both maps.
*b)*Gravity and magnetic highs in the southern areas markedly coincide.
c) In the northeastern parts where the telluric and magnetic highs can be found, there are definite gravity lows.

If the three maps in Enclosure 1 and the depth map of the pre-Tertiary basement (Fig. 3) are compared, it is obvious that the latter principally resembles the telluric map.

If we compare our maps with the structural geological map of the pre-Tertiary basement (or with its simplified version given in Fig. 2) it can be seen that there is an obvious link between the directions of the megastructural lines and the directions of the three magnetic anomaly zones in the magnetic map. The gravity map favours with its sharp gravity minimum zone the Middle Hungarian line that separates the Pelso unit and the Tisza unit from each other. In the telluric map these zones are not really perceptible, although later we will show details that in some subareas this statement is not true.

However, it should be mentioned that similarly to the southern part of the West Hungary telluric map, northwest–southeast directions perpendicular to the previous ones (Balkan) should be seen in this telluric map as well, also in the southern part, for instance at the edges of Makó graben, Békés basin and Orosháza–Battonya basement elevation separating them.

5.3. More detailed interpretation of certain aspects of the telluric map

The telluric map of East Hungary can be divided into several larger units based on the results of recently available geological and geophysical investigations (*Fig. 6*), within which certain findings can mostly be generalized. We consider that one of these larger units is the southeastern Plain, mainly its region east of the Tisza river. Another one might be north of this, the area extending till the Middle Hungarian Line, within this, however, several sub-units can be distinguished (e.g. the flysch zone and the Miocene volcanic zone of Nyírség). Finally, from many viewpoints the so called Palaeogene basin lying north of the Middle Hungarian Line is

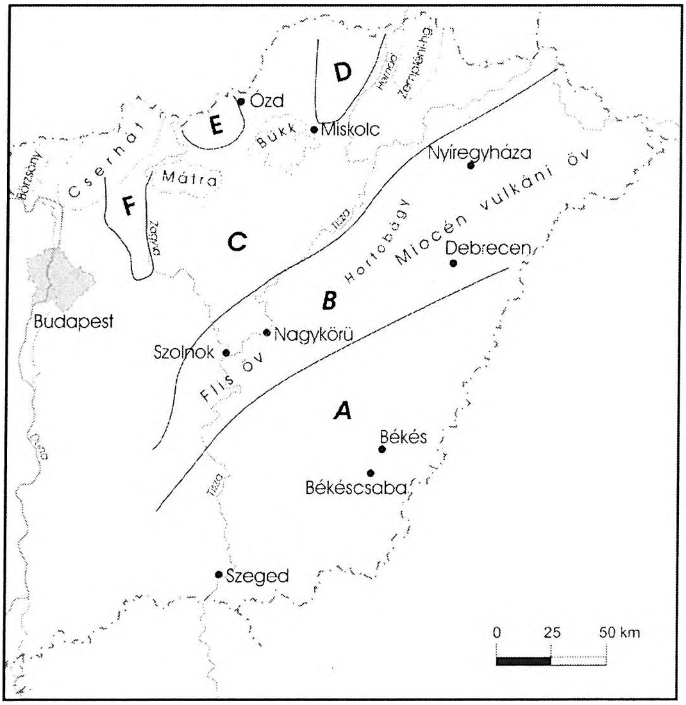

Fig. 6. Area units for interpretation of the individual parts of telluric map
Legend: A—SE Plain; B—Flysh zone, Miocene volcanic zone; C—Northern Plain; D—Cserehát; E—Ózd basin; F—Zagyva graben

6. ábra. Területegységek, a tellurikus térkép egyes részleteinek értelmezéséhez. Jelmagyarázat: A— DK-Alföld; B— Flis-öv, miocén vulkáni öv; C—É-Alföld; D—Cserehát; E—Ózdi-medence; F—Zagyva-árok different as are the basins in the Northern Middle Ranges. Parts of the latter one are the Cserehát, the Ózd basin and the Zagyva graben.

5.3.1. Southeastern Plain

This area was described in [NEMESI et al. 1981]. It was suggested that very likely the conductance of the sedimentary sequence is the highest in the whole Carpathian Basin; this arises not only from the locally 6–7 km depth of the Neogene, dominantly Pliocene basin, but it can also be ascribed to the extremely thick, low resistivity — reaching even a lower limit of 2–5 Ωm — Early Pannonian (Pliocene) clayey sequence. At the same time we also indicated that according to the evidence of deep direct current and magnetotelluric soundings there are very significant differences in the average resistivity of the individual sub-basins. Resistivity of the sedimentary sequence in the maximum about 7 km deep Makó graben that lies in the eastern side of the Tisza river, close to the southern country border is roughly one and a half to two times higher than that of the Békés basin of the same depth (close to the southeastern border. Or in the southern part of region in the western (right) bank of the Tisza river, in the area of Kiskunfélegyháza–Gátér–Csongrád, the average resistivity of sediments is the highest here in the whole Plain, about three times higher than the average resistivity determined at the GEAB-I principal base due to the relatively thick Late Cretaceous, Miocene and, of course, Pliocene sequences overlying the high resistivity basement formations at a depth of 3–4 km. Therefore this basin does not appear as a minimum on the telluric map.

It is also a point of interest that in the middle of the Békés basin, in a zone of northeast–southwest direction and with the town of Békés roughly at its centre, where in the basement's geological map the basement of Cretaceous age can be seen, the high resistivity basement lies even several km deeper than the high velocity one.

In point of fact — as early as at the end of 1960s and the beginning of 1970s — we laid down as well, that after all in geoelectric investigation of southern Plain the most important result is that telluric measurements mapped for the very first time the two most remarkable basins, and the basin depth data relevant even today were obtained by means of sediment resistivity correction determined from direct current (dipole equatorial) soundings and these data were published as well [NEMESI et al. 1981].

Prior to the telluric measurements the only known thing was that the basins might be deeper than 3500 m. We were also able to find that the telluric method detected all those anticline structures which were detectable at all with the given measurement station density. These structures are important from the viewpoint of hydrocarbon exploration.

Twenty years ago, however, we could not find any factual explanation for the fact that gravity measurements did not image these basins, nor the reason for the approximate coincidence of gravity and magnetic anomalies, etc. The only unambiguous reality was that the source of gravity and magnetic anomalies should be sought for in intervals below the basement horizon.

Later we carried out model calculations with the assumption that the tapered Earth crust causes the gravity and magnetic anomalies [NEMESI, STOMFAI 1992]. In other words, the primary source of anomalies is an elevation of the mantle whose susceptibility and density is higher than the crust's 2.7 t/m^3. The tapered crust (mantle plume) is just below the deepest basins. Nowadays deep seismic and deep magnetotelluric sections also justify these hypothetical models [POSGAY et al. 1996, ÁDÁM et al. 1996].

5.3.2. Central northeastern–southwestern region of the Plain (flysch zone and the belt of Miocene volcanism)

As can be seen from the title of this section the flysch of Cretaceous age represents the pre-Tertiary basement and this distinguishes this area from the southern Plain's areas in the zone's western half, and in addition to this the Miocene volcanites cause a variation in the geoelectric properties in the zone's eastern part.

The flysch-type formations are of Late Cretaceous age in the zone's western part and their resistivity is roughly similarly low as that of the Miocene sediments (generally 10 Ωm, Zagyvarékas, Nagykörü). In this region the geoelectric basement lies deeper than the high velocity basement. Moving eastward, in the vicinity of the Hortobágy (Nádudvar), however, the basement is of Early Cretaceous age, it consists of strongly metamorphosed, high resistivity rocks that are also the basement for geoelectric measurements. It is interesting that Miocene rocks of volcanic origin are known in this region, but from among them the resistivity of tuffs detected by seismics, borehole and well-logging prospecting does not differ from that of the Early Pannonian (Pliocene) clays (Görbeháza).

In the eastern third of the zone the Miocene volcanites are the geological formations determining the results of the geophysical surveys, the interpretation, their total thickness, certified by drilling, reaches even 3000 m (Nagyecsed). Geoelectric methods have provided eminent results in their investigation. With their help this area could be classified into four types. Details about this were published in 1981 [NEMESI et al. 1981]; the investigation results of the team dealing with the Neogene volcanism on Hungarian territory summarized in 2004 lean strongly, too 'on the geoelectric investigation results' [ZELENKA et al. 2004], to which here we refer only briefly:

As a result of telluric measurements, direct current soundings, magnetotelluric measurements and deep (long offset) transient soundings four basic geological buildup types can be distinguished in the area:

— Type 1 is the sector of eruptions marked with magnetic and telluric highs, but gravity lows. Here, in the deep Tertiary basin very thick volcanites overlie the Tertiary basement, and the resistivity of these latter two is commensurable. The 4000 m deep Nagyecsed well that was drilled after the publication of the report on this area can be found in this sector. It did not reach the Tertiary basement, but below young sediments of 1000 m thickness it was then drilled through 3000 m thick Miocene volcanic formations.

— Type 2 can be found moving further from the eruption zones where the volcanic material (frequently ignimbrites) overlies older sediments; its thickness is commensurable with its depth from the surface. This type can be characterized by a four-layer geoelectric model, the uppermost one is the Quaternary and Pliocene sediment of low resistivity, below this is the thick volcanic sequence of high resistivity (at least 500–1000 m thick 'shielding'), then deeper an older sedimentary sequence, and finally the fourth layer is the pre-Tertiary basement.

— Type 3 differs only slightly from the previous one, the volcanic sequence is thin and was detected only in boreholes, the geoelectric methods did not sense the 'shielding' plate.

— In type 4, in the regions between the large eruption zones there are virtually no volcanites, or possibly they are present only in the form of roundels or tuffs. Such, for example, is the Mátészalka basin that is therefore a telluric minimum as well.

5.3.3. From the Middle Hungarian Line to the Northern Middle Ranges

In this zone the pre-Tertiary basement is less known from wells than in the areas to the south, but based on our present knowledge it might be either Early Palaeozoic crystalline or Mesozoic carbonaceous rock, but in any case it is of high resistivity. The decisive sediment of the sequence overlying it is the Oligocene clayey sequence that can generally be characterized by a resistivity of 10 Ωm and its thickness may reach 1–2 km and the significance of the Pliocene (Pannonian) sedimentary sequence playing a basic role in filling up the southern Plain is substantially lower, it may even be missing.

Telluric results reflect well the Middle Hungarian Line separating the southern and northern types. As an example a relative conductance map part is shown in *Fig. 7* where, south of the Miskolc–Szerencs line — roughly at the Emőd-Tiszadob line — there is a significant change not only in the conductance values, but the size and directionality of anisotropy ellipses change decisively. It is not only the deepening of the pre-Tertiary basement from north to south that causes this significant change, but it also stems from the qualitative change taking place in sediments overlying the basement. On average, the resistivity of the mainly Oligocene sequence detected north of this sector is roughly twice as high as that of the dominantly Pliocene (Pannonian) sequence detected south of this sector.

Due to the geological buildup favourable for geoelectric methods (high resistivity basement, low resistivity sediment) this area can be well investigated using telluric and magnetotelluric methods. Telluric measurements correctly recognized the morphological elements even in the northern part of the section, at the foothills, even where the Miocene volcanic formations of the Mátra Mountains occur covered with younger sediments. Here the diffractions caused by the volcanites generate difficulties for seismic measurements [NEMESI et al. 1990].

It should also be mentioned that in this sector the regional gravity anomalies — similarly to the Southern Plain — do not map correctly the basin that deepens from the 1000 m at the foothills of the Northern Middle Ranges down to 5000 m at the Tisza. It is likely that due to the crust tapering, the mantle elevation characteristic of the deep basins gravity results shows an image just the reverse to the depth conditions of the Tertiary basin. In this sector, too, tellurics reflects the correct depth conditions of the basin.

Fig. 7. Telluric isoarea map in the vicinity of Polgár with the anisotropy ellipses
Legend: 1—Detail of the megatectonic line separating the Tisza and Pelso units based on the telluric measurements

7. ábra. Polgár környékének tellurikus izoárea térképe az anizotrópia ellipszisekkel.
Jelmagyarázat: 1—A Tisza-egységet és a Pelso egységet elválasztó nagytektonikai vonal részlete a tellurikus mérések alapján

5.3.4. The intra-mountain basins
(the three northern separated areas in Enclosure 1)

Variety characterizes the geology of the basins between the mountains and the geoelectric properties of their formations. Whereas in the area of Carpathian Basin, as a general rule, high resistivity characterizes the pre-Tertiary formations and the Tertiary formations are of low resistivity, here we experienced very low resistivity formations in the old basement and, on the other hand, the resistivity of the Tertiary Miocene volcanic rocks is frequently very similar to that of Early Palaeozoic formations. To mention only the extreme cases including those on the surface as well: in addition to the Devonian and Triassic limestones of several hundred or even several thousand Ωm resistivity in the Bükk Mountains — though these are frequently karstified and therefore of much lower resistivity — it is worth mentioning the Carboniferous graphitic shale of lower than 1 Ωm resistivity in the Uppony Mountains, and the Miocene andesite of 60–80 Ωm in the Cserhát and Mátra Mountains.

The most important examples of the sedimentary sequences filling up the basins are the fairly homogeneous Oligocene clayey sequences of significant (1–2 km) thickness, tuffs and weathered rocks of Miocene volcanic sequences and other younger sediments complete it. Their resistivity is, however, always low — not more than 10–20 Ωm.

From this inexact geological picture it obviously follows that the results of telluric measurements cannot be interpreted uniformly even within one and the same basin. In this sector changes in the thickness of low resistivity cause only a part, frequently less than a half of the conductance anomalies in the telluric map. Interchanging of the low and high resistivity basement tracts, and the fracture zones all generated characteristic conductance anomalies, but their identification and distinction from the sediment conductance became possible mostly only after comparison with other geophysical measurements, or even after drilling the well.

The above notwithstanding, in addition to the generalities it is worth mentioning some details as well:

—The Cserehát, the basin of the Hernád river hardly larger than 1000–1200 km^2, was the first intra-mountain basin where telluric measurements took place as early as in 1964.

It was obvious already at the time of measurements that the homogeneity of the field of the telluric current regular in the large plains ceased to exist here. While it was natural in the plain that the signal shape was identical even at measuring stations 100 km apart (there were differences at best in the amplitudes' magnitude), here frequently even within a separation of only 10 km the signal shape of only one of the two measured orthogonal components was similar, and the other component was totally different. Therefore it was necessary to use three telluric base stations within the relatively small area and to take a great deal of care in selecting the roving stations; in other words the interpreter processing the photo records with manual, analogue methods must see similar signal shapes. In the isoarea (relative conductance) map that can be seen in *Fig. 8* András Simon plotted the dominant anisotropy directions (current directions of the linearly polarized field); from these it can be perceived that in certain extreme cases these current directions are nearly orthogonal. As it turned out not only the narrow valleys filled with conductive sediments generate the channelling, but frequently the alternating high and low resistivity basement tracts as well. Thus, on the basis of the above it is no longer surprising that the low resistivity basement formation, graphitic shale in the Alsóvadász–1 well plays a significant role in generating the dominant conductance anomaly (shown in green) in the conductance map detail of this region in Enclosure 1, and the basin filled with Tertiary sediments and detected by seismics is only of secondary importance. The well was located just here precisely to reveal 'the contradictions', because here the 'geo-electric basement' is much deeper than the 'high density, high velocity' basement.

—The interpretation of the *Ózd basin's conductance map* covering about 800 km^2 is in many ways similar to the previous one. Here, however, several decades later and already in possession of magnetotelluric measurements all this caused less surprise, but the fact has not changed that since the early 1980s the already digital telluric instruments have also been fully capable of measuring electromagnetic waves most frequently occurring only in nature with a period time of 20–30 s, and therefore the telluric map equally reflects changes in the depth of the sedimentary basin, in the conductance of the sedimentary sequence, and in the conductance of basement [MADARASI 1990]. Anomalies of the telluric map showing an unusual and significant variability of conductance highs and lows were investigated with magnetotelluric soundings to separate as much as possible these three effects. The magnetotelluric sounding curve measured at a well that reached the basement and can be seen in *Fig. 9* bears evidence of

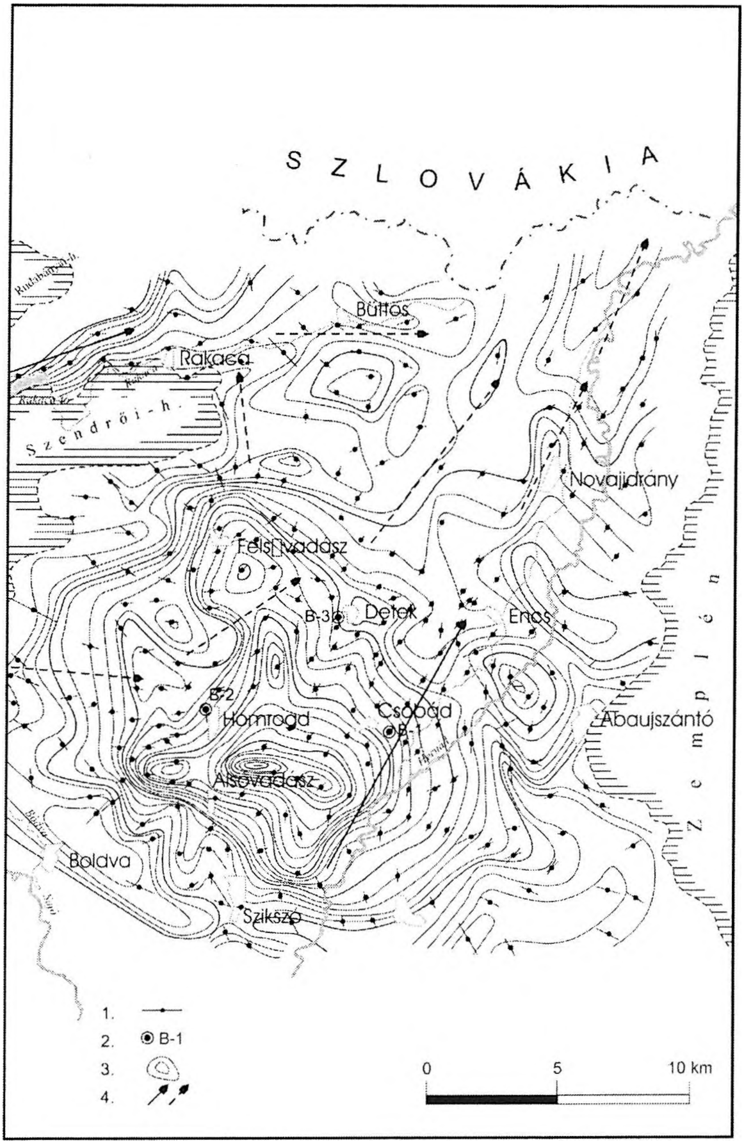

Fig. 8. Results of telluric measurements in the Cserehát (valley of Hernád)

Legend: 1—telluric measurement station with the local current direction; 2—telluric base station; 3—isolines of conductance; 4—anisotropy directions characterizing individual sub-areas

8. ábra. A cserehati (Hernád völgy) tellurikus mérések eredményei.

Jelmagyarázat: 1—tellurikus mérési pont a helyi áramiránnyal; 2—tellurikus bázisállomás; 3—vezetőképesség izovonalak; 4—egy-egy területrészre jellemző anizotrópia irányok

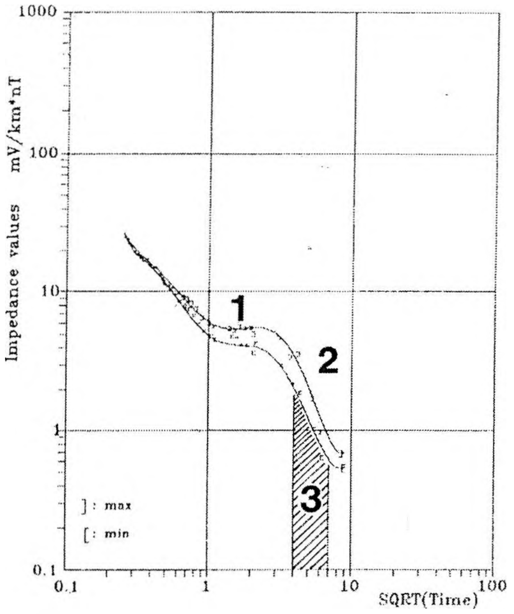

Fig. 9. Magnetotelluric sounding curve measured at the well Susa–1
Legend: 1—S interval; 2—effect of the conductor within the basement; 3—period range of telluric measurements

9. ábra. Susa–1 fúráson mért magnetotellurikus szondázási görbe. *Jelmagyarázat:* 1—S tartomány; 2—az aljzatbeli vezető hatása; 3—a tellurikus mérések periódustartománya

the proposition's promise, because it can be perceived that from the soundings performed at the individual telluric anomalies both the depth to the basement and the conductance of the young sediments can be determined, and the excess conductance above these can be ascribed to the basement's conductance. Recognition of the real geological image from such a variable telluric anomaly image requires a relatively high number of magnetotelluric soundings, but such a combination of telluric and magnetotelluric measurements is, even so, significantly less expensive than investigating the area with magnetotelluric soundings alone. Although financial sources available from the budget for investigations at the end of 1980s did not allow measurement of a sufficiently dense magnetotelluric grid, the construction of a contour map of the pre-Tertiary basement with a contour line interval of 500 m [MADARASI 1990] was successful.

— In the about 800 km^2 *northern part of the Zagyva graben between the Cserhát and Mátra Mountains* — in addition to the gravity and magnetic measurements — reconnaissance telluric and magnetotelluric, seismic surveys took place as well [NEMESI et al. 1990].

Out of these three intra-mountain areas this is the least variable considering both the anomaly image and the geological interpretation. In *Fig. 10*, in the telluric isoarea map the absolute ellipses can be seen as well. In the northern third of this map detail the conductance values are primarily proportional to the sediment thickness in the Tertiary basin, in the southern two third parts first of all the Neogene asymmetric eastward dipping graben can be recognized. On its eastern bank, at the foot of the Mátra Mountains andesite appears on the surface, its resistivity is one order of magnitude higher than that of the basin sediments, it channels the current field. And — in contrast to the generally characteristic north-east–southwest directionality of anisotropy ellipses — here the north–south directionality becomes dominant.

One of the map's curiosities is the narrow conductance anomaly of east–west direction that can be seen east of the village of Buják, south of

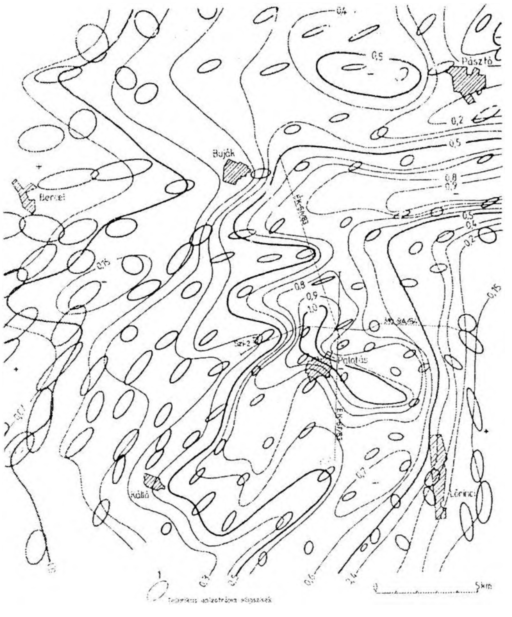

Fig. 10. Telluric isoarea (relative conductance) map of the Zagyva graben with the anisotropy ellipses

10. ábra. A Zagyva árok tellurikus izoárea (relatív vezetőképeség) térképe az anizotrópia ellipszisekkel

Pásztó, and it divides the map into a northern third and southern two thirds. In this zone the direction of the smaller anisotropy ellipses characteristic of the high conductance turns also in the anomaly's east–west strike direction. At the same time this anomaly is the northern border line of the Mátra Mountains as well, but it is much more than this, too: it is the structural border separating the Pelso and Western Carpathian units that can be seen in Fig. 2. This is a megastructural line to the north of which Early Palaeozoic crystalline rocks known from wells (Szécsény) constitute the basement, and the basin sediments are primarily of Palaeogene age. South of the line Mesozoic carbonaceous basement is assumed, and in the overlying 6 km thick sequence — in addition to the assumed thick Palaeogene sequence — the Neogene formations, primarily a thick Miocene sequence of volcanic origin and the overlying almost 2 km thick Pannonian (Pliocene) sequence are significant as well. This latter interpretation can be formulated based on the seismic–magnetotelluric profile marked ÉK–6 and measured in the Zagyva graben in approximately north–south direction.

6. Summary

Almost 100 years ago Loránd Eötvös pioneered the detection of geological structures with his torsion balance. Since then, geophysics has become the most important method of structural investigation and, within it primarily of hydrocarbon exploration. For decades, gravity measurements became a synonym for geophysics then seismics — the most effective even today — appeared, but it is much more expensive and far more sophisticated than gravity. Therefore wherever integrated surveys are performed, it has been realized that it is more practical to get to know the megatectonic conditions from inexpensive reconnaissance gravity measurements, and make use of concentrated seismics only at the most promising areas. This approach has shown mixed results: sometimes absolute success, sometimes no success. For example — in the western part of the Carpathian Basin this principle generally worked well, however in the eastern half discussed here it did not work. Thus, recently it has been stated that below the 5–8 km deep subbasins filled with young sediments the crust is thin, i.e. the mantle material, where density is much higher than that of the crust forms a plume below the basins, this results in a gravity high that in some cases reduces significantly; in other cases, however, it masks the young basins' effect. Over the deepest basins in East Hungary gravity highs can be found. Despite its much lower cost the telluric method correctly imaged the basement's structural and depth conditions in these areas as well. In other words, we consider it practical anywhere in the world's deepest basins to apply reconnaissance tellurics in addition to gravity, or with the up-to-date instrumentation of multi-station magnetotellurics.

Telluric surveys in Hungary started 50 years ago. There are great differences in effectiveness and reliability between the present instrumentation and the instruments then in being, and between the manual and digital processing. In certain parts of the presented map the station density of coverage strongly varies as well. Even so it can be stated that after the most modern seismic measurements and drilling evidence telluric measurements detected each expectable structural element on the basis of station density. This holds true down to details of 2–5 km.

Besides all of this 50 years ago researchers dealing with tellurics realized that not only changes in the thickness of saline marine sedimentary sequence conducting well the electric (telluric) current cause conductance anomalies but changes in its resistivity determined by lithological composition, grain size, etc. as well. Therefore after the reconnaissance telluric measurements direct current, then later magnetotelluric soundings were regularly carried out in a looser grid that allowed changes in the resistivity of sedimentary sequences to be taken into consideration and thus the contour map of the high resistivity was enabled, too. These geoelectric measurements provided for the first time depth maps acceptable even today of the 6.5–7.5 km deep basins in the southeastern Plain, the Makó graben and the Békés basin between 1967 and 1973 [NEMESI et al. 1981].

Fifty years ago researchers did not take into account that the old basement — in the Carpathian Basin mostly Palaeozoic crystalline and Mesozoic carbonaceous rocky of high density and high propagation velocity — may be of low resistivity locally too. This is the third most essential source of conductance anomalies in the telluric map. In most known cases Cretaceous sediments or older graphitic shale, meta-anthracite have such properties, but in other places megastructural lines generate band-like conductance anomalies.

In possession of the present knowledge on the geological conditions the most important contribution of telluric measurements is that they are able to provide other results, other anomalies than gravity, magnetics or even seismics the resolution of which is much higher. Clarification of the reasons for these anomalies leads to new geological information.

In all those areas of the world where deep structural investigations are only in their early stages, e.g. in the period of finishing off the gravity measurements before the seismic surveys, it is worthwhile to carry out telluric, magnetotelluric measurements too in a quasi-grid, especially when the assumed depth of the basins may be more than 3–5 km. Obviously, those organizations who constructed 100–200 station magnetotelluric systems also recognized that these measure, at the majority of stations, only electric (telluric) components. It should be emphasized, however, that the integrated geological interpretation must not neglect knowledge of geoelectric properties anywhere, in any depth interval, anywhere in the world.

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Kelet-magyarország tellurikus térképe

MADARASI András, NEMESI László, VARGA Géza

Kovácsvölgyi Sándor és munkatársai az Országos Tudományos Kutatási Alap-tól (OTKA) elnyert támogatás keretében (T 026515 sz. téma) klaszter analízissel vizsgálták a gravitációs, földmágneses, tellurikus kutatási eredményeket és a pre-tercier medencealjzat mélységtérképét. Ennek anyagi forrásaiból sikerült a K-Magyarország 1:500 000-es méretarányú tellurikus vezetőképességtérképet is kinyomtatni, amely mellett az összehasonlítás kedvéért a gravitációs és földmágneses térképek is láthatók (1. melléklet).

A tellurikus mérések alapvető célját Kántás Károly fogalmazta meg 1954-ben, akadémiai székfoglalójában. Ennek lényege, hogy a tellurikával mindenek előtt az üledékes medencék aljzatának mélysége, és az üledék átlagos fajlagos ellenállásának laterális változása kutatható, ami elsősorban a szénhidrogén-kutatás szempontjából érdekes. Leszögezte, hogy: "*a klasszikus kutatómódszerekkel összehasonlítva a tellurikus kutatások helyét a gravimetria és a szeizmikus kutatások közé tehetjük*".

A mellékelt tellurikus térkép három magyar intézmény — a Miskolci Egyetem Geofizikai Tanszéke, a magyar olajipar (OKGT) Geofizikai Kutató Vállalata és az Eötvös Loránd Geofizikai Intézet (ELGI) — kvázihálózatos méréseinek eredményei alapján, átlagosan 25 s periódusidejű oszcillációkat felhasználó mérésekből született abszolút vezetőképesség térkép. A relatív tellurikus mérési eredményeket magnetotellurikus szondázások segítségével számítottuk át abszolút értékekre. A térkép színkulcsa megegyezik a 2000-ben megjelent Ny-magyarországi tellurikus térképével, amelynek magyarázójában részletesen kitértünk a mérésekhez használt műszerek és feldolgozási eljárások ismertetésére is.

Meg kell még jegyeznünk, hogy a most mellékelt terület 30 000 km^2-nyi részén történt geoelektromos kutatási eredményekről, azok földtani értelmezéséről 1981-ben a Geofizikai Közlemények különszámában részletesebben is beszámoltunk.

A most bemutatott térkép értelmezését geoelektromos kontrollok — nagymélységű egyenáramú szondázások, magnetotellurikus mérések — után elsősorban a gravitációs Bouguer-anomália, a földmágneses ΔZ anomália térkép és a pre-tercier medencealjzat térképpel történő összehasonlítás alapján végeztük. Megállapíthattuk, hogy a tellurikus térkép az 5–8 km mélységű üledékes medencékről, azok mélységéről, szerkezeti viszonyairól igen jó kvalitatív képet mutat, szemben a gravitációs, vagy földmágneses térképekkel, amelyek anomáliáit, K-Magyarországon elsősorban köpeny-kiemelkedésekkel magyarázhatjuk Ez a tény fényesen igazolja a módszer szénhidrogén-kutatásban történő alkalmazásának fontosságát, mégpedig a gravitációs és földmágneses mérések után, a szeizmikus méréseket megelőző kutatási fázisban.

Ha a neogén medence feltöltésében jelentős mennyiségű (miocén korú) vulkáni anyag is előfordul, akkor ezeken a területeken a tellurikus kép nem a pre-tercier aljzat mélységével arányos, mert a vulkanitok fajlagos ellenállása összemérhető az aljzatképződményekével. Ilyen ÉK-alföldi területen (Nyírség vidéke) a tellurikus anomália-kép leginkább a mágneses anomália képhez hasonlít.

A méréstechnika és a gépi feldolgozástechnika fejlődése az 1980-as évektől lehetővé tette az anizotrópia ellipszisek ábrázolását is. Ez a vezetőképességanomáliák mellett, igen szemléletessé teszi a jelentősebb szerkezeti vonalak kimutatását is, pl a Tisza-egység és a Pelsoi-egység, vagy a Pelsoi-egység és a Ny-Kárpáti-egység között.

Az É-i Hegyvidék belső medencéiben gyakran fordul elő a pre-tercier aljzatban kis fajlagos ellenállású képződmény, pl. grafitpala. Ez a tény a harmadkori üledékek vastagságváltozásából adódó vezetőképesség-változások mellett sokszor jelentős anomáliák okozója.

A mai ismeretek szintjén, amikor bemutatott térképeink területén a pre-tercier aljzatot több ezer mélyfúrás érte el — és sokszor a tellurikus mérések sűrűségét jóval meghaladó szeizmikus vonalhálózat szolgáltatja kutatási eredményeit — a kvalitatív tellurikus térképnek és más kvalitatív (gravitációs, földmágneses) térképnek is az a legfőbb értéke, hogy bizonyos területekről egymástól eltérő képet mutatnak, amelyek konkrét földtani okai sokszor még nem ismeretesek. Ezek az eltérések hívják fel a figyelmet a geológiai érdekességekre, esetleg eddig feltáratlan nyersanyagok létezésére.

ABOUT THE AUTHORS

András Madarasi (1951) graduated as a geophysical engineer from Miskolc University in 1974 whereupon he was offered a post at the Eötvös Loránd Geophysical Institute of Hungary. His research interests are potential fields and geoelectric methods. Initially he dealt with exploration for sulphide ores in Hungary, Mongolia and Cuba, but in the last decade he has been working on magnetotelluric measurements and their interpretation. He is a member of the Association of Hungarian Geophysicists.

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From 1962 until his retirement in 1996, he worked for the Eötvös Loránd Geophysical Institute of Hungary dealing primarily with the methodology and interpretation of telluric measurements. However, he was also active in other fields, publishing papers on deep structural investigations, hydrocarbon, groundwater and thermal water exploration, as well as geothermal energy prospecting using geoelectric methods. Over the years he took part in geophysical explorations in Austria, the Czech Republic, Libya, Mongolia, and Slovakia. He has published well over 100 technical

articles; in particular, studies dealing with large areas of the Carpathian Basin; not only was he the first author of the latter studies, but he was also the principal organizer of the scientific investigation and co-operation lasting 8–10 years. He is a member of the Association of Hungarian Geophysicists.

Géza Varga (1944) is a geophysicist; qualifying at the Eötvös Loránd University of Sciences in 1968. Since his graduation he has been working for the Eötvös Loránd Geophysical Institute of Hungary. His main research interests are electromagnetic methods, and the development and application of the magnetotelluric method in geological exploration. He has taken part in numerous exploration projects in Hungary and abroad, the most important being prospecting for geothermal energy in the Republic of Korea, co-operation with the United States Geological Survey in the framework of the U.S. – Hungary Joint Fund, the regional magnetotelluric survey in Slovakia, and the Geological Base Lines project in Hungary. He has been a member of the Association of Hungarian Geophysicists since 1968.

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Bouguer anomaly map of Hungary

János KISS*

The Bouguer anomaly map of Hungary on a scale of 1:500,000 is given as Encloure 2. The main stages in construction and some geophysical–geological viewpoints are given.

Keywords: gravity surveys, Bouguer anomalies, Hungary

Gravity measurements have been carried out in Hungary since 1901. At the beginning one used the Eötvös torsion balance; later, from the 1940s — regarded as modern — gravimeters were used. In the meantime, although the methods of measurement and preprocessing have not changed, the accuracy of field measurements has increased. This was due to the more up-to-date and precise gravimeters as well as to the more strict altitude-determination because of the increased accuracy (exact determination and consideration of the measuring mass and of the altitude of the instrument stage).

During the period of the cold war, gravity data were top secret, which caused a great many problems concerning the processing and interpretation of the measured data. The unified gravity network of Hungary was completed in the 1950s, and since that time gravity processing for geological purposes uses this so called MGH–50 basic network.

Because of the uniform data system and because of the pre-processing of gravity data (various corrections) the demand for computer based data processing arose very early. Doubtless this is why gravity survey data became the basis of ELGI's first digital database. The preliminaries of database handling started in the 'big-computer' period, in 1968, but the standardized form of stored gravity data became final and general in database processing only in 1984 [KOVÁCSVÖLGYI 1993]. Data were stored first in data files organized according to map sheets on a scale of

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1:25,000; later, in order to speed up database operations, on a scale of 1:100,000.

There are more than 380,000 gravity points in Hungary [KOVÁCSVÖLGYI 1994a, KISS 2001] and there are only a few places where one cannot get useful geological information of gravity data because of lack of data. In that most data originate from state-supported measurements the database is qualified as open access. The territory of Hungary is totally covered with measurements in a quasi-network, with sparse but uniform density along roads. The dense gravity field measurements in a regular network are connected with industrial raw-material prospecting, mainly with oil, gas, coal and bauxite prospecting, and some of these measurements are no longer open access.

The survey density for the whole country is, on average, 4 point/km^2; but there are parts where the density does not reach 1 point/km^2. Such places were for example, W Mecsek and its surroundings, where there was practically no measured point on an area of 240 km^2 up till 2002 [KISS 2002]. The efforts of the last years tried to terminate this situation. As geophysical preparation for geological prospecting with a view to the deposition of radioactive waste deposits we hope to rectify this.

A countrywide gravity map on a scale of 1:500,000 was first prepared in 1978. Later, in 1984, Szabó and Sárhidai [SZABÓ 1989], and in 1996 Kovácsvölgyi and Stickel prepared subsequent variations — the latter only for internal application. Thanks to the readiness of the database as well as the development of the processing and printing representation capacities [VÉRTESY 2002], and to the financial support by OTKA of ‘Hungary’s gravity lineament map’ topic the latest printed version of the Bouguer anomaly map could be finished on a scale of 1:500,000 (Enclosure 2).

Because of the inequality of the measurement density and the need to prepare a gravity map of Hungary we made use of interpolated data to obtain grids with a size of 500 or 1000 m. The choice of a smaller grid could result in pseudo-anomalies in interpolation; e.g. one might show during the processing the measuring tracks instead of geological effects. We filtered out false and double points as well as testing by multiple interpolations which grid size and blanking distance should be applied for a given measurement density [KISS 2002]. While constructing the Bouguer anomaly map we interpolated the data in a 1000 m grid, and carried out further interpolation only so that we could achieve a better presentation by making the original grid more dense.

When constructing a Bouguer anomaly map reduction-density is a very important parameter, being 2000 kg/m^3 on basin-areas, and in outcrop regions about 2670 kg/m^3. Since in the framework of the OTKA project we basically examined the structural relationships of the basin areas covered with young loose sediments — faults and formation borders appear with good identifiability in the areas of outcrops — we applied as a basic map the Bouguer anomaly map calculated with a 2000 kg/m^3 reduction-density (Enclosure 2).

During processing we applied the MGH–50 gravity system — this is the gravity database system, on the Potsdam base-level, applying the Cassinis-like (1930) normal field formulae, and calculating with the Adrian-altitude. This has been used in Hungary since the 1950s for geology-oriented geophysical prospecting.

Bouguer anomaly maps — achieved as a result of gravity measurements and serving as the basis for interpretation — can be used in practice for the following purposes:

—tracking the relief of high-density basin-basement;

—proving the lateral density variations in the basement;

—examining density inhomogeneities of the sedimentary sequences filling the basin;

—delineating high-density magmatic formations settled in between the basin filling sedimentary sequences.

Almost all geological problems can be linked with one of the listed items. During raw-material prospecting (oil, gas, coal or bauxite), thermal water prospecting, geothermic surveys, as well as geological mapping, a Bouguer anomaly map is used as a kind of initial map. With the help of new digital processing programs, gravity interpretation based only on Bouguer or residual gravity maps is already outdated. When processing the map data we have at our disposal: iterative depth estimations by two-layers model; various possibilities of space and frequency domain filtering, depth slicing, and the delineation of below-surface bodies are also available — given that the geological model of the area makes such a resolution possible.

Based on the experience gained in interpreting Bouguer anomaly maps and from comparing the Hungarian Bouguer anomaly map and borehole and well-logging data it can be stated that the territory of Hungary is characterized by a number of different gravity models — though the main-structure is well reflected. In most parts of the country normal or basic mountain (roughly two-layers) models can be applied. Here the relief of the Tertiary basement defines the main characteristics of the Bouguer anomaly map; there are low density, loose basin sediments above the basement. The other type is the Plain-model where, against deep basin depths, we observed local maxima; this means that there is a contradiction between the relatively large basement depth and the Bouguer anomalies. A number of factors may play a role in this. These are worthwhile analysing:

1. The density-depth relationships of the debris sediments [SZABÓ, PÁNCSICS 1999, MÉSZÁROS, ZILAHI-SEBESS 2001] show that at a 2–3 km depth the density of these sediments relates to the basement; in other words, the deeper basins have no gravity effect or only a very small one. This is confirmed by automatic gravity processing and modelling along profiles [KISS 2000, BODROGI, KISS 2000, VÉRTESY et al. 2000].
2. From examining different sites other authors [such as KOVÁCSVÖLGYI 1994b, 1995, 2005] see the lower crust-mantle density inhomogeneities reflected in the Bouguer anomaly values — since in the upper layers there are no sequences with anomalously high density.
3. The starting point of this explanation based on considerations similar to point 2 above, is a huge regional gravity maximum in the Carpathian Basin [WYBRANIEC et al. 2005, HORVÁTH 2004], and as an effect of this there are increased anomaly values in the Great Hungarian Plain. This regional effect can be determined on the basis of a European or Central-European Bouguer anomaly map and can be filtered out from the national data system. Thanks to the OTKA project and the CELEBRATION programme this can be done in the near future. As a result of the filtering one obtains a gravity anomaly map for the Hungarian Great Plain, which corresponds more to a normal basic mountain model. Despite the relevance of the previous two points perhaps one can increase the accuracy of the gravity anomaly map by crossing the border.

Bearing in mind the last three remarks a new perspective is given to apply the old data system on a modern European level, thereby giving a new impetus to gravity prospecting.

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Magyarország Bouguer-anomália térképe

KISS János

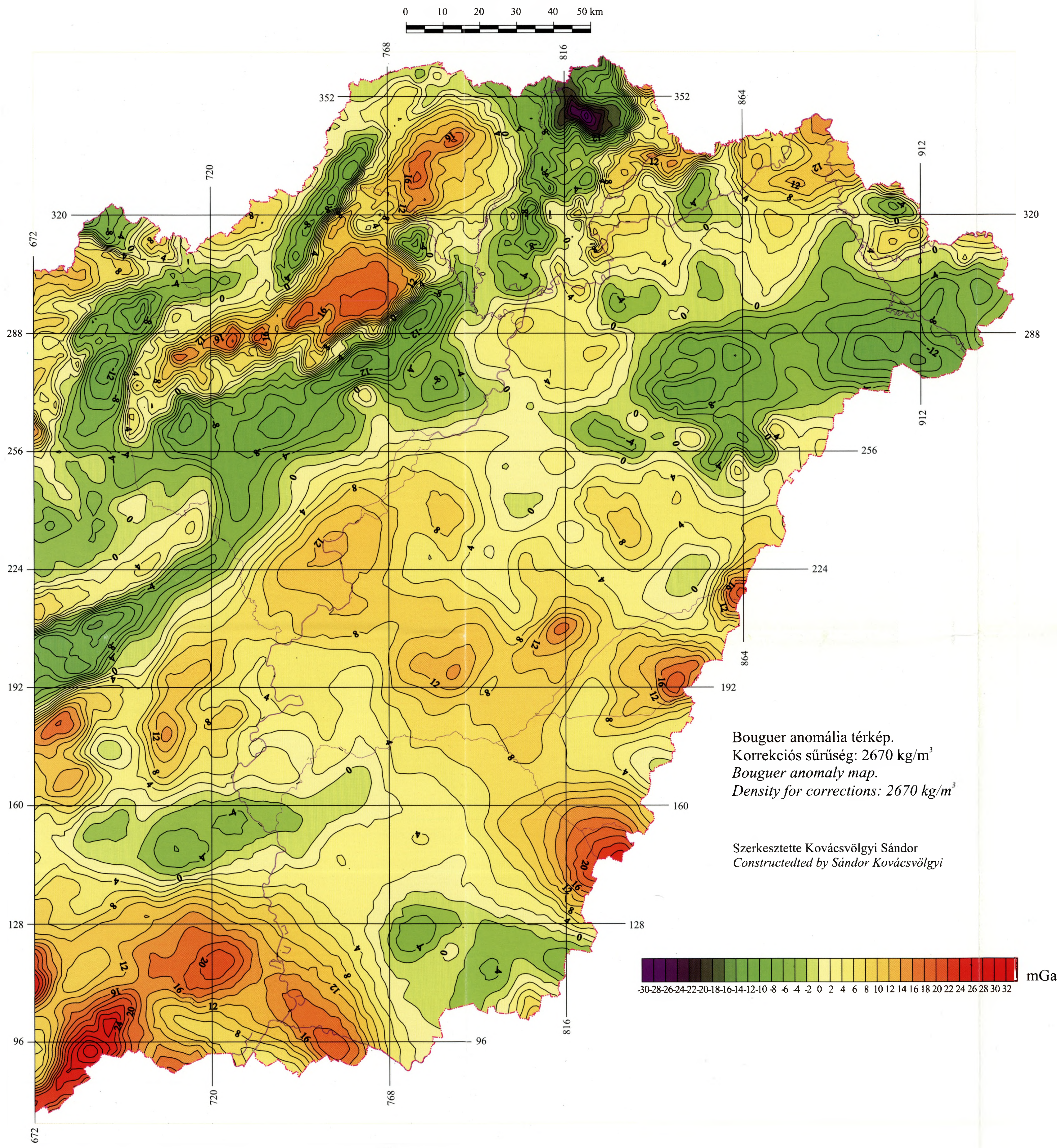
Magyarország Bouguer-anomália térképét a 2. sz. mellékletben közöljük. Rövid összefoglalást adunk a térkép szerkesztés geofizikai-geológiai szempontjairól és a történelmi előzményekről.

ABOUT THE AUTHOR

János Kiss graduated as a geophysicist at the Mining University of Saint-Petersburg. He has been working in ELGI since 1986. His main fields of interest are potentional field methods, processing and interpretation. Currently he is working with a country-size data set of gravity, magnetic and airborne geophysical methods. Since 2003 he has participated in the PhD education programme of the West-Hungarian University in Sopron.

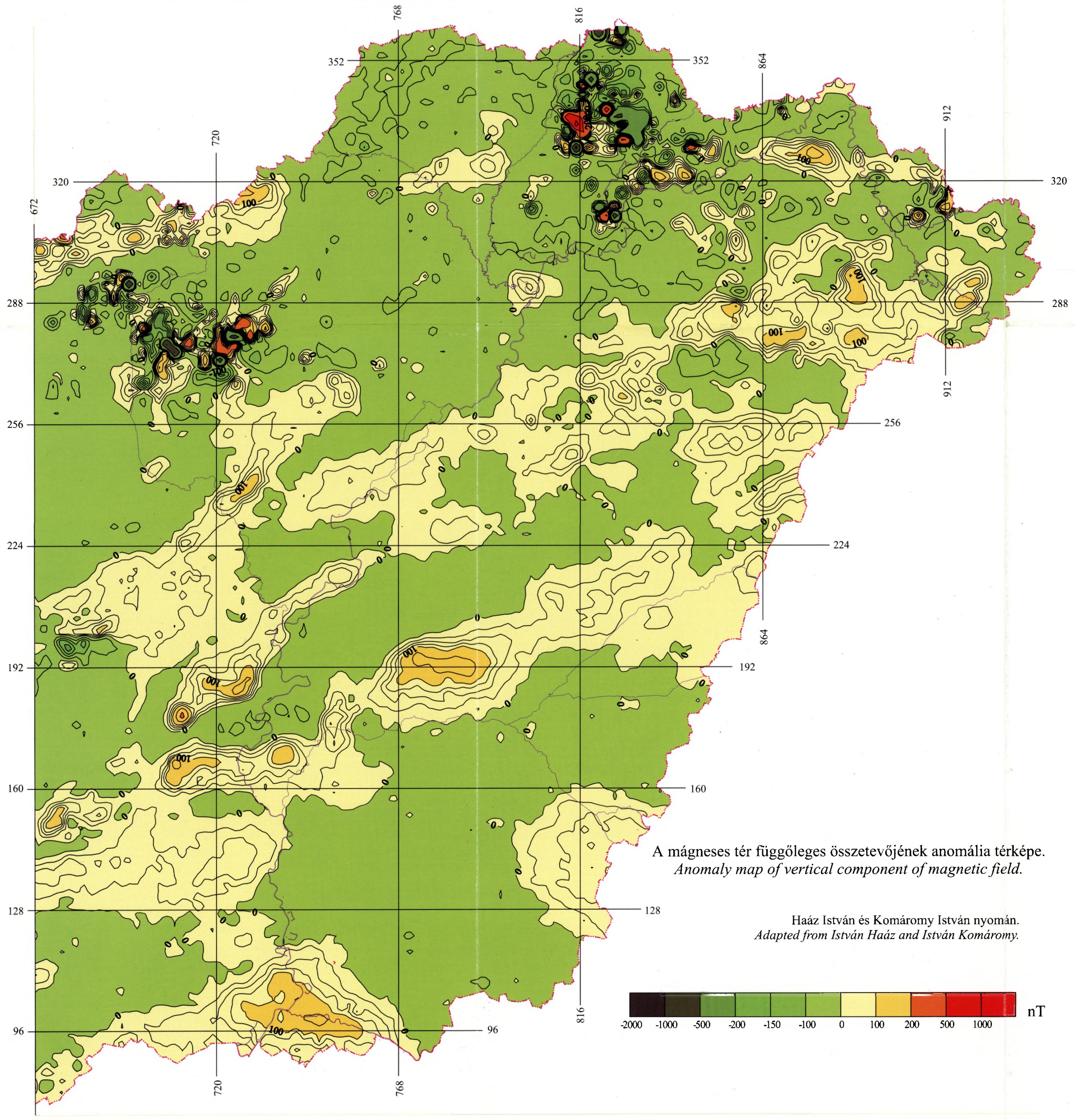
KELET-MAGYARORSZÁG GRAVITÁCIÓS ÉS MÁGNESES TÉRKÉPE
GRAVITY AND MAGNETIC MAP OF EAST HUNGARY

1 : 1 000 000



Bouguer anomália térkép.
Korrekciós sűrűség: 2670 kg/m³
Bouguer anomaly map.
Density for corrections: 2670 kg/m³

Szerkesztette Kovácsvölgyi Sándor
Constructedted by Sándor Kovácsvölgyi



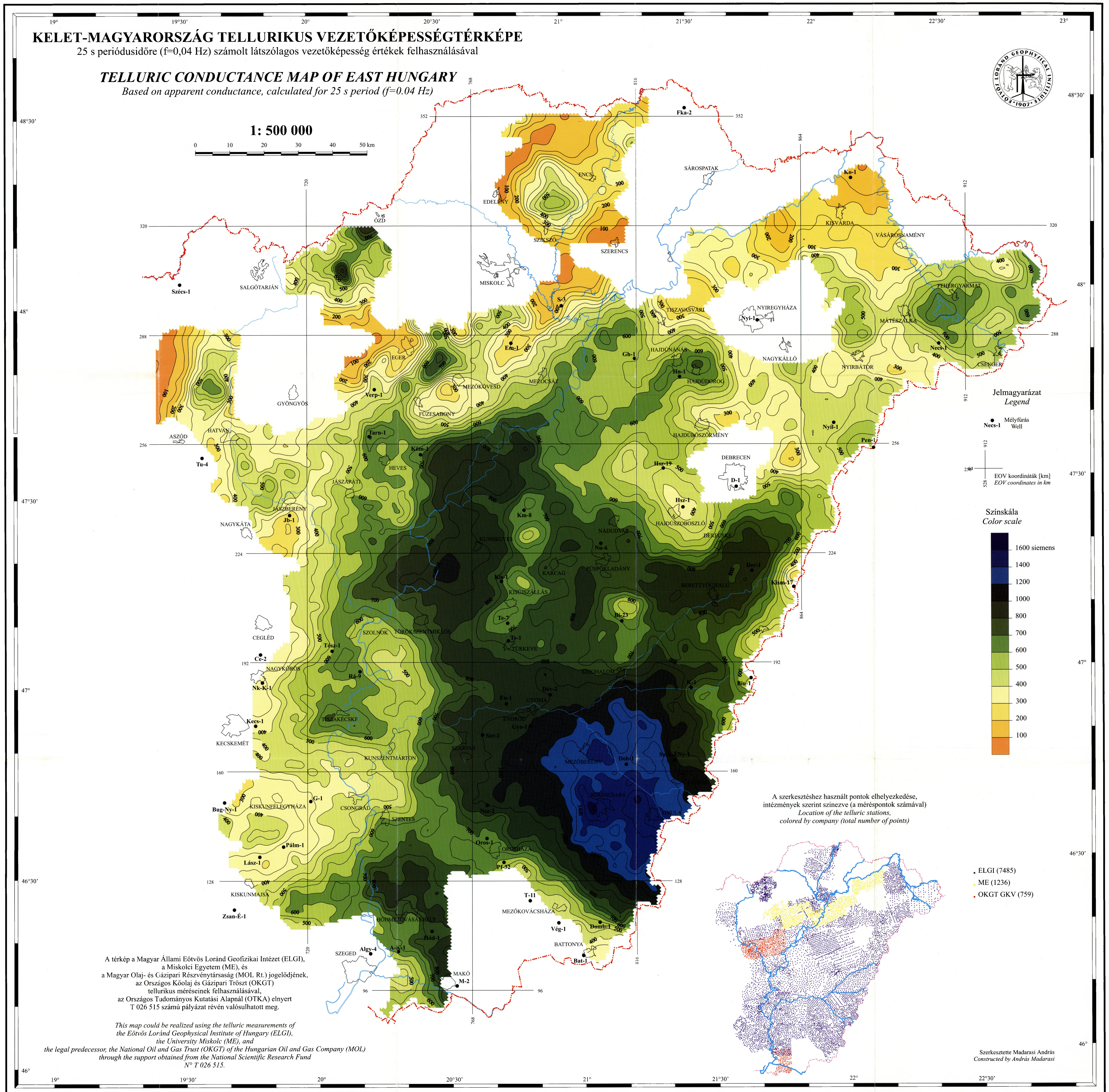
A mágneses tér függőleges összetevőjének anomália térképe.
Anomaly map of vertical component of magnetic field.

Haáz István és Komáromy István nyomán.
Adapted from István Haáz and István Komáromy.

KELET-MAGYARORSZÁG TELLURIKUS VEZETŐKÉPESSÉGTÉRKÉPE
25 s periódusidőre (f=0,04 Hz) számolt látszólagos vezetőképesség értékek felhasználásával

TELLURIC CONDUCTANCE MAP OF EAST HUNGARY
Based on apparent conductance, calculated for 25 s period (f=0.04 Hz)

1: 500 000



Jelmagyarázat
Legend

Necs-1 Mélyfúrás
Well

EOV koordináták [km]
EOV coordinates in km

Színskála
Color scale

1600 siemens
1400
1200
1000
800
700
600
500
400
300
200
100

A szerkesztéshez használt pontok elhelyezkedése,
intézmények szerint szinezve (a méréspontok számával)
Location of the telluric stations,
colored by company (total number of points)

- ELGI (7485)
- ME (1236)
- OKGT GKV (759)

A térkép a Magyar Állami Eötvös Loránd Geofizikai Intézet (ELGI),
a Miskolci Egyetem (ME), és
a Magyar Olaj- és Gázipari Részvénytársaság (MOL Rt.) jogelődjének,
az Országos Kőolaj és Gázipari Tröszt (OKGT)
tellurikus méréseinek felhasználásával,
az Országos Tudományos Kutatási Alapnál (OTKA) elnyert
T 026 515 számú pályázat révén valósulhatott meg.

This map could be realized using the telluric measurements of
the Eötvös Loránd Geophysical Institute of Hungary (ELGI),
the University Miskolc (ME), and
the legal predecessor, the National Oil and Gas Trust (OKGT) of the Hungarian Oil and Gas Company (MOL)
through the support obtained from the National Scientific Research Fund
N° T 026 515.

Szerkesztette Madarasi András
Constructed by András Madarasi

Topográfiai alap: Országos Topográfiai Adatbázis (OTAB)
Digitális változat: Madarasi András

Topographic base: National Topographic Database
Digital version: András Madarasi

A TÉRKÉP A MAGYAR ÁLLAMI EÖTVÖS LORÁND GEOFIZIKAI INTÉZETBEN KÉSZÜLT BUDAPESTEN, 2001-BEN.
THIS MAP HAS BEEN PREPARED IN THE EÖTVÖS LORÁND GEOPHYSICAL INSTITUTE OF HUNGARY, BUDAPEST 2001.

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Responsible publisher: Tamás Bodoky

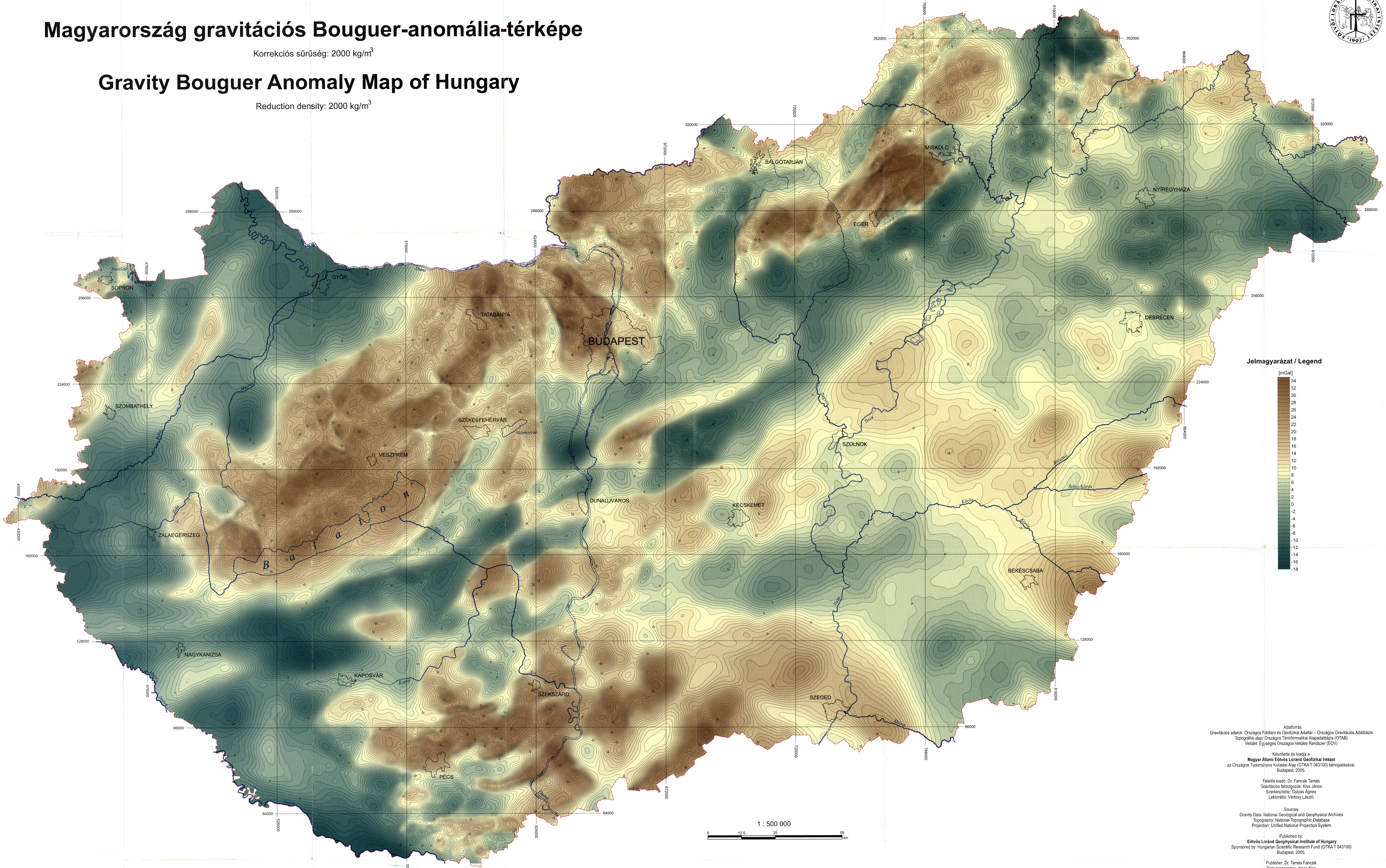
Sokszorosította a CARTOGRAPHIA Kft

Magyarország gravitációs Bouguer-anomália-térképe

Korrekciós sűrűség: 2000 kg/m^3

Gravity Bouguer Anomaly Map of Hungary

Reduction density: 2000 kg/m^3



Adatforrás
Gravitációs adatok: Országos Földtani és Geofizikai Adattár – Országos Gravitációs Adatbázis
Topográfiai alap: Országos Térinformatikai Alapadatbázis (OTAB)
Vetület: Egységes Országos Vetületi Rendszer (EOV)

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Budapest, 2005.

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Szerkesztette: Gulyás Ágnes
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Sources
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Topography: National Topographic Database
Projection: Unified National Projection System

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Reviewer: László Vértesy

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