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Geophysical results

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Results of deep geophysical survey

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Investigation of the pre-Tertiary basement
Geophysical results concerning the thickness of the Pannonian and lithofacies issues

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The internal structure of the basement (crust)

Geophysical textbooks and standard geophysical knowledge explain the gravity and magnetic anomalies by thickening of the young low density basin sediments, by basement structures or buried volcanic masses. These are the most obvious explanations.

In this situation it is enough to look at the Bouguer anomaly or magnetic D*T* anomaly map and at the contour map of the pre-Tertiary basement to recognize that these standard interpretations cannot be applied here. The Bouguer minimum of the Vienna Basin suggests a much larger mass deficiency than that of the large Danube–Rába Basin between Bratislava and Gyõr, though the depth to the basement is 5000 m in the former, and 8000 m in the latter. We look in vain for such features like the intensive magnetic anomalies of the central basin in the gravity or basement contour map, there is no correlation between them. And we look in vain for volcanites in the reflection image of the most up-to-date seismic section K–1, those certainly do not exist down to a depth of 8000 m in the deepest part of the basin. These facts have led us to search for other explanations for the phenomena. Recent calculations with different geophysical methods and joint interpretation of the results found the explanation in crustal structures and phenomena probably suggesting a mantle plume.

The starting point of our studies was that there is a series of maxima in both the magnetic and stripped gravity maps that follows the curve of the Rába–Hurbanovo Line. The sources of these maxima certainly lie below the surface of the pre-Tertiary basement. These sources can be found along the deep seismic profile K–1 measured between Bratislava and Gyõr. In this section there are no reflections within the crust, the Mohorovièiæ discontinuity cannot be seen, but before the reflections disappear there are signs suggesting an upward trend in the horizons.

Finally, it is necessary to point out that the existence of a crust-mantle anomaly in the central part of the Danube Basin is obvious. In the Vienna Basin anomalies of varying intensity can be obtained depending on the density parameters, these are negligible if compared to the previous ones. Thus, the existence of a mantle plume is unlikely there.

Subseqently, gravity modelling was performed using the MAGIX programme (INTERPEX Ltd.). In Figs. 1 and 2 modelling of the straightened seismic profile K–1, running between Bratislava and Gyõr, is shown. The difference between the two figures is that one of them displays the elevation of the lower crust and mantle with a continuous transition, while the other one with a step-like structure. The density model is based on published data, the density of the "granitic upper crust" is 2.7 t/m^3, the density of the "basaltic lower crust" is by 0.3 t/m^3, that of the upper mantle is by 0.5 t/m^3 higher. The results of modelling correlate closely with the seismic section. In its northern half, N of the crust-mantle structure the Mohorovièiæ discontinuity can clearly be seen. Thus, here we have data for the thickness of the crust as well. In the northern part of the profile reflections were obtained from the crust, while in its other half, as far as the Rába Line where the source of the gravity anomaly is located the seismic image is free of reflections. (It is mentioned that we have numerous seismic sections which show that S of the southern edge of the source (*i.e.* S of the Rába Line) there are reflecting horizons again within the basement.)

This kind of gravity interpretation is supported by the seismic image and its interpretation. It correlates also with the magnetotelluric results; the depth to the bottom of the Neogene is about 8 km and the depth to the gravity source is 10 km.

Sources of the magnetic anomalies should be searched for within the basement. Seismic and magnetotelluric measurements absolutely preclude the possibility of sources within the sedimentary sequence. This holds true for the sources of the anomalies of larger extent and amplitude even if some wells penetrated Miocene andesite below the Pannonian sequence, *e.g.* close to the Rába; and smaller Pliocene basalt bodies can be found on the surface, too. Accordingly it was reasonable to assume a common interpretation and identical sources of the gravity and magnetic anomalies. This has, however, partly failed. It can only be said that the location of the magnetic anomalies coincides with that of the gravity anomalies, but they are found sometimes in the middle, sometimes at one of the edges of the gravity source, sometimes in the fault zone bordering the gravity source, sometimes between two fault lines (borders). If we consider the conclusions drawn from the magnetic measurements alone then due to the ambiguity of the inversion the magnetic body can be placed equally within the sedimentary sequence, at the depth of the basement or even deeper, using either the oldest or the most up-to-date inversion techniques. If we take into account the depth and geothermal conditions of the basin, a Curie temperature of 578 °C can be expected at a depth between 10 and 25 km. As sources of the intensive anomalies bodies with a susceptibility of 3–7˘10^{-3} SI, of considerable size but with a density not higher than 2.7 t/m^3 can be imagined (because such bodies do not cause gravity anomalies), the upper surface of which lies close to the basement. Thus, finally a magnetic interpretation can be found which is not in contradiction with other data. These magnetic bodies can be assumed to be low-density (2.7 t/m^3) andesitic or basaltic bodies intruding upwards (not higher than up to the bottom of the sediments) from the melt mantle plume along the weakened zones.

Geophysical results in tectonic studies

Tectonic maps are, of course, based on surface observations, aerial and satellite images, well data and results of geophysical surveys. The compilers of the DANREG tectonic maps used all these kinds of information. They examined all utilizable seismic profiles from the region, and carefully studied the fractures in the basement and the "flower structures" within the sediments. Since no data are available in the deep basins attempts were made, at drawing tectonics for example, conclusions from the gravity data available everywhere. The filtered maps, gradient maps and the so-called lineament maps could be used. A dozen versions of these maps were constructed because effects caused by sources at different depths and of differ-

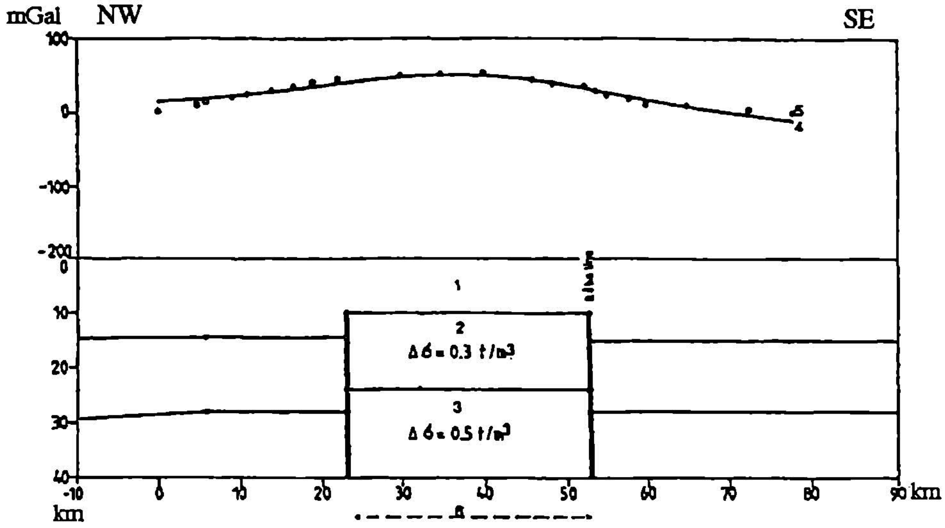

Fig. 1. Gravity model calculation along the seismic profile K–1 (for suddenly descending model)

1—granite layer of basement and crust; 2—basalt layer of crust (its density is 0.3 t/m³ higher than that of the basement); 3—mantle (its density is 0.5 t/m³ higher than that of the basement); 4—Bouguer anomaly without the effect of the Neogene basement; 5—calculated Bouguer effect of the crust-mantle elevation in the model

ent lateral dimension, sometimes not by tectonic features but simply by changes say, in rock density can be enhanced by different filters. There are, however, tectonic features which are clearly reflected already in the Bouguer anomaly map, by reduced isoline separation, *e.g.* the Hurbanovo Line. That version of the lineament map series is attached which enhances those variations of the gravity field showing the closest correlation with different verifiable geological and geophysical data and can be interpreted as effects caused by faults and structural lines. This map should be considered as an extension of reliable information from certain areas to less reliable, less known areas.

One of the most significant results of geophysical surveys is the Rába–Hurbanovo–Diósjenő Line detected by the magnetotelluric method. This is of special interest because the geological literature has been dealing with the question of the Rába Line only since 1949 (SCHEFFER 1965). Sometimes it was mentioned as the most significant structural line of the region, sometimes as a mistake, therefore its very existence was denied. Different ideas were elaborated about its location if it did, indeed, exist, and there were different ideas about its continuation on Slovak territory. The existence of the Rába Line was confirmed by the magnetotelluric measurements of the last one and half decades. Its location was determined; measurements carried out in the framework of the DANREG programme in the past five years demonstrated that the Rába Line continues in the Hurbanovo Line in Slovak territory, then in the so-called

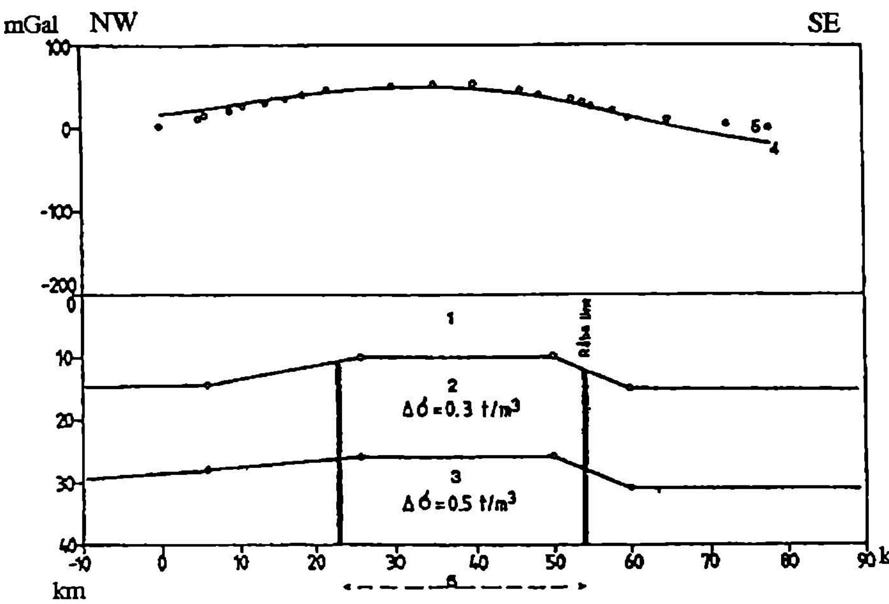

Fig. 2. Gravity model calculation along the seismic profile K–1 (for slowly descending model)

1—granite layer of basement and crust; 2—basalt layer of crust (its density is 0.3 t/m³ higher than that of the basement); 3—mantle (its density is 0.5 t/m³ higher than that of the basement); 4—Bouguer anomaly without the effect of the Neogene basement; 5—calculated Bouguer effect of the crust-mantle elevation in the model

Diósjenő dislocation zone. The magnetotelluric measurements revealed the differences primarily in the basement formations at two sides of the line. At the S, SE side of the line, where the Transdanubian Range can also be found, a geoelectric layer of 1–3 Ωm was detected within the basement at a depth of 4–10 km. The two areas can unambiguously be distinguished even by qualitative analysis of the sounding curves measured N and S of the line because the curves are strikingly different (Fig. 3). The low resistivity of this deep layer can be explained in different ways (lithologic, petrologic or hydrochemical origin), its absence pn the other side remains a basic fact and demonstrates the boundary nature of the line within the basement. The magnetotelluric measurements keep the Rába–Hurbanovo–Diósjenő Line within a 4–6 km zone along a length of almost 250 km. The plane of the fault cannot be determined from the measurements but this striking difference between the two sides of the line suggests a strike-slip structure rather than an overthrust.

The seismic characteristics of the Rába Line were studied by KILÉNYI *et al.* (1991). They described significant differences in the reflection image of the basement, in the dip of the basement reflections, and how the reflections can be traced. On the other hand, it is interesting that so-called flower structures reflecting tectonic movements can be found on the S side of the Rába Line in the Neogene sediments while on the N side the seismic image suggests a more or less undisturbed layering.

The palaeomagnetic surveys are also worth mentioning (MÁRTON 1990). According to these the Transdanubian Range unit got into its present place after a rather consnderable strike-slip and rotation before the Neogene period and this unit might belong to the African plate. The N side, with completely different palaeomagnetic directions is part of the Indo-European plate.

Any of the theories might be true. One thing is certain: the geophysical measurements have unambiguously detected the Rába–Hurbanovo–Diósjenő Line based on different physical parameters.

Magnetotelluric investigation of the Vienna Basin

Measurements financed by the Austrian GBA were carried out in the last year of the DANREG programme, which joined the Hungarian section of the magnetotelluric profile K–1 and traversed the Vienna Basin. The measurements produced interesting data about the depth of the basin, resistivity of the sediments and the bedrock, but these meant no substantial novelty compared with the previous knowledge. It is worth mentioning, however, that approaching the Bohemian Massif the Late Cretaceous–Paleocene flysch is much closer to the Neogene formations bearing in mind its physical parameters (similarly to the situation in the Carpathian Basin) than to the Mesozoic–Palaeozoic rocks of the pre-Tertiary basement. The magnetotelluric image of the Mur–Mürz Line is even more interesting. We can see not only sharp changes in the depth of the basin and in the physical parameters of the sediments along the magnetotelluric profile at this line (at the Danube) but a typical subduction zone was revealed as well. The conductor which appears close to the basement in the vicinity of the Danube gets deeper southeastward. We could trace this conductor for about 20 km down to a depth of several tens of kilometres (Fig. 4). The phenomenon can be explained as the southeastward subsidence of the ocean-

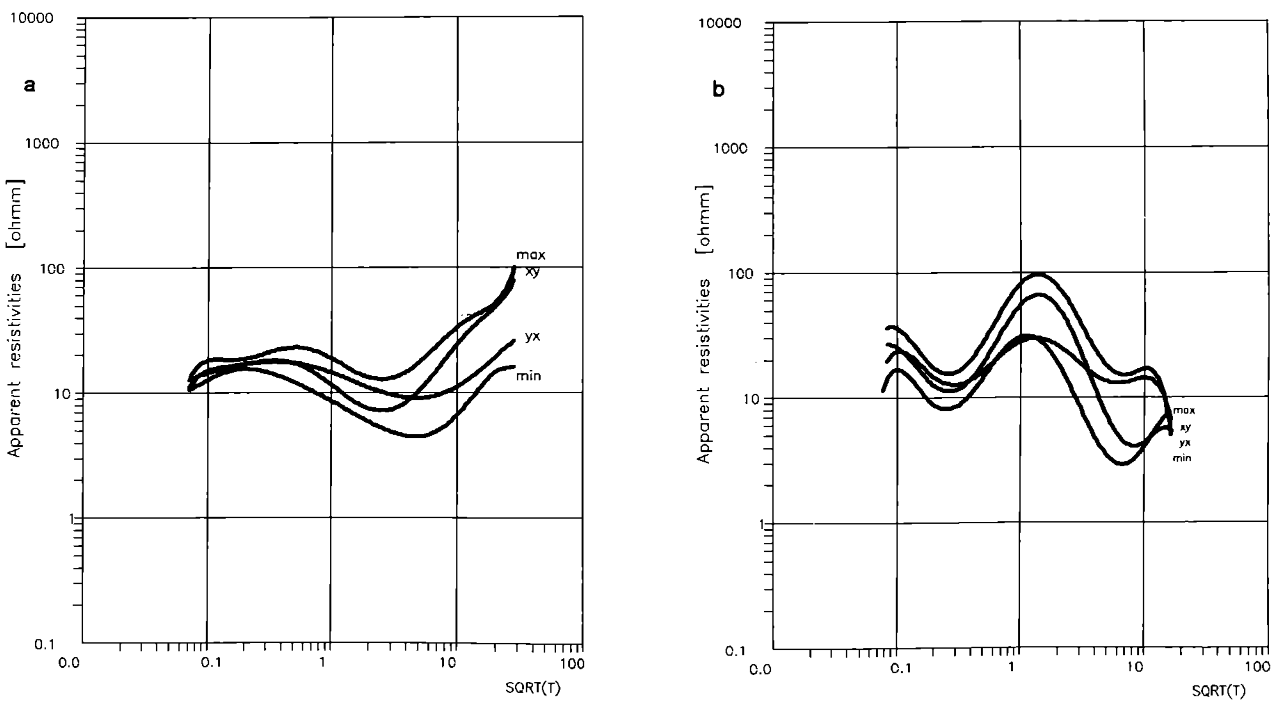

Fig. 3. Characteristic magnetotelluric sounding curves from two sides of the Rába–Hurbanovo Line
a) station SDU3–7 can be found on the northern; b) station SDU3–4 on the southern side of the line

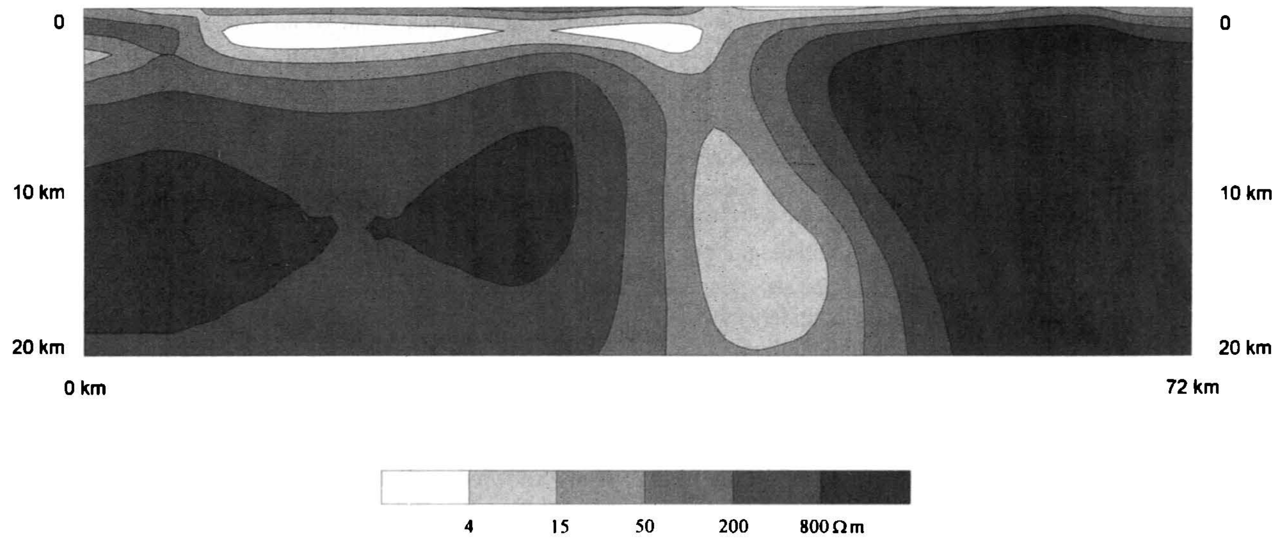

Fig. 4. 2D (RRI) inversion of the MT profile crossing the Vienna Basin

ic plate, the Mesozoic basement of the Vienna Basin below the continental plate with crystalline basement.

We are aware of the different opinions about the type, nature and mechanism of genesis (subduction, strike-slip or combination of these) of these two significant tectonic lines, *viz.* the Rába–Hurbanovo–Dósjenő and Mur–Mürz lines. According to the magnetotelluric measurements the geoelectric images of these lines are completely different. At the Rába–Hurbanovo–Diósjenő Line the sediments seem to be uniform from the surface down to the bottom of the Neogene at the two sides of the line, flower structures might appear in the Neogene–Pliocene sequence only. The layers within the basement, their dip and resistivity are entirely different. Evidence of subsidence of any of the microplates, however, cannot be seen. (This suggests strike-slip.)

In addition to the deep structure suggesting typical subduction at the Mur–Mürz Line it is obvious that (at the crossing of our profile and the Danube) the thickness of the Pleistocene coarse-grained gravel is several hundred metres on the left bank (based on the resistivity distribution), while on the right bank of the Danube this sequence is either completely missing or its thickness is insignificant.

In our opinion the above facts should be taken into consideration in creating different theories, independently of the idea finally accepted by the experts of tectonics.

Investigation of the pre-Tertiary basement

The basement of the Neogene basins is one of the geophysically best detectable horizons in the Carpathian Basin and in the Vienna Basin after the formations underlying the Pannonian, because there is a significant difference between the physical parameters of the basement and the non-metamorphosed young sediments. In spite of this almost every geophysical method encountered difficulties in the area of the large central Danube–Rába Basin. It has been shown that gravity and magnetic anomalies are caused by sources within the basement or crust. The frequency range of telluric measurements was sometimes too high because of the unexpectedly great depths. Dynamite seismics struggled with drilling difficulties due to the gravel deposit of the Danube. The great depth caused lack of energy for the vibroseis method. Finally, all methods encountered interpretation problems because no wells penetrated the basement and therefore none of the geophysical horizons could be reliably identified as the basement. This problem appeared, however, only in the regions deeper than 6000 m. The map in the attached sheet is based primarily on the seismic measurements, in addition to well data. The basis of this depth map is the "Pre-Tertiary Basement Contour Map of the Carpathian Basin beneath Austria, Czechoslovakia and Hungary" constructed by KILÉNYI, ŠEFARA, ŠUTORA, BIELIK, KRÖLL, STEINHAUSER, WEBER, PINTÉR and SZABÓ using the results of ÖMV, Geofyzika Brno, SLOVNAFT, OKGT and ELGI, and well data (KILÉNYI *et al.* 1991). Just because of the above mentioned problems of the deepest basin parts HRUŠECKÝ and ŠEFARA constructed new map parts from up-to-date reprocessing of earlier measurements. On Hungarian territory NEMESI and SZEIDOVITZ modified the existing map on the basis of new telluric, magnetotelluric and seismic measurements.

Geophysical results concerning the thickness of the Pannonian and lithofacies issues

Formations of Pannonian age can be found primarily in the large basin between Bratislava and Komárom, and in the Vienna Basin. Reflection seismic measurements played a decisive role in the investigation of the basins; such surveys were performed everywhere, although with different line density. (Unfortunately, we have received no seismic material from the Austrian territory, therefore we can discuss in detail only the Slovak and Hungarian territories.) The most important thing is to point out that the strongest reflections which can unambiguously be traced on the time sections as well have been obtained from the layer underlying the Pannonian series within the basins. Thus, one of the most reliable results of geophysical investigations is the depth map to the bottom of the Pannonian sequence (see the attached sheet).

The Slovak and Hungarian maps —although based on measurements performed at different times, with different instruments, with different line density, and though the processing methods were also different— fitted perfectly along the border, in spite of the fact that the depth to this horizon is zero at the edges of the basin (*e.g.* at Bratislava or Tata), but exceeds even the 5000 m in the central basin (at Gabèíkovo).

To construct the map, the seismic measurements of Geofyzika Brno were used in Slovak territory. VVNP expert HRUπECK˝ constructed the map from the up-to-date reprocessed versions of sections. The seismic material in Hungarian territory comes from the measurements of the Hungarian oil industry (GKV) and partly from the measurements of ELGI. At the beginning of the DANREG programme the map constructed by the GEOS group which combined the results of the two Hungarian institutions was available. This was modified in the deepest part of the basin based on the most recent measurements of ELGI performed in the framework of the Kisalföld and DANREG programme, using the results of PÁPA, HERCZEG and SZEIDOVITZ.

The determination of the thickness of the layers overlying the Pannonian is by no means unambiguous. Although the 5000 m thick sedimentary sequence is rich in reflections neither the bottom of the Quaternary nor the boundary between the Pliocene and Pannonian (between the Lower and Upper Pannonian according to others) is a characteristic horizon for any geophysical method. This is probably due to the continuous sediment deposition. Geoelectric measurements revealed a monotonous decrease in resistivity downwards which suggests a general downward decreasing trend in the grain size. (This is also clearly demonstrated by the magnetotelluric measurements shown in the attached sheet.) Thus, we ventured to determine the thickness of the cover sequence only along some profiles. These were handed over to the Geological Working Group as working material.

It is mentioned for the sake of interest that the resistivity of the complete Neogene sedimentary sequence, and particularly of the Pannonian formations, is about two times higher in one of the largest and deepest basins of the Carpathian Basin than the usual value in the other subbasins. It is interesting to connect this with the fact that here hydrocarbon exploration has not been successful. The higher resistivity reflects either a grain size not fine enough for hydrocarbon generation or the sediments are more cemented and this is an obstacle to migration or there is no really impermeable layer which is a prerequisite of trapping after migration.

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