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Magnetic anomalies in the area of the DANREG project

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Printed verions of the magnetic anomaly maps for the territories of Austria, Hungary and Slovakia were published between 1955 and 1987. The major difficulty in constructing the unified DANREG map at the Geophysical Department of the Vienna University, however, was not caused by the changes in instrumentation but by the necessity of using airborne ΔT values measured at different altitudes and ground ΔZ values. For constructing the unified map the ΔZ values had to be converted to ΔT anomalies by means of the iclinations. The distortions caused by the different national normal fields were eliminated by the application of a common normal field.

The most charateristic magnetic anomaly, a 100 km long maximum range which traverses the Gabčíkovo basin as well, can be found in the middle of the map; its location and shape show a remarkable similarity to the stripped gravity map presented in an other paper of this volume and to the Rába–Hurbanovo line. The source of this anomaly should be looked for in the pre-Tertiary basement.

The smaller anomalies (in the E part of the map) are associated with Miocene andesites; some other small anomalies that can be seen in the national maps disappeared due to the transformation and the large contour interval.

Keywords: magnetic anomalies, geological interpretation, DANREG

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1. Introduction

In the framework of the DANREG project it was decided to combine the already existing magnetic data of the three participating countries. In Austria data from an aeromagnetic survey [GUTDEUTSCH, SEIBERL 1987] were available, whereas in Hungary a ΔZ map constructed from the data of a regional ground survey [HAÁZ, KOMÁROMI 1966] existed; the observation data were digitized in the framework of the DANREG project. The Slovak part of the DANREG project area was covered by ground [BÜRGL, KUNZ 1955] as well as airborne measurements. The data sets were handed over to the team of Austrian geophysicists that supervised the magnetic project. The data set of the map shown in *Fig. 1* came into being at the Geophysics Department of Vienna University; the map was printed out in ELGI to ensure the unified format of the DANREG geophysical maps.

2. Theoretical basis for the construction of the unified map

Several obstacles needed to be faced when constructing the unified map. The first and most important of these was that in some areas only ΔT values observed at different altitudes were available, and in other areas there were only ground ΔZ values. In addition, in calculating the anomalies different reference fields, i. e. normal corrections were used in the three countries, the existing maps referred to different epochs, etc. Under such conditions no correct solution could be achieved. The unified map could only be constructed by means of approximations and by neglecting certain factors.

It was decided that the unified map would be a ΔT map (but a ΔZ map has also been constructed). In Hungary only ΔZ anomaly values were available, therefore these had to be transformed into ΔT data. The following relation exists between the components of a magnetic anomaly:

$$\Delta T = \sqrt{\left(\Delta H^2 + \Delta Z^2\right)} \tag{1}$$

where ΔH is the horizontal component of the anomaly.

The horizontal component can be expressed using the inclination (I) and the vertical component:

$$\Delta H = \Delta Z(\tan I)^{-1} \tag{2}$$

where I is the inclination of the total vector of the Earth's magnetic field.

Such transformation of the ΔZ component into ΔT assumes the existence of induced magnetization only (without any remanence).

Because the inclination values are not available at each station an approximation had to be used. Thus, the I values were determined for each station using the following normal equation:

$$I = 61°39.46' + 0.97448\Delta\varphi + 0.04731\Delta\lambda - 0.0004938\Delta\varphi^2 + \\ + 0.0000252\Delta\varphi\Delta\lambda - 0.00003186\Delta\lambda^2 \quad (3)$$

where $\Delta\varphi = \varphi - 45°30'$ and $\Delta\lambda = \lambda - 16°00'$.

The above normal equation was based on 300 Hungarian stations and determined by ACZÉL and STOMFAI [1968].

After having transformed the ΔZ data into ΔT data determination of the unified ΔT anomaly system was the next step. To eliminate the distortion along the borders caused by the different normal fields used in the participating countries the equation determined in ELGI for the territories of Austria, Hungary and Slovakia [SZABÓ 1985] was used as common normal field. In determination of the normal field for Hungary and Slovakia data of the magnetic base network measurements referring to the epoch of 1980.0 were used. Because in Austria only the data referring to the epoch of 1960.0 were available, the time variation between 1960 and 1980 had to be taken as a correction. Determination of the time correction was carried out using a quadratic function calculated from the time series of the magnetic observatories in the nearby countries (Niemegk, Wien-Koblenz, Fürstenfeldbruck, Hurbanovo, Nagycenk, Surlari, Grocka, L'Aquila). Coefficients of the quadratic function most closely approximating the field were determined by means of adjustment from Slovak, Hungarian and corrected Austrian data.

To unify the ΔT data set established by the Austrian colleagues in the framework of the DANREG project the difference between the common normal field mentioned above and the normal fields applied originally by the individual countries was calculated for each station in all the three countries. The common data set was corrected using the obtained differences; thus the distortions caused by the deviations between the originally applied reference fields were eliminated. Using the unified data set the ΔT map was constructed in ELGI by means of the contouring program developed by A. SÁRHIDAI (Fig. 1).

To check the reliability of the above transformation some profiles were measured in 1991 which traversed characteristic anomalies in all the three countries.

3. Description of the map

If we look at Fig. 1 the immediate impression is that the magnetic pattern within the Carpathians differs considerably from that outside the mountains. The reason for this is not the fact that the measurements in Hungary and on a significant part of the Slovak territory were carried out about twenty years earlier than in Austria. Even so, it is, of course, true that the accuracy of the measurements performed in Austria in 1987 is by nearly two orders of magnitude higher than, for example, that of the earlier measurements in Hungary. The real reason is that the Vienna Basin is not so abundant in magnetic anomalies as the region within the Carpathians.

Some details of the data acquisition and interpretation might be mentioned. In the eastern part of Austria the airborne magnetic measurements were carried out with a proton magnetometer (accuracy ±0.125 nT) mounted on a fixed-wing aircraft. The line separation was 2 km, the flight altitude 800 m above sea level. Thus the clearance above the ground surface varied between about 600 and 750 m in the Vienna Basin. To improve the data quality tielines were flown perpendicularly to the lines at every 10 km. The sampling rate of the magnetometer was 1 s (~50 m sampling interval along the line). Flight path recovery was made by means of 35 mm films. The daily variation of the magnetic field was measured at local base stations; their data were later tied to the main magnetic observatory in Austria (Wien-Koblenz). The epoch 1977.7 was used in processing.

The magnetic anomaly pattern in Austria can be characterized by relatively low amplitudes. In the NW part of the map shown in Fig. 1 traces of the SE portion of a very wide regional anomaly can be recognized. This latter is caused by a deep-seated body (10–20 km below the surface); in the strike direction it starts from S of Munich, then through Salzburg it runs along the N part of the Kalkalpen (Calcareous Alps). It joins via Vienna the complex magnetic anomalies around Brno (Moravian anomaly). The tectonic setting of this anomaly belt is still a controversial issue. This magnetic structure is most likely caused by an old basement (Proto-Europe?) which has been conserved between the consolidated Hercynian Bohemian Massif

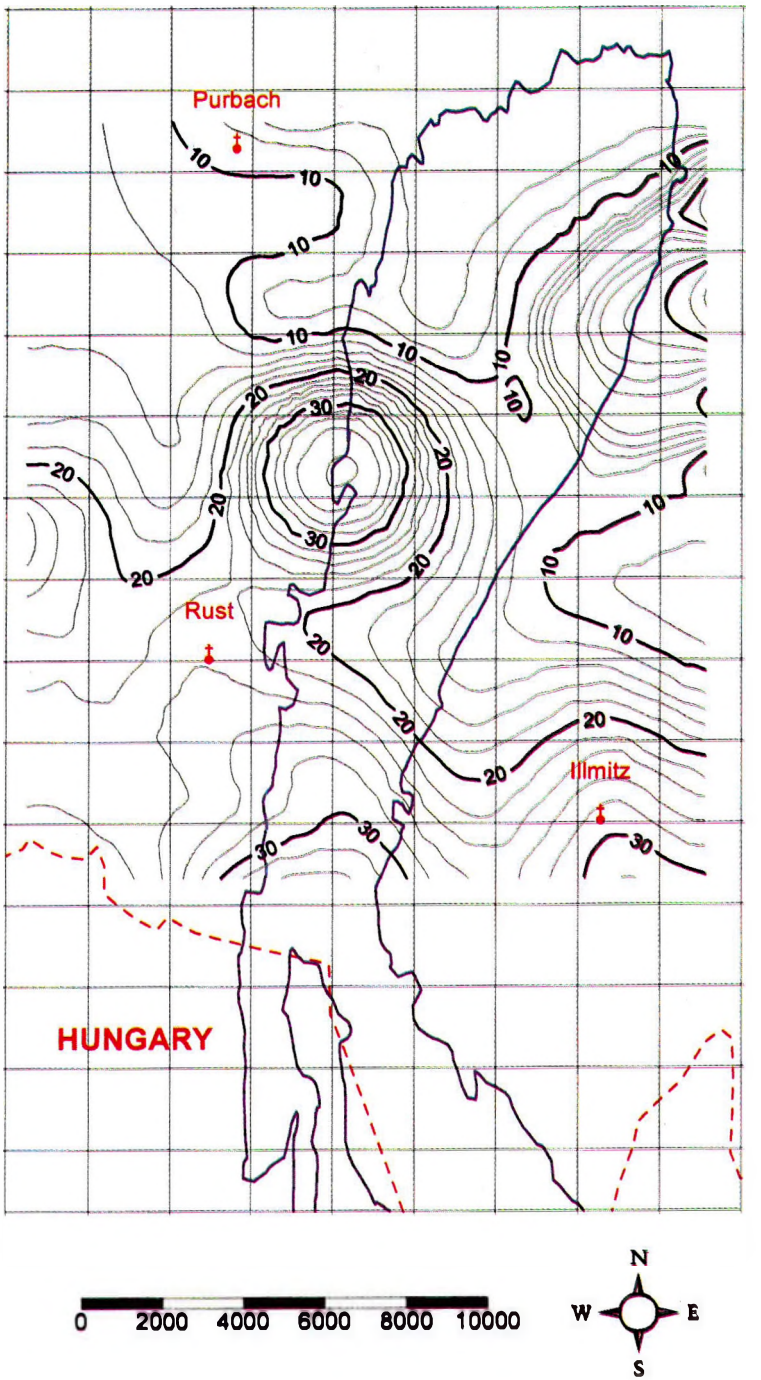
Purbach
Rust
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Fig. 2. Magnetic anomaly near Rust

2. ábra. A ruszti mágneses anomália

and the Alpine–Carpathian zone. Younger geological sources — remnants of a North Penninic oceanic crust — have also been considered for the western part of this anomaly [GNOJEK, HEINZ 1993].

There are no magnetic rocks on the surface that could cause the small magnetic anomalies W of Eisenstadt. They might be connected to the young Tertiary volcanic activity that can be observed along the whole eastern edge of the East-Alpine units.

An interesting magnetic anomaly can be found 6 km NE of Rust, right on the W side of Neusiedlersee. The lateral extension of this anomaly is approximately 6×5 km and its amplitude is 24 nT (*Fig. 2*). Using a Werner modelling algorithm a source depth somewhat greater than 2 km can be obtained [HEINZ et al. 1987]. If we consider an average flight altitude of 700 m then the magnetic body lies at a depth of 1.5 km. It is likely that this anomaly is also evidence for the above mentioned Tertiary volcanism because sulphuric mineral water can be observed at the nearby town of Rust.

The most significant magnetic anomaly belt in the area of the DANREG project with a more than 100 km strike length lies mainly on Hungarian and Slovak territory. Only some marginal parts of this belt can be observed in Austria, E of Neusiedlersee and S of the town of Hainburg.

Considering its extension the most significant anomaly in the area is that positive anomaly arc which starts S of Mosonmagyaróvár, its strike direction is NE; it turns N of Dunajská Streda and via Surány, Dubnik and Kamenin, with a dominant strike of E–SE it terminates at the mouth of the river Ipoly. Taking into account geological and other geophysical data this anomaly is part of a multiple arc structure. The Leitha Mountains and the Carpathian chains form the outermost arc. The next arc is the magnetic anomaly discussed here whose maximum zone coincides with the NW and N edges of the assumed source of the stripped gravity anomaly. The next arc is the stripped gravity anomaly itself; the innermost arc is the SE–S edge of the stripped gravity anomaly, which coincides with the Rába–Hurbanovo line detected by numerous geophysical methods. All these phenomena suggest that the tectonic events associated with the formation of the Leitha Mountains and the Carpathians have affected the area of the arcs as well and determined fundamentally the present geology.

The spatial coincidence with the outer edge of the stripped gravity anomaly arc is so close that the magnetic anomaly follows the small bulge that can be seen N of Dunajská Streda and also the 15–20 km southward shift

of the northern edge of the stripped gravity anomaly E of the Hurbanovo–Nové Zámky line.

The spatial coincidence with the deep structural zone reflected by the stripped gravity anomaly suggests that the source of the magnetic anomaly arc is magmatic rock intruded along the deep fracture. We do not have, however, other direct information about these rocks and their spatial position. Within the basin sediments only smooth, parallel reflections can be recognized in the seismic section K–1, which was measured close and parallel to the Danube, over the Hungarian part of the Gabčíkovo anomaly — that can be considered as part of the anomaly arc. Thus, within the sediments no volcanic structure of suitable size could be assumed which would be able to cause this anomaly. Based on the seismic data the assumable shallowest source of the magnetic anomaly is the volcanic rock directly overlying the basement at a depth of about 6 km [NEMESI et al. 1994]. But the magnetic susceptibility of the rocks penetrated by the borehole at Surány (S–1) is not high enough (1.5×10^{-3} SI) to explain the whole anomaly.

It should be noted that the anomaly arc bypasses the Kolarovo gravity anomaly, i.e. only non-magnetic rock can be assumed as the source of the gravity anomaly.

It is possible that the source of the positive anomaly E of Kapuvár is similar to that of the anomaly arc but considering the location of this anomaly it is associated rather with the Rába–Hurbanovo line, i.e. with the inner edge of the stripped gravity anomaly arc. In the area of this anomaly Miocene volcanic rocks are known from several boreholes; however, lava plays only a very limited role among them, thus the directly known formations certainly cannot be considered as the source of the regional magnetic anomaly. It is possible that the rocks penetrated by the boreholes represent the uppermost level of a larger volcanic-subvolcanic sequence [NEMESI et al. 1994].

East of the regional anomaly arc, mainly in Hungarian territory two further zones of different magnetic anomaly pattern can be distinguished. Between Esztergom and Diósjenő, on both sides of the Danube (Börzsöny and Dunazug Mountains) dense alternation of positive and negative anomalies of small extent can be observed. These are caused by the Miocene volcanites making up the two mountains. The reason for the negative anomalies is the strong negative remanent magnetization of some of these volcanites — a feature verified by paleomagnetic measurements [BALLA, MÁRTON 1980].

South of Diósjenő starts an anomaly zone with a strike direction of E–NE and a width of about 5 km, it continues E of the area and having a strike

length of 100 km it terminates in Slovak territory. Because of the scale of the map it cannot be seen but this zone actually consists of two parallel positive anomalies. The anomaly zone is associated with the so called Diósjenő dislocation belt. According to the geologic interpretation the source of the southern anomaly is primarily Mesozoic greenschist of Meliata type or weakly metamorphosed basic rock, and the northern source is primarily Paleozoic basic rock of Gemeric type, metamorphosed up to the greenschist–amphibolite facies [BALLA 1989].

Finally, there are magnetic anomalies of small amplitude and extension on the original magnetic maps of the Hungarian and Slovak territories that cannot be seen on the unified map due to the relatively large contour line interval. Such small anomalies can be found at the edges of the large isometric anomaly S of Kapuvár. The source of these is the Pliocene basalt lying close to the surface; this is evidence that the crust structure has not come to rest even in recent times.

4. Some words about the magnetic modelling

The researchers' interest has been focused on the sources of the large magnetic anomaly belt within the Carpathians, on their depth, age and origin since the coming into being of the first observation results. POSGAY performed the first modelling of the anomaly at the Danube (Gabčíkovo anomaly) thirty years ago [POSGAY 1967]. His conclusion was that a source of Paleozoic age should be at a depth of 4 km. FILO and ŠEFARA obtained very similar results twenty years later. In the framework of the DANREG project ARNDT got also a depth of 4 km for the same source, using an up-to-date 3D computer modelling program. Nevertheless, as we have already described, the seismic and magnetotelluric measurements certainly preclude this depth — at least if we assume that the source of the anomaly is basic volcanic rock, as could be demonstrated in each case within the Carpathians. Based on the velocity and resistivity data of the seismic and magnetotelluric measurements performed both in Hungarian and Slovak parts of the area, on the reflection image and the 2D geoelectric model (without evidence from boreholes) we might unambiguously say that an undisturbed Lower Pannonian sedimentary sequence can be found in this depth interval. Therefore — although there are results demonstrating the possibility of enrichment of magnetite in sedimentary environment and this might cause an anomaly — we have not found an

explanation for the origin of this material. Our idea is that in all probability a superimposed effect of several sources has been encountered. In possession of all geophysical data measured in this region our view is that these sources should be located within the pre-Tertiary basement. NEMESI et al. [1994] succeeded in carrying out modelling in which the source was at a depth of at least 6 km, i.e. really within the basement. ŠEFARA assumes a complex body as the source of the anomaly, which consists of parts with normal and reverse magnetization or several bodies with normal magnetization but various dippings. PAŠTEKA [1996] obtained by means of Werner deconvolution 7–7.5 km for the upper boundary of the source. In the next paper of this volume [DRASKOVITS et al.] we return to this problem, taking into account the results of other methods as well.

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Mágneses anomáliák a DANREG projekt területén

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A DANREG projekt területén az áttekintő mágneses mérések már közös munkánk megkezdése előtt léteztek, de mindhárom országról külön-külön. A szlovák részről BÜRGL és KUNZ 1955-ben, a magyar részről HAÁZ, KOMÁROMI 1966-ban, az osztrák részről GUTDEUTSCH, SEIBERL 1987-ben jelentetett meg térképet.

Az *1. ábrán* látható egységes térkép a Bécsi Egyetem Geofizikai Tanszékén készült és az ELGI-ben nyomtattuk ki az egységes DANREG topográfiai alapra.

Az egységes térkép megszerkesztésének egyik feladata abból adódott, hogy az eredeti mérések egy része földi ΔZ mérés volt, más részei viszont különböző magasságokban mért, légi ΔT mérések voltak. Az átszámítás az (1) és (2) képlet segítségével közelítően megoldható, az inklináció számítása ACZÉL és STOMFAI [1968] képlete alapján történt. A különböző epochára vonatkozó normálterek egységesítése Niemegk, Wien–Koblenz, Fürstenfeldbruck, Hurbanovo, Nagycenk, Surlari, Grocka, L'Aquila obszervatóriumok idősorának felhasználásával történt [SZABÓ 1985]. Az obszervatóriumok idősorából meghatározott függvény segítségével 1980,0 epochára számítottuk át a különböző országok mágneses alaphálózatának méréseit. Az időbeli változással korrigált alaphálózati adatokból kiegyenlítéssel határoztuk meg a földmágnese teret legjobban megközelítő másodfokú függvény együtthatóit. Hogy az országhatároknál fellépő torzulásokat elkerüljük, a Bécsi Egyetem Geofizikai Tanszékén a mért és transzformált adatokból előállított közös adatrendszert az ELGI-ben javítottuk az egységes és nemzeti normálterek különbségével. A térkép megrajzolása a közös DANREG topográfiai alapon a SÁRHIDAI-féle térképszerkesztő programmal az ELGI-ben történt (*1. ábra*).

A térkép anomáliáiról a következőket kell kiemelnünk.

— A legszembetűnőbb anomália a Kárpátokon belül a legmélyebb medencének megfelelő helyen található. Első látásra hasonló ívet látunk, mint a Kárpátoké, vagy a gravitációs fejezetben látható, üledékhatástól megtisztított gravitációs térkép maximum vonulata. Ezekhez egészen hasonló a projekt keretében végzett magnetotellurikus mérésekkel is alátámasztott Rába–Hurbanovo–Diósjenő szerkezeti vonal íve. A mágneses anomália hatói a szeizmikus és magnetotellurikus mérések eredményeivel összhangban, egyértelműen a harmadkori medence aljzatában, legfeljebb annak felszínén vannak. A mágneses hatók — bár nem azonosak a gravitációs hatóval — feltétlenül kapcsolatban vannak azzal, többnyire annak peremén találhatók [NEMESI et al. 1994].

— A magyarországi területen (a térkép K-i felén) található, tagolt mágneses anomáliakép, a Börzsöny és a Dunazug hegység felszíni miocén korú vulkanizmusával magyarázható. Feltűnő a Diósjenői diszlokációs öv hosszan elnyúlt pozitív anomália sora.

— Ausztria területén a térkép szinte anomáliamentes, legalábbis az alkalmazott szintvonalközökkel. Ha az egész Bécsi-medence sűrűbb izovonal-közű mágneses térképét néznénk, akkor tűnne fel, hogy itt egy olyan regionális mágneses anomália keleti végéhez

értünk, amely Münchentől indul és Salzburgon, Bécsen át kapcsolódik a Morva anomáliával. Ennek a Proto-Európa anomáliának a hatója 10–20 km mélységű. A Fertő-tó környékére kisebb kiterjedésű zárt anomáliák már jellemzők és valószínűleg miocén korú vulkanizmussal magyarázhatók.

— Meg kell említenünk szlovák és magyar területeken is olyan kis amplitudójú anomáliákat, amelyek az eredeti részlet-térképeken látszanak és általában fiatal, esetenként pannon korú bazalt-vulkanizmus hatásai.

A hatók mélységének meghatározására már 1966-ban is végeztek számításokat [POSGAY 1967]. Legutóbb a DANREG program keretében, osztrák részről ARNDT végzett hatószámításokat a Werner-féle, háromdimenziós modellező algoritmus felhasználásával. Az újabb eredmények nem különböznek lényegesen a régiektől, így a térkép legmarkánsabb (Gabčikovói) anomáliájára, a korábbiakhoz hasonlóan, 4 km-es mélységet kaptak, amelyet viszont a szeizmikus és magnetotellurikus adatok nagy valószínűséggel kizárnak. A Fertő-tó Ny-i oldalán, a ruszti 24 nT értékű mágneses anomália hatómélységére 1,5 km adódott (*2. ábra*).