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In memoriam András Erkel

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CHAPTER 1

Telluric Map of Transdanubia — Introduction

László NEMESI*

Transdanubia is situated in Central Europe, in the Carpathian Basin, corresponding to the western third of Hungary on the right side of the River Danube, covering an area of about 40 000 km^2 (*Fig. 1.1*).

The first measurements with a geophysical aim were carried out in Hungary by Loránd Eötvös. Eötvös performed the first experimental gravitational measurements (with his torsion balance) between 1901 and 1903 in Transdanubia, on the ice of the frozen Lake Balaton. The first result used in crude oil exploration was achieved in 1916 some kilometres to the north from the present study area; in other words, near Gbely (Egbell) in what is now Slovakia where, below a flat surface, the oil containing anticline was mapped. Gravitational oil exploration was set in train with this discovery.

Gravity (today mostly gravimetric) and geomagnetic networks with distances of 0.5 to 2 km between stations cover the whole area of Hungary in an approximately regular network. A map of the geomagnetic ΔZ anomalies on a scale of 1 : 500 000 was constructed by István Béla Haáz and István Komáromy (Eötvös Loránd Geophysical Institute) in 1966; their map was published in printed form, too [HAÁZ, KOMÁROMY 1967]. At that time maps of the Bouguer anomalies were strictly secret, as they contained information that could be used for computing rocket paths, but gravitational measurements also covered nearly the whole country, too. Measurements continued and in 1989, when secrecy was no longer considered necessary, Zoltán Szabó and Attila Sárhidai (ELGI) prepared a map of the residual gravity anomalies; this map was also published on a scale of 1 : 500 000 [SZABÓ, SÁRHIDAI 1989]. Then, in 1996, Sándor Kovácsvölgyi (ELGI)

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constructed a map of the Bouguer anomalies which was based on all gravity measurements made in Hungary, including in certain areas the gravimetric measurements of the oil industry, performed in a rigorously regular network with station distances 500 x 500 m, and measurements for bauxite exploration in an even denser network. (This map has not yet been published.)

The primary objectives of gravity and magnetic measurements carried out in basin areas thus, in Hungary too, are qualitative regional mapping, and detection of potential hydrocarbon-bearing structures. Such measurements tended to be followed by seismic measurements and borehole drillings.

Telluric (earth) currents were first used for geophysical exploration by the Schlumberger Company in France. M. Schlumberger published the first paper on telluric exploration in 1939 [SCHLUMBERGER 1939] and in 1948 Migaux spoke at the 3rd World Petroleum Congress about 'a decade of its application....' [MIGAUX 1948]. Somewhat later, a correct mathematical–physical treatment of the telluric–magnetotelluric methods was developed by TICHONOV [1950] and CAGNIARD [1953].

The role of the telluric method, which uses electromagnetic waves arriving vertically to the surface of the Earth, was practically the same as those of the gravity and geomagnetic methods, viz. exploration of sedimentary basins for the oil industry. The amplitude of the variations of the telluric currents measured on the surface of the Earth is a function of the conductivity of the low resistivity sediments supposing a high resistivity basement. This supposition is, however, not always correct, as is the case of the gravity method where the idealized exploration conditions are also not always fulfilled. In other words, sediments are not everywhere homogeneous and of low density, neither are basement rocks always of uniformly high density. The same is valid for geomagnetic exploration, with regard to the susceptibility relations of sediments and basement. Interestingly, even though researchers overlooked these shortcomings of the previously very successful gravity and geomagnetic methods (in that these latter two methods do not always give information about the target formation), they did not overlook the same problems of the telluric methods. Nevertheless, telluric measurements were intensively used in the 1950s and 1960s in France, in the Soviet Union, in Germany, China, Hungary and in other countries; subsequently, however, throughout the world such measurements came to a standstill. This was also true in Hungary despite the fact

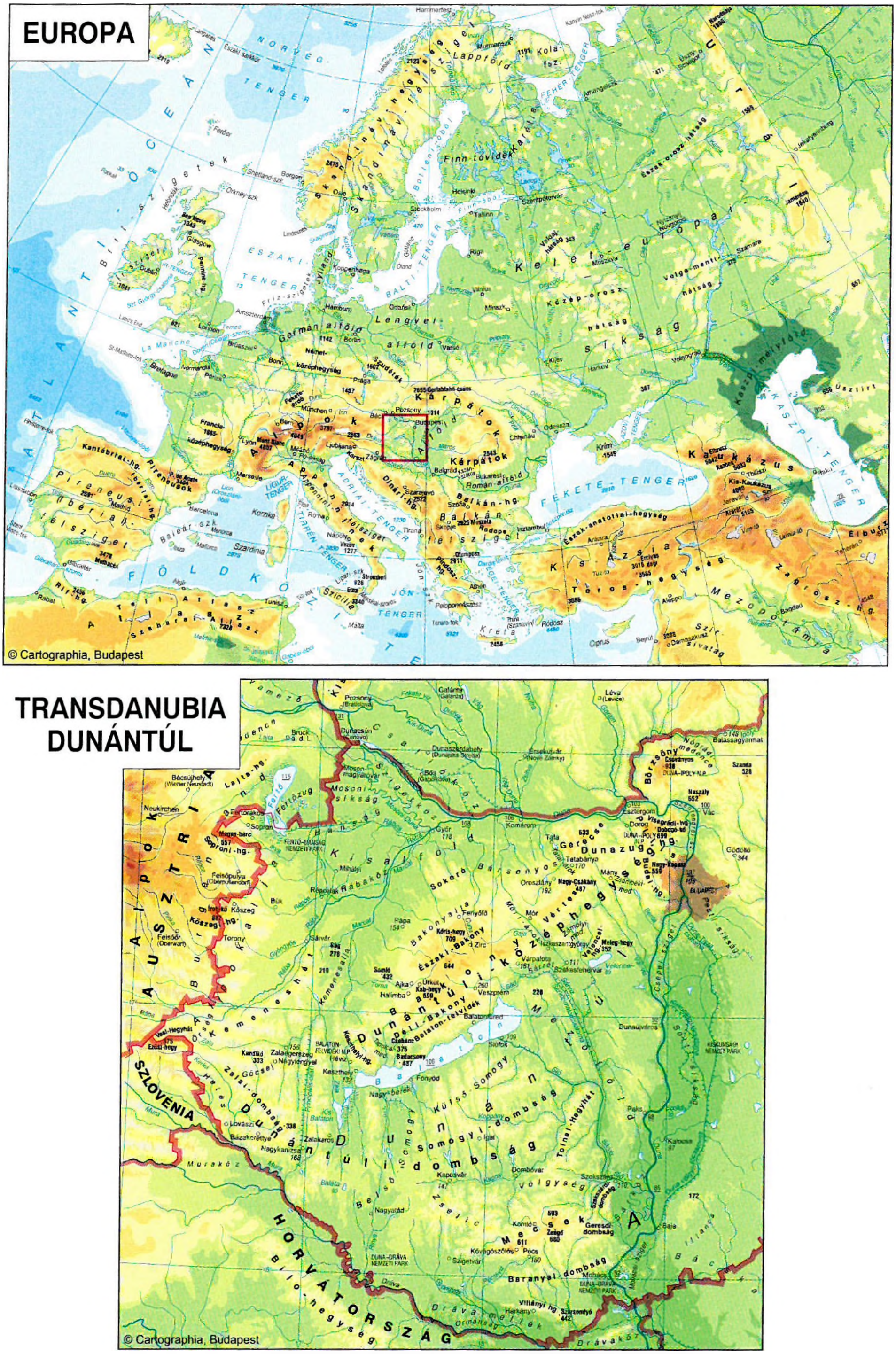

Fig. 1.1. Survey area

1.1. ábra A kutatási terület

that it could be shown that in SE Hungary there are basin areas covering several thousands of square kilometers filled with Neogene sediments where gravity and geomagnetic methods did not see anticline structures which emerge from a 7 to 8 km deep basement of Palaeozoic–Mesozoic carbonates to a depth of 1.3 to 2 km whereas the telluric method mapped them correctly.

Owing to several interruptions of the telluric measurements in Hungary, a summary was published in 1981 dealing with an area of about 30 000 km^2 in the eastern part of the country, as at that time it seemed that no continuation would be possible. Later, however, the activity was resumed and now regional telluric measurements are considered as finished in the western part of the country, too. Correspondingly the major part of Hungary is covered by telluric stations, only the central part covering an area of 8 to 10 000 km^2 has remained without telluric stations (*Fig. 1.2*). At present, since there is no hope of carrying out measurements in this area, representatives of the three institutions carrying out the measurements decided to collect, summarize, interpret, and publish hitherto unpublished data. There were several preconditions to publication. One such condition was that of putting the results from all the three institutions into a common database. This was made possible by the new Hungarian Mining Law enacted in 1993: this law required that the results of all previous geophysical explorations funded by the state should be collected by the data bank of ELGI, being a part of the Hungarian Geological Survey (MGSZ).

The other essential precondition was to reduce existing relative telluric conductivity values to a common, uniform base. This was enabled by magnetotelluric measurements at more than 30 telluric base stations. These measurements were carried out by the staff of ELGI, using ELGI instruments, equipment and processing programs. The expenses were covered by Scientific Research Fund (OTKA) project T 024 097 (led by the present authors) and T 0155882 led by Professor Antal Ádám.

From the very beginning, interpretation of the telluric measurements was a major issue of all three institutions carrying out the measurements and also of the Geophysics Department of Miskolc University whose staff participated in the measurements in Transdanubia with the first experimental profiles, but who took a significant part in elaborating the method, in its interpretation, and in measurements in the eastern part of the country. This process meant on the one hand a more complete use of the information of the measurements (e.g. by studying frequency and direction dependence),

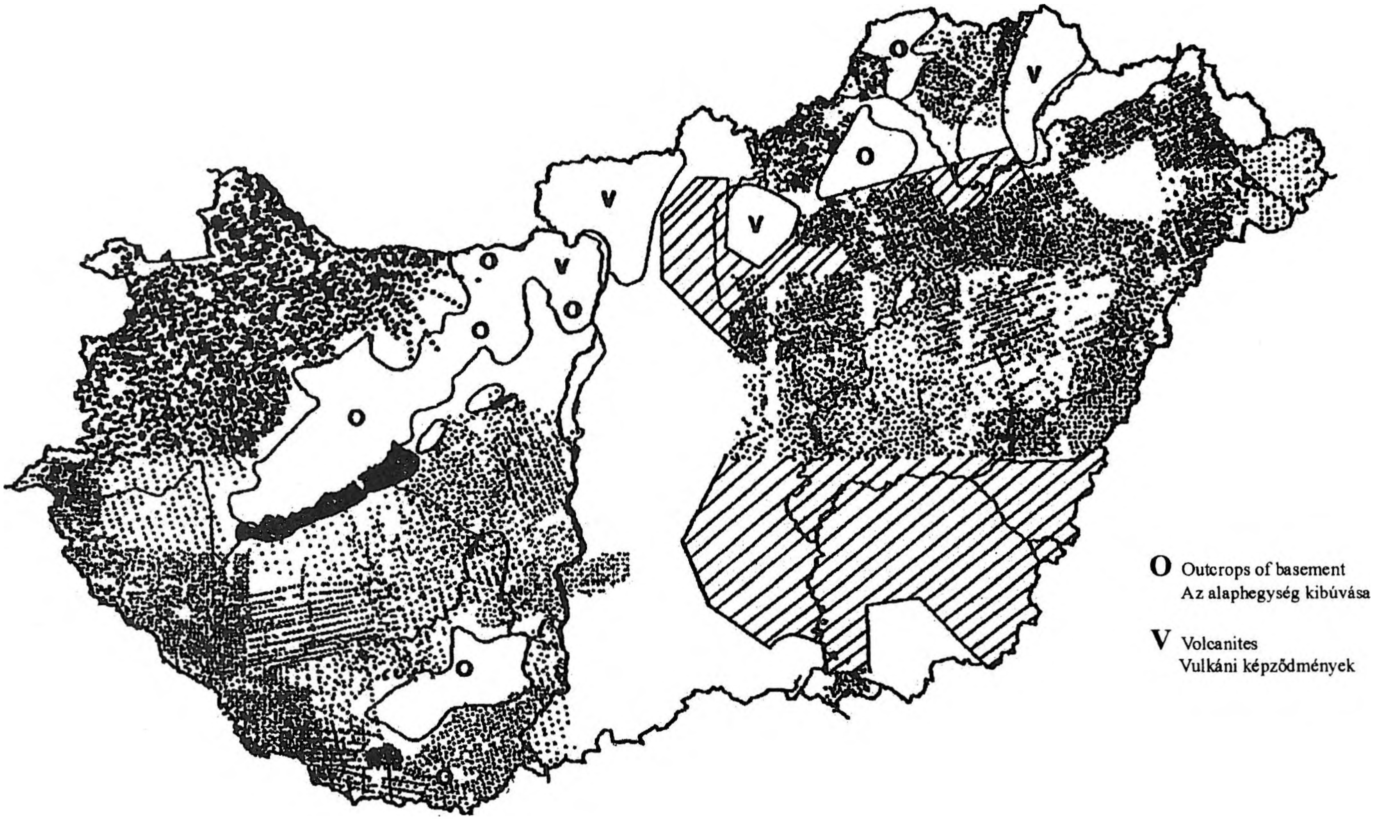

Fig. 1.2. Telluric coverage of Hungary (as yet, our database does not contain the data from hatched areas)
1.2. ábra. Magyarország tellurikus felmértsége (a sraffozott terület adatai még nem szerepelnek adatbázisunkban)

on the other hand the completion and checking by other geoelectric measurements. These measurements initially consisted of deep penetration geoelectric DC soundings; later, magnetotelluric and deeply penetrating transient measurements and frequency soundings using artificial fields were included. Integrated interpretation led to several results which could not be achieved by any of the methods alone, if we consider, for example, only the correlations with gravimetric, geomagnetic and electric results.

With this publication our intention is to present all these results and experiments to those interested in the corresponding geological structures and in the telluric method, too.

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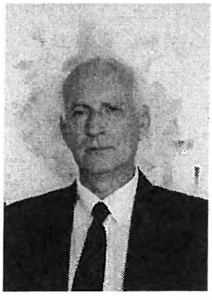
I. FEJEZET

A Dunántúl tellurikus térképe — Bevezetés

NEMESI László

A magyarországi rendszeres térképező, tellurikus kutatások, elsősorban olajipari megbízásból, a 60-as években indultak. Összefüggő tellurikus térkép 1981-ben csak az ország keleti 1/3-áról, a Tiszavidék és Tiszántúl terülretéről jelent meg. A 90-es évek elejéig befejezettnek tekinthető dunántúli mérések három intézményben születtek, de a sok kisebb területből álló relatív vezetőképesség térképek egységes térképpé transzformálásához szükség volt a közös adatbázis létrehozására és a mintegy 30 bázisállomásra vonatkoztatott relatív vezetőképesség egységes szintre, abszolút vezetőképességre történő átszámítására. Ez a tellurikus bázisokon 1997–99-ben végzett magnetotellurikus szondázások révén valósulhatott meg, amelynek anyagi fedezetét a T 024 097 és a T 0144 882 számú OTKA témák biztosították. Az 1:500 000-es méretarányú tellurikus térkép létrehozásában és értelmezésében a méréseket is végző három intézmény kutatói együttműködtek.

ABOUT THE AUTHOR



László Nemesi (1939) received his diploma in geophysics from the Eötvös Loránd University of Sciences in 1962. Miskolc University awarded him his D.Sc. in 1983.

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.

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CHAPTER 2
History of telluric exploration in Transdanubia

Zoltán NAGY*, László NEMESI**, József VERŐ***

The introduction of telluric measurements in Hungary took place in Transdanubia, at the Geophysics Department headed by Károly Kántás, at the University of Mining and Metallurgy in Sopron. Ernő Takács and Pál Egerszegi carried out the first experimental measurements in 1951. Later, photorecorders for routine measurements were also manufactured in Sopron, at the Factory for Geophysical Instruments, under the guidance of Antal Ádám. The first experiments in ELGI started in 1954 under the supervision of Károly Sebestyén, but András Erkel was the first to carry out routine measurements. Telluric measurements started in OKGT GKV in 1963, under the supervision of Zoltán Nagy. From this time onwards ELGI, OKGT and MTA GGKI carried out the mapping telluric measurements in Transdanubia.

Telluric surveys stopped in the first half of the 1970s and started again in 1977–78, but for the most part already with digital instruments and primarily within the framework of ELGI. The last measurements took place in 1994.

Station density and distribution according to institutions of telluric measurements in Transdanubia in a quasi-grid can be seen in the lower left part of the attached telluric map.

Keywords: tellurics, Transdanubia, history

The cradle of telluric exploration was in Sopron, a Transdanubian town; exploration related not only to Transdanubia, but to the whole of Hungary.

Professor Antal Tárczy-Hornoch was already lecturing on geophysics at Sopron's Mining Academy at the end of the 1930s. Károly Kántás was appointed Professor of the Physics Institute in 1949. Prior to taking up his professorial post he had been the chief geophysicist of the Hungarian–American Oil Company (MAORT). The Mining Academy of Sopron established a new Geophysics Department in 1951 which was also headed by him. Having previously dealt mainly with borehole geophysics, Kántás

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had good contacts with the Schlumberger Company, especially with the leading figure of telluric developments there, with Hungarian-born Géza Kunetz. Thus he gained first hand acquaintance with this new ‘exploration method of basins’. Kántás also realized that galvanometers with scale values of $10^{-8} - 10^{-9}$ A/mm/m used in borehole measurements could be used to record telluric currents.

The first measurements with the experimental instrument (produced at the Geophysics Department) were carried out in 1951 by Ernő Takács, Pál Egerszegi and by other members of the staff, at first at the edge of Sopron Mts, later between the villages Mihályi and Szany.

The Sopron staff (Antal Ádám, Ernő Takács, Pál Bencze, Ákos Wallner) played a basic and determinant role not only in telluric measurements in Hungary, but they also concerned themselves with the theory of the method, they developed instruments, and they dealt with processing and interpretation methods, too. The method was also introduced into the education curriculum, and geophysicists from various institutions were trained in both the method and the processing of the telluric measurements.

These activities did not remain within the framework of the university, but the staff of the Geodetic and Geophysical Working Group of the Hungarian Academy of Sciences (MTA) was also involved. This group later became — in 1955 — a Geophysical Research Laboratory, and subsequently it became the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (MTA GGKI) which has maintained the Nagycenk Geophysical Observatory. The Sopron branch of the Factory for Geophysical Instruments manufactured the instrument types T–9, T–14 and T–20 for routine measurements. The Geophysics Department of the Mining Academy was transferred in 1959 to Miskolc to become part of the Technical University of Heavy Industry.

Károly Sebestyén and Sándor Lakatos, who also came from well logging, carried out the first experiments with the telluric method in the Eötvös Loránd Geophysical Institute of Hungary (ELGI) in 1954. The most important role, however, was played by András Erkel who graduated as a geophysicist from Sopron’s Mining Academy. He organized the first field party. The first experimental measurements were made in 1956 on the Great Plain (Nagyalföld), but the first Transdanubian profile was also measured under his management between Sopron and Devecser. A report was published in 1957 on this profile.

These measurements were followed by several experimental profiles, mostly on the Great Plain in order to clarify the application of the method in Hungarian geological conditions. By virtue of the success of the experiments, and after trials in France, the Soviet Union, and Germany, systematic telluric measurements started in a more-or-less-regular network. The MTA put forward a proposal for a regional telluric survey in Hungary, and the leaders of the Hungarian oil industry decided to carry out this task. The latter decision was of the utmost importance as for one and a half decades 70–80% of the funding for geoelectric (especially telluric) measurements in Hungary was by the oil industry. (For the record, it is mentioned that the name of the responsible oil company changed several times: for some time it was the Hungarian Oil and Gas Trust (OKGT), it later became the Hungarian Oil and Gas Company (MOL)).

Telluric measurements in a more-or-less-regular network were started by the Geophysics Department of the Technical University of Heavy Industry, Miskolc, (1960, Great Plain, Eger–Mezőkeresztes area) and by ELGI (1960, Great Plain, Hortobágy area).

The first telluric measurements in a regular grid were made in the area of Szigetvár by an ELGI party led by András Erkel and József Hobot with participation by the geophysicists Judit Salamon and Gyula Fábián. These measurements were commissioned at both institutions by the Hungarian oil industry. Afterwards an area of about 1000 to 1500 km^2 was covered each year by telluric stations at both institutions; in 1963 OKGT created its own geoelectric field party mainly for carrying out telluric measurements.

Methodological, i.e. processing, and interpretation developments were achieved by the staff in Sopron [e.g. ÁDÁM, VERŐ 1961] and by Ernő Takács who participated at that time in the telluric measurements carried out by the Hungarian geophysical expedition in China. He created the mechanical integrator used for many decades in ELGI, the so-called 'total counter'. In addition to developing instruments and methods, ELGI staff were concerned with the geological interpretation of the results.

In the first half of the 1960s ELGI's telluric measurements were concentrated in the central part of southern Transdanubia, essentially in the southern part of Somogy county, in 1961 Szigetvár–Szentlőrinc, in 1962 Kaposvár, in 1963 Nagyatád were the centres of the measurement areas. In these three years a comparatively regular network was established with a station density of 2–3 km^2/station on an area totalling 4500 km^2 (Erkel, Hobot). The instruments used were two-channel type T–9–B photorecorders made in ELGI and types T–9–A and T–14 manufactured by the Factory for Geophysical Instruments. Areas of the relative ellipses were computed from analogue records, from manually measured variation vectors at two stations (areas of the relative ellipses referred to the basis give the relative summarized horizontal conductivities of the stations).

During this time there were several problems of interpretation which were investigated by ELGI's staff. One of these problems concerned the accuracy of determining the depth of the 'basement', of the high resistivity substratum below the low resistivity sediments from telluric measurements, as well as the possibility of detecting the structural elements of the basement, both being of interest for the oil industry. Based on borehole data András Erkel developed a useful method but because sediments are not homogeneous and because of lateral changes of the resistivity of the sediments anomalies may result that are comparable to those arising from basement elevations and depressions. Another important aspect was the application of the method in areas where no boreholes were available to help interpretation. That is why the instruments of deep geoelectric sounding were developed and the telluric map of southern Transdanubia was in 1965 already corrected with average sediment resistivities obtained from the data of the geoelectric deep soundings (dipole equatorial, DE, soundings) (András Erkel, László Szabadváry, Margit Szabó, Ernő Király). These pioneering geophysicists constructed the first geoelectric map of basement depths. It was shown some ten years later by Miklós KASSAI [1980] that in a significant part of the basin lying parallel with the valley of the River Dráva the 'electric basement' lies deeper than is the depth of the basement of the Tertiary basin as determined from seismic measurements. Miklós Kassai supposed the difference to be due to the low resistivity Carboniferous basement (containing meta-anthracite).

The story of the interpretation of telluric measurements is of historical significance as results similar to those mentioned had an adverse influence on opinions about the method both in Hungary and abroad. Now and then it detected something different from the target of the investigation, the Tertiary basement. However, the main advantage of the method is now seen just in such cases. It does not always produce the same information as do other geophysical methods but it is precisely these deviations that lead to new geological-structural findings which perhaps would never be found without geoelectric measurements.

In the second half of the 1960s, telluric measurements were also made by the geoelectric team of the oil industry in southern Transdanubia. The Geophysical Exploration Unit of the Oil Industry (later legal successors: from 1968 OKGT Geophysical Exploration Unit (GKÜ), 1971–1991 Geophysical Exploration Company (GKV), 1991–1993 Geophysical Exploration Unit of MOL, after 1993, Geophysical Services (GES) Ltd.) was originally established for seismic measurements, but in 1963, they started to use non-seismic methods, too. The geoelectric department was established in 1963, under the leadership of Zoltán Nagy, engineer of geophysics with Miklós Lantos and Adorján Divéky as staff geophysicists. The first method applied was tellurics. Activities commenced in 1963 not in Transdanubia but in the area of the Great Plain, in a Palaeogene basin near the village of Nagykáta, then work continued in 1965–1967 in the Jászság area and in 1968 in the boundary region of the Makó Graben. The greatest contiguous region covered by their measurements was, however, in southern Transdanubia along the Hungarian border from the River Rába up to the southwestern corner of Lake Balaton, then to the River Dráva, in the region of Felsőszentmárton, covering an area of roughly 3000 km^2. The 1700 stations measured here represent the most dense network in Transdanubia.

Telluric measurements of the oil industry in Transdanubia started in 1968 and they continued from the north towards the south in the Zala Basin, then in 1972–1973 at Szentgotthárd–Ivánc–Nádasd, in 1974–1979 in the Dráva Basin and in the region southwest from Lake Balaton, as well as in the Sávoly–Nagybakónak area. The telluric measurements of the oil industry were completed in the exploration area Csurgó–Fityeháza in 1979.

The reason for discontinuing the telluric measurements was partly the wearing out of the instruments used for the measurements, but the main reason was because of the development and introduction of new geoelectric methods (magnetotelluric measurements and electromagnetic frequency soundings with digital recording) into the Hungarian oil industry's geophysical exploration work, and these new methods far better fulfilled the exploration's objectives.

The oil industry's telluric measurements were also performed with type T–14 instruments. Measured data were processed from the very beginning using the so-called telluric straight lines method [NEMESI 1963] for determining the area (A^{-1}) by adjustment thereby enabling the elements of relative impedance (*a, b, c, d*) to be determined. The isoarea maps constructed from the measurements were contiguous, nevertheless they did not refer to a common base and they were not transformed to a common base station.

One of the methodological problems of the telluric measurements in this period was that of comparing base stations, i.e. computation of the relative ellipses between them, in order to be able to construct common relative conductance maps from maps of areas referring originally to different base stations. The method of adjusting levelling networks was adopted for this task in ELGI [NEMESI 1969], but it was soon realized that not only do random, so-called measurement errors occur but the coefficients of the transfer function may also depend on the period of the pulsations used at the different base stations, and in certain cases on the dominant direction of the primary telluric currents, too. In spite of the use of this triangulation method (like in levelling networks) for base comparisons, it became obvious precisely from the rather long records including several period ranges that the resistivity of the basement cannot be supposed as being infinitely high in all cases. This fact meant a problem not only in determining the transfer functions between bases, but it also caused some doubt about the application of the method for exploring the basement depth. It was not realized that the three main components of the conductance values determined by the telluric method, viz. the thickness of the sediments conducting the current, the laterally changing conductance of the sediments, and the changing conductivity of the basement can be separated either by the application of corrections obtained from other methods or by simple correlation analyses.

During this period of time problems emerged about the application of the telluric method not only in Hungary, but everywhere in the world where the method was used. That is why several countries and a number of large organizations discontinued the use of the telluric method. This resulted in Hungary in a setback of telluric exploration, too. No company or institution found it necessary to do telluric mapping.

It is interesting to note that the same problems could have emerged in connection with gravity and geomagnetic data, as anomalies are produced by inhomogeneities lying in different depth ranges and they are not exclusively due to changes in the depth of the basement. It is difficult to explain why such problems did not emerge in connection with these methods. Perhaps the reason was the existence of a much denser network of measurements. It is more likely that these methods were and are less expensive and for the design of seismic profile networks some information is anyhow necessary. The most likely reason is, however, that it was usual to construct maps of residual anomalies, of regional anomalies, etc. and even digital filters were first applied in geophysics just for these methods and thus a separation according to depth became possible, too. Moreover, as was mentioned in the Introduction (Chapter 1), at the time that the maps of Bouguer anomalies were prepared, they were strictly secret in the socialist countries whereas filtered maps were not; therefore the problems of gravity maps were known to only a small group of experts.

With all the above in mind the confidence of the leaders of the many Hungarian firms who were concerned with the telluric method wavered in the mid-1960s and early 1970s. Those who were actually dealing with the method, however, found newer and newer corrections for the effective interpretation of the results of the method, which is considerably cheaper and quicker than the seismic method.

At this time the first magnetotelluric instruments already existed. Both in Hungary and world-wide the Sopron and the Miskolc groups were in leading roles. The initial form of the magnetotelluric method (analogue instruments, frequency range corresponding to variometeric measurements, inability to resolve the sedimentary complex, analogue-manual processing) had already enabled us to determine the S-interval that is of utmost importance for telluric measurements and thus it informed us about the frequency range which could be applied for the exploration of the basement relief.

The long gap in the telluric measurements of ELGI was, however, not solely due to these problems, but rather it was due to decisions made by the leading heads of Hungarian geophysical exploration, and to agreements between them. József Fülöp, the then Director of the Hungarian Geological Institute (MÁFI) became in 1964 also the director of ELGI, and somewhat later president of the Central Office of Geology (KFH) supervising both institutes. He managed to put into practice 'the detailed and comprehensive exploration programme of Hungary' for the two institutions from state funds. He chose the first area to be explored: the Szolnok area on a 1:100 000 map where everybody from the two institutes had to work, measure and bore, independently of the prospecting for raw materials in this area and of the possibilities of the different geophysical methods in the Great Plain.

In particular there was an objective for the telluric method in this area, but when the 'systematic exploration' reached (in 1966) the Algyő hydrocarbon field which was just being discovered, ELGI had to follow a different direction. OKGT commissioned telluric measurements in the neighbouring Békés Basin, while the state exploration programme had to leave for northeast Hungary (Jászság–Nyírség area). At that time ELGI's new managers strove to strengthen the seismic department, and as geoelectric methods had serious difficulties there due to significant quantities of Miocene volcanites in the Neogene sedimentary complex, the exploration of the basement of the Tertiary basin was difficult, therefore the management set aside no money for these methods, but funds originally allotted to electric measurements should also be spent on seismic exploration. Unfortunately, of course, seismic methods could not overcome the difficulties, either.

With the completion of operations in the Békés Basin, telluric measurements were stopped. However, geoelectric measurements continued on a small scale in the framework of the programme of the so-called Geological Base Profiles. The area of these explorations was Transdanubia, too. The money from this programme was spent mostly on magnetotelluric soundings which at that time were at an initial stage of development. Nevertheless, very serious problems emerged in the quantitative processing and interpretation of magnetotelluric soundings. Direction dependence and different distortions caused tasks that were far too difficult at the given level of effectiveness and reliability for the method using the then inadequate variometric instruments, (being in the 0 phase of development) for the available computational technique and computers. To some extent these problems could be solved by having the telluric profiles parallel with the magnetotelluric profiles as they then yielded qualitative information at least about regional structural conditions. This idea revived and gave new impetus to the telluric method which, as elsewhere, was in the doldrums in Hungary, too.

Telluric measurements in Transdanubia were continued by ELGI from state funds in 1977, covering the area between Lake Balaton and the Mecsek Mts, in profiles parallel with the MT basic profiles.

MTA GGKI was also commissioned in 1977 to carry out telluric exploration in two areas in the vicinity of Sopron: to explore the crystalline basement below the Dudlesz Forest (Antal Ádám, Lajos Holló, József Verő) and in the Fertőrákos–Fertőszentmiklós area (Ákos Wallner).

The oil industry also recognized the possibilities of the telluric method, thus in 1978 a GKV telluric party started measurements in the Nagybakónak–Sávoly area.

In 1978, an important discovery was made: in Zselicség, in the area of a known Mesozoic basement in a depth range of 500 to 1000 m, a telluric minimum was found with conductance values hinting at a sedimentary complex of a thickness of 3000 m taking into account the average sediment and basement parameters of the Carpathian Basin. This anomaly proved to be of interest to the uranium industry (Mecsek Ore Mining Company, MÉV). They supposed that as in the Dráva Valley the telluric measurements found a low resistivity Carboniferous formation, the same situation might occur here, too; the likelihood being that the telluric minimum was caused by the same agent. If there are Carboniferous sediments there, then above them, Permian sediments may occur, too — this rock is the host rock of uranium. Therefore telluric mapping started again.

Quite a large area (1500 km^2) was covered by telluric stations from state funds in 1979 to the south of the eastern basin of Lake Balaton and of Lake Velence.

In ELGI, the development of a TEM–80 type digital telluric instrument (Gábor Széles, András Borsányi, László Nemesi) was successful. One of the first measurement series (commissioned by Mecsek Ore Mining Co. in 1981) was a survey around the Villány Mts.

From the point of view of Transdanubian telluric surveys one of the most important projects was the Kisalföld (Little Plain) programme financed by KFH from 1982 onwards. In this framework, MÁFI and ELGI spent significant sums in an attempt to solve the geological problems connected with the construction of the Bős–Nagymaros Barrage System. The project took into account that OKGT had contemporaneously started a programme to clarify the hydrocarbon perspectives of the Little Plain. However, this programme only covered the shallower part of the basin where the basement depth was less than 3000 m and no telluric measurements were planned. This project meant telluric measurements covering an area of about 6000 km^2. Between 1982 and 1990 ELGI measured about 2000 telluric stations (together with other measurements) using the TEM–80 digital instrument.

On the basis of a telluric survey commission by OKGT in 1990 ELGI carried out work in the northern part of Mezőföld (south of Budapest, west of the River Danube).

The area of southern Transdanubia not yet covered by a telluric network was covered by measurements in the framework of the integrated geological and geophysical mapping project of Somogy–Baranya counties, started in 1990 and interrupted in 1993. These measurements were funded by KFH and by its legal successor, the Hungarian Geological Survey (MGSZ), and measurements were made by an ELGI field party.

A very general reconnaissance (density 4–5 km^2/station) survey was also carried out at this time in the Zala and southern Somogy region previously without telluric measurements (1992).

The telluric survey of the Transdanubian basin areas was completed by the telluric measurements of MTA GGKI around Paks in 1985–1987 which aimed at clarifying the earthquake risk of Paks Nuclear Power Plant by exploring the tectonic setting and deep structure of the area.

Thus, by the mid-1990s the basin areas in Transdanubia had become completely covered by telluric measurements. However, a basin detected mainly by gravity between Lake Velence and Budapest (Baracska Basin) with an estimated depth of 3–5 km remained without coverage, but here the DC tramway of Budapest and the closeness of the Ráckeve electrified railway line caused disturbances which prevented telluric measurements.

Two obstacles remained before constructing a contiguous telluric map from different regional measurements: the first one was that the partial maps (maps of the relative conductances) consist of many independent units, referred to a great number of base stations; the second one was that these maps had been prepared by and belonged to different organizations.

The Hungarian Mining Law enacted in 1993 is still valid. This law stated (as mentioned earlier) that geological–geophysical exploration results financed earlier by the state should be delivered to the state data bank of MGSZ. Thus the obstacle to the data collection disappeared, as all measuring and commissioning institutions were state-owned ones when the Transdanubian telluric measurements had been commissioned and carried out.

Responsibility for data collection by ELGI was undertaken by József Csörgei and András Madarasi, with the highly efficient support of the staffs of the other institutions.

The first task in constructing the common map was to compare the base stations (more than 30). Acknowledgement is due here to the OTKA for their support. The method used for comparison was synchronous magnetotelluric soundings at base stations which were made using RMTS–2 type instruments (ELGI, Hungary) and commercially available Geotools' processing programs.

Measurements and processing were carried out by ELGI staff (László Nemesi, András Madarasi, Géza Varga). Magnetotelluric soundings enable us not only to compute the transfer functions but they also yield information on the distribution of horizontal conductance in the area of the base stations, on the direction and period dependence of the telluric parameters, and with their help relative conductance values can be transformed into absolute conductances. The latter could, in theory, then easily be extended and connected to maps of other parts of the country.

When this map was being constructed the depth to the Tertiary basement in Hungary became known on the scale of the present maps (1:500 000). The horizontal conductance of the sedimentary complex, however, does contain information not used earlier. The hydrocarbon perspectives of sedimentary basins of high average resistivity may be lower because the marine sediments in which hydrocarbon would have been expected to be generated were not of sufficiently fine grain. It is likely that the greatest quantity of new geological information will be obtained in the future from comparing the results of a variety of geophysical methods, mainly from gravimetry, geomagnetics and magnetotellurics. New data will be obtainable from positive and negative (anti-) correlations. By deducing the conductance of the sedimentary complex from the summarized conductance, data will be obtained about the less known zones, in other words the structural elements of the basement of high conductivity, and this information may be important in future explorations for raw materials.

Here, we should like to publish the names of those who participated in the telluric survey of Transdanubia, in the introduction of the method, the development of instruments and methods, the interpretation of the results, and in the preparation of specialists' reports, and scientific papers. Namely,

Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (GGKI) and the Geophysics Department of Miskolc University (and its predecessors):

Károly Kántás, János Csókás, Ernő Takács, Pál Egerszegi, Antal Ádám, József Verő, Pál Bencze, Ákos Wallner, Judit Czuczor, Ferenc Märcz, Lajos Holló;

the oil industry (GES Ltd of the Hungarian Oil and Gas Company MOL, and its predecessor, OKGT GKV):

Zoltán Nagy, Balázs Beke, Adorján Divéki, Csilla Formán, Zsuzsa Karas, Ilona Landy, Miklós Lantos, Gyula Lux, István Nemes, Béla Péterfai, Pál Simon, Erzsébet Simon, István Zimányi;

Eötvös Loránd Geophysical Institute of Hungary (ELGI):

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, András Milánkovich, András Madarasi.

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2. FEJEZET

A Dunántúl tellurikus kutatásának története

NAGY Zoltán, NEMESI László, VERŐ József

A magyarországi tellurikus mérések meghonosítása a Dunántúlon a Soproni Bányászati és Kohászati Egyetem Kántás Károly vezette Geofizikai Tanszékén történt. Az első kísérleti méréseket Takács Ernő, Egerszegi Pál 1951-ben végezte. Később a rutinmérések fotoregisztrálói is Sopronban készültek a Geofizikai Mérőműszerek Gyárában, Ádám Antal irányítása alatt. Az ELGI-ben az első kísérletek 1954-ben Sebestyén Károly irányításával kezdődtek, de a rutin-méréseket Erkel András valósította meg. Az OKGT GKV-ben 1963-ban kezdődtek el a tellurikus mérések Nagy Zoltán irányítása alatt. A továbbiakban az ELGI, az OKGT és az MTA Geodéziai és Geofizikai Kutatóintézete végezte a dunántúli, térképező tellurikus méréseket.

A 70-es évek első felében a tellurikus kutatások leálltak és 77–78-ban kezdődtek újra, de már zömmel digitális műszerekkel és elsősorban az ELGI keretei között. 1994-ben történtek az utolsó mérések.

A Dunántúl kvázihálózatos tellurikus méréseinek pontsűrűsége és intézmények szerinti megoszlása a tellurikus térképmelléklet bal alsó részében található.

ABOUT THE AUTHORS

Zoltán Nagy (1936) graduated as a geophysical engineer from the Technical University of Heavy Industry Sopron/Miskolc in 1959. He then joined the Geophysical Exploration Co. of the National Oil and Gas Trust, predecessor of MOL Hungarian Oil and Gas Company. From 1959 to 1963 he was employed as an exploration geophysicist conducting reflection and refraction seismic surveys, including interpretation. From 1963 to 1992 he managed the geoelectric department of the company, during which time he introduced additional electromagnetic methods into oil and gas exploration in the Pannonian Basin (magnetotellurics, long offset frequency domain sounding) and also dealt with interpretation of data and results. In the 1980s his main field of interest was R&D of electromagnetic methodology for integrated interpretation of geoelectric and seismic data as well as the development of methods for direct location of hydrocarbon deposits and prospecting for high enthalpy geothermal reservoirs. After 1993 he was employed by the MOL Hungarian Oil and Gas Co. as senior adviser and chief interpreter in electromagnetic methods. Although he retired in 1998 he continues to act as a consultant.
He is a member of the Association of Hungarian Geophysicists, and in 1980 he was awarded honorary membership. He is a member of the European Association of Geoscientists & Engineers and the American Geophysical Union.

Nemesi László for a photograph and biography, see this issue, p. 120

József Verő (1933), graduated from Sopron University as a geophysics engineer. After a short time with the Uranium Exploration Company, in 1957 he joined the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences, Sopron, where he is at present deputy director. He is a professor at the University of Western Hungary and lectures in physics; in 1995 he became a corresponding member of the Hungarian Academy of Sciences. Since its inception in 1966 he has been involved with Acta Geodaetica et Geophysica Hungarica, where he is now editor-in-chief. His main scientific interests are geomagnetic pulsations and electromagnetic induction studies. He is author of some 200 papers, many of them in international co-operation. He is an honorary member of the Association of Hungarian Geophysicists.

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CHAPTER 3
Natural and geological conditions of Transdanubia

László NEMESI*

The intention was to apply the telluric method to investigate the sedimentary sequence (its thickness and the structure of the underlying high resistivity basement) of mainly Cenozoic age and low resistivity in the Carpathian Basin. During the four decades of investigations our geological knowledge has increased as has our knowledge on determining the applicability of the method. We have arbitrarily separated four periods and have attempted to summarize their factual knowledge most important from the viewpoint of this method.

As a summary it can be stated that the penetration depth of the natural electromagnetic waves of 20–30 s period time used in the bulk of the measurements was suitable to realize the set aim over the largest part of Transdanubia. The apparent anomalies originating from the inhomogeneities within the sedimentary sequence can be corrected by means of the earlier direct current and later magnetotelluric soundings. The anomalies caused by the basement inhomogeneities, on the other hand, gave new geological information.

Keywords: Transdanubia, tellurics, magnetotelluric surveys, basement

3.1. Natural conditions, geology of the surface

Transdanubia belongs geographically to the Carpathian Basin, it is essentially the area between the foothills of the Alps and the rivers Danube and Dráva. The major part of the area is plain, at most hilly. This is the region in which the telluric measurements took place, where Pleistocene and Holocene fluvial, lacustrine and eolian sediments cover the surface. Older sediments occur at the foot of the Transdanubian Central Range, including, for example, Oligocene formations being mostly of clayey character.

The axis of the region is occupied by the Transdanubian Central Range having a strike direction of NE–SW, where the surface is mainly covered

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by Mesozoic (Triassic, Jurassic, Cretaceous), mostly carbonate formations, but Carboniferous granite is known from the Velence Hills. And to the NE in the area of the Danube bend, Miocene andesites do occur, too. In the SE part of the region, in the Mecsek Mts, Mesozoic rocks are accompanied by Late Palaeozoic, essentially Permian rocks, but also by Carboniferous granites, too. In the small, Villány Mts Mesozoic carbonate rocks steeply dip; below them boreholes found Permian rocks, too.

In the mountainous areas no telluric measurements were carried out, with the exception of a few experiments.

The surface geological formations of Transdanubia are presented in *Fig. 3.1*, as a part of the map prepared by the Hungarian Geological Institute (MÁFI) [JÁMBOR 1989].

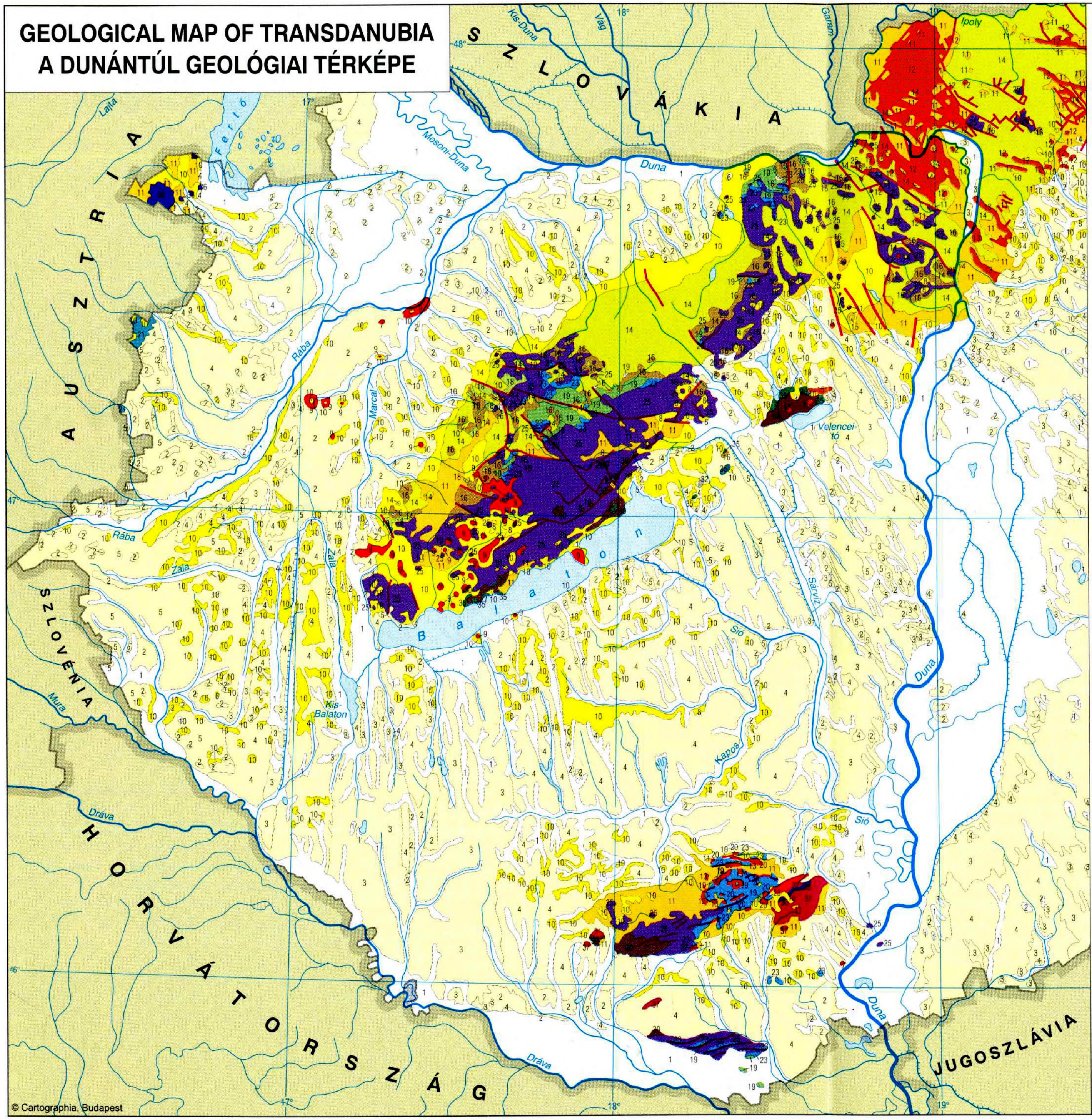
This map on a scale of 1:500 000 was published in 1984; the editor-in-chief was József Fülöp, the chairman of the board of editors Géza Hámor, the secretary Áron Jámbor. The map was constructed by András Rónai, Géza Hámor, Elemér Nagy, József Fülöp, Géza Császár, Áron Jámbor, Rudolf Hetényi, Margit Deák, Pál Gyarmati. We have used a simplified, 1:1 000 000 version of this map which was published in the 'high-school atlas' of Cartographia Ltd in 1999 [PAPP-VÁRY et al. 1999].

3.2. Significant geological structures of the sedimentary basin and information from telluric exploration

According to the geological knowledge in the days at the beginning of telluric investigations, the pre-Tertiary basement in the Carpathian Basin was known to have practically infinite specific resistivity, the young, mainly Neogene sediment, layered above it was known to have about 10 Ωm specific resistivity. It was nowhere supposed that the basement could be deeper than 3500 m. In other words, it meant that electromagnetic waves with a period time higher than 10 s could surely reach the basement, but they could not penetrate it, i.e. the method is able to map the conductance depending on the thickness and specific resistance of the sedimental layers.

With the increase of geological and geophysical knowledge these assumptions were not confirmed, and this fact hardly influenced the results of the investigations. Sometimes it was a disadvantage, but mostly it became an advantage, since it led to new information.

Regarding the above mentioned facts, in this section we try to give an overview about the opportunities of telluric research, about deep-



CENOZOIC

Quaternary

- 1 Fluvial sand, gravel, flood-plain mud, clay, lime mud, peat and drift sand — Holocene
- 2 Fluvial and flood-plain sand, gravel mud infusion, loess — Pleistocene
- 3 Drift sand — Pleistocene
- 4 Loess and loessic sediments — Pleistocene
- 5 Slope clay, red clay — Pleistocene
- 6 Fresh water limestone — Pleistocene
- 7 Potash-basalt and its pyroclastics — Pleistocene

Tertiary - Neogene

- 8 Fresh water limestone, marl — Pannonian
- 9 Soda basalt and its pyroclastics, geyserite — Pannonian
- 10 Clayey marl, sand, lignite, gravel — Pannonian
- 11 Coarse limestone, clayey marl, sandstone, conglomerate, brown coal — Miocene
- 12 Andesite, dacite and their pyroclastics — Miocene
- 13 Rhyolitic tuff and rhyolite — Miocene

Tertiary · Paleogene

- 14 Clayey marl, sandstone, gravel, varicolored clay — Oligocene
- 15 Subvolcanic andesite — Eocene
- 16 Nummulitic limestone, clayey marl, sandstone and brown coal — Eocene

MESOZOIC

- 17 Ultrabasic veins — Late Cretaceous
- 18 Marl, limestone, conglomerate, sandstone, brown coal and bauxite — Late Cretaceous
- 19 Marl, limestone, sandstone, varicolored clay and bauxite — Early Cretaceous
- 20 Basalt, alkaline basalt and their pyroclastics, phonolite — Early Cretaceous
- 21 Phyllite, greenschist, metagabbro, metaconglomerate — Early Cretaceous-Jurassic Cretaceous
- 22 Diabase, gabbro — Early Cretaceous-Jurassic Cretaceous
- 23 Red, nodular and white limestone, marl, radiolarite, sandstone, black coal — Jurassic
- 24 Shale, siliceous schist, metasandstone — Jurassic
- 25 White and gray limestone, cherty limestone, dolomite, marl, red sandstone, anhydrite — Triassic
- 26 Gray shale and siliceous schist — Triassic
- 27 Metabasalt, metaandesite, metarhyolite and their tuffs — Triassic
- 28 Diabase, gabbro — Triassic

PALEOZOIC

- 29 Black limestone, dolomite, varicolored sandstone, anhydrite — Permian
- 30 Red sandstone, conglomerate, siltstone — Permian
- 31 Rhyolite tuff — Permian
- 32 Grey sandstone, conglomerate — Late Carboniferous
- 33 Grey sandstone and shale with limestone lenses — Late Carboniferous
- 34 Granite and its vein rocks — Late Carboniferous
- 35 Dark grey shale, sandstone and white crystalline limestone — Early Carboniferous, Early Paleozoic

PRECAMBRIAN

- 36 Mica-schist, gneiss, hornblendite, phyllite
- 37 Migmatitic granite, mica-schist

- Tectonic lines of primary importance
- Anticline
- Syncline

(after Áron Jámbor)

Fig. 3.1.

Part of the Geological Map of Hungary, constructed in the Hungarian Geological Institute and simplified by Áron Jámbor, from the atlas of Cartographia Ltd.

3.1. ábra

A Magyar Állami Földtani Intézetben készült Magyarország Földtani Térképének Jámbor Áron által egyszerűsített részlete, a Cartographia Kft. atlaszából

geological information influencing its results from the viewpoint of telluric investigations.

At a very early stage geological information about the Carpathian Basin reached an internationally high level. It is sufficient to refer here to the fact that in the 15–16th centuries most gold and copper was produced in the mountains around the basin and here (at Selmecbánya) one of the first Mining Academies of the world was founded where expert mining engineers and geologists were educated. Ore mining was of course bound to mountains, nevertheless, our predecessors had a good idea about the geology of the plain areas, too. Moreover, gravity measurements started some 40 years earlier than telluric measurements, and the first hydrocarbon wells were drilled 25 years earlier, too; the first seismic measurements were also made 20 years earlier. Taking all these efforts into account, there seems to be some justification for asking: What was unknown? Why were telluric measurements needed? There is no complete answer, but the fact is that when telluric measurements were started, productive oil wells were only working in the immediate vicinity of the southwestern border of the country. In those parts of Transdanubia which were considered as perspective areas systematic seismic measurements were carried out only a few years earlier than telluric measurements. Gravity and geomagnetic measurements had been made somewhat earlier, but a large part of the area was not covered with an acceptable density by these measurements. Knowledge of the Transdanubian Neogene — and especially of the Pliocene — layer sequence and its basement was one of the most important tasks of hydrocarbon exploration, as the bulk of Hungarian hydrocarbon was found in Neogene traps, and these remain productive nowadays, too.

Palaeogene sediments are known only from a relatively small part of the Transdanubian basin areas, but they may be present in a much wider extent. They are mostly low resistivity, mostly Oligocene clays with some carbonate–marly Eocene complexes.

When routine telluric measurements had been started, exploration of the pre-Tertiary basement was a topical task, and tellurics was considered as having a potential role in it. A look at some of the geological maps constructed at the end of the sixties tells us that the bottom of the Tertiary was supposed as being at depths of 3 to 3.5 km in the deepest parts of the basins. As is nowadays known, the correct depth would be in the deepest parts of the basins, in grabens 5 to 8 km.

Four stages can be categorized in the geological–geophysical exploration of the Transdanubian basin areas:

1. MAORT age
2. The following years until the mid-1960s
3. Two decades between the mid-1960s and the 1980s
4. The 1990s.

In the following we try to give an account of these stages to show what kinds of exploration results were expected from tellurics at the time, with interpretation of the results based on the current state of knowledge about the structures.

3.2.1. Most important results of the MAORT age

The time between 1933 and the beginning of World War II is often known as the MAORT (Hungarian-American Oil Company) age. One of the best summaries of the activities in those times was given in a paper by Raul VAJK [1941].

The author described geological exploration carried out very carefully over a period of 8 years in a part of Transdanubia (covering an area of 12 000 km^2), including stratigraphic and palaeontological studies. The tectonic results indicated that in 'such an area' only geophysical methods can yield acceptable results. Therefore 16 800 torsion balance points, 6200 gravimetric points, and 11 600 magnetic points were measured, together with 10 000 explosions for seismic purposes at 2500 sites.

These studies led to the construction of the first maps of the Tertiary sediments in Transdanubia. The data were checked by boreholes and no contradiction was found between the geophysical data and the well results. It became known that between the structures detected by geophysical measurements, buried hills and fractured structures may also occur. One such finding was that the western part of Transdanubia, the Körmend –Őriszentpéter area, is a basin which developed by sinking and which includes E–W striking folds. The Hahót–Pusztaszentgyörgy structure was identified as a syncline over a sunken Mesozoic structure. To the south of Lake Balaton measurement detected the southward dip of the Early Palaeozoic crystalline basement which sinks then along huge fractures into great depths. It was supposed that the depth of the basin between Lake Balaton and River Kapos reaches 3 km or more.

At the start of telluric measurements in Hungary these were the data which could be used for planning. The geological interpretation has remained valid even taking into account most recent knowledge.

3.2.2. Information collected between World War II and the late-1960s

During World War II, MAORT could not operate, but a Hungarian-German Oil Company (MANÁT) was founded and, after the war, during the Soviet occupation the Hungarian–Soviet Oil Company (MASZOLAJ) came into being. In the framework of technical consolidation in the 1950s, the development of geophysical exploration led to the expansion of ELGI, too: the staff increased from a dozen to several hundreds. Furthermore, there were a number of other developments, as indicated in the previous chapter.

These organizations relied on the well trained staff of MAORT. Geophysical exploration and well data were interpreted by top-rate experts, including Károly Kántás, Egyed László, György Kertai, László Kőrössy, Viktor Scheffer. For orientation purposes one needs a fairly good background about their work as their synthesizing ideas mostly remained valid, even if the depth data and the tracing of tectonic lines had to be corrected.

The most important results are summarized as follows.

a) Kőrössy summarized information about the structure of the basins [1963]. His map of the great structural units of Hungary and of the primary, secondary and tertiary fractures separating them are presented here as *Fig. 3.2.*

Among Kőrössy's primary dislocation zones, the Rába line and the Central Hungarian line (Palaeogene boundary) are situated in Transdanubia. Among the great structural units, separated by dislocation zones the following lie in the study area:

— the great structural unit of Kőszeg–Mihályi,
— the great structural unit of Central Transdanubia,
— the great structural unit of the Dráva Basin–Mecsek–Nagykőrös.

In addition to primary dislocation zones, he also identified secondary and tertiary ones which further divide the great tectonic units.

It should also be mentioned from Kőrössy's results that he divided tectonic processes in Hungary into four structural levels. They are the following:

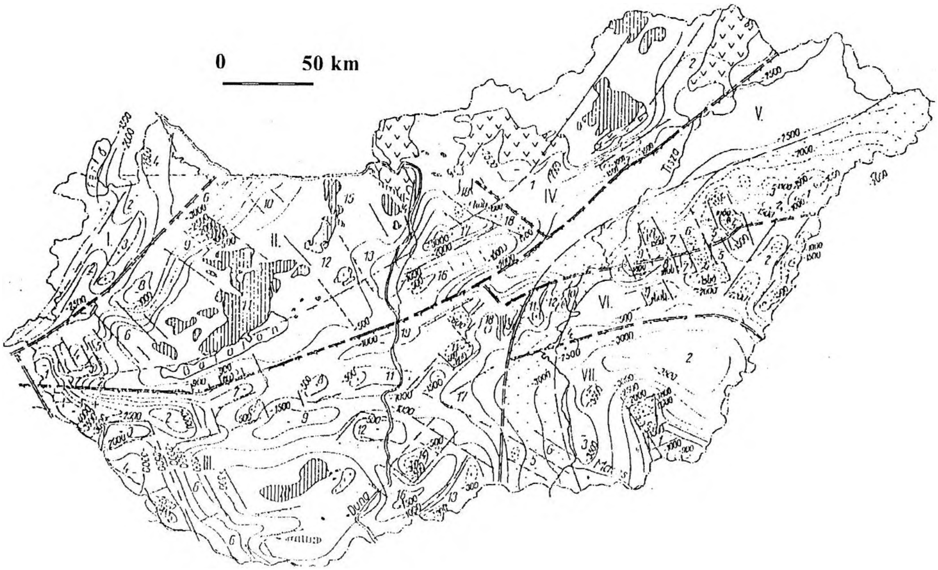


Fig. 3.2. Map of the great structural units [by KŐRÖSSY 1963] and the dislocation strips separating them
3.2. ábra. KÖRÖSSY [1963] térképe a nagyszerkezeti egységekről és az azokat elválasztó diszlokációs övekről

— The lowest tectonic level is represented by formations older than Variscan movements.
— The second tectonic level includes Late Palaeozoic and Mesozoic formations with ages between Variscan and Austrian movements.
— The third structural level contains Late Cretaceous-Palaeogene formations, with ages between the Austrian and Savic movements.
— The fourth level includes Quaternary basin sediments having ages after the Savic movements.

It will be shown that the telluric method indicates the greatest part of tectonic lines in Transdanubia, including the two primary dislocation zones of the area. Nevertheless, these lines would not be detected exclusively on the basis of the telluric measurements, but magnetotelluric sounding made at the locations of telluric anomalies unambiguously detected them. The latter fact is important as the course and even the existence of the Rába line as presented by Kőrössy and later by Scheffer, too, was denied by later authors.

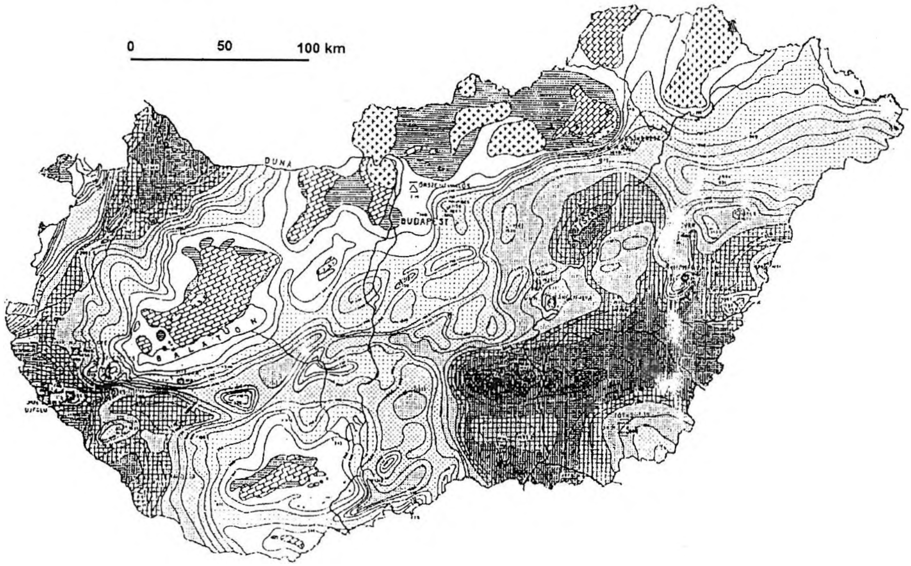


Fig. 3.3. Map showing the thickness of the post-Sarmatian sediments [by KERTAI 1957]
3.3. ábra. KERTAI [1957] térképe a szarmatát követő üledékek vastagságáról

b) The most important points from KERTAI's [1957] paper are the following:

— Areas and structures being of importance for hydrocarbon exploration are not indicated by the strips bounded by NE–SW striking main tectonic lines, but they do indicate depressions characterized by the thickness of the Pannonian (Pliocene) basin sediments (*Fig. 3.3*).

— The main tectonic lines, the directions of great tectonic units are characteristic of the structure of the Mesozoic basement, of the covering mountains. They are correlated with the directions of younger volcanism, too, but they do not inform us about the structure of Lower Palaeozoic, Triassic, Jurassic and Cretaceous basement.

— Below the pre-Tertiary basement, Mesozoic and Palaeozoic blocks have an irregular chessboard-like distribution with irregular polygons and the strikes of the blocks are different.

Kertai identified seven basin areas from the point of view of hydrocarbon exploration which include three in Transdanubia:

— the Pliocene basin in southwestern Transdanubia and its Mesozoic border,
— the Neogene basin of northern Transdanubia (Little Plain),
— the southeastern Transdanubian Neogene basin with Early Palaeozoic basement.

Already in the 1960s these telluric exploration results meant that by virtue of its rapidity and low cost the method had had a significant role in the exploration of low resistivity (2 to 10 Ωm) Pannonian–Miocene complexes, as the resistivity of the Mesozoic–Palaeozoic basement was orders of magnitude higher than that of the covering sediments judging from the electric well logging data of all previously drilled boreholes.

Today it is already known that the pre-Tertiary basement has not everywhere such a high resistivity, and from magnetotelluric measurements it is also known that several kms below the pre-Tertiary basement very low resistivity formations do occur which are not yet known from boreholes. These facts resulted in doubts about the application of the telluric method in the exploration of the pre-Tertiary basement. It is, however, also known that exactly these formations may be of specific interest according to present geological–geophysical ideas. The telluric method indicates the character of the 'basement' and the economic and scientific significance of this situation will eventually be evident only later.

c) The following results obtained by SCHEFFER [1960], should be emphasized:

The Rába line was considered by Viktor Scheffer as the most important tectonic line in Central Europe. The name itself was coined by him, too [1948]. He determined its existence and its course from geophysical measurements. He supposed it to be an overthrusting zone. This idea has today several supporters, nevertheless it is likely that the arguments for strike-slip movement are stronger (e.g. Zoltán Balla, Emő Márton).

In the basement of southwestern Transdanubia, Scheffer supposed a so-called 'internal block', the 'Transdanubian–Bácska Palaeozoic threshold' (*Fig. 3.4*) which would be responsible for the change of the tectonic directions in the Carpathians and Dinarids with respect to the E–W direction in the Alps.

In lectures held and papers published in 1964 and 1965, he described the 'crustal high' below the Carpathian Basin which was deduced from gravity and seismic measurements and seismological data. In other words,

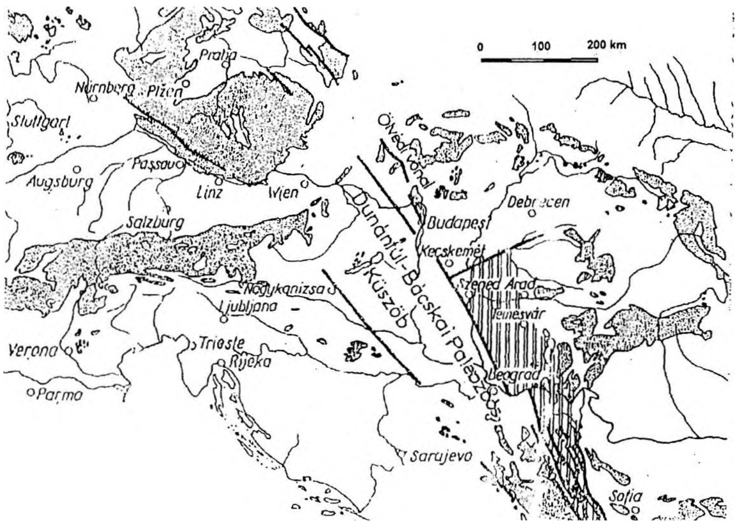


Fig. 3.4. Map on the Transdanubian–Bácska Palaeozoic threshold [by SCHEFFER 1962]
3.4. ábra. SCHEFFER [1962] térképe a Dunántúl–Bácskai paleozoós küszöbről

this would be a thinning out of the crust, and due to it, a 'hyper-thermal zone' where the heat flow is about twice the world average.

It is even today accepted as a fact that boreholes in the Carpathian Basin found temperatures increasing by 1°C in 20 m and all new seismic and magnetotelluric measurements, gravity model computations have confirmed the significantly thinner crust in the Carpathian Basin.

Among Scheffer's results, one of the most important is the problem of the N–S or NW–SE Balkanic structural lines in southern Transdanubia. It has remained valid even if the idea of a 'Palaeozoic threshold' between the Dinarids and the Czech Massif is not viable. The strike direction of the Permian and Carboniferous sediment collecting basins is without doubt near to the supposed N–S line, and it is indicated by telluric data, too, as will be shown. In contrast, in most earlier and present geologic maps of the deep structure, the dominance of the NE–SW lines suppresses all other directions. These main structural directions are connected to Austrian movements the most important of which ended in Miocene times.

NW–SE directions are dominant both on KASSAI's [1980] maps of the Permian–Late Carboniferous sediment collecting basin and on Elemér NAGY's [1968] map of the extension of Mesozoic carbonate formations.

3.2.3. Most important results between the mid-1960s and end of the 1980s

Beginning with the mid-1960s, an increasing number of more and more exact and detailed geophysical measurements and borehole data became available from the basin areas explored by the telluric method, too. The tectonic image of the pre-Tertiary basement improved, and information about age and material of the basement rocks improved and previously supposed 'structural units' became separated into small parts, into strips (*Fig. 3.5*).

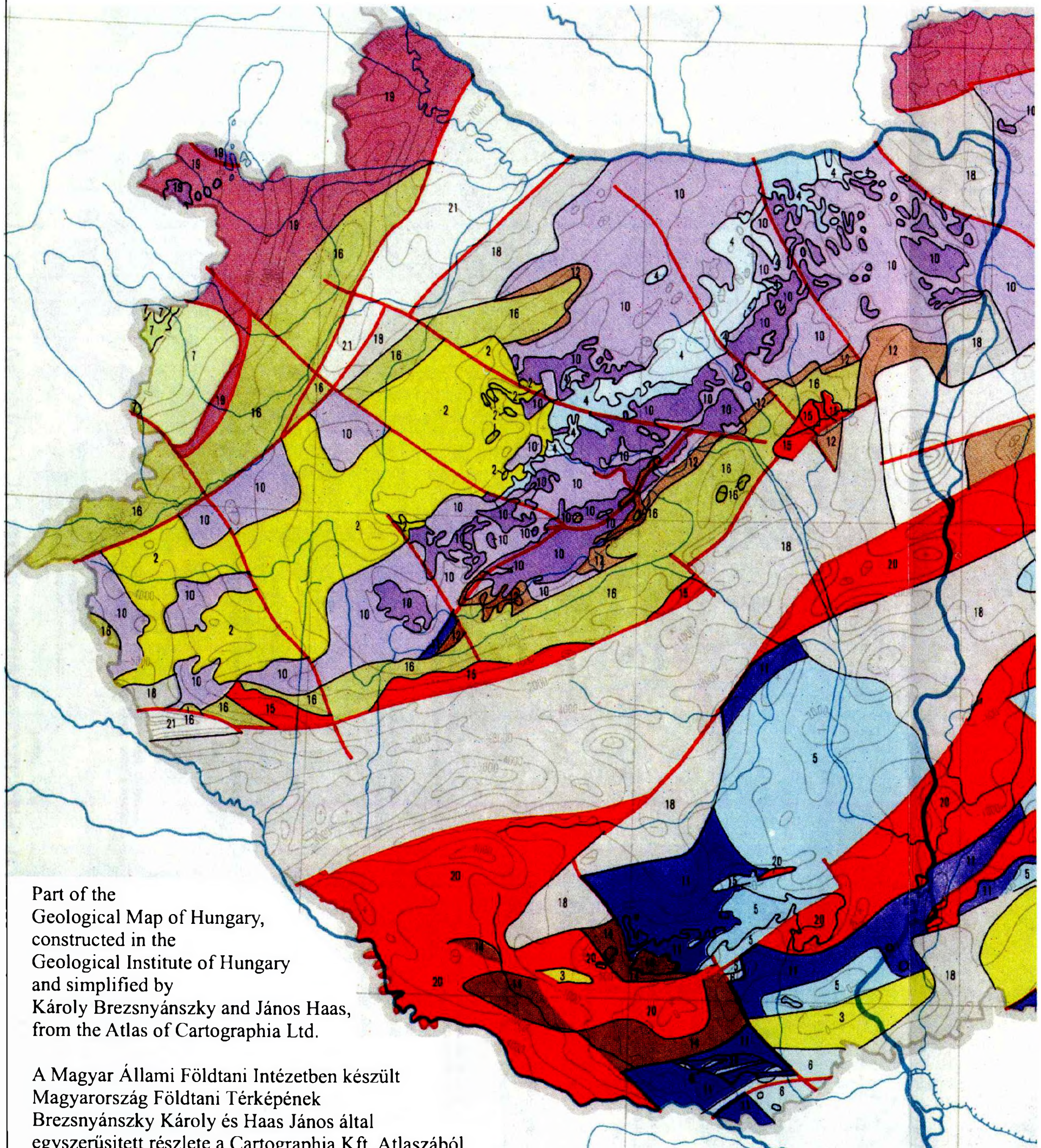
The 1:500 000 version of this map: 'Hungary's Geologic Map without Cenozoic cover' was published by MÁFI [FÜLÖP, DANK 1987]. The editors were József Fülöp and Viktor Dank the members of the board of editors: Andor Barabás, Béla Bardócz, Károly Brezsnyánszky, Géza Császár, János Haas, Géza Hámor, Áron Jámbor, Éva Sz. Kilényi, Elemér Nagy, János Rumpler, Tibor Szederkényi, László Völgyi. The simplified, 1:1 500 000 version of this map was used for *Fig. 3.5*. It was constructed by Károly Brezsnyánszky and János Haas and published in the Hungarian National Atlas in 1989. This Atlas was published by Cartographia Ltd. under the direction of the Geographic Research Institute of the Hungarian Academy of Science as reproduced in the Ágoston Tóth Cartographic Institute of the Hungarian Army [BREZSNYÁNSZKY, HAAS 1989].

The map of the depth to the basement became significantly modified: it became more accurate, getting much deeper in the areas of great basins (*Fig. 3.6*). In these changes telluric-magnetotelluric results played a role, too; even so, apart from these changes the new maps did not bring very much new information vis-à-vis the old ones.

The map of the depth of the pre-Tertiary basement was based on data of hydrocarbon wells and on a very large number of geophysical measurements commissioned by MÁFI and carried out by GEOS Gmk. The depth map was constructed by Éva Sz. Kilényi and János Rumpler and reproduced in the Ágoston Tóth Cartographic Institute of the Hungarian Army [KILÉNYI, RUMPLER 1984]. The basis of Fig. 3.6 is this map, but south of Sopron, near the western border of the country it was substituted by a later map of ELGI (Pre-Tertiary Basement Contour Map of the Carpathian Basin Beneath Austria, Czechoslovakia and Hungary. [KILÉNYI, ŠEFARA 1989].

The new element of these maps — that cannot be seen in static figures — is plate tectonics. Many authors (György Wein, Viktor Dank, István Bodzai, Elemér Szádeczky-Kardoss, Lajos Stegena, Miklós Kassai, Barnabás Géczy, Ferenc Horváth, Emő Márton, Zoltán Balla) dealt with this problem and constructed maps of the microplates moving between the African and European plates, on strike-slip movements, on rotations of certain plates, on the connection of the Transdanubian Central Range with the Alps. Thus, for example, a solution obtained by Ferenc Horváth and Antal Ádám (*Fig. 3.7*) was used as a means of explaining the resistivity anomaly discovered by the telluric–magnetotelluric measurements. In this microplate ÁDÁM et al. [1977] supposed low resistivity graphitic schists such as

SUBSURFACE GEOLOGICAL MAP OF THE PRE-TERTIARY BASEMENT
A HARMADIDŐSZAKI MEDENCEALJZAT MÉLYFÖLDTANI TÉRKÉPE



Part of the
Geological Map of Hungary,
constructed in the
Geological Institute of Hungary
and simplified by
Károly Brezsnyánszky and János Haas,
from the Atlas of Cartographia Ltd.

A Magyar Állami Földtani Intézetben készült
Magyarország Földtani Térképének
Brezsnyánszky Károly és Haas János által
egyszerűsitett részlete a Cartographia Kft. Atlaszából

- a | b — **a**. Surface formations / Felszíni képződmények; **b**. Subsurface formations / Felszín alatti képződmények
- 2 — Upper Cretaceous sedimentary rocks (of Bakony type) / Felső-kréta (bakonyi típusú) üledékes kőzetek
- 3 — Upper Cretaceous sedimentary rocks (of Alföld type) / Felső-kréta (alföldi típusú) üledékes kőzetek
- 4 — Jurassic-Lower Cretaceous sedimentary rocks (of Bakony type) / Jura-alsó-kréta (bakonyi típusú) üledékes kőzetek
- 5 — Jurassic-Lower Cretaceous sedimentary and volcanic rocks (of Mecsek type) / Jura-alsó-kréta (mecseki típusú) üledékes és vulkáni kőzetek
- 6 — Jurassic-Lower Cretaceous limestone (of Villány type) / Jura-alsó-kréta (villányi típusú) mészkő
- 7 — Jurassic-Cretaceous metamorphic rocks (of Alpine type) / Jura-kréta (alpi tipusú) metamorf kőzetek
- 10 — Triassic limestone and dolomite (of Bakony type) / Triász (bakonyi típusú) mészkő és dolomit
- 11 — Triassic sandstone, limestone and dolomite (of Mecsek type) / Triász (mecseki tipusú) homokkő, mészkő és dolomit
- 12 — Permian sandstone (of Bakony type) / Permi (bakonyi típusú) homokkő
- 14 — Carboniferous-Permian sedimentary and volcanic rocks (of Villány type) / Karbon-permi (villányi típusú) üledékes és vulkáni kőzetek
- 15 — Carboniferous granite / Karbon gránit
- 16 — Palaeozoic schist / Paleozoos pala
- 18 — Poorly known Palaeozoic and Mesozoic formations / Kevéssé ismert paleozoos és mezozoos képződmények
- 19 — Old crystalline schist / Idős kristályos pala
- 20 — Old granite and crystalline schist / Idős gránit és kristályos pala
- 21 — Unknown basin substratum / Ismeretlen medencealjzat
- Depth of pre-Tertiary rocks as relative to sea level / A harmadidőszak előtti képződmények felszínének tengerszint alatti mélysége
- Tectonic line / Tektonikai vonal

Fig. 3.5.
3.5. ábra

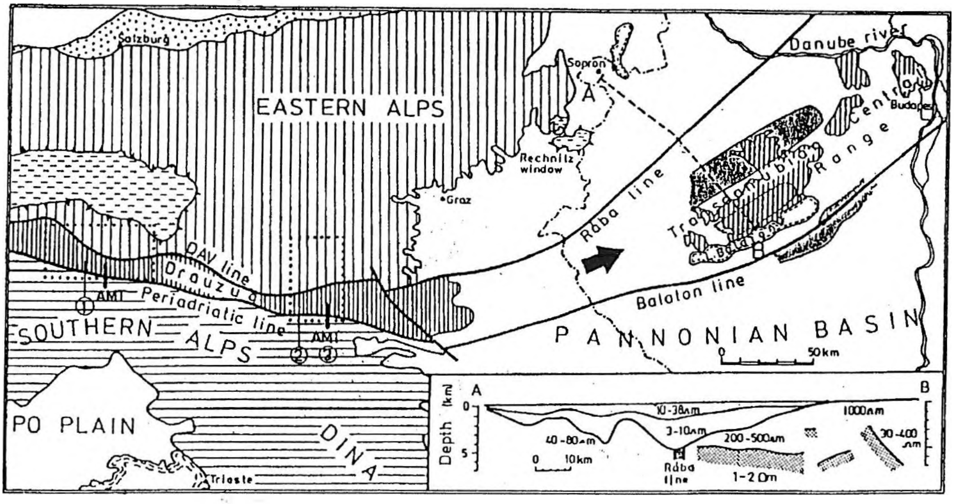


Fig. 3.7. Map detailing the graphitic strip between the Rába line and Balaton line [by ÁDÁM et al. 1977]

3.7. ábra. ÁDÁM et al. [1977] térképe: grafitos öv a Rába és a Balaton vonal között

occur in the Alps on the surface and which may also occur in the basement of the Transdanubian Central Range and in that of its surrounding area.

3.2.4. Geological knowledge in the early 1990s (after HAAS)

Obviously our ideas about geology change with increasing level of exploration, with the increase of knowledge. The geological knowledge at the time of finishing the telluric measurements — in the early 1990s — is demonstrated on the basis of a summary by János HAAS [1993].

Great-tectonic and structural units are represented in *Figs 3.8* and *3.9*. In the geological structure of Hungary, the consequences of three main historical periods are reflected.

The *pre-Alpine period* is connected to the pre-Cambrian–Palaeozoic history of Central Europe, but it is virtually impossible to reconstruct this period.

The *Alpine period* includes the Late Palaeozoic, Mesozoic and Palaeogene development of Tethys together with (Eo-Alpine, Palaeo-Alpine, Meso-Alpine) orogenic events which resulted in folded nappe tectonism and in great strike-slip movements.

The *Pannonian (Neo-Alpine) period* began in Early Miocene and lasts until the present. This section is characterized by small tensional basins,

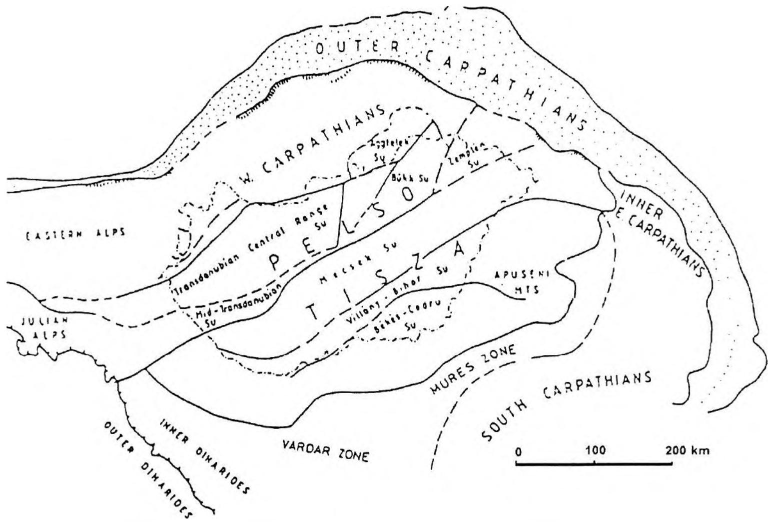


Fig. 3.8. Map showing structural units and subunits (Su) in and around Hungary [by HAAS 1993]

3.8. ábra. HAAS [1993] térképe: Szerkezeti egységek és alegységek (Su) Magyarországon és környékén

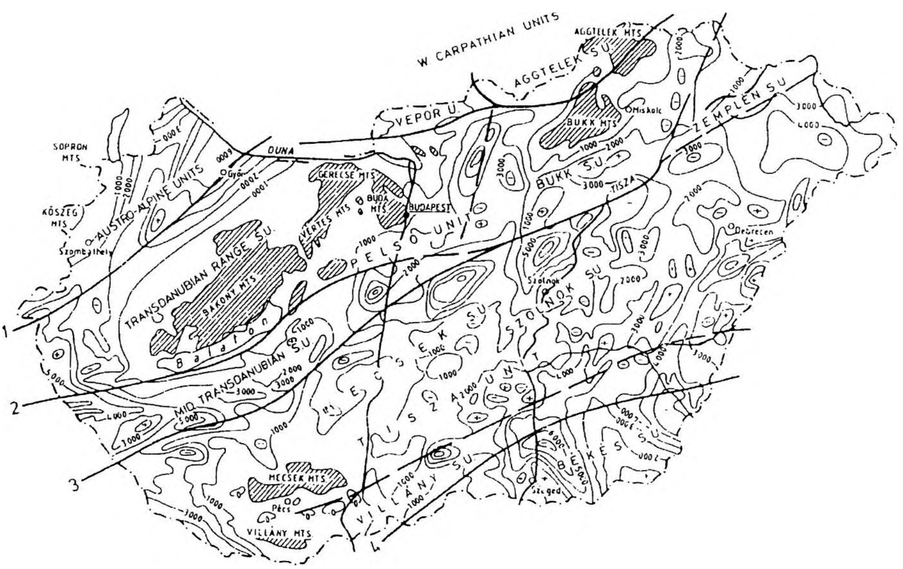


Fig. 3.9. Megastructural units (Su) of Hungary and depth to the basement.
1. Rába line, 2. Balaton line, 3. Mid-Hungarian lineament, 4. Békés line [after HAAS 1993]

3.9. ábra. Magyarország nagyszerkezeti egységei (Su) és az aljzat mélysége (m-ben)
1. Rába vonal, 2. Balaton vonal, 3. Középmagyarországi lineamens, 4. Békés vonal [HAAS 1993 nyomán]

then by the development of the Pannonian Basin accompanied by large-scale sinking. Young basins determine basically the present geological structure and physical geography, they are filled with fine grain sediments of continental origin, but sedimented in a saline internal sea, and in some places they also contain magmatic rocks of considerable thickness.

Based on to the development of the pre-Tertiary formations, Hungary's area can be divided into the following megatectonic units:

Tisza Unit

South of the Central Hungarian line, the Tisza Unit can be outlined, which includes the Mecsek and Villány Mts as well as their continuation beneath the surface in the basement of the Great Plain; the Unit is then found in western Romania and in Slavonia. The strongly metamorphosed basement is covered by German-type Permo–Triassic, a continental, shallow marine series. Cretaceous and Jurassic follow upwards with different facies enabling the separation of the sub-units Mecsek, Villány and Békés (Eastern Hungary). The Mecsek sub-unit is characterized by thick, Gresten-type deep sea, Liassic Age facies from Late Dogger, with a Mediterranean palaeontological set and intensive early Cretaceous submarine alkali volcanism. In the Villány (-Bihor) sub-unit Jurassic is found characterized by a high number of stratigraphic hiatuses, then the Early Cretaceous of the Urgon facies follows. In the Békés (-Codru) sub-unit Late Jurassic/Early Cretaceous formations discordantly cover earlier deformed rocks of different ages. Palaeogene siliceous (flinty) fragments of the flysch facies are known only from the subsurface part of the Mecsek sub-unit (Szolnok flysch belt). The Zemplén sub-unit in northeastern Hungary is also thought to belong to the Tisza Unit based on its Palaeozoic and Early Mesozoic series.

Pelso Unit

The Pelso Unit is situated between the Rába line and the Central Hungarian fracture zone. It is characterized by marine Early Palaeozoic formations of very low and low metamorphisation, other continental and marine Late Palaeozoic series being in affinity with the South-Alpine and Dinarid ones. Mesozoic is characterized here by formations of the passive continental rim, but in some basements remnants of the oceanic basement are known, too. The facies has Alpine–Dinarid connections. The intensive Eocene intermediary volcanism is an important and specific feature of this unit, because it is unknown from the Tisza Unit.

The Transdanubian Central Range sub-unit is characterized by continental–marine Late Permian. And then, beginning with the Early Triassic, by multiphase transgression, by rift development within the shelf accompanied by volcanism in Middle Triassic, by thick tidal valley carbonate series in Late Triassic, by rift development within the shelf and by general deepening in the Jurassic and, finally, by tectonically controlled trans- and regression cycles in Middle and Late Cretaceous and in the Eocene. The Central Transdanubian sub-unit consists of strongly tectonized, heterogeneous blocks which are known only from boreholes. Marine Permian and Triassic platform formations have Dinarid features. Slightly metamorphosed deep marine sedimentary and volcanic rocks were also discovered.

The **Bükk sub-unit** belongs to northeast Hungary, thus it is not described here in detail.

Western Carpathian Units

The Aggtelek–Rudabánya (Southern Gemer) sub-unit contains in its upper cover carbonate platform Triassic and deeper marine Jurassic having Western Alpine connections. Lower nappes consist of Middle and Late Triassic of the somewhat metamorphosed deep marine facies, as well as from a Jurassic luminous schist being similar to its counterpart in the Bükk Mts. To the north of the Diósjenő line, the Vepor Unit is a crystalline complex which also reaches Hungarian territory. It is known only from boreholes.

Austro-Alpine Units

The Penninian Unit appears in the Hungarian part of the Rohonc (Rechnitz) window with Jurassic–Early Cretaceous metamorphites of the green schist facies (Kőszeg Mts, and subsurface continuation in the basement of the Little Plain).

Lower Austro-Alpine Unit: Palaeozoic metamorphosed formations from the Sopron Mts.

Upper Austro-Alpine Unit: rocks of very low to low metamorphisation are known from the basement between the rivers Répce and Rába representing the continuation of the Graz Palaeozoic series.

3.3. Possibilities of telluric exploration in the given geological conditions

By developing the geological–geoelectric model we shall try to outline the expected results of telluric exploration in the given geological situation in relation to the exploration of the pre-Tertiary basement and in relation to the new information about the basement itself. For this survey, the theoretical bases of the method as well as data on the resistivity of sediments and basement and experience with measurements are to be included.

3.3.1. Bases of the method

Telluric currents are the electric components of electromagnetic waves incident on the Earth's surface. Depending on the frequency and resistivity of the underlying rocks, they penetrate into the crust. The penetration depth is in a homogenous half-space described by the following formula:

$$P_{km} = \frac{1}{2\pi}\sqrt{10\rho T}$$

where:

P_{km} is the penetration depth in km,

ρ the electric resistivity of the homogeneous half-space in Ωm,

T the period of the wave in seconds.

There are no homogeneous half-spaces in nature, but this notion can be substituted by the 'average' resistivity of the sediments or of the basement. The average resistivity is defined in the case of n layers of different thicknesses and resistivities as:

$$\rho_\sigma = \frac{H}{S} = \frac{h_1 + h_2 + \ldots + h_n}{\dfrac{h_1}{\rho_1} + \dfrac{h_2}{\rho_2} + \ldots + \dfrac{h_n}{\rho_n}}$$

where:

ρ_σ is the average resistivity

$h_1, h_2, \ldots h_n$ the thicknesses of the layers,

$\rho_1, \rho_2, \ldots \rho_n$ the resistivities of the layers,

H the total thickness of the layer sequence (Σh_i)

S the summed longitudinal conductance of the layer sequence (ΣS_i)

$S_i = h_i/\rho_i$

3.3.2. *Most important geoelectric data based on geological information*

Data on the geoelectric structure of the basin were already available at the time of the first telluric measurements. Well logging was carried out in boreholes reaching the pre-Tertiary basement. Information could be collected about the geoelectric data of the Tertiary sediments from borehole data as well as from geoelectric Schlumberger and dipole soundings, even if their quality and areal distribution were far from optimum. Nevertheless, these data could be used as a first approximation and even in possession of later information the initial considerations should not be considered as being without a firm foundation.

Surface Quaternary layers are fluvial, lacustrine and eolian sediments, mostly of a clayey–sandy–gravelly character. Their thickness is between a few m and 600 to 700 m in the Palaeo-Danubian alluvial fan. The resistivity is in the order of magnitude of ten to one hundred Ωm. It is also characteristic that the thickest Quaternary sediments are of the highest resistivity, but the conductance is only a few siemens, being not more than a small percentage of the total conductance of the sediments.

Regardless of what is said above, beneath the relatively high resistivity surface sediment layers mostly with lower and lower resistivities follow. Saline marine clays of Early Pannonian age have resistivities of about 2 Ωm and the thickness may reach 1000 m or even more. Early Pannonian sediments at depths of 2 to 3 km are more compact with lower water saturation, they are often marly, correspondingly the resistivity increases at this depth to about 10 Ωm.

Judging from our experience, the resistivities of Oligocene clayey complexes and the detrital-sedimentary Miocene layer sequence are also around 10 Ωm, even if in the Dráva Valley (e.g. in the Felsőszentmárton area) they reach 30 to 40 Ωm, too; similar values are to be found in the deep southern Transdanubian basin south of Lake Balaton where Miocene andesitic formations are known. Less frequently occurring Eocene formations are mostly carbonates and represent a similarly high resistivity group. Taking into account that higher resistivity Miocene and Palaeogene formations are thickest mostly in the deepest basins, telluric anomalies are much smoother in these basins than would be supposed solely on the basis of the sediment thickness.

In summary the average resistivity of the Tertiary and Quaternary sediments of the basins is in the range 5 to 10 Ωm and the same value was supposed at the beginning of the telluric measurements.

The rocks of the pre-Tertiary basement have resistivities by at least one, but mostly by two and sometimes by three orders of magnitude higher than the average resistivity of the sedimentary complex. Therefore if pulsations of periods are used for the measurements which have penetration depths in a medium of a resistivity between 5 and 10 Ωm greater than the depth to the basement, then the morphology of the basement can be explored by the telluric method, as these variations do not penetrate into the high resistivity basement because of the high resistivity contrast. Therefore the potential gradient measured at the surface would be a function of the conductance of the sediments.

3.3.3. Application of telluric measurements in the given geological conditions and electric parameters of the formations

At the beginning of the telluric measurements, instruments could reliably record pulsations with periods longer than 10 s. The periods of the most often occurring pulsations are in the range 22 to 28 s at Hungary's latitude. In practice, this means that in 90 per cent of the measurements, pulsations with periods of 20 to 30 s were used. Pulsations with periods longer than 30 s occur significantly less frequently. Among them, periods around 60 s occur relatively more often. (Digital instruments produced later were manufactured to record pulsations only in the period range 10 to 100 s.)

Based on this experience it is worth computing the penetration depths of pulsations with different periods.

average resistivity Ωm	period s	penetration depth km
10	10	5
10	25	8
10	100	16
5	10	3.6
5	25	5.7
5	100	11.3
100	10	16

It is evident that taking into account the average resistivity of the basin sediments, the most frequently occurring pulsations were correctly supposed to be applicable for exploring the conductance of sedimentary basins that are not deeper than 3 to 3.5 km, i.e. the relief of the high resistivity basement.

Since the time that the first work was carried out, two additional facts have been discovered which should be taken into account:

- There are basins deeper than originally supposed, this means that pulsations may not always reach the pre-Tertiary basement. Nevertheless, such areas are relatively small and, moreover, conductance values of telluric measurements indicate the deepening of the basins.
- There are also areas where the resistivity of the basement is not higher (or, indeed, it may be lower) than the average resistivity of the basin sediments. There may also be situations where the immediate basement of the Tertiary rocks has a high resistivity, but the penetration depth of pulsations reaches an additional conductive formation at a greater depth. In such a case, a part — mostly unknown — of the telluric anomaly is caused by deep formations and not by the thickness and resistivity of the sediments.

It was precisely these problems that led to the standstill in telluric measurements in several countries, and similarly the problems were the major factor in Hungary, too. Later introduced magnetotelluric measurements carried out in a much wider range of frequencies are able to solve the problem. That is why most countries/firms which applied earlier the telluric method, switched over to magnetotellurics. Magnetotellurics is, however, even in the previously discussed traditional frequency range of the telluric method a more sophisticated but less quick method than is tellurics utilizing only electric components. As the amplitude and frequency of the magnetic components of the electromagnetic plane waves depend less within distances of about 100 km on the distribution of resistivity with depth than those of the electric components, many — (50 to 100) — component instruments were developed in the 1990s that measure the magnetic components at a single central station, and electric components are only recorded at the other stations.

This is essentially a modern telluric method.

All four institutions (the three that took part in the Transdanubian measurements and the Geophysics Department of the Miskolc University which carried out telluric measurements in large areas in Eastern Hungary) carrying out telluric measurements in Hungary somehow approximated this idea beginning in the 1960s. At first, telluric measurements were combined with deep penetrating DC dipole soundings — naturally with a density much less than that of the telluric measurements. This yielded a control concerning the depth of the basin and the average resistivity of the rocks in the basin, and even the resistivity of the basement could be determined.

The magnetotelluric method has been applied since the mid-1960s using more and more sophisticated instruments: at first variometers and analogue instruments, then the frequency range was extended by induction coils and digital recording, finally satellite transmission was used to access remote reference stations in real-time mode of operation. Telluric measurements could be easily combined with the much less dense magnetotelluric measurements and they helped to monitor telluric data. They promoted the interpretation of telluric measurements made in a less advantageous range of frequencies and relative telluric maps (referred to a certain base station) could be combined related to a common base, thus producing a uniform map.

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3. FEJEZET

A tellurikus kutatások elvi lehetőségei az adott geológiai viszonyok között

NEMESI László

A tellurikus módszert a Kárpát-medence főként kainozoós korú kis fajlagos ellenállású üledékes összletének (vastagságának, nagyellenállású aljzatszerkezetének) kutatására kívánták alkalmazni. A kutatások 4 évtizede alatt a módszer alkalmazhatóságát is meghatározó geológiai ismeretek változtak, bővültek. Önkényesen négy korszakot különítünk el, amelynek módszerünk szempontjából legfontosabb ismeretanyagát megkiséreljük összefoglalni.

Összegzésként megállapitható, hogy a mérések zöménél felhasznált 20–30 s periódusú természetes elektromágneses síkhullám behatolási mélysége a Dunántúl legnagyobb részén alkalmas volt a kitűzött célok megvalósítására. Az üledékes összlet inhomogenitásából származó látszólagos anomáliák a korábbi egyenáramú és a későbbi magnetotellurikus szondázásokkal korrigálhatók. Az aljzat inhomogenitások okozta anomáliák pedig új földtani ismeretekhez vezetnek.

ABOUT THE AUTHOR

Nemesi László for a photograph and biography, see this issue, p. 120.

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CHAPTER 4
Data acquisition and processing

László NEMESI*

Telluric measurements in Hungary were carried out with Hungarian-made instruments. The T–9 and T–14 photorecorders were manufactured in the Sopron branch of the Factory for Geophysical Instruments, and the digital instrument used after the end of the 1970s (TEM–80) in ELGI. Processing of analogue measurements was performed initially by the relative ellipse, then by the straight line, finally by the total ellipse method. The last of these — by means of TEM–80 — was performed digitally, partly in real time. This provided an opportunity to make the best of direction dependent information.

Keywords: tellurics, data acquisition, data processing, Hungary

4.1. Telluric instruments

The first instruments applied in telluric surveys of Hungary were manufactured by the Geodetic and Geophysical Working Group of the Hungarian Academy of Sciences comprising university research staff under the supervision of Professor Károly Kántás, Head of Mining Academy's Geophysics Department based on French (Schlumberger) experience and personal contacts, and they made use of French-made Piccard galvanometers. The Hungarian team also carried out the first measurements in Hungary using these instruments. Antal Ádám and Ernő Takács got as far as China with the experimental measurements, and they returned from there in 1955 with an order for 60 instruments. This gave an impetus to the mass production of telluric photorecorders in the Sopron branch of the Factory for Geophysical Instruments. Those instruments were manufactured here, too, with which research workers and technicians of the

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Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (MTA GGKI), the Eötvös Loránd Geophysical Institute of Hungary (ELGI), and the Geophysical Exploration Company of the Hungarian Oil and Gas Trust (OKGT GKV) performed telluric measurements over a large part of Transdanubia. In addition, an instrument developed here but never used widely in practice (the T–20), provided the basic idea for the digital instrument development in ELGI in the 1970s.

4.1.1. T–9 photorecorder

This instrument's 'soul' was a mirror (light beam) galvanometer of 10^{-9} A/mm/m sensitivity, with liquid damping. Depending on the effect of the slow period (telluric) current led in the coil suspended on the torsion wire the coil deviates in the magnetic field which surrounds it. The T–9 records the light thrown on the mirror, mounted on the coil, and the light is then reflected onto film or photographic paper.

The total length of the light beam led through lenses and diaphragms in the optical system of the photorecorder instrument is 0.5 m; the velocity of the film (paper) advancing mechanism is 2–4 cm/minute which was ideal for analogue evaluation of the oscillations of 20–30 s period time used dominantly in measurements. By means of its own chronometer it gave time signals at one-minute intervals.

Among the electric circuits of the instruments can be found an SP compensator supplied with a 1.5 V battery and suitable to buck out the spontaneous potential developing between the electrodes and the undesirable slow period telluric currents, a potentiometer (later a helical one) allowing one to adjust the resistance (2 kΩ or 4 kΩ) of the measuring circuit, a Wheatstone bridge capable of measuring the resistance of the measuring circuit, and a set of series resistors to set the four sensitivity ranges (*Fig. 4.1*).

4.1.2. T–14 telluric photorecorder

After the T–9 the next generation of photorecorders, the type T–14 instrument family, was manufactured in the Sopron branch, which operated as a unit of the Factory for Geophysical Instruments in the early 1960s. Although this family had more sensitivity ranges, primarily its mechanism changed compared to the previous one: as a consequence the photopaper feed became more reliable and smoother. More up-to-date electric parts

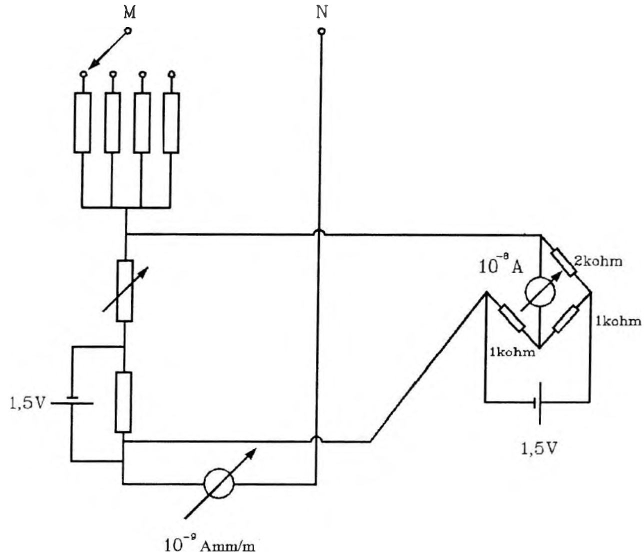

Fig. 4.1. Sketch of electric circuits of the T–9 telluric recorder
4.1. ábra. A T–9 tipusú tellurikus fotoregisztráló elektromos áramköreinek elvi vázlata

were, of course, also used in manufacturing. An illustration of the instrument can be seen in *Fig. 4.2.*

A considerable number of the telluric measurements in Transdanubia were performed with these two types of telluric photorecorder. In practice, all three institutions worked with these instruments between 1960 and 1980. The manual processing technology and the sensitivity of these instruments allowed the evaluation of oscillations, pulsations of 0.1 mV (or higher) amplitude.

4.1.3. TEM–80 digital instrument

This digital telluric instrument was developed in ELGI at the end of the 1970s after which it was used for most measurements. (ELGI used solely these after the end of the 1970s; the oil industry no longer performed measurements; the MTA GGKI was still employing the photorecorders around the Paks Nuclear Power Plant in 1985–1987.) The TEM–80 begins processing in real time using the method of total ellipses (described later). In this respect, designers used some of the basic ideas of the T–20 developed earlier in MTA GGKI.

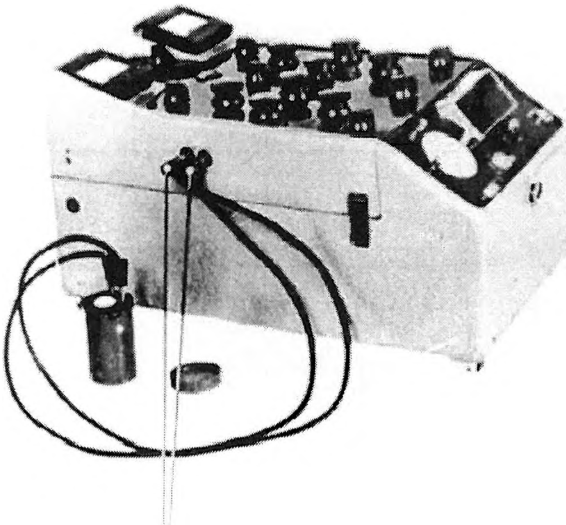

Fig. 4.2. T–14 telluric photorecorder
4.2. ábra. A T–14 típusú tellurikus fotoregisztráló

In appearance the T–20 looks like the T–14 photorecorder, but the beam reflected from the galvanometer of the former reaches a photodiode through an optical system and not the photopaper and by means of this it calculates values of total changes electronically.

The TEM–80 took over this principle but it solved time synchronization between the base and roving instruments, and it also filtered out undesirable noise signals; these features made it suitable for carrying out routine field measurements. *Fig. 4.3* shows a block diagram of the TEM–80.

The most important technical parameters of the instrument are:

Number of measuring channels	2
Noise reduced to input	0.3 μV (rms)
Input impedance	10 MΩ
Highest sensitivity (T=30 s)	0.5 μV/bit
Limits in four sensitivity ranges:	
Range 4	166 μV
Range 3	500 μV
Range 2	1.5 mV
Range 1	5.0 mV

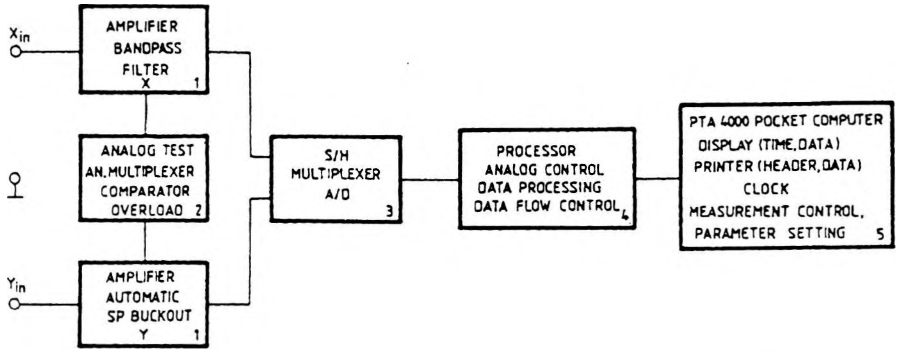

Fig. 4.3. Block diagram of the TEM–80 digital telluric equipment
4.3. ábra. A TEM–80 típusú digitális tellurikus műszer blokk-vázlata

Resolution	11 bit + sign
Noise suppression (f_0 = 0.5 Hz)	80 dB/octave
Limits of band filters in period time	
upper limit	60 s or 100 s
lower limit	10 s or 40 s
Amplitude identity between the channels	± 1.5%
Linearity of the individual channels	± 0.5%

The analogue, digital and computer units of TEM–80 were completed with a commercially available analogue recorder. All these were mounted in a 500x600x800 mm instrument box in which a controlled temperature fan heater ensured the temperature required by the instrument's operation independently of weather (potentially at an automatic measuring station as well). The electric energy necessary to operate the instrument unit was provided by a commercially-available generator.

It can be seen from the figures and the data, too, that the TEM–80 is a significantly more sensitive instrument than the photorecorders. Its further advantage is that it avoids measuring the undesirable period range because it filters these signals by means of its high slope analogue filters.

The digital signal form allowed the processing of measured data to begin (for each measurement of 5-minute interval) simultaneously with the measurements using the PTA–4000 calculator mounted in the instrument. Synchronization of base and roving stations takes place by means of the digital clocks mounted in the instrument, the accuracy of these clocks can be checked using the time pips of broadcasting stations and by means of them they can be set.

In addition to digital signal recording, analogue (total values) printing of results is also possible; the use of a recorder even allows pulsations to be recorded. The importance of the latter is that the interpreter can visually decide from these recordings which 5-minute intervals can be accepted and which not. (Disturbing industrial impulses, intervals affected by cable rupture, electrode and other technical troubles can be deleted.)

High sensitivity digital instruments not only increased productivity: but improved the reliability of processing by almost an order of magnitude. This enhanced reliability was the result of more accurate sampling. (5–10 times more pulsations could be processed than those used in analogue processing from the same length of field record.)

4.2. Processing of telluric measurements

In the great age of tellurics first of all the French, German, Russian and Hungarian schools developed more than a dozen analogue processing methods.

In Transdanubia, at first (in the early 1960s) the relative ellipse method was used to process telluric measurements. The oil industry processed their measurements using the so called straight line method. After the middle of the 1960s the total ellipse method was applied in ELGI (using the mechanical integrator and nomograms of TAKÁCS [1962]), and then — in the 1970s — calculations were carried out with programmable calculators. The digital telluric instrument TEM–80, which performed the first steps of processing in real time as well, applied the total ellipse method, too.

The methods of telluric measurement and processing applied forty years ago were understandable and unambiguous for the geoelectric experts practising at that time. Nowadays, the situation is somewhat different: the methods are not even taught at university. In view of this, it might well be of interest to introduce the earlier most frequently applied three methods in a somewhat more concrete manner — not because measuring and processing methods basically determine the reliability and realizable accuracy.

Therefore, we would like to erect a small monument to the tricks and to the methods from some 20–40 years ago and to provide their critical evaluation in the following section.

4.2.1. Relative ellipse method

The starting point of each telluric processing method is that the (primary) electromagnetic wave arriving to the Earth's surface is — as a good approximation — a plane wave. This means that differences in the amplitude of the field and the phase shift between the electric components can be due only to geological causes within a region of 100 km order of magnitude. The expression of geological 'difference' is the relative conductance (relative ellipse) tensor which transforms the electric variation vector measured at the base station for the same time interval to the electric variation vector of the roving station.

The relation between the electric variation vectors of the base and roving station is

$$Eu_i = \mathbf{a}Ex_i + \mathbf{b}Ey_i$$

$$Ev_i = \mathbf{c}Ex_i + \mathbf{d}Ey_i$$

where Ex_i and Ey_i are the components of the electric variation vector belonging to arbitrary ΔT time at the base station; Eu_i and Ev_i are the components of the electric variation vector belonging to the same ΔT at the roving station; **a**, **b**, **c** and **d** are tensor components, their determination (or determination of the tensor's $\mathbf{A} = \mathbf{ad}-\mathbf{bc}$ value, the area of the relative ellipse) is the task of telluric processing.

In practice, 20–24 variation vectors were selected by the interpreter in the record of both the base and roving stations (*Fig. 4.4*), then the corresponding amplitudes were measured using a mm rule. In the next step the magnitude of the vector was normalized to a circle of unit radius (*Fig. 4.5a*), and magnification (or reduction) of the vectors of the roving station in the same ratio enabled the endpoints of the new vectors to determine the relative ellipse; its area (length of its axes) was determined graphically by estimating the length of the major and minor axes (*Fig. 4.5b*).

It is not difficult to realize that this processing required great precision and practice. For the sake of better determination of the ellipse care should also be taken to choose vectors uniformly from each quadrant. However, it

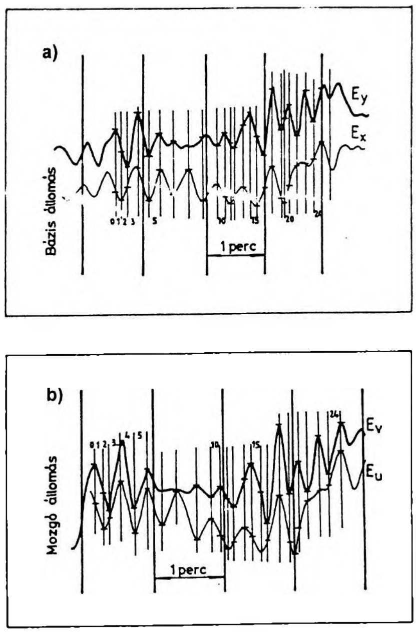

Fig. 4.4. Telluric photorecord with the selected variation vectors.
a) Base station; *b)* Roving station
4.4. ábra. Tellurikus fotoregisztrátum a bejelölt változásvektorokkal

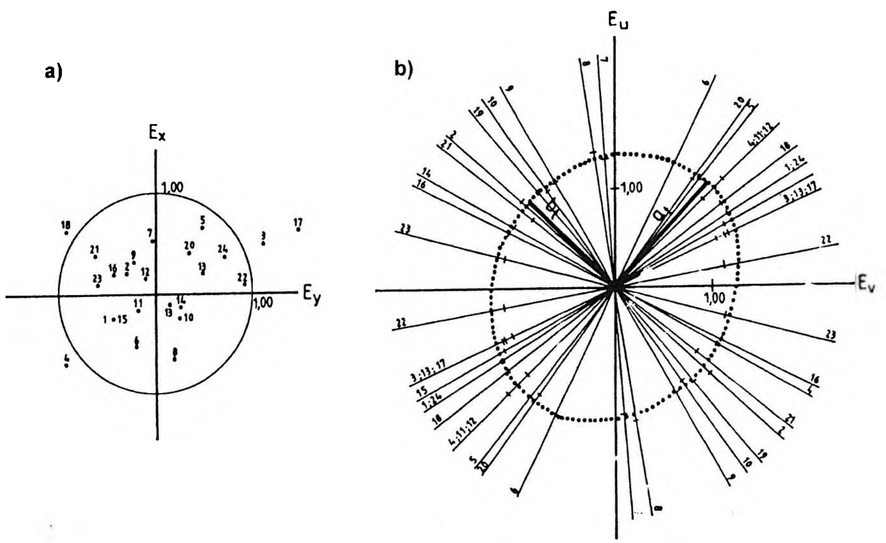

Fig. 4.5. Construction of relative ellipse from the variation vectors
4.5. ábra. A relativ ellipszis előállítása a változásvektorokból

can be sensed as well that by using this classic processing method the final result, the axes of the ellipse and the area calculated from them, could be obtained only with a quite high (10–20%) relative error.

4.2.2. Straight line method

A process developed later which is more labour-intensive but more reliable and uses the same basic data set is the straight line method [NEMESI 1963]. The only conceptual difference is that the relation between the variation vectors of the base and roving station is transformed into the following form:

$$Eu/Ey = \mathbf{a}\ Ex/Ey + \mathbf{b} \qquad \text{and}$$

$$Ev/Ex = \mathbf{c} + \mathbf{d}\ Ey/Ex$$

If one uses the variation vectors given in the record shown in Fig. 4.4 one needs to work with the straight line method; calculation then utilizes the components of the variation vectors one after the other, i.e. the Eu/Ey, Ex/Ey, Ev/Ex and Ey/Ex values. Plotting the $Eu/Ey - Ex/Ey$ and $Ev/Ex - Ey/Ex$ data sets separately (*Fig. 4.6*) we can see by eye (graphically) straight lines which can be estimated more accurately than the ellipse obtainable from the same variation vectors. With the straight line method based on the points of the straight line plotted in one of the co-ordinate systems in the $u/y - x/y$ co-ordinate system tensor components **a** and **b** can be determined analytically; from the other set of points plotted in the $v/x - y/x$ co-ordinate system tensor components **c** and **d** can also be determined analytically, e.g. using the method of double averaging.

In this method, the processing error comes from determining the variation vectors only; further calculations contain no subjective element. Thus, the error of the telluric value determined by the straight line method is significantly smaller than in the case of the relative ellipse method.

4.2.3. Total ellipse method

If two orthogonal sinusoidal components of a telluric station are led to the orthogonal plate pair of an oscilloscope the envelope of the area covered by the recorded vectors is an ellipse. If recording is only few minutes long, this is called 'temporary absolute ellipse'. Its shape (eccentricity) and size depend on the features of the primary current field and the distribution of the horizontal conductance of the rock sequence below the observation

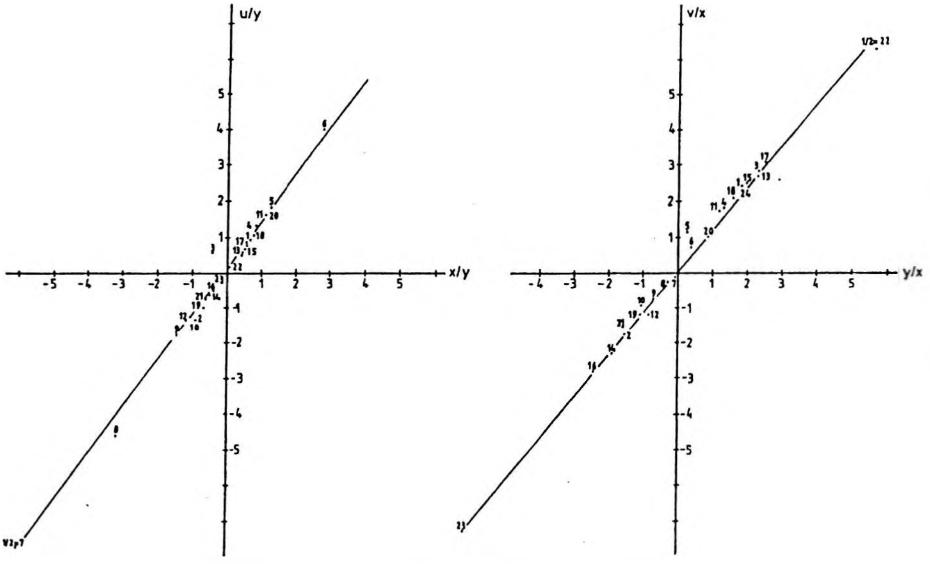

Fig. 4.6. Straight lines obtained from variation vectors, for determining the tensor components
4.6. ábra. A változásvektorokból képzett egyenesek, a tenzorkomponensek meghatározásához

point. Géza KUNETZ [1957] demonstrated that the ratio of the temporary absolute ellipses' area determined for the same time interval at the base and at a roving station is just equal to the area of the relative ellipse.

Kunetz determined the temporary absolute ellipses from the total variations. In a given time interval, the total variation of pulsations recorded in a given direction is proportional to the normal to the tangent of the temporary absolute ellipse (*Fig. 4.7*).

Thus, the area of the relative ellipse (or rather its reciprocal proportional to the summarized conductance) is the ratio, A^{-1}, of the temporary absolute ellipse's area determined at the base station and the temporary absolute ellipse's area determined at the roving station for the same time interval of measurement, according to the following formula:

$$A^{-1} = \frac{\varepsilon_x \varepsilon_y \sqrt{[(X+Y)^2 - Z_i^2][Z_i^2 - (X-Y)^2]}}{\varepsilon_u \varepsilon_v \sqrt{[(U+V)^2 - W_i^2][W_i^2 - (U-V)^2]}}$$

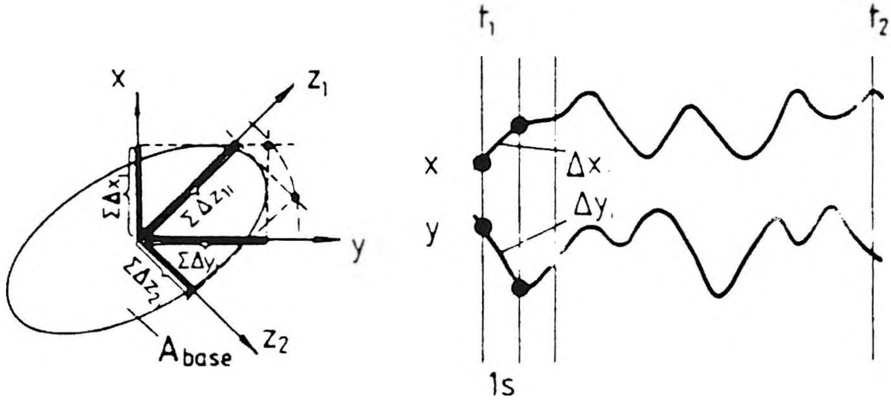

Fig. 4.7. Calculation of temporary absolute ellipse by means of the total variations
4.7. ábra. Az időszakos abszolút ellpipszis számítása a totális változásokkal

where ε_x, ε_y, ε_u, ε_v are the sensitivity factors of the two-channel instruments at the base and at the roving station.

$$X = \sum_{i=1}^{n} \Delta x_i \qquad Y = \sum_{i=1}^{n} \Delta y_i \qquad U = \sum_{i=1}^{n} \Delta u_i \qquad V = \sum_{i=1}^{n} \Delta v_i$$

$$Z_i = \frac{1}{\sqrt{2}} \sum (\Delta x_i \pm \Delta y_i) \qquad W_i = \frac{1}{\sqrt{2}} \sum (\Delta u_i \pm \Delta v_i)$$

The total ellipse method was applied in ELGI (between 1960 and 1962) in addition to the relative ellipse method. Total variations were calculated from variation vectors selected and measured for relative ellipse processing.

Later, between 1962 and 1980, the four components of total variations shown in *Fig. 4.8a* (total variations X and Y in the directions of measurement, and in directions rotated by 45° (Z_1 and Z_2), obtained by co-ordinate transformation (from the summarized and difference curves)) were determined by Takács's mechanical integrator (shown in *Fig. 4.8b*). Because one needs only three total values to determine the area of the ellipse, the fourth value already enabled one to calculate the area values in four different ways (in each case omitting one), and thus — based on the scattering —

data were obtained for the reliability of processing. To calculate the area of the ellipse the nomogram shown in *Fig. 4.8c* was used up till the mid-1960s. Later, it was calculated with minicalculators by means of a program written for the HP–97.

The digital instrument TEM–80 applied after 1978–79 represented a great change in the processing of telluric measurements; it worked with 1 s sampling interval and the four (X, Y, Z_1, Z_2) total variation values were calculated from the variation vectors for each 1 s, then from them the area of temporary absolute ellipses, for each 5-minute measurement cycle.

To calculate the area of ellipses, however, slightly different formulae were used and not those used earlier in analogue processing methods. Based on the works of PORSTENDORFER [1954] and VERŐ [1960] the major (A_i) and minor (B_i) axes of the so called temporary absolute ellipses characteristic of the processing period were determined both at the base and the roving station, and the azimuth angle between the major axis and the northern direction (α_i).

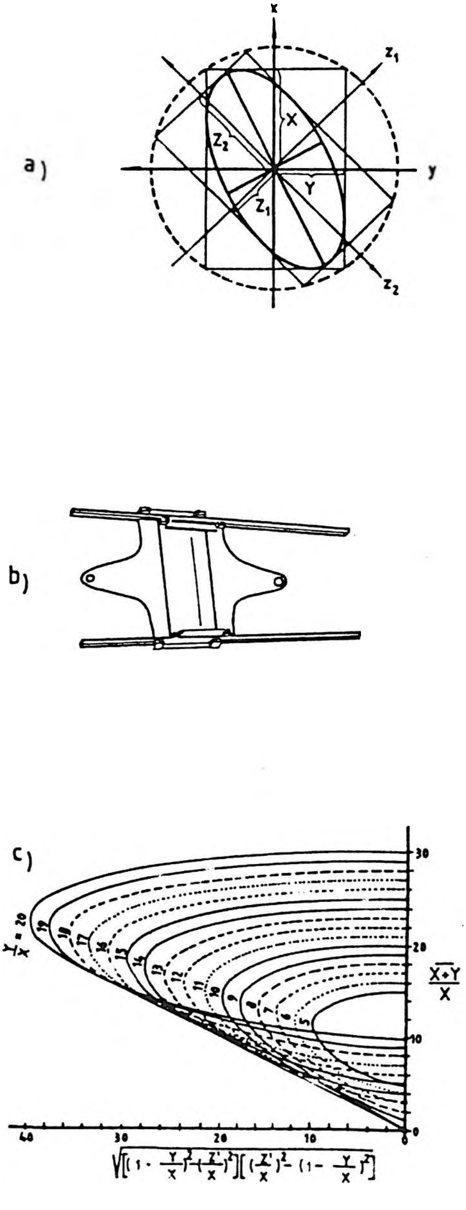

Fig. 4.8. a) total values, *b)* mechanical integrator, *c)* nomogram
4.8. ábra. a) totális érték, *b)* mechanikus integrátor, *c)* nomogram

$$A_i = \sqrt{\frac{\varepsilon_x \varepsilon_y}{2}} \sqrt{\frac{\varepsilon_x}{\varepsilon_y} X^2 + \frac{\varepsilon_y}{\varepsilon_x} Y^2 + \sqrt{(2Z_i^2 - X^2 - Y^2)^2 + \left(\frac{\varepsilon_x}{\varepsilon_y} X^2 - \frac{\varepsilon_y}{\varepsilon_x} Y^2\right)^2}}$$

$$B_i = \sqrt{\frac{\varepsilon_x \varepsilon_y}{2}} \sqrt{\frac{\varepsilon_x}{\varepsilon_y} X^2 + \frac{\varepsilon_y}{\varepsilon_x} Y^2 - \sqrt{(2Z_i^2 - X^2 - Y^2)^2 + \left(\frac{\varepsilon_x}{\varepsilon_y} X^2 - \frac{\varepsilon_y}{\varepsilon_x} Y^2\right)^2}}$$

$$\mathrm{tg}\, 2\alpha_i = \frac{2Z_i^2 - X^2 - Y^2}{\frac{\varepsilon_x}{\varepsilon_y} X^2 - \frac{\varepsilon_y}{\varepsilon_x} Y^2}$$

From these data not only can the relative telluric parameter (A^{-1}) be calculated as the ratio of the areas of the temporary absolute ellipses at the base and roving station, but the temporary absolute ellipses can be constructed as well. By using these we have gained interesting experience (discussed in more detail in Chapter 6) but our premise is that the temporary absolute ellipses very clearly mark the main structural directions in the zones of large conductance changes, they delineate structural units.

Finally, from the values of A, B and α, the tensor components a_i, b_i, c_i, d_i of the ellipses can also be calculated:

$$a_i = A_i \cos^2\alpha + B_i \sin^2\alpha$$
$$d_i = A_i \sin^2\alpha + B_i \cos^2\alpha$$
$$b_i = c_i = \frac{A_i - B_i}{2} \sin 2\alpha$$

Then, from the a_0, b_0, c_0 and d_0 tensor components of the base station's temporary absolute ellipse, components a_m, b_m, c_m and d_m of the roving station and from the area of the base station's temporary absolute ellipse (t_0) **a**, **b**, **c** and **d** components of the relative ellipse can be calculated as well, using the formulae:

$$\mathbf{a} = \frac{a_m d_0 - b_m c_0}{t_0} \qquad \mathbf{b} = \frac{b_m a_0 - a_m b_0}{t_0}$$

$$\mathbf{c} = \frac{c_m d_0 - d_m c_0}{t_0} \qquad \mathbf{d} = \frac{d_m a_0 - c_m b_0}{t_0}$$

By calculating all these values our aim was to provide a possibility to increase the information content of telluric measurements, e.g. by separating the direction-dependent parts of the information; this will be discussed in more detail in Chapter 6.

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4. FEJEZET

Mérés és feldolgozás

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A magyarországi tellurikus mérések magyar műszerekkel történtek. A T–9 és T–14 típusú fotoregisztrálók a Geofizikai Mérőműszerek Soproni Gyáregységében készültek, a 70-es évek végétől használt digitális műszer (TEM–80) az ELGI-ben. Az analóg mérések feldolgozása kezdetben relatív ellipszis, majd egyenes, végül a totális ellipszis módszerrel történt. A TEM–80 segítségével ez utóbbi már digitálisan, részben real-time üzemmódban. Ez lehetőséget adott az irányfüggő információk kiaknázására is.

ABOUT THE AUTHOR

Nemesi László for a photograph and biography, see this issue, p. 120

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CHAPTER 5
Telluric map of Transdanubia

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To construct the telluric map of Transdanubia, on the one hand the unified observation database had to be created from the measurements of the three institutions mentioned in Chapter 2; on the other hand, relative conductance data referred to more than 30 base stations had to be transformed to a common base level. This latter became feasible with the help of the recently performed magnetotelluric soundings.

A coherent absolute telluric conductance map for about 25 s was created. This is primarily proportional to the thickness of Cenozoic sediments, but there are areas where the conductivity anomaly within the pre-Tertiary basement plays the decisive or significant role in generating the anomalies (Magyarmecske, Zselic, Paks, Nagygörbő, parts of the Kisalföld south of the Rába Line). In spite of this, a map of the thickness of the Cenozoic sediments can be constructed with good approximation by means of magnetotelluric corrections even in such areas.

Keywords: tellurics, Transdanubia, maps, conductance, basement

5.1. Reduction to a common level of relative conductance values referred to different base stations

As has already become evident from the chapter (Chapter 2) dealing with the history of survey, telluric measurements in Transdanubia were not performed on the basis of a systematic plan. Maps of areas of 500–1500 km^2 covered by measurements in separate years were constructed for various clients, always with an actual objective, with different station densities; with three processing methods of different reliability; basically with two different instruments and in three institutions. Sometimes only one year elapsed between the measurements in neighbouring areas but

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in other cases it was decades during which time the reliability of instruments and processing changed.

However the main obstacle to the construction of a unified map and interpretation was that the results of the measurements were relative conductance maps referred to more than 30 base stations. To overcome this difficulty we carried out experiments over areas of 4000–5000 km^2 with connecting measurements between the base stations using different methods. We then adjusted the base station network; finally, however, we found that the best solution was to construct an absolute conductance map with the help of magnetotelluric soundings measured at the telluric base stations.

In the early 1960s, based on our background knowledge we became convinced that the basement of the Tertiary basin is uniformly of high resistivity, practically an insulator and nowhere does it lie deeper than 3–4 km. The average resistivity of sediments is orders of magnitude lower — on average it is around 5–10 Ωm. Under such conditions oscillations, pulsations of the period range 10 s< T <100 s penetrate down to the basement at each station. Practically only the sedimentary sequence causes attenuation, i.e. our measurements are carried out in the so called '*S*' interval. In this case, the relative telluric conductance parameter — the '*A*' value — depends only on the conductance of the sedimentary sequence. The reliability of the '*A*' value depends only on the accuracy of data acquisition and processing.

Because of such considerations several decades ago we had already made efforts to perform connecting measurements between the base stations with an accuracy much higher than that of the standard telluric measurements. This meant that whereas standard telluric measurements made use of 10–20-minute long records (e.g. in the case of processing with the total ellipse method), in connecting measurements between base stations records that were ten times longer were processed. The mean error calculated from the scattering of '*A*' values determined from 20–40 total intervals (2–3 hours of measurement) was 1–2%. Under such conditions adjustment of the base station network would have been a rational task.

We were able to reduce the adjustment of the base station network to the methodology of adjustment of levelling networks developed in geodesy. We constructed a network of triangles from the base stations, then each pair of neighbouring stations was connected by a measurement. It is obvious that in the case of base stations *A*, *B* and *C* the relative conductance relations between all three stations are determined if measurements are performed between stations *A* and *B*, and *B* and *C*, respectively. The measurement between stations *A* and *C* is considered superfluous, this involves the possibility for error calculation and adjustment.

We do not intend to describe this method in detail, we would however like to indicate that the errors could be distributed correctly by taking into account all base stations in the region and by measuring between all neighbouring stations. Given state-of-the-art computer technology, execution of this operation would cause no difficulty.

However, we did not apply the method described here and developed in the mid-1960s. Even so, there were cases when the measurement was repeated some years later between certain base station pairs. Again, the mean error of the measurement series was only ±1–2%, but the deviation from the previous value was sometimes 8–10%. After instrument, measurement and processing errors were sorted out we had to realize — and magnetotelluric soundings verified this later — that in the questionable cases one or the other, or both series were measured outside the '*S*' interval. We know now that there are places where the basin is so deep (8–10 km) that the most frequent oscillation of 25–26 s period time does not reach the basement. It is, however, an even more frequent case that there are low resistivity rocks, minerals (perhaps fluids) within the basement at certain places; longer period pulsations sense their existence, but those of 10 s which are frequent during magnetic storms not at all or barely. Consequently, in several regions of Transdanubia the telluric values are undoubtedly frequency-dependent even in the period range of measurements.

Obviously at first glance this causes difficulties in interpreting telluric measurements because we do not measure at the same frequency at each station. But had we measured at the same one it might well be that the wave penetrated down to the basement at only one of the stations; the wave might sense the conductive formation within the basement at another one, but frequently not its total conductance because it does not penetrate right down to its bottom, and so on.

The measurements of these 40 years, however, were performed as best they could be in the circumstances. What we can now do at best is to analyse the meaning of the relative values obtained in different regions. The most suitable tool for this subsequent analysis is the magnetotelluric method. But we rely on the several decades long experience from observatories [MILETITS 1981], based on this experience the most frequently occurring period of pulsations in the telluric range is 25–26 s at the magnetic latitude of Hungary. Our experience from the measurements coincides with this; the processing documents provide a record of the period range used in processing for several decades. Based on these documents we are able to state that at least 90% of our measurements used oscillations between 20 and 30 s.

In approaching the problem of connecting the telluric bases with measurements, our train of thought was to accept the frequency dependence and overcome the problem with magnetotelluric soundings by considering the effective conductance belonging to the period time of 25 s the value of the base station.

The effective conductance (S_{eff}) was calculated from the effective magnetotelluric apparent resistivity curves. The effective curve is the geometric mean of the E and H polarization apparent resistivities at a given frequency. From the inversion of effective curves with the Geotools 1-D program package the necessary parameters of the electric layers (conductance S, thickness h and resistivity ρ) were obtained:

$$S_1=\rho_1/h_1, \quad S_2=\rho_2/h_2, \quad \ldots S_n=\rho_n/h_n$$

The n-th layer is the last one penetrated by the pulsation of 25 s. If this pulsation penetrated down to its bottom, then h_n is the total thickness of the layer, but if it does not penetrate to the bottom, then h_n is only the depth of penetration.

$$S_{eff} = S_1 + S_2 + \ldots + S_n$$

We chose the effective conductance because practically we had more or less obtained the relative value of this conductance — the A value — referred to the base station, measuring two orthogonal components in the course of the telluric surveys but using the earlier processing methods we could not determine the main directions.

In what follows 'telluric conductance', the 'summarized longitudinal conductance' or simply conductance always mean the effective conductance defined above.

Magnetotelluric soundings performed at the telluric base stations brought about several benefits:

— We were able to decide whether the range (10 s $< T <$ 100 s) of telluric measurements lies in the 'S' interval at the given base station (and its vicinity) because electromagnetic waves of period time less than 10 s or more than 100 s were not processed. The analogue filters of the digital instrument used after the 1980s also cut steeply below and above these period times.

— We were able to determine the conductance belonging to 25 s and in this way we solved the connection of base stations with measurements, because all base stations have an absolute ('*S*') conductance and this allows one to obtain the absolute conductance from the relative conductance of all telluric stations. This opened the possibility of constructing a unified telluric map.
— The impedance polar diagrams constructed from the magnetotelluric measurements provide an image of the horizontal conductance distribution below the base station. This latter also means that if the telluric relative ellipses are not normalized to a circle but to the anisotropy ellipse of the base station — to the magnetotelluric polar diagram — the relative ellipse constructed for the roving station will become the absolute ellipse characterizing the site of measurement.

The series of magnetotelluric soundings provided the basis for unifying the telluric measurements in Transdanubia, the possibility for conversion to one single map; we were able to carry out these soundings with ELGI's magnetotelluric instrument and processing program in 1997–98 supported by projects T 024097 and T 0144882 of the Hungarian Scientific Research Fund (OTKA).

Finally, the most important results from connecting the base stations with measurements (MT soundings) can be summarized as follows:

The three institutions used altogether 33 stations which served as the base for at least some dozens — but mostly for several hundreds or more than one thousand — roving stations. In addition there were about a dozen stations which proved to be unsuitable after a short operation, e.g. due to electrical disturbance, to act as a base station. The few points referred to such bases were reduced to the stable base during the measurement period. Now we are not able to deal with such base stations of small significance.

The geographical distribution of the 33 significant telluric base stations can be seen in *Fig. 5.1.*

In *Table 5.1* the serial number of each of the base stations can be found which denotes the station in Fig. 5.1, together with the name of the base, the identifier used for the MT sounding, the number of the 1:100 000 scale map sheet where the station can be found, the co-ordinates of the station, the effective conductance value determined from the MT soundings for 25 s, and the name of the institution which located the base station.

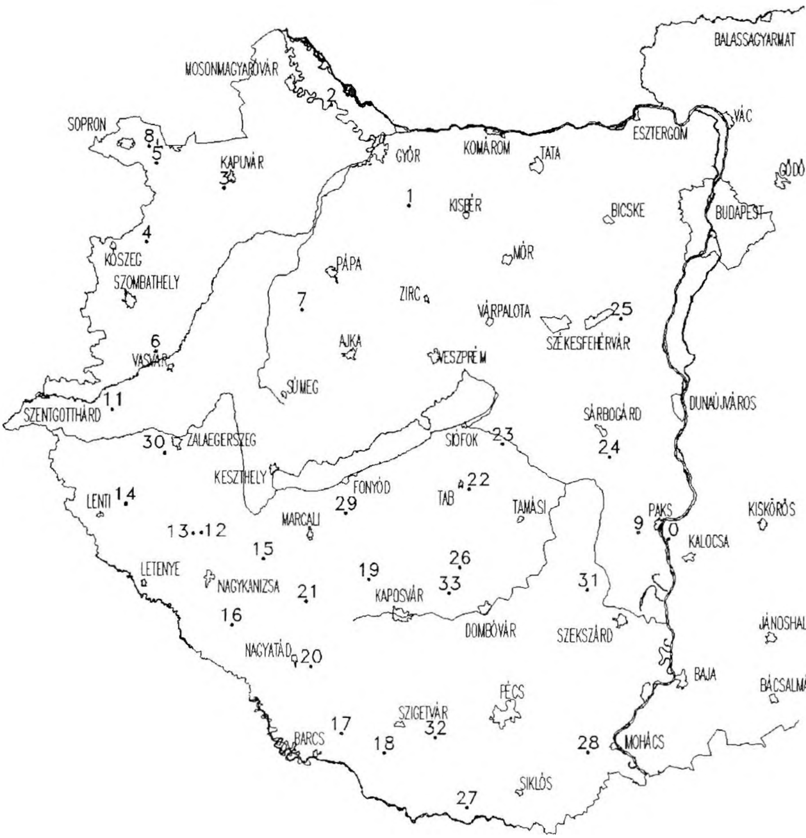


Fig. 5.1. Telluric base stations in Transdanubia
5.1. ábra. A Dunántúl tellurikus bázisai

The magnetotelluric measurements at the base stations in 1998–99 were carried out with ELGI's RMTS–2 instrument which can perform real-time synchronized measurements in the frequency range 200 Hz > f > 0.001 Hz. Time synchronization and positioning of base stations were performed with GPS instruments.

MT measurements were processed with a Geotools program package. We have plotted a series of impedance polar diagrams for the frequency range of 0.1 Hz > f > 0.001 Hz (frequency range of telluric measurements) at each base station. In *Figs. 5.2, 5.4* and *5.6* polar diagram series of three stations can be seen as examples. These figures indicate that the characterizing feature is either polar diagrams of almost circular shape (the ideal 1-D structure) or — in the worst case — their orientation does not change as

No of base station	Name of base station	Institution	No of EOTR sheet	X_{EOTR}	Y_{EOTR}	S (25 s)
1.	Nyalka	ELGI	63	243 100	554 960	**510**
2.	Lickópuszta	ELGI	73	275 140	529 830	**600**
3.	Kapuvár	ELGI	62	248 440	496 060	**500**
4.	Csepreg	ELGI	61	231 300	471 630	**270**
5.	Nagycenk	MTA, ELGI	71	256 480	474 580	**590**
6.	Rábahidvég	ELGI	51	197 000	474 720	**610**
7.	Dabrony	ELGI	52	210 180	521 170	**690**
8.	Sopron	MTA	71	261 940	472 060	**125**
9.	Paks	MTA	35	139 380	628 840	**500**
10.	Dunaszentbenedek	MTA	35	137 270	638 530	**560**
11.	Nádasd	OKGT	41	178 610	461 160	**620**
12.	Kacorlak	OKGT	32	139 470	489 790	**370**
13.	Zalaszentbalázs	OKGT	32	139 220	487 105	
14.	Hernyék	OKGT	31	148 500	465 640	**285**
15.	Zalakomár	OKGT	32	131 180	509 530	**390**
16.	Iharos	OKGT	22	110 230	499 500	**690**
17.	Szulok	OKGT	13	76 081	534 800	**410**
18.	Bürüs	OKGT, ELGI	13	69 820	548 450	**340**
19.	Mezöcsokonya	ELGI	23	124 530	543 220	**440**
20.	Lábod	ELGI	22	97 220	524 930	**430**
21.	Böhönye	ELGI	22	117 690	523 240	**370**
22.	Tab	ELGI	33	153 110	575 070	**520**
23.	Ádánd	ELGI	44	167 475	585 550	**650**
24.	Alap	ELGI	44	163 530	619 670	**520**
25.	Gárdony	ELGI	54	207 460	622 980	**250**
26.	Nak	ELGI	33	128 325	572 200	**425**
27.	Cun	ELGI	3	52 325	575 020	**240**
28.	Bóly	ELGI	14	69 900	613 430	**320**
29.	Buzsák	ELGI	33	145 610	535 600	**280**
30.	Bazita	ELGI	41	164 780	477 980	**460**
31.	Zomba	ELGI	24	121 132	612 760	**500**
32.	Szentlörinc	ELGI	13	74 720	564 780	**155**
33.	Kisgyalán	ELGI	23	120 130	568 880	**400**

Table 5.1. Telluric base stations in Transdanubia
5.1. táblázat. Tellurikus bázisállomások a Dunántúlon

a function of frequency, which suggests a 2-D structure. We have altogether three base stations where the orientation of polar diagrams also changed with changing depth of penetration (e.g. Fig. 5.8).

In *Figs. 5.3, 5.5, 5.7* and *5.9* the 1-D inversions are shown of the effective apparent resistivity and phase curves. From these figures it can also be seen that the majority of telluric measurements were performed in the '*S*' interval both in the case of 1-D and 2-D, even of 3-D models (Figs. 5.3, 5.5 and 5.9). This statement is valid with good approximation for 30 out of the 33 base stations.

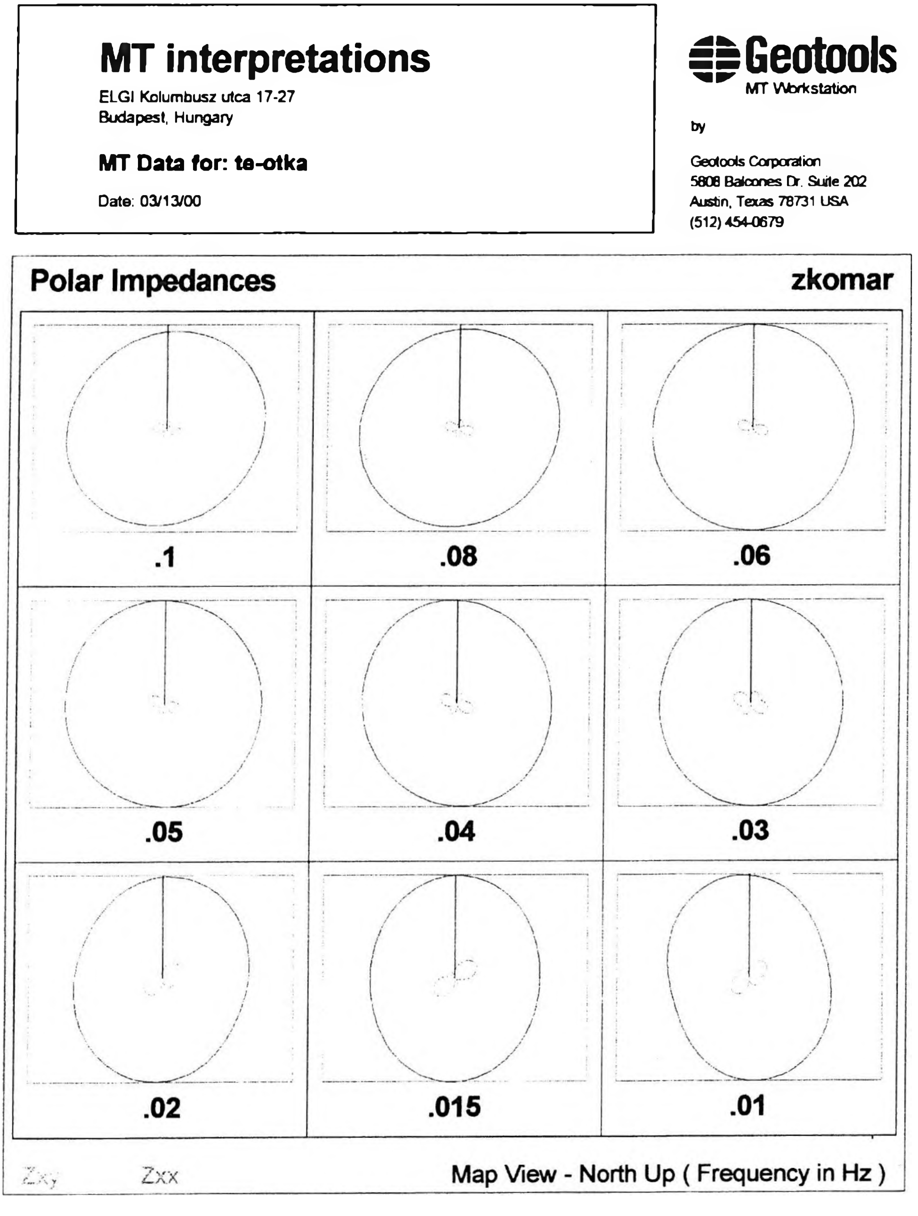


Fig. 5.2. Polar diagrams of the Zalakomár site

5.2. ábra. A zalakomári méréspont polárdiagramjai

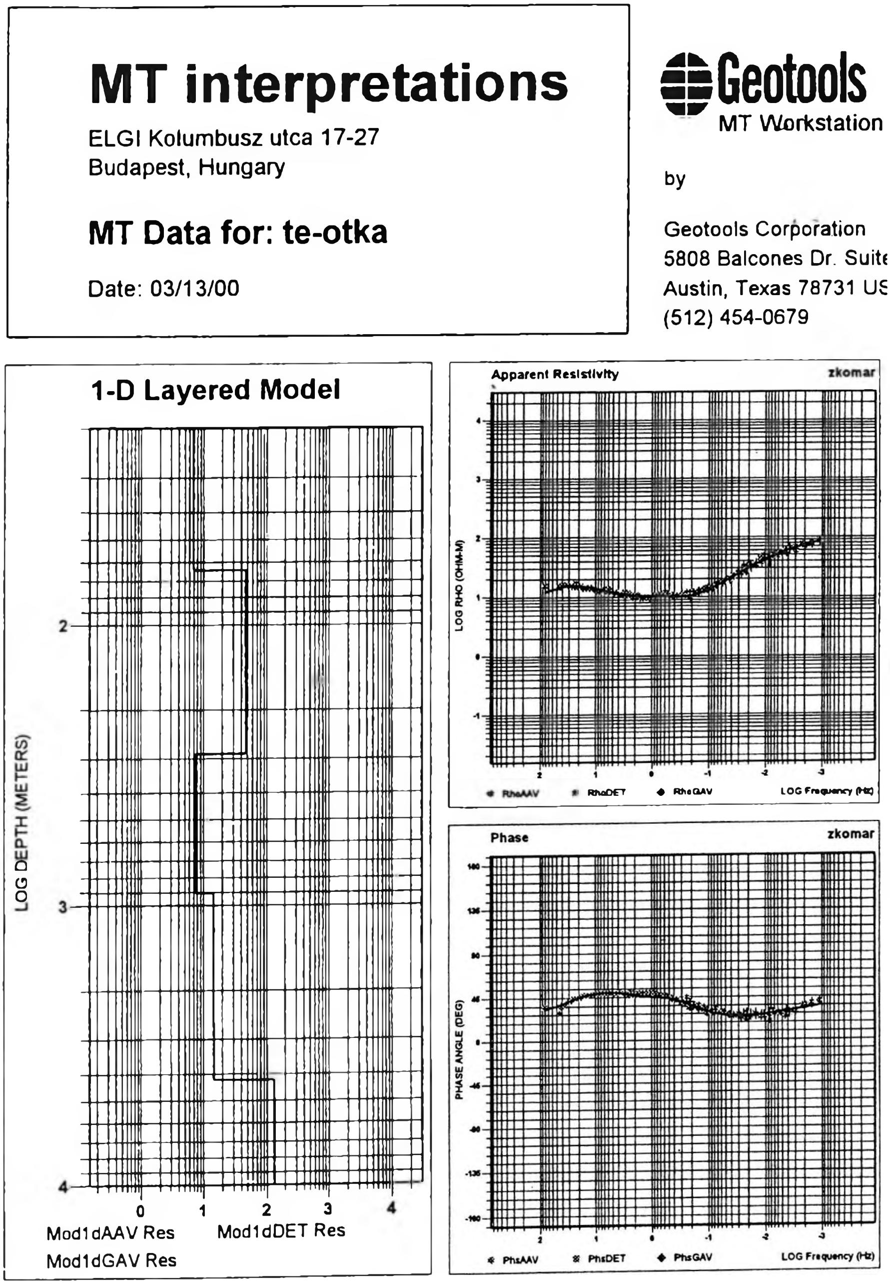


Fig. 5.3. 1-D inversion of the ρ_{eff} curve of the Zalakomár site

5.3. ábra. A zalakomári ρ_{eff} görbe 1-D kiértékelése

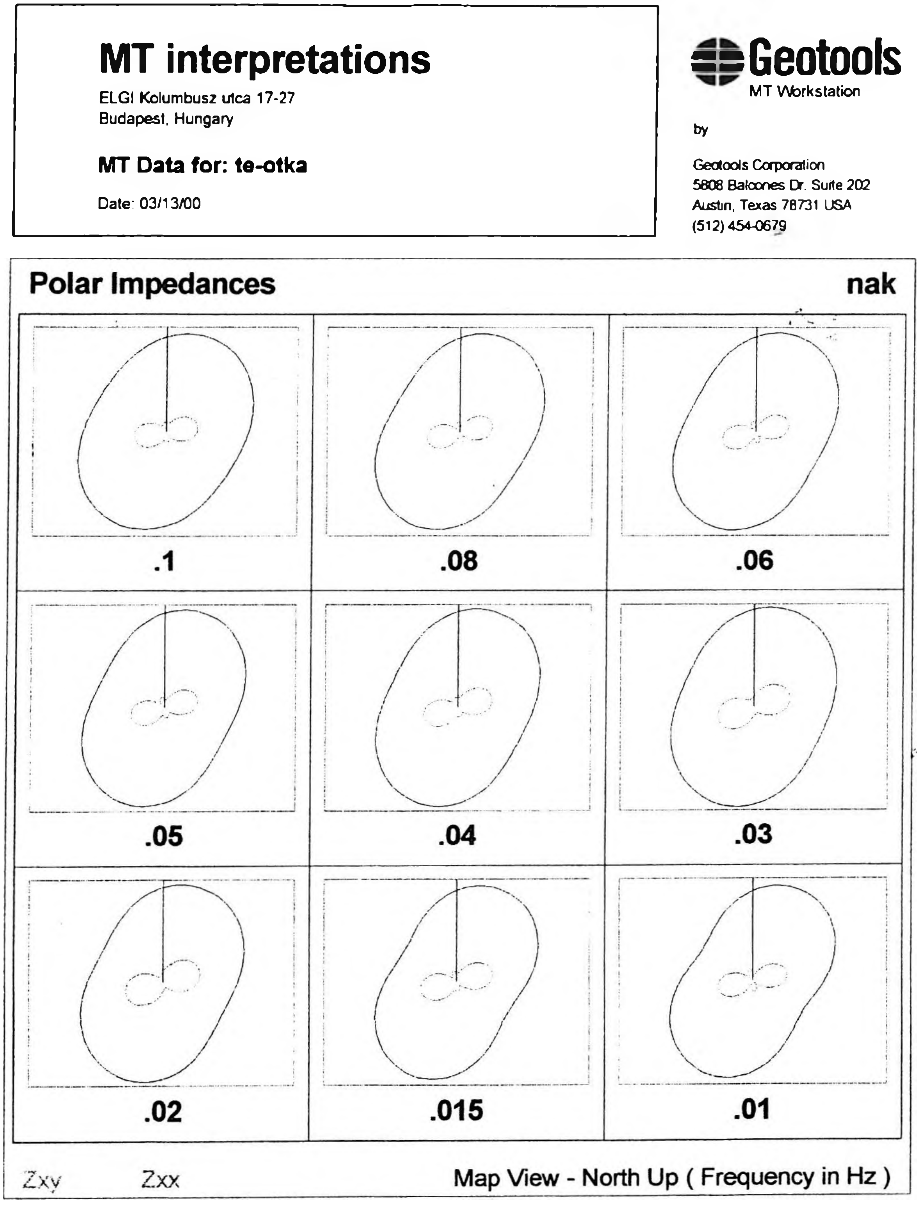


Fig. 5.4. Polar diagrams of the Nak site

5.4. ábra. A naki méréspont polárdiagramjai

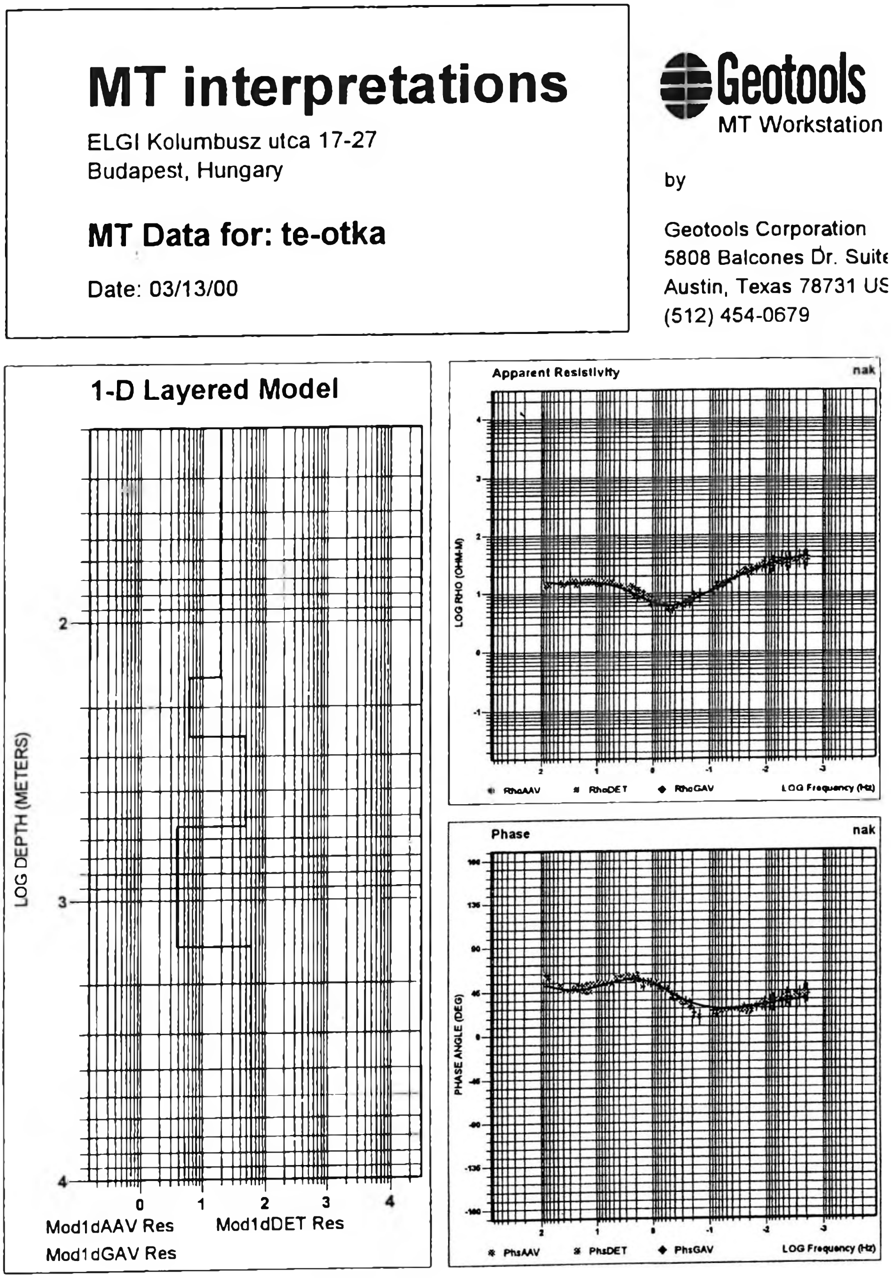


Fig. 5.5. 1-D inversion of the ρ_{eff} curve of the Nak site

5.5. ábra. A naki ρ_{eff} görbe 1-D kiértékelése

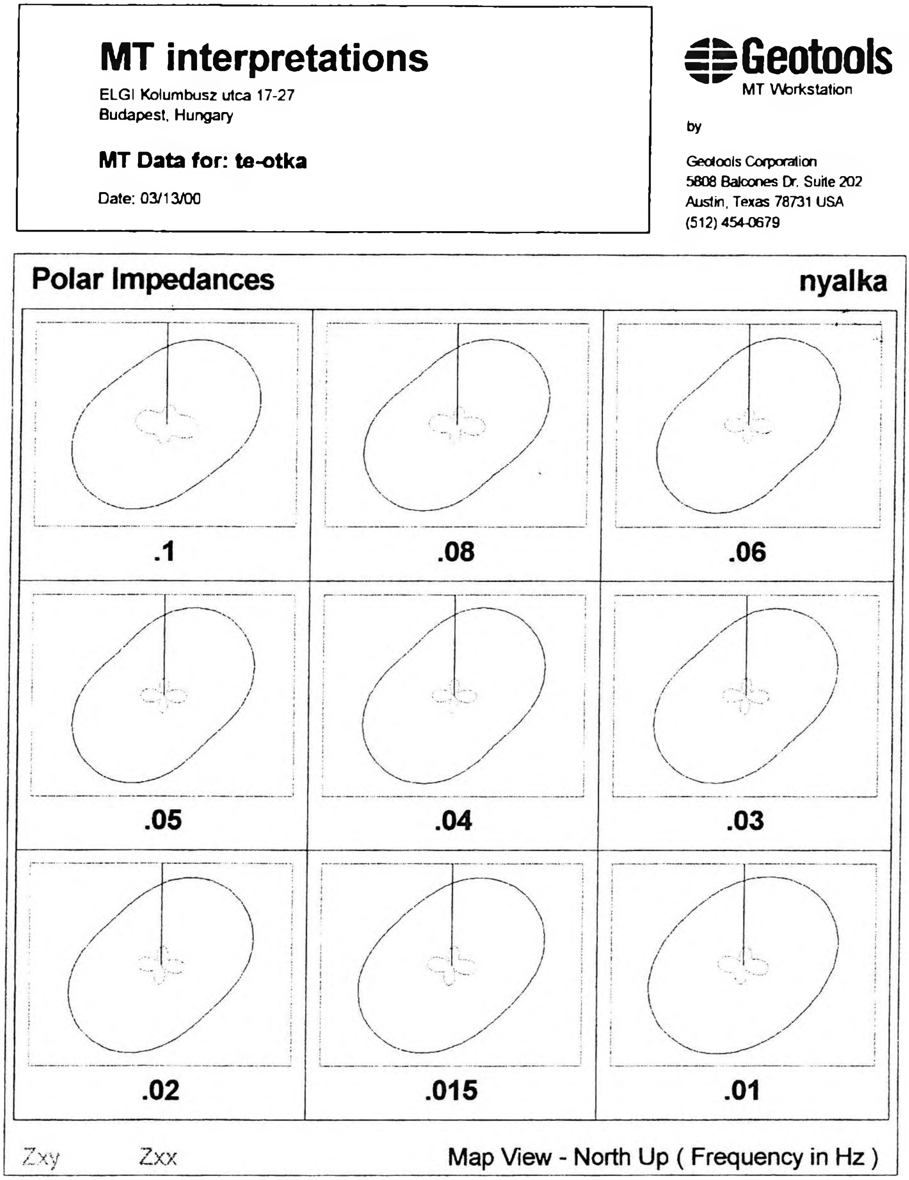


Fig. 5.6. Polar diagrams of the Nyalka site
5.6. ábra. A nyalkai méréspont polárdiagramjai

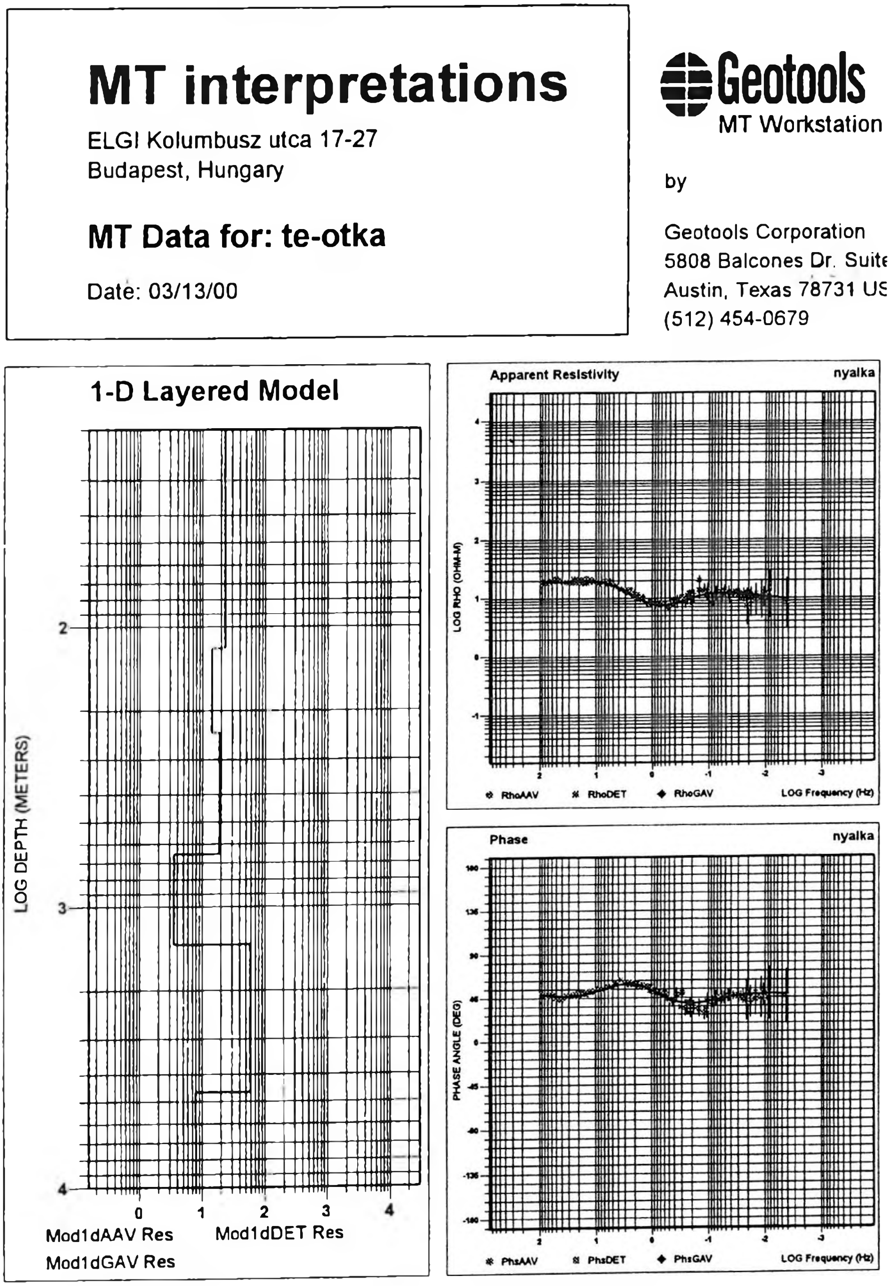


Fig. 5.7. 1-D inversion of the ρ_{eff} curve of the Nyalka site

5.7. ábra. A nyalkai ρ_{eff} görbe 1-D kiértékelése

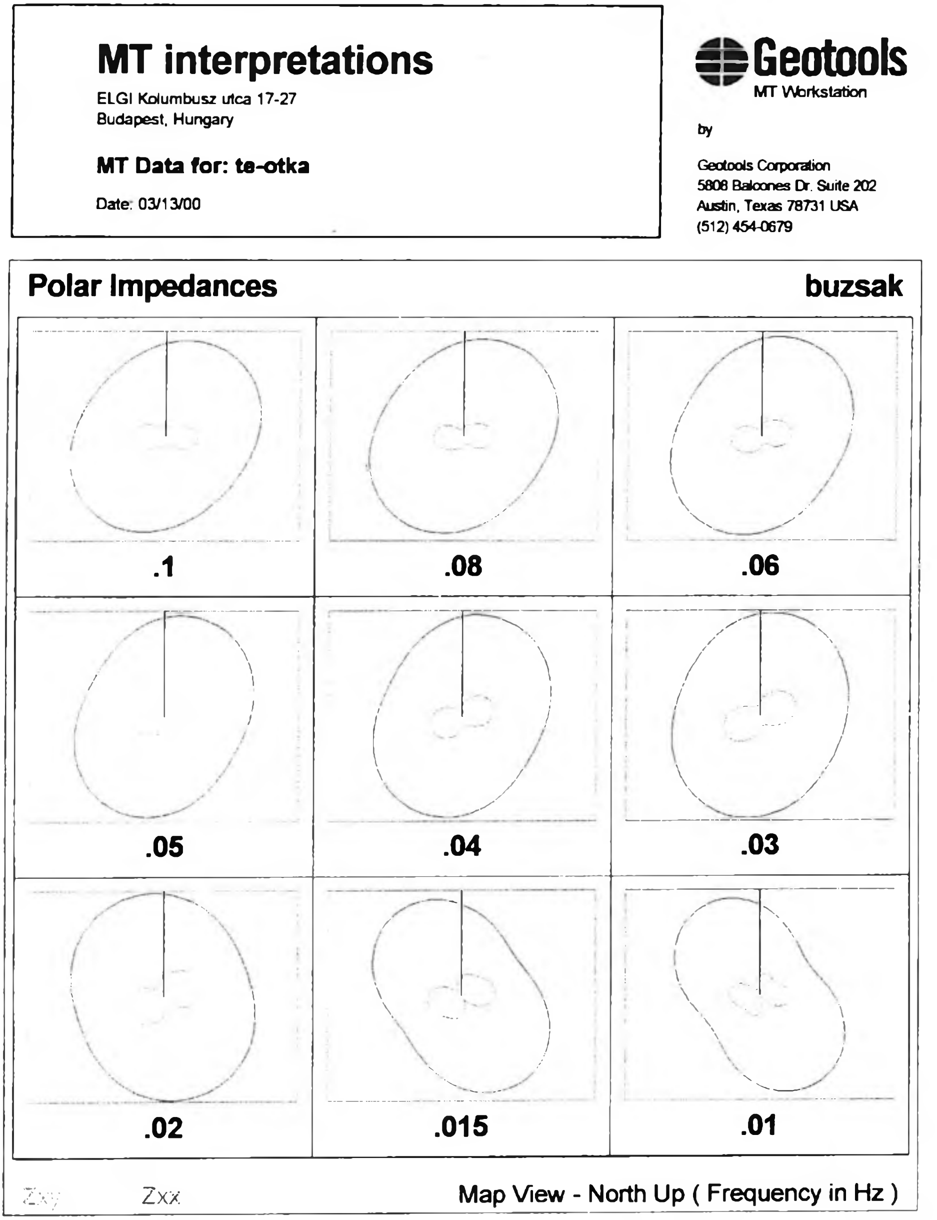


Fig. 5.8. Polar diagrams of the Buzsák site
5.8. ábra. A buzsáki méréspont polárdiagramjai

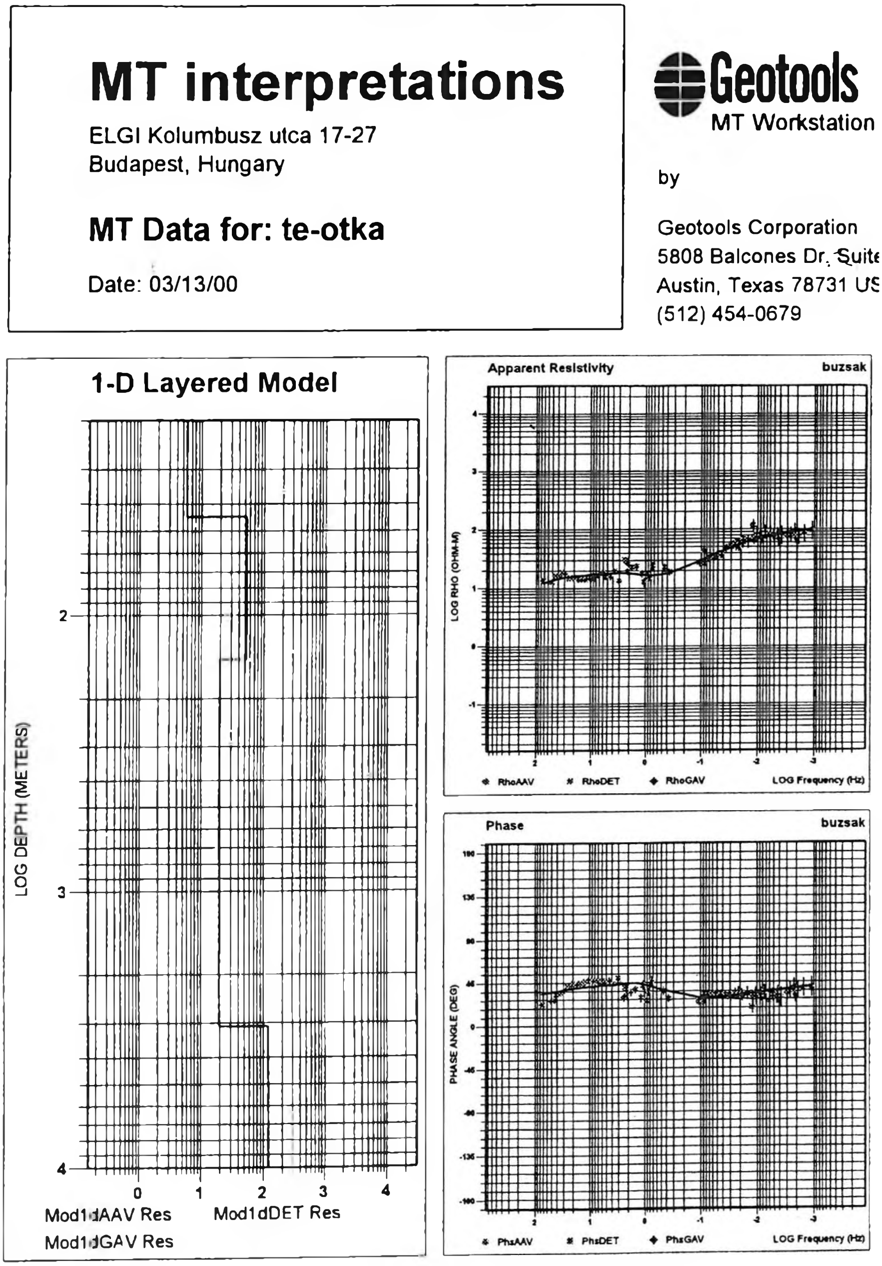


Fig. 5.9. 1-D inversion of the ρ_{eff} curve of the Buzsák site

5.9. ábra. A buzsáki ρ_{eff} görbe 1-D kiértékelése

We have only three base stations where telluric measurements were performed definitely outside the '*S*' interval, these being stations 1, 7, and 23 (shown in Fig. 5.1 and in Table 5.1). As an example the MTS curves of station 1 (Nyalka) are shown in Fig. 5.7. As we will see later, these stations (and this statement is, of course, valid for hundreds of telluric stations measured in their vicinity) lie in geological units which can unambiguously be defined: in the middle of the northern part of Transdanubia (base stations 1 and 7), or on the structural line running south of Lake Balaton (station 23 at Ádánd).

In this way, we have reached the basic objective with the magnetotelluric soundings at the telluric base stations, viz. we determined the effective conductance belonging to the period time of 25 s, i.e. the '*S*' value, and we have thus created the basic conditions for constructing the unified conductance map for 25 s.

In addition, from the magnetotelluric soundings we have obtained a useful guide to the interpretation problems to be discussed later.

5.2. Telluric conductance map

5.2.1. Global interpretation of the map

The telluric conductance map on a scale of 1:500 000, provided as a supplement, shows the distribution of a third physical parameter characterizing half of the country after the reconnaissance gravity and magnetic map series of Hungary (their version in a scale of 1:1 000 000 can also be seen in the supplement).

Taking it into account that the telluric measurements covering this area actually took place in the '*S*' interval or very close to it over the greater part of the area, 'errors' due to the frequency dependence might occur only over smaller, well defined sub-areas. The comment that the map was constructed mainly using pulsations of 20–30 s period time is of consequence primarily in these sub-areas only. If we disregard these critical sub-areas our estimation is that nowhere in the area where measurements were carried out in the '*S*' interval does the average mean error of the map — which comes from measurement and processing errors — exceed the 10% limit. Once the interval between the isolines has been chosen, this was taken as the starting point, but bearing in mind the occasionally occurring measurements yet affected with an error greater than 10% only those anomalies were drawn which were verified at least at 2–3 neighbouring measurement stations.

If we intend to provide an overall evaluation of our map, we must compare it with the earlier constructed gravity and magnetic maps, and with the geological and depth-to-the basement maps of the pre-Tertiary basement, constructed primarily from well data and seismic measurements (see Chapter 3).

At first glance, almost no similarity can be observed with the magnetic map, only rarely considering even the minute details. However, the magnetic anomaly zones of NE–SW, or locally of nearly E–W direction, coincide with the strike direction of the large basins, of the most striking megastructural lines and these directions can also be found in the telluric anomaly map and — as we will see later — they show good correlation with the dominant major axis direction of the anisotropy ellipses.

In most cases volcanites are the sources of the magnetic anomalies in the Carpathian Basin, e.g. Pliocene, mostly effusive basalts on the surface in the NW vicinity of the Lake Balaton, Miocene effusive andesites on the surface in the NE Danube-bend. The wells drilled in the low amplitude, NE–SW oriented anomaly zone south of Lake Balaton also found these latter rocks. POSGAY [1967] interpreted the sources of the magnetic anomalies in southern Transdanubia generally as Palaeozoic volcanites. Basic mantle material which very likely did not reach the surface of the Early Palaeozoic crystalline basement intruded into the crust and according to our interpretation it is responsible for the most pronounced series of magnetic anomalies in North-western Transdanubia (i.e. the Little Plain, Kisalföld).

In this half of Hungary the telluric map is remarkably similar to the Bouguer anomaly map and to the basement depth map as well. The most significant large basins are characterized by the highest anomalies of telluric conductance whereas the basement elevations between them are characterized by conductance lows. Values of conductance (and those of the Bouguer anomaly) are not necessarily proportional to the thickness of sediments because the average resistivity of the sedimentary sequence, and also its density, is variable. In general, it can be said that the resistivity decreases (to 2–5 Ωm) down to a depth of 2000–3000 m in the deep basin and it begins to increase again with depth (up to 10–40 Ωm), mainly if Miocene volcanic and sedimentary sandstone and conglomerate sequences occur.

The result of this phenomenon is that the deepest grabens do not appear as sharp and as high conductance anomalies as might have been obtained based on their depth and in the case of homogeneous sedimentary sequence. This is true in the western part of Southern Transdanubia, in the Drava Valley, and in the deepest part of the Little Plain along the Danube.

In view of all these factors the colour code of the map was chosen to emphasize the basement depth and gravity Bouguer anomaly maps: the conductance highs characteristic of the deep basins are greeny-blue (similarly to the gravity lows representing deepening basins), the relative elevations of the basement are characterized by various shades of brown both in the telluric and gravity maps.

This overall similarity between the maps means that telluric mapping in the area of Transdanubia has in fact come up to the expectations of 40–45 years earlier when this application was launched in this area. Indeed, the map reflects in a general outline, qualitatively the thickness of sediments, the structure of the basement which is of basic importance in hydrocarbon investigation.

In regions of the Carpathian Basin not discussed here, e.g. in the 6–8 km deep sub-basins of the Great Plain, in the Békés Basin, in the Makó Graben and over the basement elevations with a 5–6 km relative depth difference between them, tellurics provided a true image of the thickness, of the extent of the Neogene sediments and of the basement structure even in those cases when basins and basement elevations of several km^2 extension cannot be identified due to the density anomalies within the crust and mantle.

Nowadays, of course, when we know the depth to the pre-Tertiary basement, its structural units, and there are remarkable results even in the resolution of the sedimentary sequence from hundreds of wells and from high resolution seismic measurements between them whose line density reaches in some places a few hundred meters (probably apart from the sub-basins deeper than 3000–4000 m), a telluric conductance map which averages the whole sedimentary sequence would have no real importance.

However, it should be mentioned that numerous items of information can be found in the available telluric measurements in addition to the recent knowledge which cannot be revealed by any other method or, otherwise, geological information can be deduced — primarily concerning the scarcely investigated basement — by comparing the telluric results with the results of other geophysical methods.

Comparison with 'other' geophysical methods meant first of all comparison with quantitative geoelectric methods: in the first half of the 1960s such comparison was with deep direct current dipole equatorial soundings; in the last few decades primarily with magnetotelluric soundings.

5.2.2. Details of the telluric map providing interesting new information

We should like to present those most striking details which call attention to new knowledge or phenomena by means of the conductance anomalies of the pre-Tertiary basement that cannot be detected by other, non-geoelectric geophysical methods.

5.2.2.1. The Drava Basin and Magyarmecske

Intensive geophysical investigation of the southern regions in Transdanubia, complemented with wells and oil industrial objectives dates back to the first half of the 1960s. In this phase of exploration gravity, magnetic, telluric and analogue seismic reflection and refraction measurements were performed. The basement maps based on the first seismic and well data were constructed at that time, together with the map of the depth to the 'geoelectric basement', based on geoelectric measurements: tellurics and direct current dipole soundings. Researchers working in this area discovered already at the end of the 1960s that the 'basement' depth maps constructed from the seismic and geoelectric measurements show systematic deviations. Miklós Kassai, the geologist dealing with this area, perceived that there is a part of the 1000 km^2 extension in the Drava Basin where the 'geoelectric basement' lies systematically deeper [KASSAI 1980]. It turned out from numerous wells — e.g. drilled in the vicinity of Szulok, Kálmáncsa, Darány — and the well-logging measurements performed in them that in this region the pre-Tertiary basement rock is Carboniferous of sedimentary origin; its density and velocity are high, but its resistivity is low. The basement in the wider vicinity is Early Palaeozoic, its density, velocity and resistivity are equally high. The low resistivity of the metamorphic Carboniferous sequence can be attributed to the metaanthracite sequence which consists of many thin beds of 0.1–0.01 Ωm resistivity and 0.8–1 m thickness, and of barren rocks of 60–100 Ωm resistivity and similar thickness between the beds.

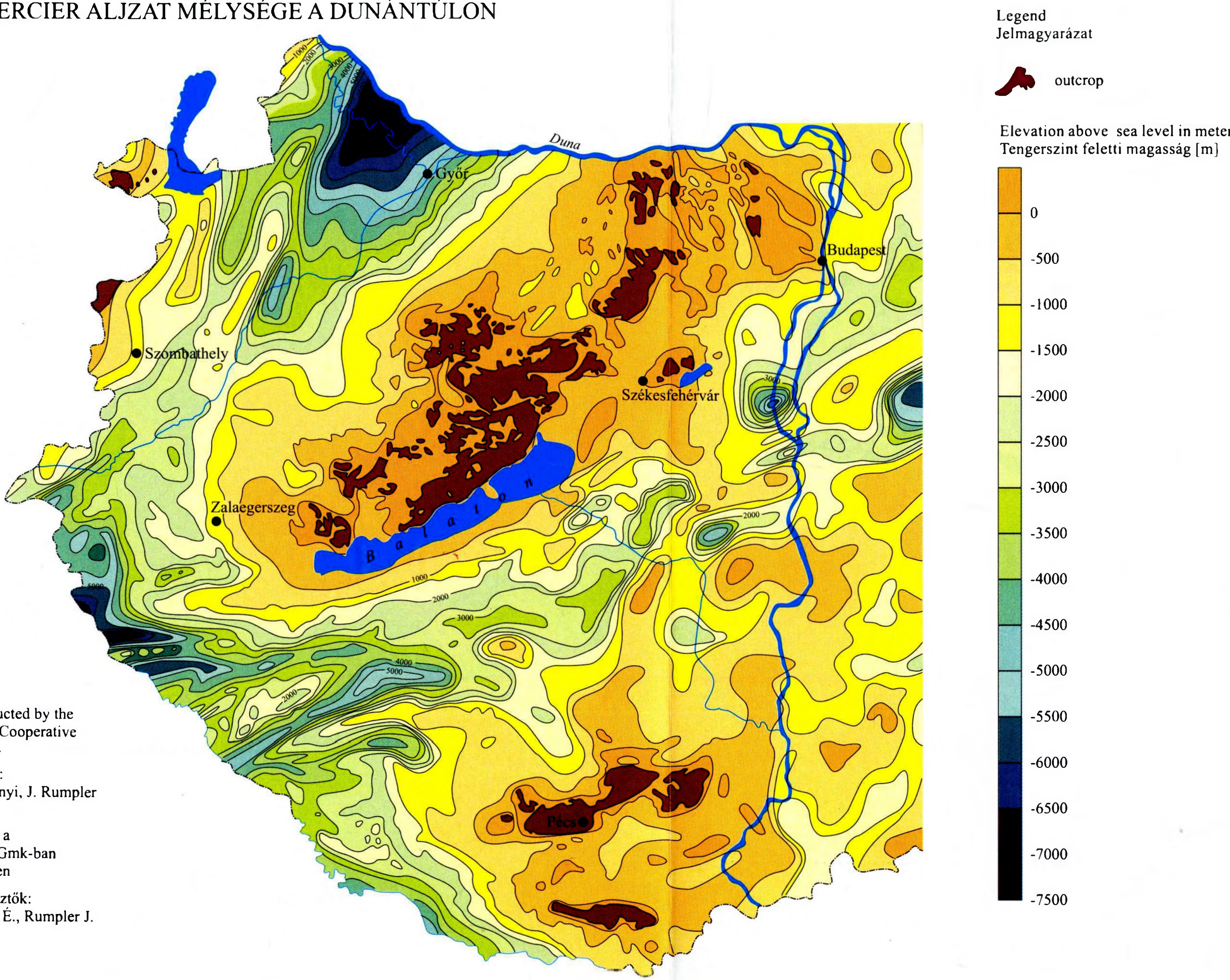
The Magyarmecske anomaly of about 100 km^2 extension can be found in this area of the Carboniferous basement (in the lower left corner of the supplement containing the 1:500 000 scale telluric map, the densely measured area marked with red in the station density map), where the highly carbonized beds are supposedly more frequent and thicker.

The telluric measurements of the 1960s detected the conductance anomaly exceeding 2000 siemens and it was delineated in 1963 using the instrumentation of that time. The deep DC soundings carried out in the telluric anomaly detected the extraordinary deepening of the high resistivity basement but the lateral extension of the anomaly and dimensions of the geometric sounding were roughly equal, therefore an accurate image of the basement could not be obtained. *Figure 5.10* attempts to compare the results of the different geophysical investigations of that time. It can be seen that the gravity Bouguer anomaly is not a bit like the telluric conductance anomaly. Seismic measurements performed here suggested — similarly to the gravity image — that the pre-Tertiary basement evenly ascends from the W to the E. This was verified by the wells hitting the basement at the endpoints of the seismic profile measured along the E–W axis of the telluric anomaly. Along this profile, however, the difference between the depth to the 'seismic' and to the 'geoelectric' basement was as much as 2000 m using the measurement and processing techniques of that time; this difference is by no means negligible at a pre-Tertiary basement depth of 400–600 m. The magnetotelluric results which can be seen in the lowermost part of the figure were obtained with the first product of ELGI's instrument development in the 1970s, from analogue magnetotelluric measurements. Although not even these results can be considered a quantitative solution, they undoubtedly verified that the resistivity of the pre-Tertiary basement is very low in the area of the telluric anomaly, its order of magnitude is 1 Ωm.

According to the seismic refraction measurements marked out for investigating the geoelectric anomaly but not presented here the velocity of the basement decreases from the 6000 m/s of the vicinity to below 5000 m/s in the area of the telluric anomaly. Reflection measurements at the same place show reflections suggesting a funnel-like, deepening basin in the pre-Tertiary basement.

We returned to the study of the Magyarmecske anomaly with geoelectric and seismic methods in the early 1990s, with the much more up to date, more reliable digital instruments of higher resolution and processing technique that had by then become available. *Figure 5.11* shows the 'new' telluric map based on a coverage of about 1 km^2/station together with the abso-

BASEMENT (PRE-TERTIARY) CONTOUR MAP OF TRANSDANUBIA
A PRE-TERCIER ALJZAT MÉLYSÉGE A DUNÁNTÚLON



Constructed by the
GEOS Cooperative
in 1984

Editors:
É. Kilényi, J. Rumpler

Készült a
GEOS Gmk-ban
1984-ben

Szerkesztők:
Kilényi É., Rumpler J.

Fig. 3. 6.
3.6. ábra

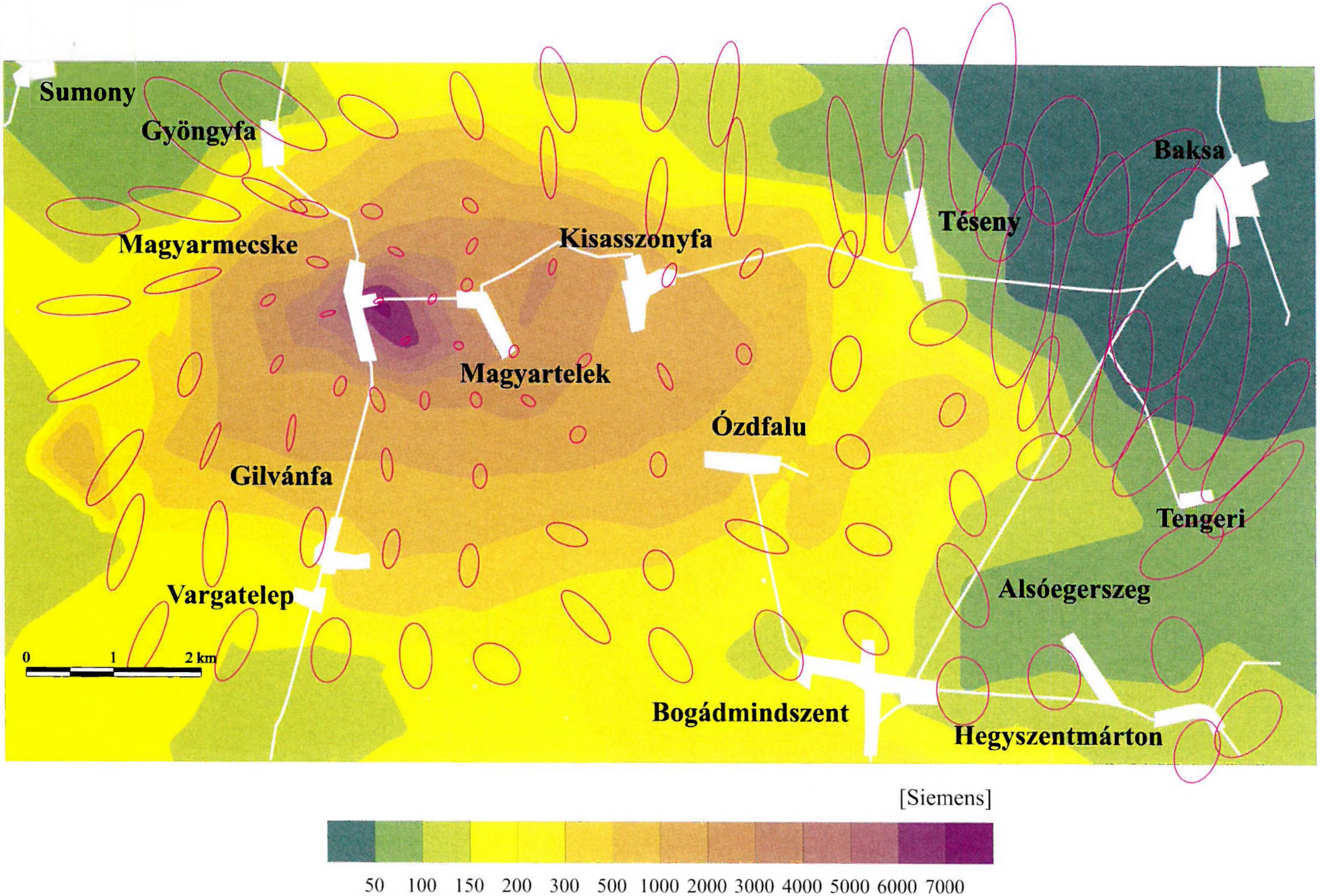
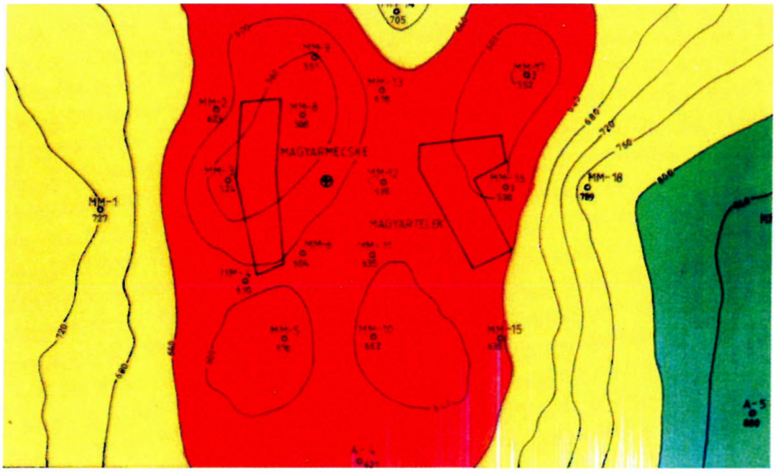
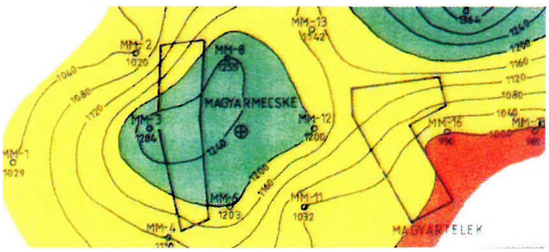


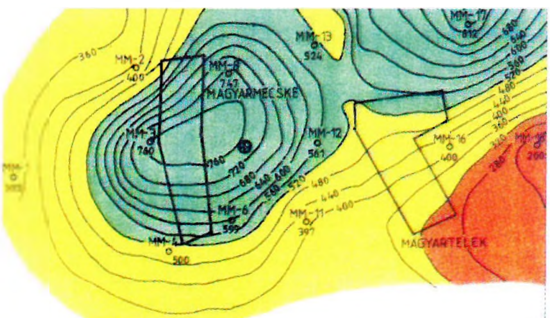
Fig. 5.11. Magyarmecske - Telluric conductance map with the ellipses of anisotropy
5. 11. ábra Magyarmecske - Tellurikus vezetőképesség térkép az anizotrópia-ellipszisekkel



Thickness of the overlying layers
Fedővastagság



Depth to the resistive basement
Feküméylség



Thickness of the Carboniferous formations
A karbon korú összlet vastagsága

Fig 5.12. Carbonaceous Carboniferous sequence at the village of Magyarmecske
5.12. ábra A magyarmecskei karbon korú "széntelepes" összlet

lute ellipses. (Unfortunately, the colour code of this map is not the same as that of the previous figure, or that of the attached map of 1:500 000 scale.) Even so, despite the image having become more accurate than that of three decades earlier, it does not show any substantial difference. The absolute ellipses, on the other hand, make the anomaly extremely expressive. Their size is inversely proportional to the summarized conductance, their orientations show the dominant current direction at each station. The major axes of the ellipses point towards the middle of the almost circular anomaly. It is not a matter of chance that just this is one of the areas where the researchers from Sopron (József Verő, József Závoti) carried out their studies concerning the path of equipotential and current lines (see Chapter 6.3).

The telluric anomaly was investigated with more recent and up-to-date magnetotelluric soundings as well. Based on these we have constructed a series of maps of the anomaly's central part of about 4–5 km^2, in the vicinity of Magyarmecske and Magyartelek (see *Fig. 5.12*). This figure shows a map of the thickness of cover overlying the Carboniferous sequence, supposedly containing coal beds, a map of the depth to the layer underlying it; and the thickness map of the coal bed sequence of low resistivity. However, the three maps do not reflect the fact that the resistivity of the Carboniferous sequence is highly variable.

It is pointed out that the resistivity of the Carboniferous sequence, confirmed by resistivity logs of wells, reaches 60 Ωm in the eastern half of the telluric anomaly of 100 km^2 extension. The resistivity of the Carboniferous sequence presumably depends on the ratio of otherwise 60–80 cm thick metaanthracite beds within the sequence.

Based on our present knowledge we cannot overcome the distortions caused by the 3-D structure and the problems of equivalence, i.e. we are aware of the limits of the reliability of the results. The thickness of the overlying layer is, however, unambiguous from seismic measurements as well and also the unusually low resistivity of the pre-Tertiary basement, especially in the western half of the anomaly. It should be checked with a borehole whether this anomaly — consistently with the assumptions — indicates promising, high quality coal, or a less valuable graphitic sequence or something else. In any case, the geologic log, geophysical logs and cores of the Bogádmindszent–1 well which can be found at the southeastern edge of the anomaly detected the extremely low resistivity metaanthracite sequence at a depth of 1200 m and of an overall thickness of hardly 20 m, and based on this we assume that at Magyarmecske, where this low resistivity sequence lies directly below the Neogene, its thickness might approximate 1000 m and the source of the anomaly is also a metaanthracite sequence.

5.2.2.2. The telluric anomaly of Zselic

This portion of the telluric map (see the attached 1:500 000 scale telluric map) is in the middle of the half lying south of Lake Balaton, south of Kaposvár–Dombóvár. It has already attracted attention based on the telluric data available for more than 20 years that tellurics provided an anomaly pattern different from any other method. Results of the comparison are shown along the profile Zse–1 of N–S direction (*Fig. 5.13*).

In the middle of the telluric profile, two local minima are separated by a relative maximum. Probably this latter is an element which can be recognized in the geomagnetic profile, too, with some northward shift (this is a natural phenomenon in the northern hemisphere). The gravity Bouguer anomaly, however, shows something quite different from the previous ones: from '0' km till 8.0 km monotonically increasing Δg values can be seen, then from there southwards the values slightly decrease. The structure and the thickness of the low average velocity seismic sequences correlate well with the gravity pattern. The relative telluric minima can also be recognized in the analogue refraction seismic image of the (lowermost) sequences of 5 km/s velocity. Finally, in the lowermost part of the figure we present a (2-D) gravity model all elements of which can be found in the magnetic, telluric and seismic images. The density data of the assumed polygons, which can be defined primarily by seismic average velocities, were changed until the calculated Bouguer effect and the measured anomaly showed the acceptable agreement demonstrated in the figure.

The results can be interpreted in such a way that the gravity image also correctly reflects the structure of the pre-Tertiary basement and the seismic horizon of 4.0 km/s velocity describes it qualitatively. Around the 4.0 km picket of the profile there is a volcanite causing a magnetic anomaly. The pre-Tertiary basement is generally represented in this region by Triassic carbonate formations which were found in the Gfa–1 well drilled at the southern edge of the profile, too. As a means of summarizing the phenomena the map series (*Fig. 5.14*) based on the most recent documents should be compared with each other. The red colour in the geologic map of the basement indicates Early Palaeozoic crystalline basement in the north, at Kaposvár and in the south as well. The telluric conductance anomaly can be found in the middle part, in the zone of the 500–1000 m deep Mesozoic,

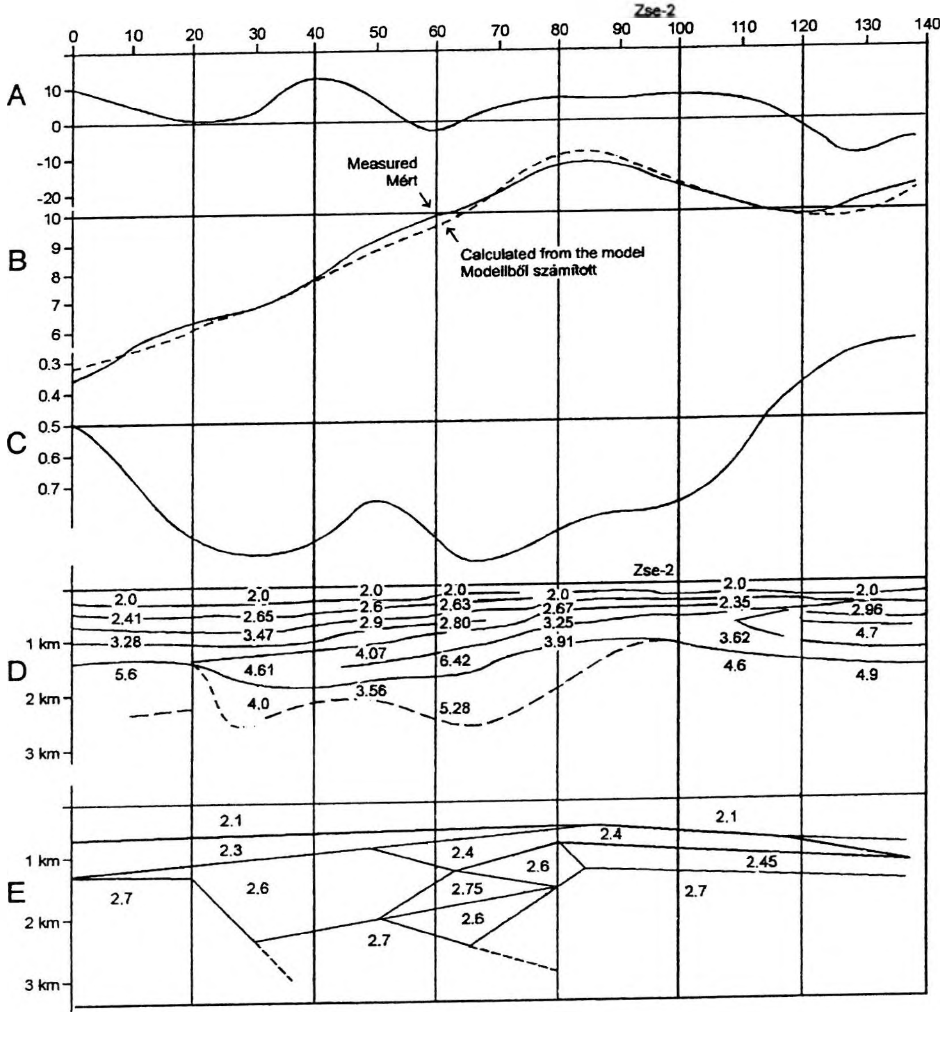


Fig. 5.13. Integrated geophysical profile across the Zselic anomaly
A—magnetic profile, B—gravity profile, C—telluric profile, D—seismic profile (interval velocities in km/s), E—gravity density model (densities in t/m^3)

5.13. ábra. Komplex geofizikai szelvény a Zselici anomálián
A—mágneses, B—gravitációs, C—tellurikus, D—szeizmikus (intervallum sebességek km/s-ban), E—gravitációs sűrűség modell (sűrűségek t/m^3-ben)

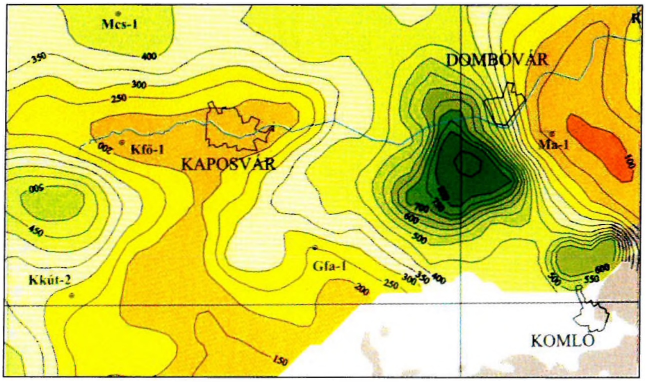
Triassic basement. The source of this should be sought for in any case in a region below the surface of the basement (at a depth of at least 2–3 km). Possibly it is caused by Late Palaeozoic sediments — perhaps similar to those at Magyarmecske, Carboniferous metaanthracite — or perhaps other formations, or maybe we have encountered conductance anomalies associated with fracture zones. The last of these may be the case because both in the western and southern directions from this Zselic region the absolute value of telluric conductance anomalies is higher even in a more than 10 km long zone than could be explained based on the depth to basement and the resistivity of the sedimentary sequence overlying the basement.

5.2.2.3. Telluric anomalies in the Paks–Tolna region

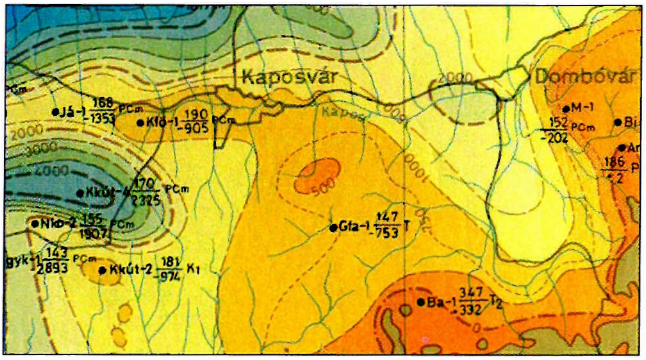
The portion of the telluric map around Paks is in the middle of southern Transdanubia, in an area partly extending across the Danube.

If this is qualitatively compared with the Bouguer gravity map, with the seismic sections measured in this region or with the geological and depth maps of the pre-Tertiary basement (*Fig. 5.15*) which are in agreement with them, then we can probably find many similarities at first sight. Only after a more careful investigation does it turn out that in the sub-basin south of the structural line that can be drawn perpendicularly to the Danube and east of the Komló–Dombóvár–Tamási basement ridge such conductance values can be observed which are generally characteristic of 2–3 km deep parts of basins in Transdanubia, but here the depth to the pre-Tertiary basement is significantly smaller (500–1000 m).

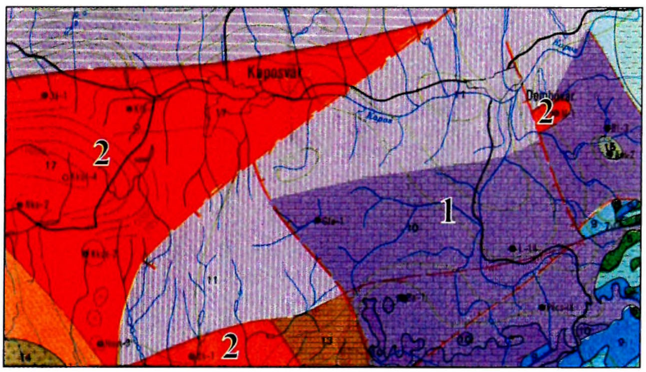
To investigate the anomaly we carried out magnetotelluric measurements at 8 sites. From this series an amplitude and a phase curve and their 1-D inversion are shown in *Fig. 5.16*. The depth to the 'basement' the resistivity of which is much higher than the overlying layers of 5–20 Ωm resistivity varies between 1300 and 2100 m. The depth data obtained at the eight magnetotelluric sites can be seen in *Fig. 5.17*. If these are compared to the depth to the basement it can be stated that the 'geoelectric basement' is about 1000 m deeper than the data of 500–1500 m plotted here. We might assume that in addition to the lack of wells penetrating the basement we have encountered the intrinsic error of basement depth based on relatively few quantitative measurements. In any case, seismic measurements on the Danube performed by the Geophysical Department of Eötvös Loránd University verified the correctness of the basement depth map there. After all, we think it more likely that similarly to the Magyarmecske region the resis-



Telluric conductivity map
Tellurikus vezetőképesség térkép

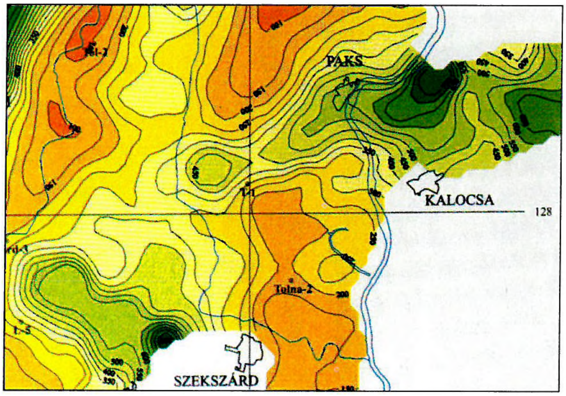


Contour map of the pre-Tertiary basement
A pre-tercier aljzat mélységtérképe

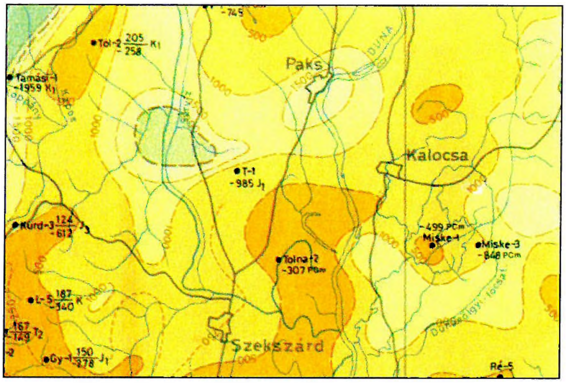


Formations in the pre-Tertiary basement
1-Mesozoic carbonate, 2-Palaeozic crystalline
A pre-tercier aljzat képződményei
1-Mezozoos karbonátos, 2-Paleozoos kristályos

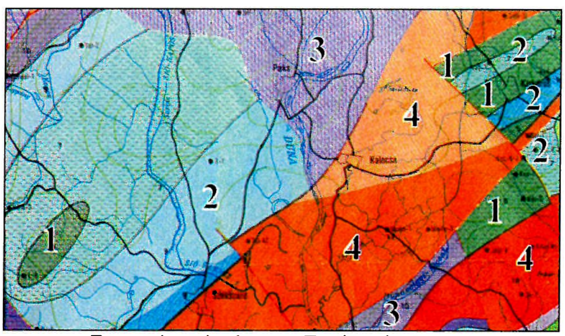
Fig. 5.14. Maps from the Zselic region
5.14. ábra Zselic térképei



Telluric conductivity map
Tellurikus vezetőképesség térkép



Contour map of the pre-Tertiary basement
A pre-tercier aljzat mélységtérképe



Formations in the pre-Tertiary basement
1-Cretaceous, 2-Jurassic, 3-Mesozoic, 4-Palaeozoic
A pre-tercier aljzat képződményei
1-Kréta, 2-Jura, 3-Mezozoos, 4-Palezoos

Fig. 5.15. Maps of the Paks-Tolna region
5.15.ábra Paks-Tolna térségének térképei

MT interpretations

ELGI Kolumbusz utca 17-27
Budapest, Hungary

MT Data for: BASE stations

Date: April, 1997

Geotools
MT Workstation

by

Geotools Corporation
5808 Balcones Dr. Suite
Austin, Texas 78731 US
(512) 454-0679

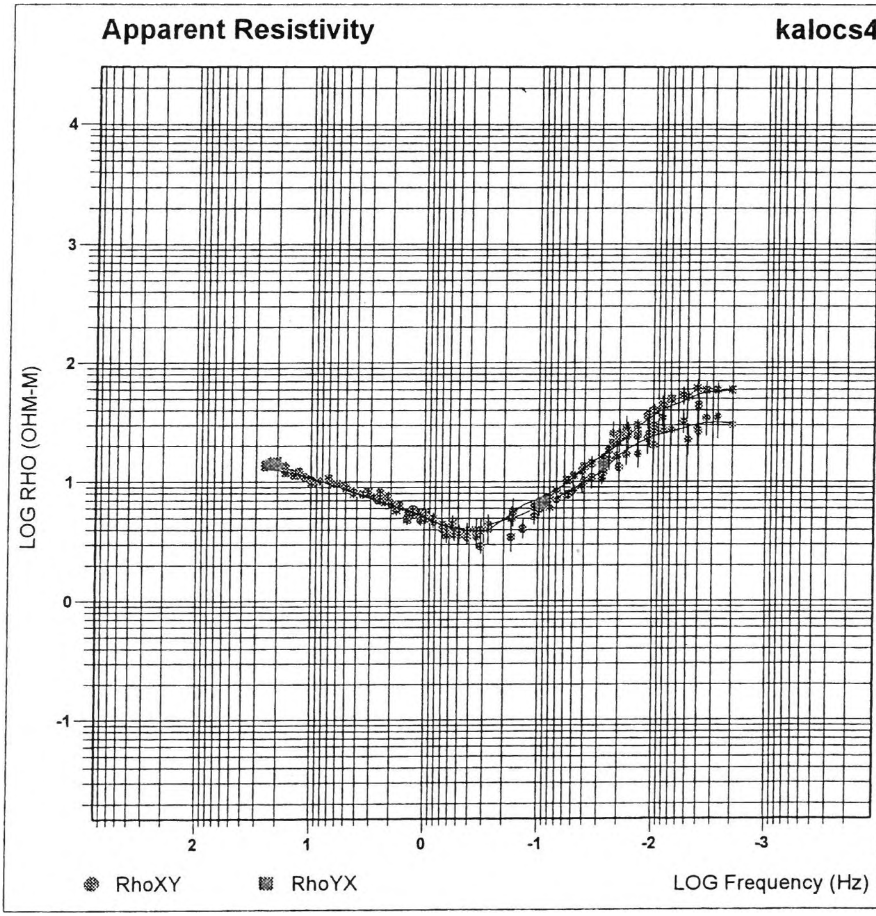


Fig. 5.16. Resistivity curves of the Kalocsa site
5.16. ábra. A kalocsai méréspont ellenállás görbéi

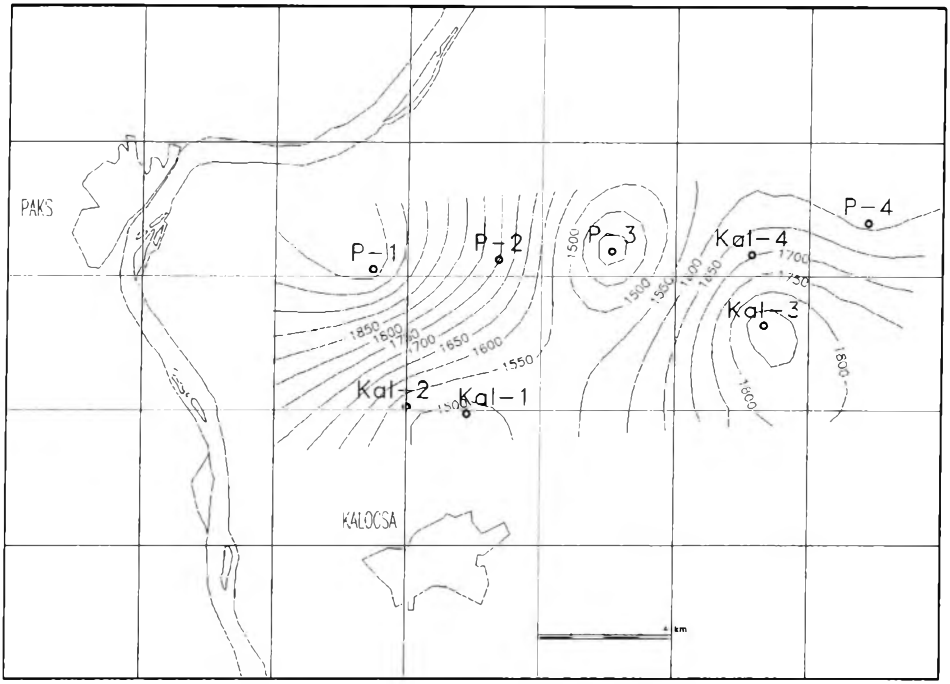


Fig. 5.17. Depth to the 'geoelctric basement' in the Paks–Kalocsa region
5.17. ábra. A "geoelektromos aljzat" mélysége Paks–Kalocsa vidékén

tivity of the basement directly underlying the Tertiary sediments is low in the vicinity of Paks and Kalocsa, too. We have no possibility for geological interpretation of the phenomenon due to the lack of wells. We would mention, however, that our experience gained east of the Danube is that in spite of the relatively high density and seismic velocity of the Late Cretaceous sediments belonging to the pre-Tertiary basement their resistivity is low (about 10 Ωm). If we look at the portion of the basement quality map in Fig. 5.15 it turns out that geologists assumed Early Palaeozoic basement marked with red at the anticline structure of 500 m depth, but at our magnetotelluric sites hardly 5 km of this, east of the structure already Cretaceous is assumed (green colour). If we assume that extension of the Cretaceous is wider westward, we have obtained a plausible explanation. The telluric anomalies not harmonizing with the basement depth might, of course, be due to other causes as well. Moreover it is not beyond the bounds of possibility that at the foot of the Komló–Dombóvár–Tamási ridge, at the western border of the anomaly zone the reason for the high conductance might be, in addition to the above listed ones, a conductance anomaly associated with a structure, a fracture zone as well.

5.2.2.4. The telluric anomaly at Nagygörbő (*Fig. 5.18*)

Nagygörbő can be found in the western continuation of the Transdanubian Central Range (in the area marked with a green rectangle in the station density map of the supplement), in a small basin of a few km diameter with outcrops of Pannonian (Pliocene) basalts, where the Nagygörbő–1 well reached the Cretaceous basement at a depth of 1164 m below sea level. The

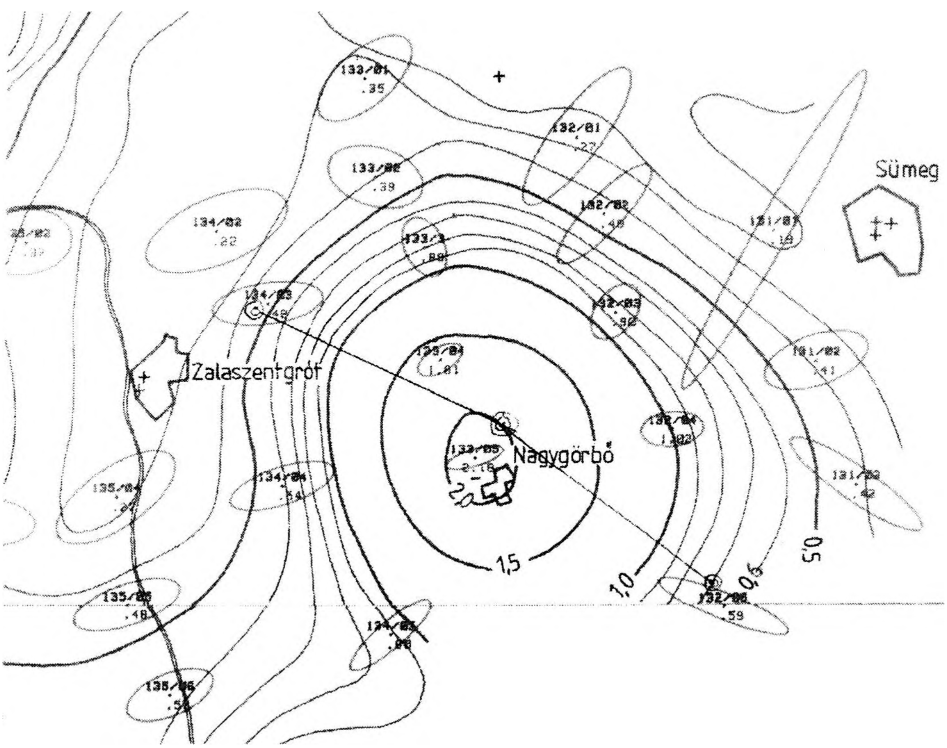
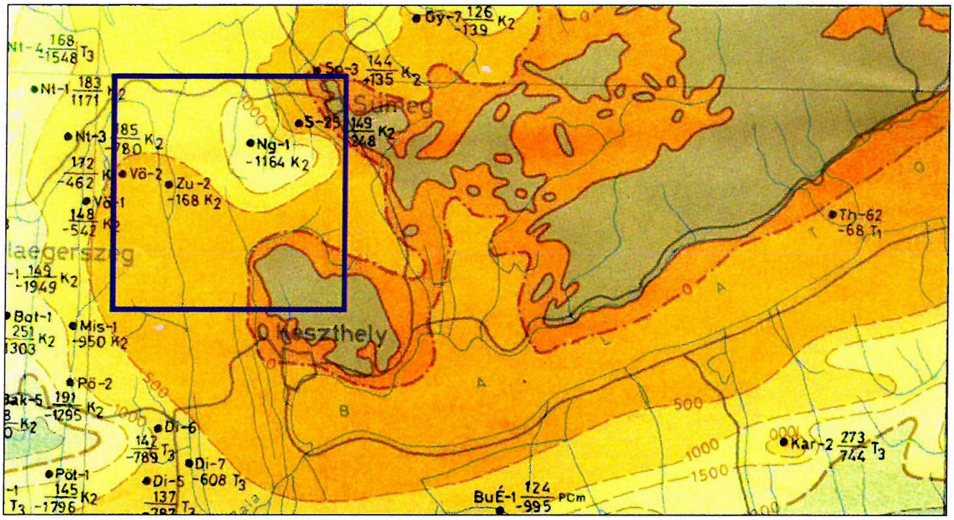


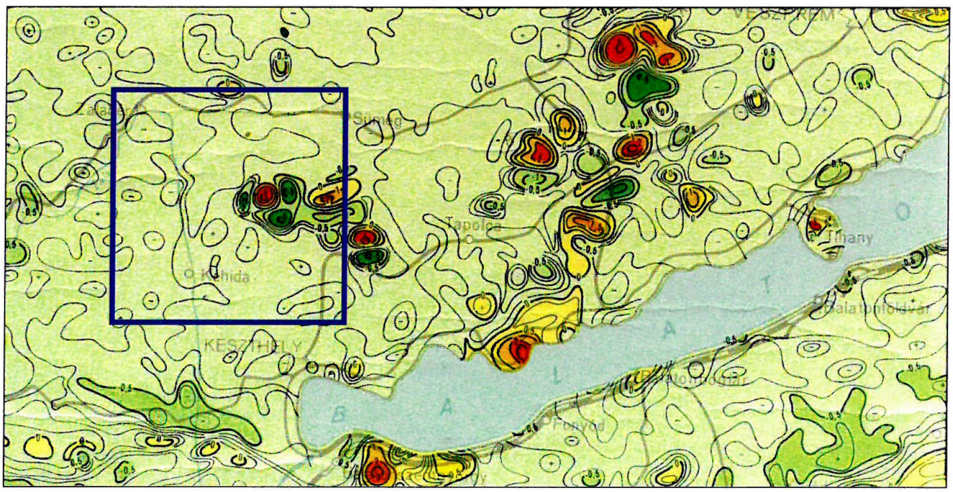
Fig. 5.18. Telluric isoarea map with the anisotropy ellipses for the surroundings of Nagygörbő (132/03 is the location of the measuring point, .22 is the telluric relative A^{-1})
5.18. ábra. Nagygörbő környékének tellurikus izoarea térképe az anizotrópia ellipszisekkel (132/03 a méréspont helye, .22 a tellurikus relatív A^{-1} érték).

basalts which can be found on the surface cause characteristic magnetic anomalies (*Fig. 5.19*). A circular telluric conductance anomaly appears in the telluric map, its value is unexpectedly high compared to this depth and it is particularly expressively indicated by the anisotropy ellipses (Fig. 5.18). Similarly to the previously discussed cases, the absolute value of the anomaly is characteristic of the conductance of much deeper basins.

We have investigated this anomaly of about 10 km diameter at three sites with magnetotelluric soundings: in the middle of the anomaly and at the two edges, approximately along a NW–SE oriented profile. We could approximate the obviously 3-D structure with 2-D inversion. Measuring the H_z component we were able to determine the tipper at each station, with the help of this we were able to decide which is the local *E* and *H* polarization direction. 2-D inversion was performed with the WinGlink program package and the result shown in *Fig. 5.20* was obtained. In the upper part of the figure the *E* polarization (TE mode) and *H* polarization (TM mode) magnetotelluric curve pairs can be seen. The measured sounding curves are plotted with dots and their 2-D approximation with a continuous line based on the model which is plotted at the lower part of the figure down to a depth of 12 000 m. At the upper 1000 m interval of the model the low resistivity Neogene basin can be perceived. Below this in the pre-Tertiary basement, but not directly at its surface there is a prismatic body of relatively small dimensions and low resistivity, downward from 3500 m. From 1-D interpretation of magnetotelluric soundings this anomaly image can be interpreted qualitatively only. The well at Nagygörbő did not hit this low resistivity body within the basement. In the interpretation of the anomaly, however, the fact cannot be neglected that basalts erupted to the surface here. The magnetic anomaly pattern may very likely be explained by this fact. The basalt of generally 60–80 Ωm resistivity cannot alone cause a conductance anomaly because its conductivity is slightly lower than that of the Pliocene–Quaternary sediments that can be found in this depth interval in other parts of the basin. As an explanation for the conductance anomaly it can be assumed that volcanism might either have resulted in mineralization, or the intruding lava metamorphosed the organic material in the older sediments and thereby gave rise to graphite. ÁDÁM and VERŐ [1964] also observed similar definite connections (basalt hill and conductance anomaly) some decades ago, e.g. at the Pliocene basalt cone of Somló Hill, about 30–35 km NNW of Nagygörbő, also associated with a magnetic anomaly. ÁDÁM et al. [1977] attributes the conductance anomalies detected in the basement of



Contour map of the pre-Tertiary basement
A pre-tercier aljzat mélységtérképe



Magnetic anomaly map
Földmágneses anomália térkép

The Nagygörbő region
Nagygörbő térsége

Fig.5.19. Maps from the surroundings
of the village Nagygörbő
5.19. ábra Nagygörbő térségének térképei

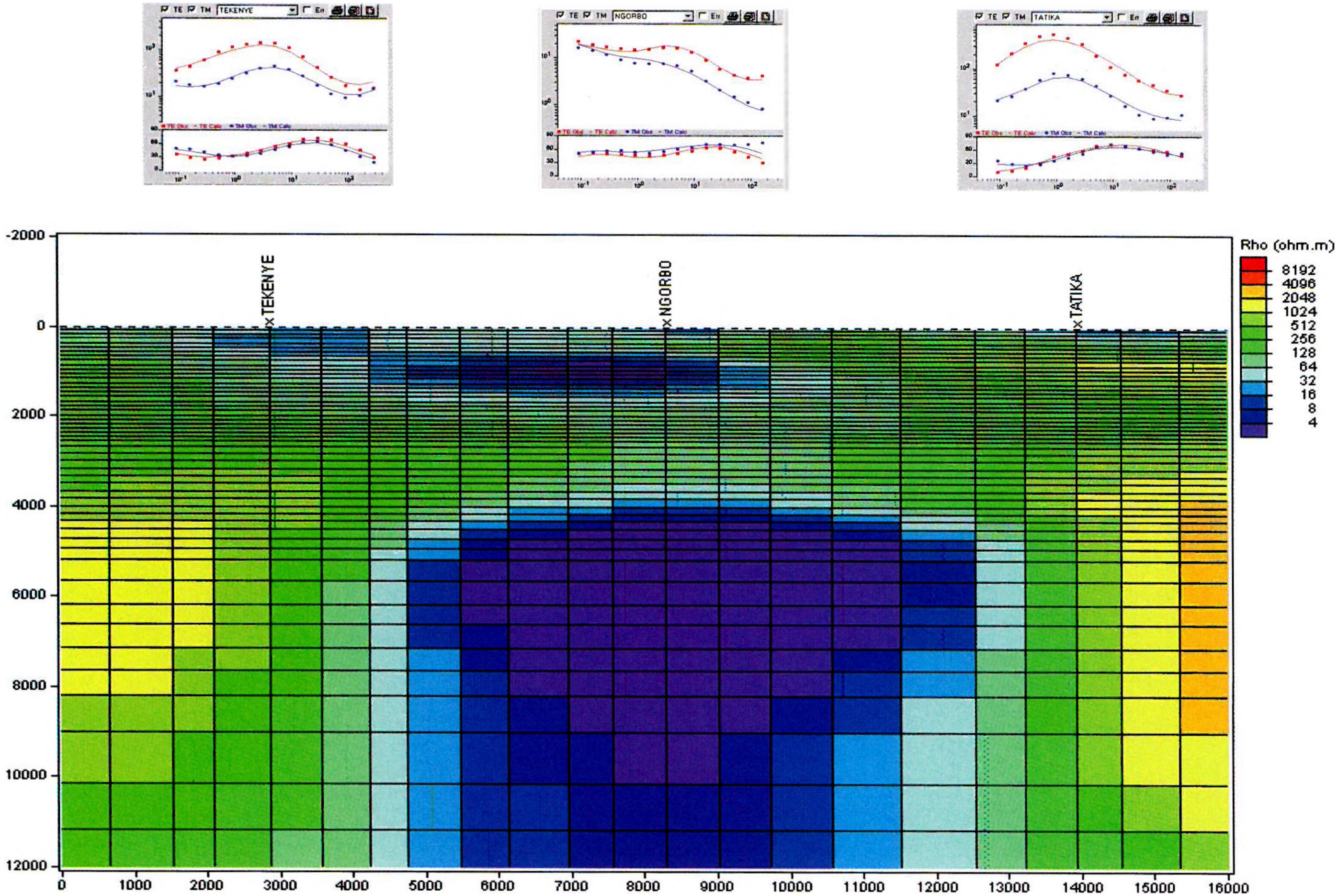


Fig. 5.20. Results of the 2D inversion of MT soundings at Nagygörbő (red - TE mode, blue - TM mode)
5. 20. ábra Nagygörbő, 2D MT inverzió (piros - E-polarizáció, kék - H-polarizáció)

the Transdanubian Central Range to graphite and assumes that the source of the anomaly of several thousand km^2 extension is actually many small dikes, many small pin-like bodies that are electrical conductors.

5.2.2.5. Global evaluation of the Kisalföld's telluric map

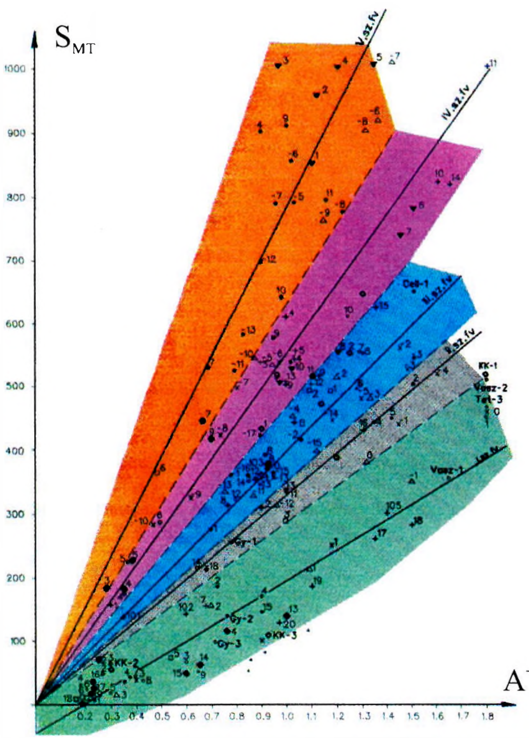
In 1994 we summarized the geophysical surveys performed in the Kisalföld (Little Plain, NW third of our map) in Volume 39 of Geophysical Transactions. On pages 193–223 of this publication, in the chapter entitled *Investigation of the Kisalföld's basement and crustal structure in ELGI between 1982 and 1990* [NEMESI et al. 1994] telluric and magnetotelluric results got a fairly big role. Rather than repeat the detailed results published there, we summarize here the ones that are important from the viewpoint of telluric investigations.

a) First of all, it should be emphasized that relative depressions and elevations of the Tertiary basin's basement known from wells, seismic measurements down to a depth of 3–4 km can be well perceived in the telluric map (either in the relative isoarea map published in 1994, or in the absolute conductance map calculated from that and published here).

b) The relationship between the telluric conductance and depth to the basement changes between sub-areas. More precisely, it is noteworthy that in the NW half of this basin, where lower east-alpine Palaeozoic crystalline rocks represent the pre-Tertiary basement, the relationship is linear within the measurement error; on the other hand, SE of the Rába megastructural line, where Mesozoic formations of the upper east-alpine nappe build up the pre-Tertiary basement, the worse the connection between the telluric conductance and depth to the basement the smaller the thickness of the low resistivity sediments overlying the basement. We know from magnetotelluric soundings that there are low resistivity formations of unknown age and rock material south of the Rába line at a depth of 4–8 km within the basement (below the high resistivity, Mesozoic carbonates). The conductance of these plays an ever increasing role in the summarized conductance calculated from oscillations of 20–30 s period time when the Tertiary, Quaternary sediments become thinner. Magnetotelluric soundings provided essential help in interpreting the telluric map; although they were measured at an order of magnitude fewer sites, the profiles provided comprehensive information on the basin. By means of 1-D interpretation of magnetotelluric soundings we determined, among other phenomena, the summarized conductance of the 0.5–8 km thick Tertiary, Quaternary sequence (S_{MT}) as well. After that, we studied its connection with the 'telluric relative conductance' (A^{-1}). The result can be seen in *Fig. 5.21*. In an ideal case — low resistivity sediments, basement of infinitely high resistivity, pulsation of suitable penetration depth — the connection between the two parameters would be a line of 45°. However, in spite of the large scattering of points regularities can be recognized. One of the most important of them is that in strips parallel with the Rába line, in fairly well definable basement depth intervals the connection is close to linear. As can be seen in the figure, five different lines averaging the points were determined for the telluric–magnetotelluric value pairs, their area of validity can also be seen in the relevant portion of the map. On summarizing the results one can draw several conclusions:

- Probably the most significant is that at the SE edge of the Kisalföld Basin the conductance within the basement is so significant that its role in the telluric map reaches — and in some places exceeds — that of young sediments; however, it seems that this deep effect is an almost constant addition to the conductance of sediments and therefore changes in resistivity can primarily be attributed to changes in the thickness of sediments even in this area.
- Only in this region of the whole of Transdanubia have we experienced that in the 6–8 km deep basin the oscillations of 20–30 s period time do not reach the basement. This sub-basin along the Danube is characterized by function V (Fig. 5.21) being steeper than 45°.
- The blue colours in the NW part of the basin suggest that the resistivity of the Palaeozoic basement is not infinitely high, but only 40–80 Ωm and, primarily in the sub-basins that are less deep, the electromagnetic waves of 20–30 s recognize the non negligible significant conductance of the basement as well. It is, however, true here too, that the dominant reason for changes in conductance should be sought for in the sediments.

Our method of constructing the basement depth map was based on telluric and magnetotelluric measurements; this is of importance first of all if the amount of seismic measurements and wells is still small in a given sub-basin. The area south of Lake Balaton was such and when the country's basement depth map was constructed this portion of the map was elaborated based on geoelectric measurements as described below.



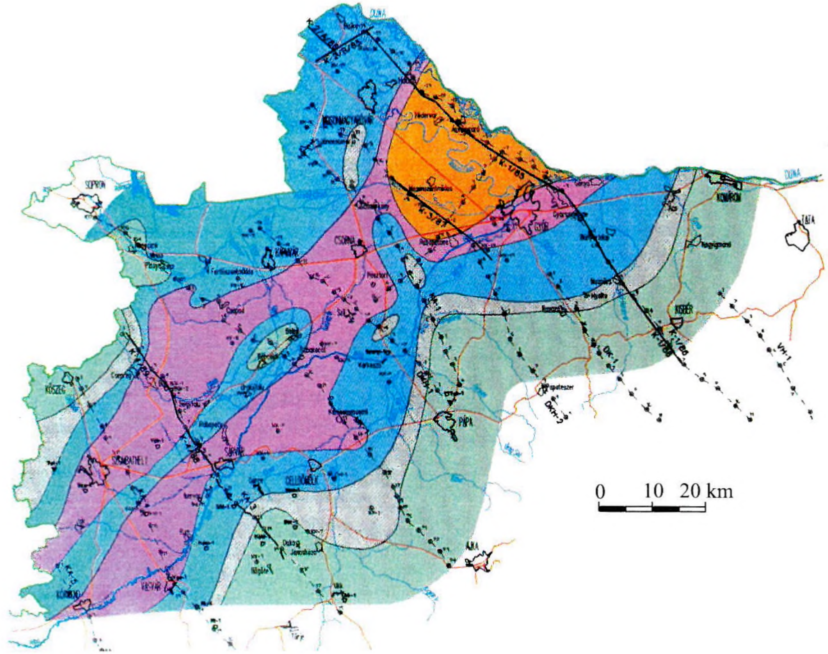


Fig. 5.21 Little Hungarian Plain - Connections between the conductivity of the sedimentary sequence (S_{MT}) and the relative telluric conductivity (A^{-1}); areal validity of the connections

5.21. ábra Kisalföld - Az üledékes összlet vezetőképessége (S_{MT}) és a relatív tellurikus vezetőképesség (A^{-1}) összefüggései, valamint az összefüggések területi érvényessége

5.3. Construction of the basement depth map from telluric and magnetotelluric measurements

In the sub-basin south of Lake Balaton the depth map of the pre-Tertiary basement was elaborated as a result of our telluric and magnetotelluric measurements. One or two features of specific interest of this area are that a deep fracture resulting in a large geoelectric conductance anomaly runs here and the resistivity of the basement is only some 5–10 times higher than that of the sediments in the southern sub-area. Telluric base station 23 at Ádánd is in this zone and this is one of the three telluric base stations out of the 33 where the telluric measurement range is not in the '*S*' interval.

Construction of the depth map was based here on the magnetotelluric soundings, too, although their station density is at least one order of magnitude less. Along one of the axes of a co-ordinate system the conductance of sediments (S_{MT}) determined from 1-D inversion of *H* polarization magnetotelluric soundings was plotted and along the other axis the relative conductance determined from telluric measurements (A^{-1}) (*Fig. 5.22*). We would have obtained a well definable straight line in the case of measurements performed in the '*S*' interval. Here, however, there is fair amount of scattering; nevertheless, some kind of order can be created if we take into consideration the basement structure known from the magnetotelluric soundings, the deep fracture running parallel with Lake Balaton, and the 10 km wide strip along the lakeshore recognized also from geological data. If the set of points plotted in the co-ordinate system is approximated by several lines it turns out that the steepest line characterizes the areas of the proper '*S*' interval, where the resistivity and thickness of the relatively shallow (500–1000 m), high resistivity Early Palaeozoic crystalline or Mesozoic carbonate basement are practically infinite. About 10 km south of Lake Balaton, at the border of the Early Palaeozoic strip, the geoelectric conductance anomaly of the deep fracture provides a larger part of the telluric conductance value; on the other hand, only a comparatively small part comes from the conductance of sediments. Even so, the data pairs measured in this 10 km wide strip give a relatively well definable straight line, the least steep in Fig. 5.22, because fortunately, the anomaly caused by the fracture line is nearly constant in this strip. Moving away from the fracture line with some arbitrariness we can choose a next strip where the effect of the fracture line is already smaller and the relationship between the telluric

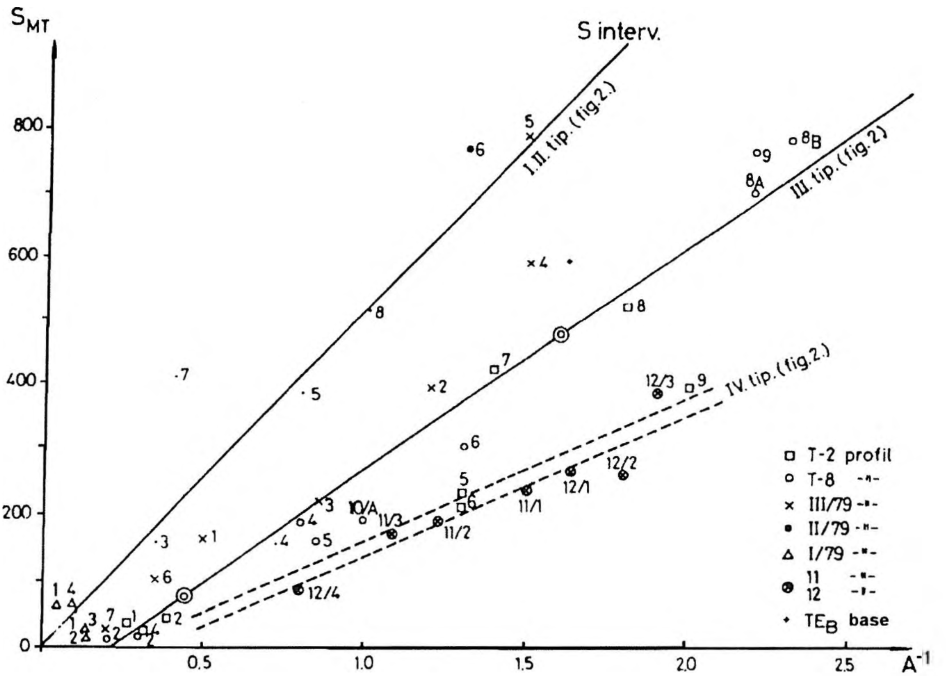


Fig. 5.22. Connection between the conductivity (S_{MT}) of the sediments deposited on the basement and the telluric A^{-1}

5.22. ábra. Az aljzatra települt üledékes összlet vezetőképessége (S_{MT}) és a tellurikus A^{-1} érték közötti összfüggés

conductance and the conductance of sediments can be characterized by another straight line. If we can define the geographic area of the validity of a line, then the telluric relative conductances can be transformed at each telluric station into absolute conductances characterizing the sedimentary sequence.

This is followed by the correction eliminating the lateral inhomogeneity existing in the resulting longitudinal conductance of sediment. This was done by constructing an isoohm map (*Fig. 5.23*) from the average resistivity values (described in Chapter 3) — ρ_σ — of sediments, earlier obtained from 1-D inversion of direct current, and magnetotelluric soundings in the last decades. From this map the value of average resistivity was interpolated for each telluric station; then, using the relationship

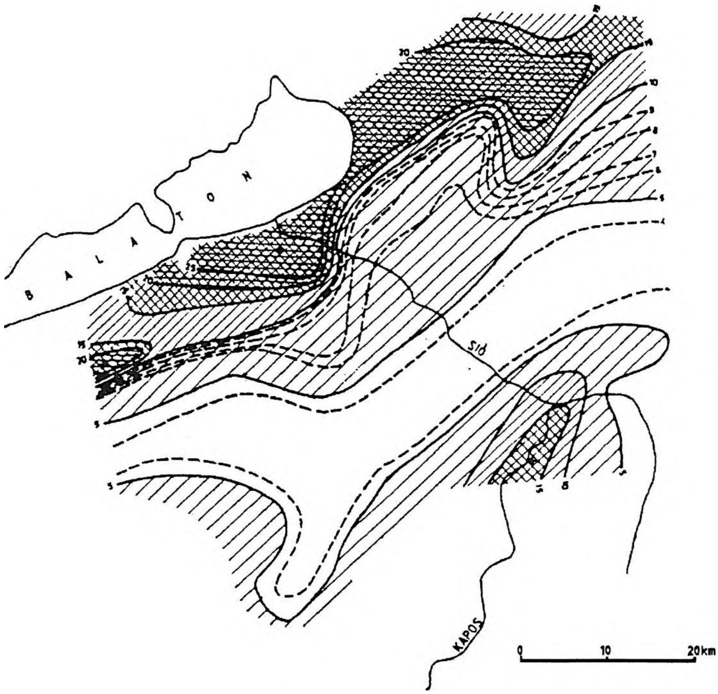


Fig. 5.23. Isoohm map characterizing the average resistivity of the Tertiary and Quaternary sediments

5.23. ábra. A harmad és negyed időszaki összlet átlagos fajlagos ellenállását jellemző izoohm térkép

$$H = S_{TE}\,\rho_{\sigma}$$

the depth was calculated for each telluric station (*Fig. 5.24*).

Using this method the depth map can be constructed for the whole area covered by telluric measurements and in the course of surveys in Transdanubia it was constructed in the area of numerous projects. For the Kisalföld such surveys were published earlier in Geophysical Transactions and for a significant part of the Drava Valley in reports prepared for clients. Today, however, we see no reason for constructing a map of this nature for the whole area covered by telluric measurements because it would be less accurate due to the lack of magnetotelluric measurements just at those places where knowledge obtained from seismic measurements provides more accurate results and even the density of wells is already higher than that of telluric stations.

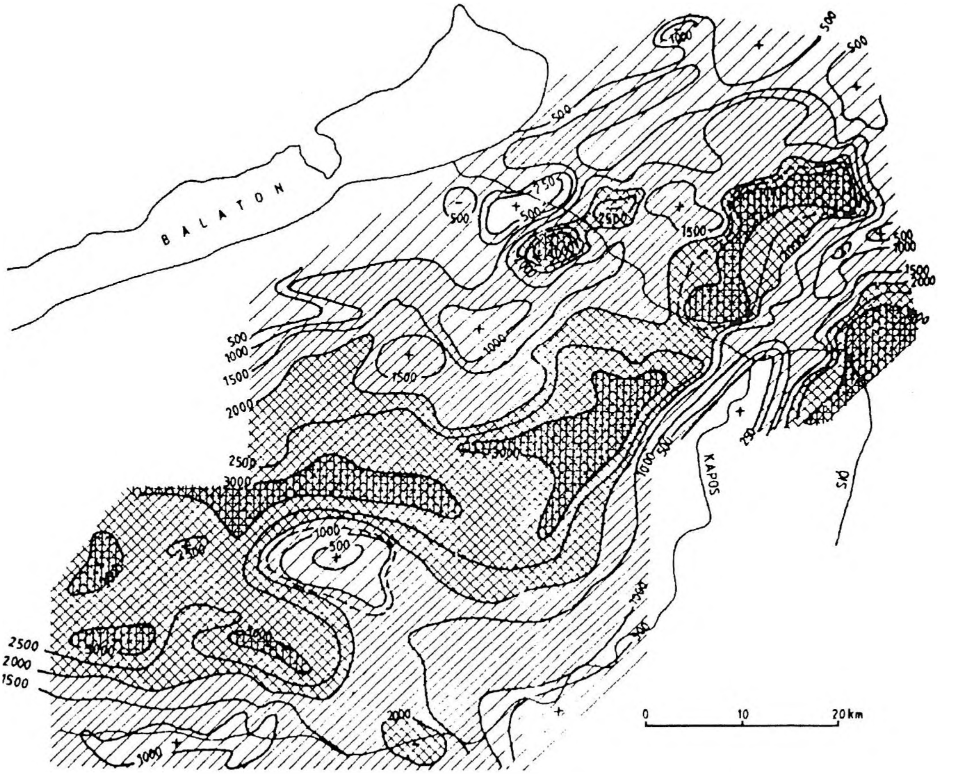


Fig. 5.24. Depth map of the presumed pre-Tertiary basement
5.24. ábra. A feltételezett harmadkori aljzat mélységtérképe

5.4. Conclusions

The telluric conductance map reflects in its main features the effect of Tertiary–Quaternary sediments, i.e. it provides an image of the young basins. In the special sub-areas presented in this chapter, however, we have obtained information primarily on the conductance anomalies within the pre-Tertiary basement. We have concluded these effects within the basement from qualitative comparisons with other methods.

In the following chapters, however, we present more objective studies as well, when from magnetotelluric measurements in a grid much less dense than that of telluric measurements and from cumulative resistivity logs of a few dozen wells we construct the conductance map of the sedimentary sequence and then it is subtracted from the telluric conductance reflecting effects from within the basement, too. The obvious defect of this method is that there are not magnetotelluric soundings at each telluric anomaly.

On the other hand, study of the gravity and geomagnetic measurements, the depth map of the pre-Tertiary basement, and the telluric map based on cluster analysis provides an opportunity for more detailed analysis. Finally, we ensure a large scope for studying the direction dependent information which makes the structural lines expressive primarily in the zones of larger conductance changes, at two- or three-dimensional structures.

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5. FEJEZET
A Dunántúl tellurikus térképe

NEMESI László, VARGA Géza, MADARASI András

A Dunántúl tellurikus térképének megszerkesztéséhez egyrészt létre kellett hozni a 2. fejezetben megnevezett három intézmény méréseiből az egységes mérési adatbázist, másrészt a 30-nál több bázisra vonatkozó relatív vezetőképesség adatokat közös alapszintre kellett átszámítani. Ez utóbbi a bázisokon most elvégzett magnetotellurikus szondázások segítségével vált lehetővé.

Kvázi 25 s-ra koherens abszolút tellurikus vezetőképesség térkép született. Ez elsősorban a kainozoós üledékek vastagságával arányos, de vannak területek, ahol az anomáliák kialakításában a pre-tercier aljzatban levő vezető képesség-anomáliáé a meghatározó, vagy jelentős szerep (Magyarmecske, Zselic, Paks, Nagygörbő, Kisalföld Rába-vonaltól D-re eső területei). Ennek ellenére magnetotellurikus korrekciók segítségével még ilyen területeken is jó közelítéssel megszerkeszthető a kainozoós üledékek vastagsága.

ABOUT THE AUTHORS

Nemesi László for a photograph and biography, see this issue, p. 120

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.

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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CHAPTER 6
Direction dependent information

László NEMESI*

Electromagnetic plane waves which produce telluric currents, too, have a wide frequency spectrum; the second basic characteristic of these waves is that their direction changes with time. This is why the telluric method has the major advantage over all methods with artificial electric and electromagnetic fields since by measuring the two perpendicular components of the currents we can explore horizontal inhomogeneities, and dip and strike directions by separating E and H polarizations.

In the magnetotelluric method, the measurement of the magnetic components directly yields this kind of information. The situation is less simple, less evident in telluric measurements; as for the processing methods discussed previously, the relative ellipse between the roving and the base station was the fundamental result. The relative ellipse, however, characterizes only the relationship between currents at two stations. The direction and eccentricity of the relative ellipse characterizes neither the geological condition of the base, nor of the roving station. For this reason, since the very beginning of the use of the telluric method experiments have been carried out to exploit the direction dependence as a means of interpreting the geological conditions at the site of the measurement (at the roving station).

It is of interest to find out which results are obtained in the case of a linearly polarized electric field and what the additional information is in the case of circular polarization.

A great deal of study has been devoted to the first problem by geophysicists in the oil industry and in ELGI, the second by the staff of the Geodetic and Geophysical Research Institute of the Academy during their investigations into the course of the equipotential lines and current threads above different structures.

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CHAPTER 6.1
Study of the stability of temporary absolute ellipses

László NEMESI*

It is shown that the temporary absolute ellipses determined from a record not longer than half an hour are stable with good approximation. In addition major axes of the ellipses point towards the centre of the anomaly in 3-D cases when the conductance anomalies span from a half to one order of magnitude, and in 2-D cases they are oriented in the strike direction at the side of the anomaly, and in the tilt direction along the ridge of the anomaly. At small conductance anomalies (not more than some 20% or 30%) the ellipse orientations are stable, but there is no definite connection with the local structural direction, much rather megastructural directions and regional direction of the primary field are dominant.

Keywords: ellipse, conductance, tellurics

6.1.1. Representation of temporary absolute ellipses on telluric maps

A possibility emerged in ELGI in 1979 with the introduction of the TEM–80 type instruments to construct absolute ellipses for the roving stations as well as the base stations. The idea was to use the formulae described in Chapter 4.2.3 for determining the tensorial components of the relative ellipse; then, with the results of magnetotelluric measurements which yield data on the distribution of the horizontal conductance in the form of a polar diagram, the vectors of variations can be referred to this curve (and not to the circle, as in the case of the method of relative ellipses); in this way an absolute ellipse can also be obtained at the roving station reflecting the distribution of the horizontal conductance at this station.

As at that time magnetotelluric soundings were only available at a very small number of base stations, telluric data were conserved as data on the

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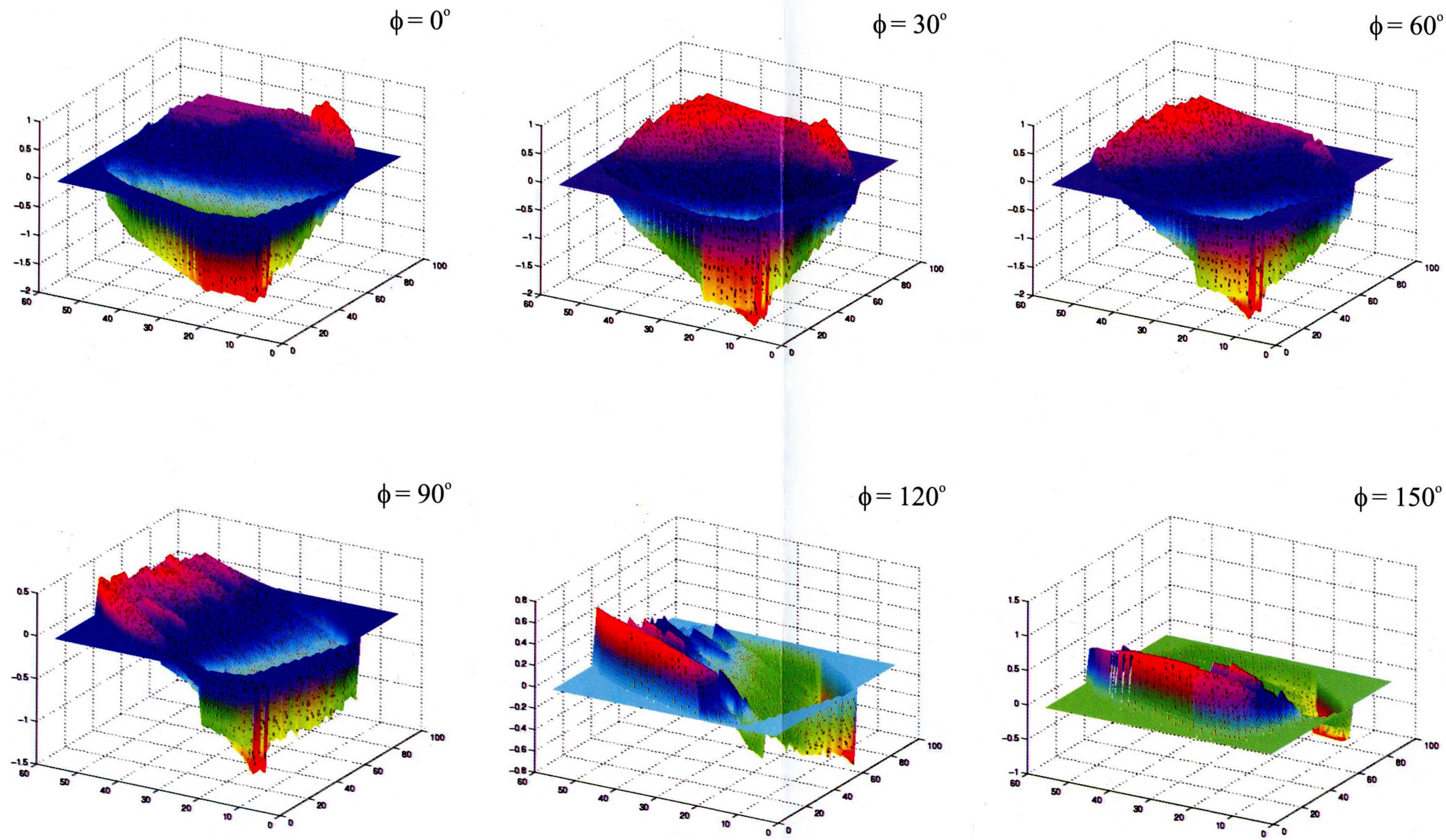

Fig.6.3.3. 3D view of the equipotential surfaces computed for the Magyarmecske region from the absolute ellipses for directions of the primary magnetic field, rotated by 30° from 0 to 150°

6.3.3. ábra. Ekvipotenciális felületek térbeli képe a Magyarmecske területről az abszolút ellipszisek alapján, az elsődleges mágnestér irányát 0 és 150° között 30°-onként elforgatva.

major and minor axes of the absolute ellipse, as well as the value of its azimuth angle (orientation), furthermore the A^{-1} values computed as a ratio of the ellipse areas from the product of the axes.

When dealing with telluric ellipses, József Csörgei [personal communication] noted the stability of the directions of the axes and the ratio of the axis lengths in a set of a dozen ellipses computed from 'total sums' of intervals with lengths of 5 min. A more exact comparison could be carried out using the data of base stations as at these stations data were available in several hundred intervals, measured simultaneously with different roving stations.

The above mentioned investigation was actually carried out for the Nyalka base station. At this station, measurements carried out simultaneously with 350 roving stations were available, having a total duration of more than 300 hours. Using these data, the ratio major/minor axis and the azimuth angle of the absolute ellipse were determined, and the scatter of these values was also computed.

The results showed that from intervals of the length 30 to 60 min (i.e. the usual length of records used for the processing of a station) the scatter of the direction is ±20°, and the scatter of the ratio is less than ±10 %. It is mentioned that the ratio of the area of the temporary absolute ellipses of the base and of the roving stations computed from the same time interval is less than ±3–5 %. These scatters of the values with respect to the Nyalka station include the effect that here the period range 20 to 30 s is outside the *S*-interval due to a low resistivity formation in the basement. This means that a part of the scatter is due to frequency dependence, and the average situation in Transdanubia is somewhat better.

Evidently the scatter of the axis direction—axis ratio can be much greater, too, if the ellipse of anisotropy is near to the circle. However, in such cases the direction dependence does not hold and the investigation no longer has any meaning. At the Nyalka base, the ratio of the axes was about 1.6.

These investigations have shown that the direction and eccentricity of temporary absolute ellipses computed from records of the duration 0.5 to 1 hour are much more stable than supposed. This is why on telluric maps constructed after 1980 'temporary' absolute ellipses were also plotted. The direction and axis ratio of the ellipses was determined from the total variations recorded at these stations and the area was chosen to be greater or smaller than the area at the base station assumed to be of unit area corresponding to the ratio of the area of the relative ellipse (low conductance — big ellipse, high conductance — small ellipse).

6.1.2. Temporary absolute ellipses on the conductance maps

The behaviour of temporary absolute ellipses, i.e. their surplus information above different anomalies (geological structures), was studied, with the following results:

At locations of 2-D and 3-D structures, where the conductance changes very quickly (within 1 to 2 km by half to one order of magnitude), the described ellipses of anisotropy indicate very clearly the anomaly of the conductance, and the deeps and highs of the basement. Some examples are given in Chapter 5. A 3-D structure is, for example, the Magyarmecske—Nagygörbő anomaly, where the anomaly is of nearly circular symmetry and the major axes of the ellipses point towards the centre of the anomaly with continuously decreasing length towards the maximum conductance.

In the case of 2-D structures being much longer than their width, e.g. in the Villány region (SE corner of the map), ellipses are arranged in the strike direction on both flanks of the elongated structure of the basement — in accordance with theoretical considerations. On the top of the structure, however, they are elongated perpendicularly, in the dip direction (*Fig. 6.1.1*).

In such cases the mapping of parameters differing from the usual ones may be worth while. Such parameters are, for example, the length ratios of the major axes corresponding generally to *E*-polarization, or from length ratios of minor axes which correspond on the sides of 2-D structures to *H*-polarization; a further example is eccentricity maps at fracture zones which hint at the elongated ellipses along the fault, etc.

Similar phenomena are apparent at great tectonic lines: for instance at the Central Hungarian Line (at the centre of the telluric map near the River Danube, in the Sárbogárd–Mezőfalva–Dunaföldvár area) (*Fig. 6.1.2*). Here to the north of the isoline of conductance 0.5, ellipses are bigger and 'thicker' than to the south of it due to the significant change in the conductance. Here the ellipses are not only smaller, but more elongated, too, and their orientation follows the sawtooth-like form of the fracture. Besides here the change in the conductance is caused less by a change in the depth of the basement than by the fact that to the north of the fracture the basin is filled with Palaeogene (mostly Oligocene) sediments which have resistivities on average twice that of the Pliocene (Pannonian) ones to the south of the line.

Telluric–magnetotelluric methods can also be used to track the Palaeogene–Neogene boundary in eastern Hungary (not presented here); this boundary is significant from the point of view of the oil industry.

In the zones of slower changes of the conductance, the orientations of the ellipses and the eccentricities are relatively more regularly ordered (they are mostly NE–SW oriented). In the areas of deep basins there are no clear connections between local structures and ellipse orientations — eccentricities. This can be explained either by the regional anisotropy in the Carpathian Basin, discovered several decades ago by Antal ÁDÁM [1969], or by the characteristics of the primary field — or by both.

Figure 6.1.3 represents a part of the Little Plain (NW Transdanubia). Here huge ellipses indicate the big changes at the southern end of the basement outcrop at Sopron, at the Kópháza fault, while in the deeper parts of the basin, e.g. in the 3000 m deep Csapod graben, there are practically no connections between ellipse orientations and eccentricities and basement structures — the course of the isolines. The characteristic orientation (which approximates the E–W direction) of the Carpathian Basin is more evident here; this somewhat differs from the general NE–SW direction.

In summary we think that temporary absolute ellipses have unexpectedly stable orientations and eccentricities in time. This is valid both in zones of conductance changes by a half to one order of magnitude and in zones of slow changes of the conductance. In the former case, however, these parameters are connected with local structural conditions, in the latter case only a scatter amounting to a few tens of degrees can be found from the regional directions in spite of the temporal stability. In the present case this regional direction coincides with the direction of the regional structures in the Carpathian Basin; nevertheless, local characteristics of the primary field cannot be excluded.

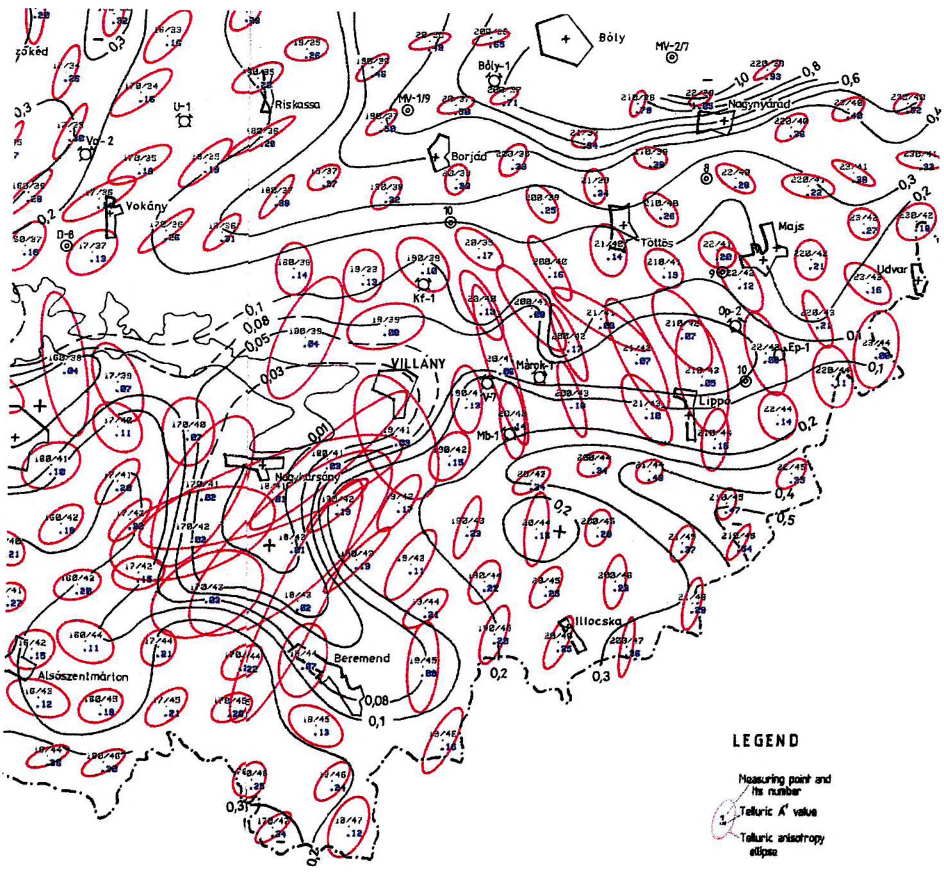

Fig. 6.1.1. Telluric isoarea map with absolute ellipses (around Villány)

6.1.1. ábra. Tellurikus izoarea térkép az abszolút ellipszisekkel (Villány környékén)

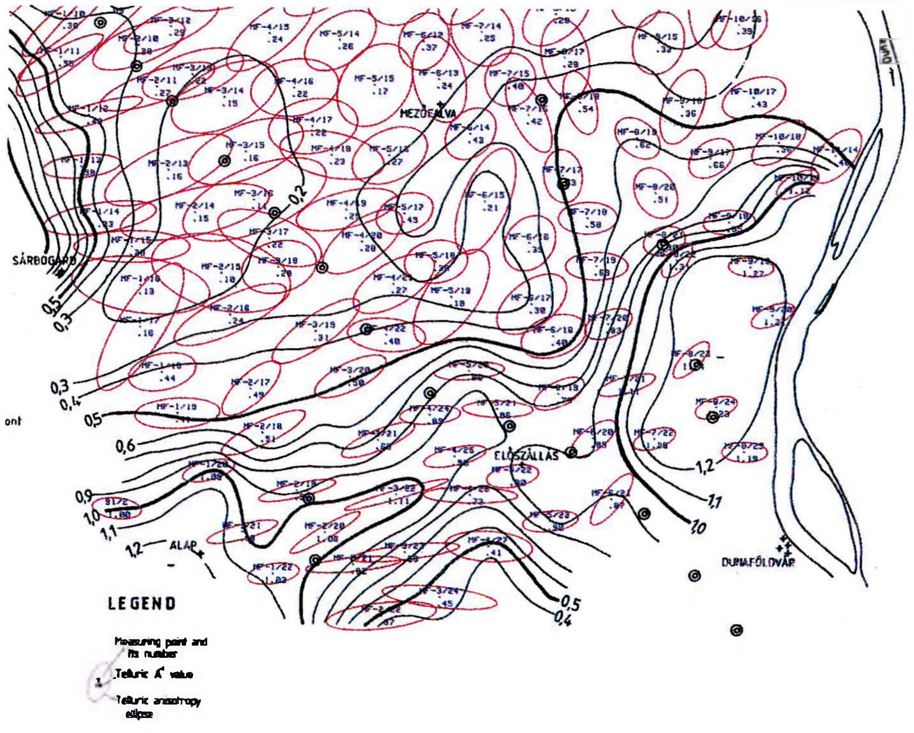

Fig. 6.1.2. Telluric isoarea map with absolute ellipses (along a section of the Central-Hungarian line)

6.1.2. ábra. Tellurikus izoarea térkép az abszolút ellipszisekkel (a Közép-magyarországi vonal egy szakaszán)

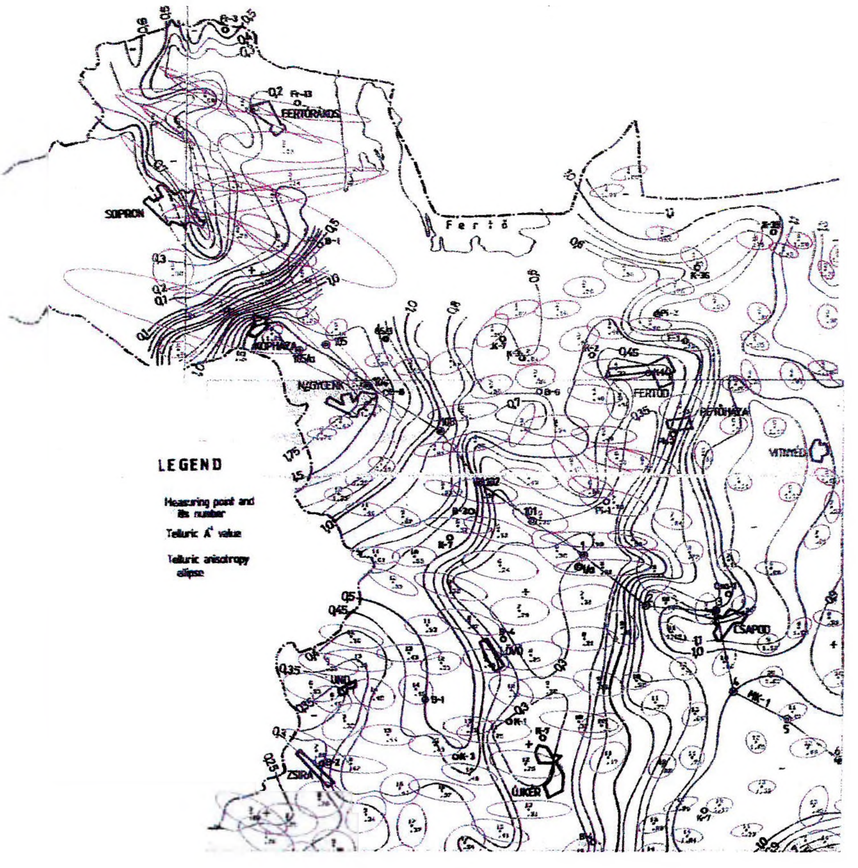

Fig. 6.1.3. Telluric isoarea map with absolute ellipses (on the NW part of the Little Plain)
6.1.3. ábra. Tellurikus izoarea térkép az abszolút ellipszisekkel (a Kisalföld ÉNy-i részén)

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6.1. FEJEZET

Az időszakos abszolút ellipszisek stabilitásának vizsgálata az ELGI-ben

NEMESI László

A már félórányi regisztrátumból meghatározott "időszakos abszolút ellipszisek" jó közelítéssel stabilak. Ezen túlmenően a fél–egy nagyságrendet átfogó vezetőképesség-anomáliáknál a 3-D esetekben az ellipszis nagytengelyek az anomália középpontja felé mutatnak, 2-D esetben az anomália oldalán csapás irányban, az anomália gerinc-vonalában pedig dőlés irányban állnak. A lassú (néhány 10%-ot jelentő) vezetőképesség-inhomogenitásoknál az ellipszis irányok stabilitása mellett sincs határozott összefüggés a helyi szerkezeti irányokkal, hanem sokkal inkább a regionális nagyszerkezeti irányok és a primér tér regionális iránya dominál.

ABOUT THE AUTHORS

Nemesi László for a photograph and biography, see this issue, p. 120

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CHAPTER 6.2

Relative and absolute telluric direction information and its connection with magnetotelluric directions based on practical examples

Zoltán NAGY* and Ilona LANDY**

Researchers from the oil industry illustrate how they constructed after Kunetz the absolute (station) ellipse at the telluric base stations which eliminates the characteristics of the primary field, then what kind of connection can be found between the relative ellipses transformed to them and the geological knowledge (e.g. orientation and eccentricity of ellipses are completely different at the two sides of the Rába line).

They also compared at 17 selected stations the telluric information obtained with the above methods with the magnetotelluric information and they state that with measurements of appropriate accuracy similar results can be obtained with both methods.

Keywords: tellurics, magnetotelluric surveys, ellipse

6.2.1. Telluric absolute ellipse transformations in structural exploration

A simple two-layer geoelectric model was chosen as the initial model in the early phase of the intensive telluric mapping of the Pannonian Basin, then assumed to be filled with Tertiary sediments [NAGY 1997]. The two layers were a low resistivity sedimentary complex and a basement of a resistivity being by orders of magnitude higher; the latter, in a first approximation is supposed as being isolating. Theoretically the parameters determined by the telluric method [VERŐ 1960], viz. area, eccentricity and orientation of the absolute ellipses, characterize the geological structure in

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the case of this simple model if the effect of the telluric base station is eliminated from the measured relative ellipses using corresponding transformations. This transformation can be made if the absolute ellipse of the telluric base station is known.

The telluric vectors of any station have a statistical distribution which is determined by the resistivity conditions below the station [KUNETZ 1957]. Therefore the so-called absolute ellipses can be determined for telluric base stations where the statistical distribution of telluric vectors can be determined from records made according to the function of the base station.

Thanks to LANDY and LANTOS [1976] this method was successfully applied in Hungarian telluric exploration, using data measured by the Geophysical Exploration Company of the oil industry (GKV) in a west-Transdanubian exploration area covered by a network of 250 stations. The base station of this area was characterized by 17000 telluric vectors measured over a period of two years and chosen by random sampling. The period range of the variations was 18 to 32 s; average vectors were determined in angular ranges of 1°.

The components of the relative telluric tensor (*a, b, c, d*) were determined using the method of straight lines, and the error of these components was about 3 to 5 %. Absolute ellipses could be determined for all points by the transformation of the absolute ellipse of the base station with the relative telluric tensors.

Figure 6.2.1 taken from the original publication [LANDY, LANTOS 1976] represents the major and minor axes of the absolute ellipses on the site of each station.

The eccentricity of the ellipses increased in the northwestern corner of the area where the boundary of Hungary has a sharp inward bend, and the orientation also changed there in a characteristic form with respect to other parts of the area. Boreholes in the Szentgotthárd area reached Palaeozoic phyllite at depths of 1000 to 1500 m.

The eccentricity and the orientation of the telluric ellipses exhibit no characteristic changes in other parts of the area. Boreholes in the eastern part reached Triassic limestone at an average depth of 3000 m. In the southern part boreholes did not reach the basement.

The authors analysed the telluric parameters in detail and presented the likely limit of the two structural units (Rába line).

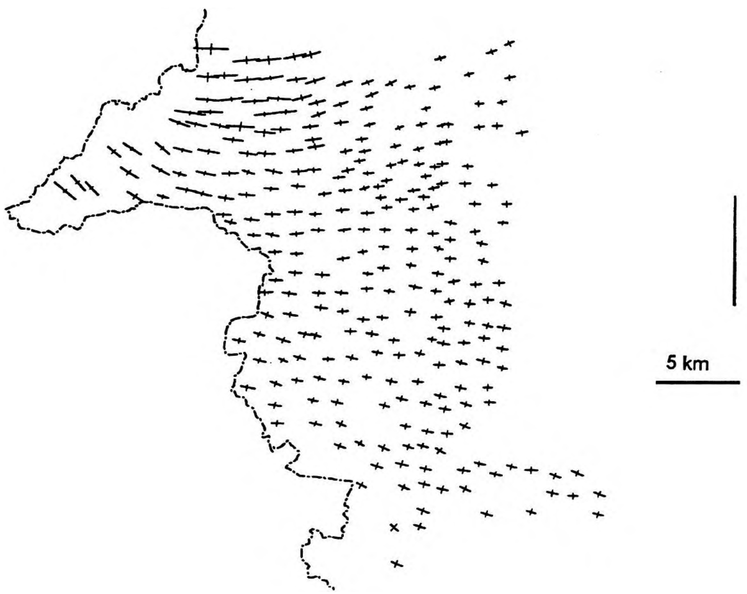

Fig. 6.2.1. Major and minor axes of the absolute ellipses transformed to the telluric base stations of Szentgotthárd–Őriszentpéter–Csesztreg [LANDY, LANTOS 1976]

6.2.1. ábra. Szentgotthárd–Őriszentpéter–Csesztreg térség tellurikus álloámspontjaira transzformált abszolút ellipszisek nagy- és kistengelyei [LANDY, LANTOS 1976]

Magnetotelluric soundings made later by GKV detected the presence of a complex with a conductance comparable to that of the Tertiary complex below the phyllitic complex. These data contributed to the development of a realistic geoelectric model of the Pannonian Basin. In possession of the first results of magnetotelluric soundings [TAKÁCS 1967, NAGY 1972] the initial two-layer model had to be changed in the early 1970s.

In this process of increasing insight, the magnetotelluric measurements of Ernő Takács played a major role. He detected in the eastern part of the Little Plain a low resistivity formation in the basement, at depths of about 5 to 6 km, below the Mesozoic rocks found in the Dabrony–1 borehole with a thickness of about 2 km. These conducting formations increased the resulting conductance by nearly one order of magnitude based on data of the usual range of periods of the telluric measurements. The guiding horizon of the telluric measurements here proved to be the top of this conductive formation instead of the surface of the basement [LANTOS, NAGY 1970, NAGY 1972].

These results rendered questionable the general utilization of the simple geoelectric model of the Pannonian Basin. It also became questionable that anomalies of the telluric conductance and direction dependent information in the period range of Pc3 pulsations can be exclusively or even primarily attributed to Tertiary formations without a priori knowledge about the frequency dependent characteristics of the transfer function of the actual structure.

This methodological problem emerged in the mid-seventies in connection with telluric measurements of the oil industry, as at that time the main task was mapping of the basement of the Tertiary basin. In consequence the magnetotelluric (MT) method was rapidly introduced as it had already reached a technical level enabling its large-scale application and, moreover, it permitted us to control the penetration depth in wide limits using frequency sounding in a broad range of periods.

6.2.2. Directional characteristics of telluric absolute ellipses and magnetotelluric directional information

The common electromagnetic source implies an inherent connection between telluric and magnetotelluric parameters. Thus telluric information can be considered as relative magnetotelluric information in a narrow frequency range. This statement is precisely true for the expression of the telluric area, corresponding to the relative electric conductance in the case of monoharmonic variations:

$$A^{-1} = \frac{S_R}{S_B}$$

Here S_R and S_B are the effective magnetotelluric conductances (siemens) for a given period at the roving and base stations respectively. This formula enables us to transform the relative telluric area of a roving station to absolute (effective) conductance using the data of the magnetotelluric sounding carried out at the base station. The validity of this value is influenced by the accuracy of the telluric parameters, by the bandwidth of the telluric variations used and by actually existing sharp differences between the electric models at the base and roving stations.

The connection of the direction dependent telluric and magnetotelluric information can also be studied starting from the common natural source of the corresponding variations. Nevertheless, knowledge concerning the 2-D and 3-D geoelectric structures collected during the development of the magnetotelluric method has shown that telluric measurements alone are insufficient for obtaining the direction dependent information necessary to describe the geoelectric structural model.

Moreover, electric charges developing at near-surface inhomogeneities cause a so-called static shift which results in a parallel shift of the TM mode apparent resistivity curves deduced from the principal components of the magnetotelluric impedance tensor. The same effect appears in telluric parameters, too, and it influences the apparent value of the eccentricity of the telluric ellipse. This effect cannot be unambiguously detected from monoharmonic measurement data.

The principal directions of the so-called polar diagrams determined from magnetotelluric measurements in a wide range of frequencies, furthermore the direction of the tipper or induction vector determined from the vertical component of the magnetic field of the magnetotelluric variations due to inhomogeneities of the geological/geoelectric model give together a possibility for unambiguously determining the geological strike direction in the case of 2-D structures and for identifying the ρ_{xy} and ρ_{yx} resistivity curves with the electromagnetic modes (TE or E polarization and TM or H polarization, TAKÁCS [1976], VOZOFF [1991]).

The orientation of the axes of the telluric absolute ellipse defines the strike direction with an uncertainty of ±90° without a priori knowledge of the geological principal directions, similarly to the uncertainty of the principal magnetotelluric directions in a similar sense without the information of the tipper.

In a general 3-D case no unambiguous geological strike direction can be defined, an ambiguity emerges if the geological/geoelectric model is a superposition of regional and local structural effects in the orientation. Experience has shown in such cases that the direction of the principal components of the impedance is more stable than that of the tipper [VOZOFF 1991]. Similar experience from the exploration results of the Hungarian oil industry led to an additional conclusion: that in the variability of the direction of the tipper, local anomalies of the electric conductance play the most important role.

6.2.3. Comparative study of telluric and magnetotelluric direction dependent information in experimental data from Western Transdanubia

Several problems needed to be clarified to achieve the main aims of this investigation: the construction of the unified telluric map of Transdanubia and the interpretation of its results. It was for this reason that we considered it necessary to supplement the previous two sections with a comparative study of telluric and magnetotelluric data which were obtained on the same spot or at stations which can be supposed as identical.

The selected area is in the southwestern part of Transdanubia, in the area Kilimán–Vörs–Somogysámson–Csákány–Újudvar. Telluric and magnetotelluric measurements were carried out here by GKV in the years 1978 to 1981.

The area has a surface of about 350 to 400 km^2 and it is covered by a telluric network with a density of 2 km^2/station. Telluric measurements were made by photorecording at 195 sites; magnetotelluric soundings were performed at 36 sites with digital magnetic tape recording (the standard procedure at that time) using a MTDR–2 type system (Geotronics Co, Texas).

The length of the electric measuring dipoles (MN) in the telluric measurements was 300 m, in the MT soundings 200 m. These values were the basis for selecting the measurement sites considered as identical. Stations were taken to be identical if either the measurements were carried out at the same spot or the distance between the TE and MT stations was less than 250 m, i. e. the centre of the MT measurement was within the distance used for the TE measurement.

An additional aspect of the selection was the quality of the TE and MT measurements with MT sounding curves constructed for the period range 1 to 100 s. It should be mentioned here that the eventual disturbing effect of TV and radio transmitters operated in Újudvar and Sávoly during the measurements remained unknown, any noise originating from the then infrastructure of the area is similarly unknown. This is why we omitted some stations following a detailed analysis due to distortions (e.g. Station No. 9 was omitted from the processing and from the corresponding tables because of this).

Bearing these factors in mind, the selection criteria were fulfilled at 22 station pairs (TE + MT stations), their locations are presented in *Fig. 6.2.2.* Station pairs will be referred to in the following by the numbers given in this figure.

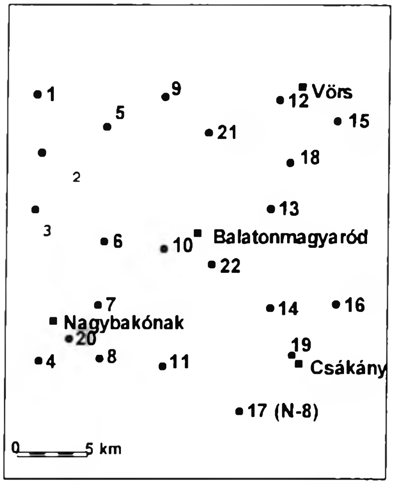

Fig. 6.2.2. Localization of the common TE and MT measurement points chosen for the examination of the direction dependent information

6.2.2. ábra. Az irányfüggő információk vizsgálatára kiválasztott közös TE+MT mérési pontok helyszínrajza

6.2.3.1. Telluric data

Telluric data at the station pairs TE + MT are given in *Table 6.2.1* (with the station number corresponding to the numbers given by GKV). The table includes the following values:

— Area according to the traditional sense $A^{-1} = S_{\text{Roving}}/S_{\text{Base}}$, determined from the tensorial elements computed with the method of straight lines [LANDY, LANTOS 1991a], referred to base station N–8. Base station N–8 corresponds to station pair No. 17 in Fig. 6.2.2. The areas were determined as averages from three straight lines for each station. Thus the scatter of these values is about ± 3–5 percent.

— Pulsations used in the processing of the TE measurements were selected according to apparent periods. Photorecording combined

TE+MT station No.	TE station original No.	Area A^{-1}	A_{TE} mV/km	B_{TE} mV/km	Pseudo-area $(A_{TE}B_{TE})^{-1}$	Direction of the major axis of the relative TE from north in clockwise direction	Azimuth A_{TE} (degree)
1	86425	0.39	163.78	88.88	0.392	150.0	165.7
2	86427	0.73	134.16	56.35	0.754	[146]	173.0
3	86429	0.95	109.12	54.94	0.951	158.5	11.3
4	85930	0.97	114.20	51.61	0.968	157.9	6.8
5	86408	0.51	124.51	89.71	0.511	147.0	178.8
6	86412	0.82	112.08	62.07	0.820	145.1	21.1
7	85913	0.93	90.70	67.65	0.930	133.3	43.1
8	85915	1.06	97.73	54.90	1.063	151.1	4.6
9	86332	0.44	144.39	89.01	0.444	116.9	48.0
10	86337	0.71	85.97	69.00	0.961	unsafe date	44.0
11	86036	0.96	117.81	50.43	0.960	162.1	28.2
12	86301	0.44	157.16	82.67	0.439	162.0	26.1
13	86305	0.63	120.50	75.04	0.631	143.5	21.6
14	86009	0.93	111.58	54.73	0.934	149.0	30.9
15	86202	0.40	161.82	87.36	0.403	152.2	14.9
16	86105	0.88	117.98	54.97	0.879	146.6	38.9
17	76006	1.00	117.87	48.39	1.000	base circle	40.1
18	86215	0.52	137.88	69.06	0.599	[153]	27.1
19	86117	1.17	103.16	47.22	1.171	102.5	48.2
20	85924/A	0.84	104.00	55.00	0.997	[147]	11.3
21	86320	0.44	149.00	81.00	0.473	145	22.28
22	86023	0.86	99.00	67.00	0.860	131	37.2
	Explanation: A^{-1}: TE area according to the formula S_{Roving}/S_{Base}						
	A_{TE} and B_{TE}: major and minor axes of the absolute ellipse from the transformation						
	Pseudo area: computed area of the absolute ellipse related to the base station						
	Azimuth A_{TE}: azimuth of the major axis of the transformed ellipse, clockwise from north (N=0°; E=90°)						
	[147] interpolated value						

with manual determination of the amplitudes did not allow us a selection according to periods: selection of periods became an integrated part of the processing with the introduction of digital recording in MT measurements. It is remarked here that routine measurements made by GKV during 15 years covered the period range 18 s $< T <$ 28 s, with the obtained values referred to a central period at T = 23 s in a good approximation.

Telluric data were also processed with the method of absolute ellipses, using the method mentioned in Section 6.2.1 [LANDY, LANTOS 1976].

Determination of the absolute ellipse of the basis station was made from a selected part of the records having variations with the necessary spectral characteristics. The total length of the records was about 5200 minutes [LANDY 1991, LANDY, LANTOS 1991b]. In the manual processing of the telluric records, the sampling interval was 5 s. Absolute values of the electric vectors determined from the corresponding electric components were averaged in angular ranges of 5° and these averages were then fitted to an ellipse.

The data of the absolute ellipse of telluric base station N–8 (Station No. 17 in Fig. 6.2.2) are the following:

major axis	A_{N-8} = 117.9 mV/km
minor axis	B_{N-8} = 48.4 mV/km
azimuth of the major axis	α (A) = 40°
direction of the azimuth:	North: α(A) = 0°
	East: α(A) = 90°

The transformed absolute ellipses of the roving stations were determined by transforming the absolute ellipse of the basis station with the tensorial components of the TE stations given in Table 6.2.1. The parameters of the transformed absolute ellipses were checked by computing the areas of the absolute ellipses from the axes and then from them pseudo-areas referred to the absolute ellipse of the base station. Table 6.2.1 shows that the data of the transformed ellipses approximate very well the measured ones

Table 6.2.1. Measuring stations selected for studying the direction dependent information and computed parameters

6.2.1. táblázat. Az irányfüggő információk vizsgálatára kiválasztott mérési pontok és kiértékelt adataik with three exceptions (Stations Nos. 10, 18 and 20) and this coincidence confirms the validity of the transformation.

A glance at the directions of the relative telluric ellipses and at those of the transformed absolute ellipses shows an apparent deviation between the orientation of the transformed absolute ellipses in the western and eastern parts of the area, respectively. The orientations of the relative telluric ellipses are, however, much less different. The validity of the results was checked by magnetotelluric data obtained independently from telluric measurements.

6.2.3.2. Magnetotelluric data

Magnetotelluric measurements were made by digital recording using a Geotronics MTDR–2 type, five-channel computer-controlled instrument; the data processing was described by LANDY et al. [1979 a, b].

In the nominal frequency range of the instrument, i.e. between 20 Hz and 200 s, data were collected in 13 frequency windows using convolution filtering. The elements of the impedance and admittance tensors were computed from selected data of the horizontal components which fulfilled a coherence condition [VERŐ 1972]. The H_z ellipse was determined from the vertical magnetic component [TAKÁCS 1976].

Several kinds of sounding curves were obtained for each measuring station, first from the apparent resistivity data pairs ρ_{North} and ρ_{East} (computed from amplitudes) and from the corresponding phases Φ_{North} and Φ_{East}, then from the extreme data pairs ρ_{max} and ρ_{min} determined by the rotation of the tensor, finally from data pairs ρ_H and ρ_E in the direction of the major axis of the H_z ellipse and perpendicularly to it, in the directions of the so-called local *H*-polarization and *E*-polarization.

It is to be added that according to the TAKÁCS algorithm [1976], the direction of the major axis of the H_z ellipse determined from the vertical geomagnetic component is perpendicular to the direction of the tipper strike, determined by the internationally accepted standard MT processing method, which corresponds to the local geoelectric strike direction [VOZOFF 1991]. This is why we call MT local dip elements [NAGY 1981] the line elements representing the direction and length of the major axis of the H_z ellipses, obtained from this processing [TAKÁCS 1976].

Table 6.2.2 contains directions determined from MT data for the period $T = 23.2$ s, the directions of the major axes of the telluric absolute ellipses (A_{TE}), and the angular differences between TE and MT directions. *Table 6.2.3* includes resistivities (ρ_{max}, ρ_{min}, ρ_H, ρ_E) for the same period. The extrema of the resistivity polar diagram could mostly be determined with high reliability. The H-polarization resistivities corresponding to the direc-

station pair TE–MT	TE station	A^{-1}	azimuth of the major axis of absolute TE ellipses (degree)	azimuth from the MT measurement for the period T=23.2 s (degree)		deviations of the azimuths (degree)		
				ρ_{MAX}	ρ_{Hpol}	$Az_{Hp}-Az_{TE}$	$Az_{max}-Az_{Hpol}$	$Az_{max}-Az_{TE}$
1	86425	0.39	166	152	180	14	–28	–14
2	86427	0.73	173	152	50	–123	102	–21
3	86429	0.95	11	146	20	9	126	135
4	85930	0.97	7	160	12	5	148	153
5	86408	0.51	179	160	180	1	–20	–19
6	86412	0.82	21	146	130	109	16	125
7	85913	0.93	43	156	46	3	110	113
8	85915	1.06	5	144	12	7	132	139
9	86332	0.44	48	180	180	132	0	132
10	86337	0.71	44	142	24	–20	118	98
11	86036	0.96	28	144	180	152	–36	116
12	86301	0.44	26	178	2	–24	176	152
13	86305	0.63	22	148	8	–14	140	126
14	86009	0.93	31	156	38	7	118	125
15	86202	0.40	15	152	22	7	130	137
16	86105	0.88	39	156	16	–23	140	117
17	76006	1.00	40	136	38	–2	98	96
18	86215	0.52	27	154	172	145	–18	127
19	86117	1.17	48	124	34	–14	90	76
20	85924/A	0.84	11	154	6	–5	148	143
21	86320	0.44	22	144	4	–18	140	122
22	86023	0.86	37	132	4	–33	128	95

Table 6.2.2. Deviations of the MT direction dependent data from the relevant TE data and the deviations of the MT ρ_{max} direction from the MT local H-polarization direction

6.2.2. táblázat. Az MT irányfüggő adatok eltérései a megfelelő tellurikus irányadatoktól, valamint az összetartozó MT ρ_{max} és lokális H-polarizációs irányok eltérései

No. of the station pair	TE area	magnetotelluric resistivity at a period of T=23.2 s [Ωm]				computed MT pseudo areas	
	A^{-1}	ρ_{max}	ρ_{min}	ρ_E	ρ_H	$S_{MT(max \cdot min)}/S_{MTBase}$	$S_{MT(E,H)}/S_{MTBase}$
1	0.39	155.81	15.64			0.575	
2	0.73	92.4	9.82	35.35	32.45	0.736	0.692
3	0.95	32.71	9.7	18.53	18.44	0.957	0.937
4	0.97	28.38	6.24	8.93	22.02	1.107	1.076
5	0.51	61.98	67.99			0.501	
6	0.82	78.47	16.99	24.49	59.57	0.668	0.652
7	0.93	32.77	12.38	17.99	21	0.900	0.914
8	1.06	38.04	10.19	20.15	22.16	0.910	0.877
9	0.44						
10	0.71	45.76	19.35	39.27	22.65	0.740	0.738
11	0.96	33.62	16.11	19.99	28.19	0.837	0.827
12	0.44	105.65	39.59	40.04	103.4	0.502	0.502
13	0.63	50	22.45		37.13	0.698	
14	0.93	22.17	12.79	19.01	14.98	0.984	0.981
15	0.4	254.03	31.37		89.32	0.428	
16	0.88	24.98	14.73	17.95	20.57	0.922	0.919
17	1	18.36	14.5	16.74	15.75	1.000	1.000
18	0.52	71.13	24.18	31.31	60.24	0.627	0.611
19	1.17	26.1	17.16	20.12	17.69	0.878	0.928
20	0.841	34.05	8.72	13.52	23.92	0.973	0.950
21	0.44	131.11	41.45	69.69	89.22	0.470	0.454
22	0.86	47.35	17.23	28.9	30.26	0.756	0.741

Table 6.2.3. Values of MT apparent resistivities of ρ_{max}, ρ_{min}, and ρ_E, ρ_H determined for the period time T=23.2 s and the relative value of effective conductances determined from MT resistivities used as a magnetotelluric pseudo-area

6.2.3. táblázat. A T=23,2 s perióduson meghatározott ρ_{max}, ρ_{min}, ρ_E és ρ_H MT látszólagos fajlagos ellenállás adatok, valamint ezek alapján a bázisállomásra vonatkoztatva meghatározott relatív elektromos vezetések, mint pszeudo-area értékek adatai tion of the local dip element are, however, incomplete for several stations due to the non-fulfillment of the coherence conditions.

The conductance can be obtained from the resistivity measured at an arbitrary period T:

$$S\,[\text{siemens}] = 395\sqrt{\frac{T\,[\text{s}]}{\rho\,[\Omega\text{m}]}}$$

The relative values of the effective conductances determined from MT data referred to the base station were also computed as they are a kind of magnetotelluric pseudo-area. Results are also included in Table 6.2.3.

6.2.3.3. Comparison of TE and MT results

Comparison of the values deduced from amplitudes

In addition to a study of the direction dependent information, we also studied quantities deduced from amplitudes using the data presented in the tables.

The quite exact equality of the relative areas from telluric measurements and pseudo-areas obtained from transformed absolute ellipses has been already mentioned in connection with Table 6.2.1.

A similar comparison was made between the MT pseudo-areas determined from MT resistivities at a period of $T = 23.2$ s by two different methods. The connection between the two values was computed as linear regression.

The aim of this investigation was to prove that the pseudo-area $S_{\text{MT}(E,H)}/S_{\text{MTBase}}$ is invariant in the actual exploration area corresponding expectedly to a 3-D model. This pseudo-area was determined as the product of the resistivities in the directions of the H and E polarizations, obtained using the local dip and strike directions computed with the H_z component by the rotation of the impedance tensor. If the invariant character is correct, then this value has to agree with $S_{\text{MT(max min)}}/S_{\text{MTBase}}$.

Figure 6.2.3 illustrates the regression between the two kinds of pseudo-areas with data of the 17 pairs of stations where the H_z ellipse yielded acceptable results. In spite of a few outliers (due to noises in the records of the H_z component) the regression approximates quite closely the theoretically expected coincidence. Thus we concluded that the two values are equal, they are invariant.

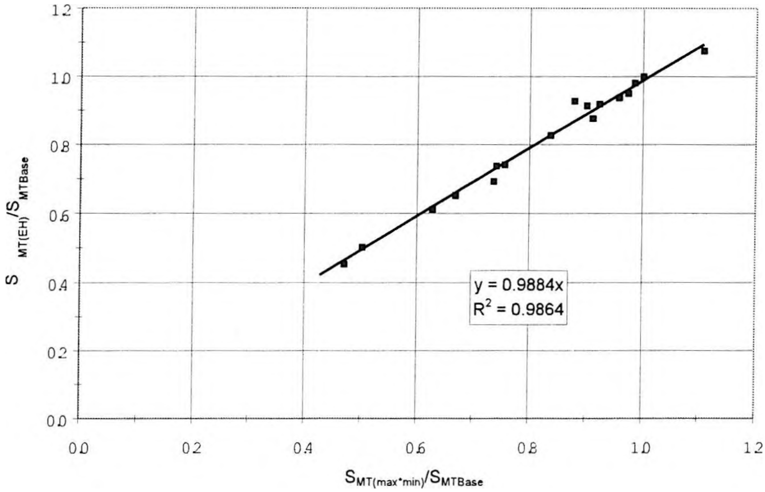

Fig. 6.2.3. Regressional connection between MT pseudo-areas obtained from the product of the values in the directions of the MT polar diagrams, ρ_{max} and ρ_{min}, and those obtained from the product of the values in the directions of the dip and strike directions determined with the vertical geomagnetic component. All values are related to the corresponding value at the base station

6.2.3. ábra. A magnetotellurikus polárdiagramokból a főtengelyek iránya szerinti ρ_{max} és ρ_{min} fajlagos ellenállásból kapott, illetve a vertikális mágneses térösszetevő szerinti csapás- és dőlésirányban meghatározott ρ_{Hpol} és ρ_{Epol} fajlagos ellenállásból kapott, a bázispontra vonatkoztatott "MT pszeudo area értékek" invariáns jellegét igazoló regressziós kapcsolat

The theoretically supposed close connection between telluric areas and magnetotelluric pseudo-areas, however, does not exist in all cases, partly due to practical difficulties, partly due to the geological model of the exploration area.

One of the possible causes of these differences is the different frequency selectivity concerning the variations used in the telluric and magnetotelluric data processing. The period (23.2 s) given for the MT values, really represents a narrow range of frequencies for the corresponding data. In contrast the period range was, as mentioned previously, 18 s < T< 28 s, but the superposed effect of even longer periods cannot be excluded due to the manual selection and processing method.

According to the MT soundings, ρ_{max} values are within the so-called S-range, i.e. the conductance computed from the area values. ρ_{max} values are only slightly influenced by the width of the frequency range used. In contrast, many ρ_{min} values belong at this period to the section of the sounding curves which are of a descending character and correspond to the case of a low resistivity basement. The scatter of the effective conductance computed from both ρ_{max} and ρ_{min} values can sometimes be considerably increased if the width of the frequency range of the variations increases.

Figure 6.2 4 represents the connection between telluric areas and MT pseudo-areas. The straight line corresponding to the range of ±15 % with respect to the expected $m = 1$ coefficient between the two variables is also indicated. Three values outside this limit were omitted from the computation of the linear regression plotted in *Fig. 6.2.5*. The slope of the straight line so obtained corresponds quite well to the theoretically expected connection in spite of the greater scatter of the data.

Results of the study of the direction data

In the study of the TE and MT direction data it is to be taken into account that the effect leading to distortions in the areas can also influence orientation data.

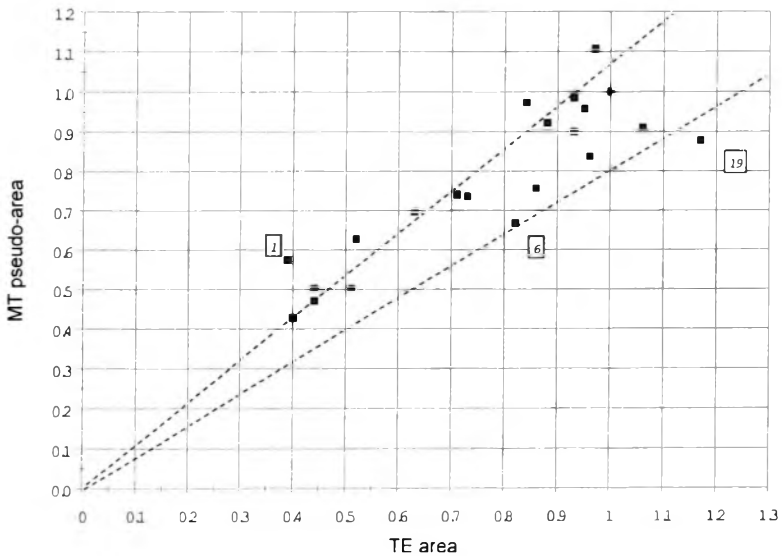

Fig. 6.2.4. Connection between telluric areas and MT pseudo-areas. Points with deviations more than ±15 % from the theoretical slope, $m = 1$ are also indicated

6.2.4. ábra. A mért tellurikus area értékek és a számított MT pszeudo area értékek összefüggése, az elméleti értékhez viszonyított ±15%-os eltérést jelentő tartományból kiütő pontok megjelölésével

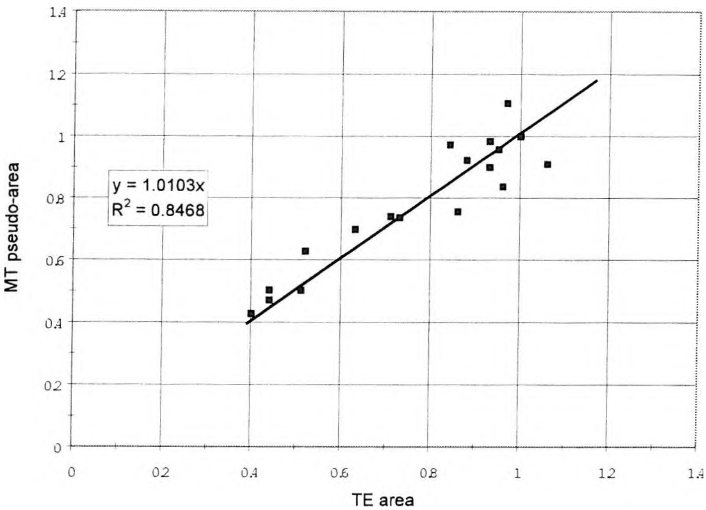

Fig. 6.2.5. Regression between measured telluric areas and computed MT pseudo areas with omission of outliers (see Fig. 6.2.4)

6.2.5. ábra. A mért tellurikus értékek és a számított MT pszeudo area értékek regressziós kapcsolata a 6.2.4. ábra kiütő pontjainak elhagyásával

It is known from the principles of the magnetotelluric interpretation of the inhomogeneous model that the directions of the *H*- and *E*-polarizations determined from the H_z component coincide exactly with the directions of the extrema of the impedance polar diagram only for models with 2-D inhomogeneities, i.e. with the strike and dip directions characteristic for the given model.

For models with general 3-D geometry the direction of the tipper strike has deviations with respect to the directions of the extrema of the impedance polar diagram according to the site of the station, with respect to the geometry of the actual model, and also depending on the mode of the polarization of the field.

Direction data are compared by using figures constructed from the data in Table 6.2.2.

Figure 6.2.6 represents the deviations between the directions of the maximum of the MT impedance polar diagram and of the major axes of the telluric absolute ellipses versus the telluric area. There is no clear trend in the deviations versus area, but only 8 values indicate a parallel or perpendicular situation between the two directions out of the 22 cases studied. In the case of the other data, i.e. for two thirds of the stations, the deviations

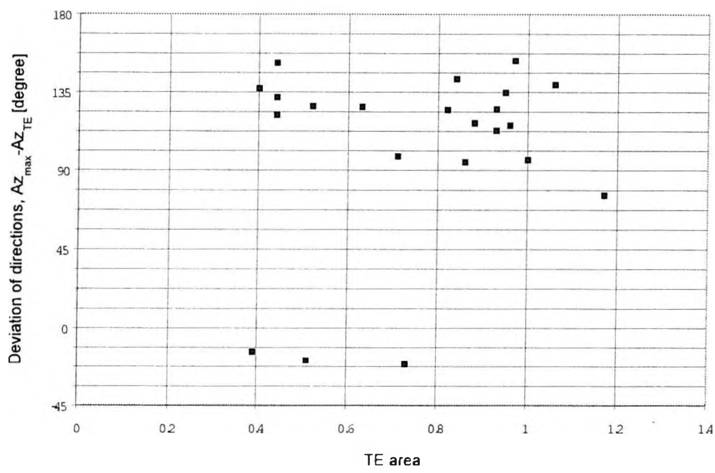

Fig. 6.2.6. Deviations between directions of the maxima of the MT impedance polar diagrams and those of major axes of the telluric absolute ellipses versus telluric area

6.2.6. ábra. A magnetotellurikus impedancia polárdiagramok maximum értékéhez tartozó irány és a tellurikus abszolút ellipszisek nagytengelyeinek iránya közötti eltérések a tellurikus area érték függvényében

are in the range 112° to 150° the most characteristic deviation being about 125°.

This result can be explained by the superposed 2-D + 3-D structure of the region being also known from borehole data and from the results of other geophysical methods.

Application of the telluric area is advantageous here as the small areas are characteristic of the northern part of the exploration region where the Palaeozoic basement is in a less deep position whereas the value $A^{-1} = 1$ corresponding to the area of the base station corresponds to Mesozoic basement in a deeper position. This Mesozoic basement is covered by volcanic formations of increasing thickness. Any trend of the areas may thus correspond to a connection with the geological model.

Figure 6.2.7 represents the deviations between MT local dip elements and the orientation of the telluric absolute ellipses versus the telluric area. The situation here is quite different: deviations of about 135° are characteristic for only 4 cases, nearly perpendicular direction was found in one case, and in the remaining 77 % of the stations the deviations were between –22° and +12° which indicates — taking into account the possible inaccuracies in determining the directions — that the orientation of the telluric absolute

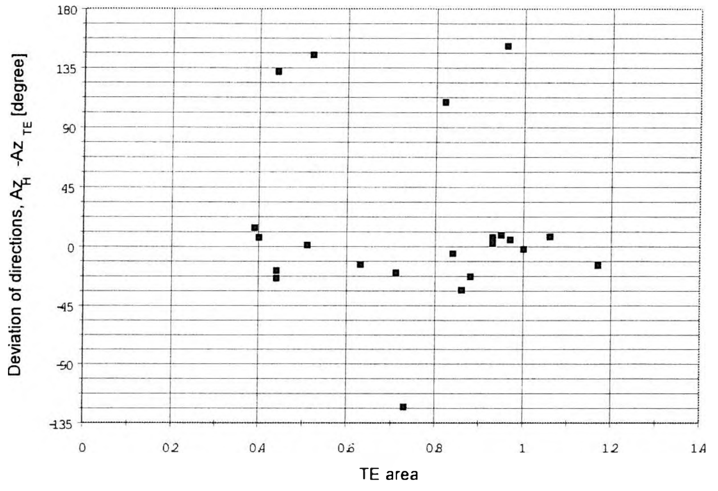

Fig. 6.2.7. Deviations between directions of the major axes of the telluric absolute ellipses and those of the local dip elements determined from H_z ellipses vs. telluric area

6.2.7. ábra. A tellurikus abszolút ellipszisek nagytengely irányának a magnetotellurikus lokális dőléselemek irányához viszonyított eltérései a tellurikus area érték függvényében

ellipses corresponds in the majority of stations to the MT data corresponding to the local dip direction.

Figure 6.2.8 illustrates the conclusion following from the previous results, too, viz. that the directions of the maxima of the MT impedance polar diagrams and of the local dip elements determined from the H_z component seldom have characteristics of a 2-D structure (i.e. perpendicular or parallel directions), the deviations between the directions are mostly in the range 112° to 150°. These deviations can be considered as resulting from the superposition of 2-D and 3-D models.

6.2.4. Conclusions

A study of the telluric parameters has shown that values obtained from the transformation of the absolute ellipses and those obtained with the method of the straight lines are the same.

The directions obtained from transforming the absolute ellipses have different relationships with the orientations of the relative telluric ellipses.

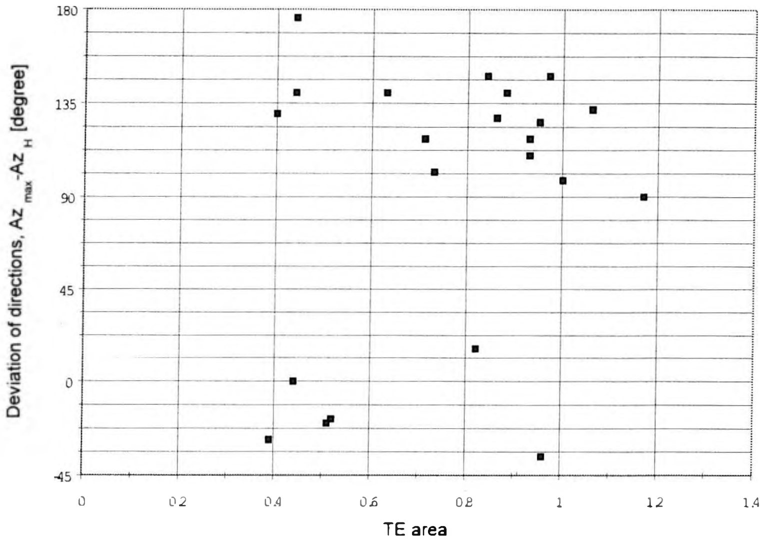

Fig. 6.2.8. Deviations between directions of the maxima of the MT impedance polar diagrams and those of the local dip elements determined from H_z ellipses vs. telluric area

6.2.8. ábra. A magnetotellurikus impedancia polárdiagramok maximum értékeinek iránya és a H_z ellipszisekből meghatározott lokális dőlésirány eltérései a tellurikus area érték függvényében

The validity of the results obtained by this comparison has been verified by a comparison with the magnetotelluric parameters.

In a half-space with 3-D inhomogeneity the direction of the extrema of the impedance polar diagrams and the directions of the *H*- and *E*-polarizations may deviate from each other due to the laws of the distribution of magnetotelluric fields. This phenomenon was apparent in the present investigation, too.

Consideration of the consequences of this phenomenon reveals that the two kinds of effective conductivities: those determined from the ρ_{max} and ρ_{min} values and those determined from the resistivities ρ_{Hpol} and ρ_{Epol}, where the resistivities are computed in different directions, coincide; the effective conductance is invariant.

The direction of the major axes of the transformed absolute ellipses corresponds for the majority of the stations, in more than 75% of them to the MT dip element (to the direction perpendicular to the local strike determined from the H_z component); in the remaining cases the direction corresponded to the direction of the ρ_{max} resistivity. It follows that absolute ellipses resulting from the transformation have orientations that are in a close connection with the directional characteristics of the geoelectric model.

Transformation using the absolute ellipse of the TE base station is a suitable means of enhancing directional characteristics without changing areas.

Determination of the directions of the field polarization modes is impossible from the transformed telluric absolute ellipses without the magnetotelluric H_z information, therefore transformed telluric absolute ellipses cannot be used for the absolute orientation of the structural strike and dip directions.

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6.2. FEJEZET

Relatív és abszolút tellurikus irányinformációk és kapcsolatuk a magnetotellurikus irányokkal, tapasztalati adatok alapján

NAGY Zoltán és LANDY Kornélné

Egyrészt bemutatják, hogy Kunetz nyomán miként szerkesztettek tellurikus bázisaikon a primér tér sajátságait kiküszöbölő abszolút (állomás) ellipszist, majd az ezekre transzformált relatív ellipszisek milyen kapcsolatba hozhatók a földtani ismeretekkel. (Pl. az ellipszisek irányítottsága, excentricitása egészen más a Rába-vonal két oldalán). Másrészt 17 kitüntetett állomáson összehasonlították a fenti módszerekkel nyert tellurikus információkat a megnetotellurikus információkkal és megállapítják, hogy megfelelő pontosságú mérésekkel mindkét módszerrel hasonló eredményekre lehet jutni.

ABOUT THE AUTHORS

Zoltán Nagy for a photograph and biography, see this issue, p. 133

Ilona Landy graduated in geophysics from the Eötvös Loránd University of Sciences in 1972. She began working at the Geoelectric Department of the Geophysical Exploration Co. of the National Oil and Gas Trust, dealing with the magnetotelluric method. She carried out various tasks associated with this method, from computer program development to interpretation of the results of field measurements.

During this period she participated in more than 40 geoelectric reports. She is author or co-author of over 25 publications, primarily dealing with telluric and magnetotelluric and associated topics. Since January 2000 she has been an independent geophysics consultant.

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CHAPTER 6.3

Equipotential lines and current threads in areas densely covered by telluric measurements

József VERŐ* and József ZÁVOTI*

A description is given of the method developed to construct the equipotential lines and current threads perpendicular to those, assuming a primary current field of arbitrary direction. After having solved the complicated mathematical problem the authors of this section constructed the equipotential lines and current threads for the Magyarmecske anomaly, assuming a primary current field rotated by 30°. The equipotential surfaces constructed in this way provide an extremely clear, almost 3-D image of the anomaly.

Keywords: tellurics, Magyarmecske, Hungary

6.3.1. Introduction

The dimensions of relative ellipses computed from telluric (earth current) measurements (referred to a base station) do not exhaust the information content of such measurements. Moreover, the relative ellipse itself omits one of the four parameters obtained, even if the change of the ellipse dimensions with the period of the applied variations is neglected. The area of the ellipse contains only two of the four parameters resulting from the measurements for a given period, viz. lengths of the semi-major and semi-minor axes, but it does not contain the direction of the major axis nor the deviation of the direction of the primary electric field — this is perpendicular to the direction of the magnetic field — from the direction of the observed electric field for a given direction of the primary electric field, e.g. in the direction of the major axis. Other combinations of the parameters can

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also be used but the conclusion remains the same. Nevertheless, methods can also be developed which use more of the results of the telluric measurements. Such a method is to plot equipotential lines or current threads for a given direction of the primary electric field, then to rotate the primary field by certain steps and then repeat the calculation. Thus two series of maps can be constructed from the results. The map constructed from the equipotential lines presents high resistivity formations by dense isolines, low resistivity formations by sparse isolines. In contrast, the map of the current threads has densifications over low resistivity zones, and sparse lines over high resistivity formations. If, say, the primary field is rotated by 30° each time, up to 150°, then a composite map from six will show high and low resistivity zones, independently of direction. Similar maps have already been constructed for ionospheric currents for different directions of the geomagnetic field, and the results were presented as a movie. This movie proved to be very informative. A somewhat similar method has also been used for the presentation of internal stresses, where the changing direction was that of the external force. These positive examples led to the idea to construct such maps from the measurements of the geoelectric field for selected area(s). These maps conserve the fourth parameter from the information of the measurements, too, i.e. they reflect better the actual geological situation and help to increase the efficiency of the exploration.

6.3.2. Computation of the telluric vector for electric fields of arbitrary direction from the parameters of relative ellipses and the potential difference between two points from gradients

The results of telluric measurements are the parameters of relative ellipses referred to a suitable base. The data of these ellipses are, in addition to the co-ordinates of the site, the lengths of the semi-major and semi-minor axis and the direction of the one of the axes, e.g. of the major axis. The area of the ellipse is inversely proportional to the conductivity of the geological formations below the measurement point, the direction (e.g. of the major axis) and the eccentricity (the ratio of the major to the minor axis) characterize the distortion of the field in the measurement area. This formulation is very loose as many factors influence the mentioned parameters. Such a factor is the period of the pulsations or other variations used for the construction as these determine the penetration depth of the corresponding currents. For the S-interval (identified on magnetotelluric sounding curves in a system of co-ordinates log T—log ρ by a branch increasing at 45° which indicates a constant transfer function between the magnetic and electric fields (impedance tensor)) in the corresponding range of periods hinting at a constant total horizontal conductance of the layers within the penetration depth, the basement below the sedimentary cover is taken to be non-conductive. If we suppose that telluric measurements are carried out just in this range, it means that absolute ellipses refer both at the base and at the roving station to the S-interval, in which case the transfer function between the two fields, the relative ellipse, does not depend on the period. The absolute ellipse would mean the geometric place of the endpoints of telluric vectors in the case of (magnetic, or perpendicularly to them oriented) electric variations when the endpoints of the electric (telluric) vectors at a station over a completely homogeneous substratum (homogeneous semi-sphere below the station) would be a circle of unit radius for corresponding magnetic vectors of unit length.

Absolute ellipses are determined by four parameters, i.e. the telluric vectors of the roving station corresponding to two telluric vectors of the base station not in the same direction (according to what was said earlier) the endpoints of the vectors of the base station lie on the unit radius circle. As from the earlier routine processing of the measurements only three parameters are available instead of the four, not all data of the absolute ellipse can be determined from them, and some supposition is necessary concerning the fourth parameter. The most appropriate assumption is that the structure is 2-D, i.e. there is no angular distortion in the direction of the major and minor axes of the ellipses of the primary and secondary (neither at the base station nor at the roving station) electric fields, the direction of both vectors in the direction of the two axes remains the same after the transformation at both stations. With this supposition, the electric field vector at the roving station can be computed for a vector of arbitrary direction of the primary field (assumed to be of unit length).

Using the method outlined in the previous section, the electric vectors of all points of a regional survey can be computed corresponding to a primary electric field of unit vectors in an arbitrary direction, having an angle φ with the direction north. As the electric field is rotation-free, the sum of the potential differences in a triangle composed of three arbitrary points must be zero. In other words if we start from an arbitrary point and compute the sum of the potential differences along the sides of a triangle, then the sum must be zero (or if the potentials are computed at the points as far as the initial point in an arbitrary closed path, the original initial potential value must be obtained). The task is theoretically the same as the processing of the Eötvös torsion balance measurements, when the values of g are determined from measured gradients of the gravity field. The problems emerging in the computations are the same, too. In other words at first the sum of the computed potential differences is not the same using the measured values. In comparison with the gravity field, the parameters of the telluric absolute ellipse are valid with an acceptable error in an area being different (mostly smaller) from that of the validity of the gradients of the torsion balance measurements. Therefore the source of the errors in the case of gravity measurements lies mostly in measurement and computational inaccuracies, while in the case of the telluric field, it is mostly due to regular errors, i.e. to errors due to the fact that the electric field is not always correctly described by the electric vectors measured (more exactly, computed) at the endpoints of the section between the two points, as an arbitrary electric inhomogeneity may occur between the two stations. Therefore the closure errors are expected to be relatively greater in the triangles than in the case of gravity measurements. This phenomenon is the more likely the larger the (absolute or relative) ellipses and the greater their eccentricity. Both characteristics, large dimensions and high eccentricity of the ellipses are due to the relatively thin conducting sediments, therefore the method will fail in areas covered by thin sedimentary layers. This is why telluric measurements have a small amount of information in hilly or mountainous regions. It would be easy to define some kind of area of representativeness for telluric stations, where the dimensions of the area would be proportional to the thickness of the sedimentary layers, or more correctly, to the horizontal conductance of the sedimentary cover.

Nevertheless, the omission of the areas with thin sedimentary cover influences the telluric field in the neighbouring regions. As the electric field is also free of divergence, current threads must be continuous everywhere. The omission of an area which is avoided by most current threads influences the current distribution in distant areas, too. As the coverage necessary for an exact computation of the current threads cannot be achieved in such regions (necessary distances between stations of a few hundred m), this fact must be accepted as unavoidable. In contrast, the dimensions of the ellipses are representative for greater areas, as the thin sedimentary cover occupies a greater region.

The previous discussion has shown that several approximations are necessary for plotting equipotential lines (or current threads). There is, however, an additional problem. The task is essentially the solution of a set of differential equations and, accordingly, boundary conditions should be given, too. One such boundary condition would be, for example, that the field is homogeneous at considerable distances from the measurement area, but such a homogeneous field cannot be determined from the measurement data themselves. There are two possible solutions. The first is simply to neglect boundary conditions and to suppose that the potential at one point, e.g. in the gravity centre, is zero, and the potential values are then computed using this initial value. (It would be possible here to use a rigorous adjustment but this would be rather complicated and tedious with respect to the result, as in each case a system of equations consisting of several hundred equations should be solved and what would be especially difficult to handle is an outlier that would falsify all the computed data in a previously unaccountable manner.) The other possibility is to suppose a homogeneous field along a geometrical figure, e.g. an ellipse which includes the complete measurement area, and the magnitude of the homogeneous field is fitted experimentally to the existing measured and computed values so that the result would best fit to them. This solution similarly involves difficult problems of computation techniques. Neither the rigorous adjustment nor the experimentation with the boundary conditions is impossible; nevertheless, for the present purpose a simpler and easily usable method is needed. Even in this case the computational problems are considerable.

The steps of the computation are thus the following: at first the area of the whole data set is to be covered by a network of triangles using an appropriate program, then the electric potentials are computed along the sides of the triangles, and after adequate adjustment the final potentials are obtained. By interpolation within the triangles, the equipotential lines can be plotted. Current threads are everywhere orthogonal to equipotential lines.

These computations were carried out for two smaller areas and some parts of the results are presented in *Figs 6.3.1–6.3.3*. The difficulties that emerged during these computations, are the following:

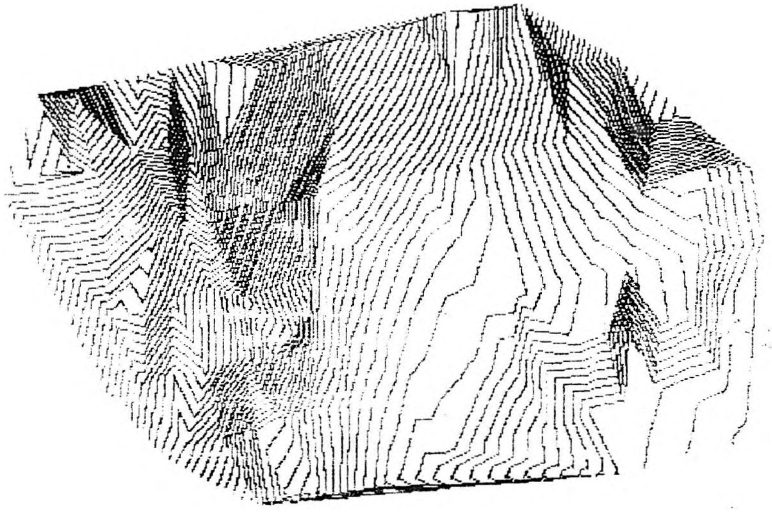


Fig. 6.3.1. Isolines of the equipotential surfaces in the Magyarmecske area at 0° to the primary electric field

6.3.1. ábra. Az ekvipotenciális felületek izovonalai a Magyarmecske területen 0°-os irányú primér elektromos tér esetén

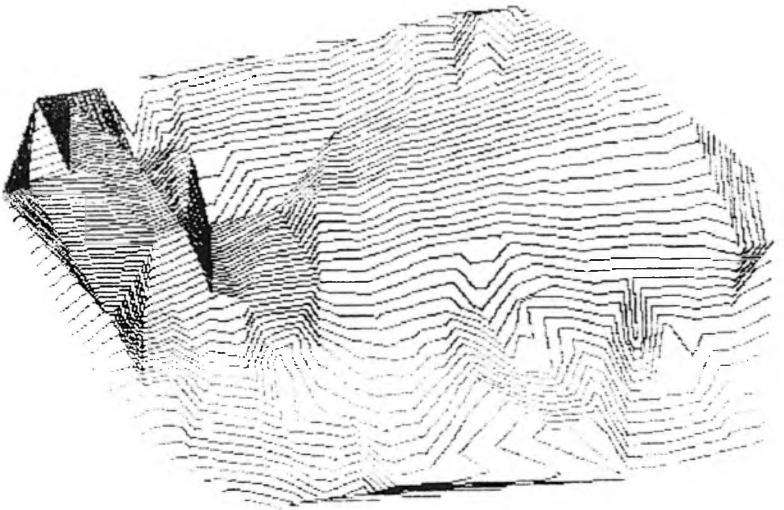
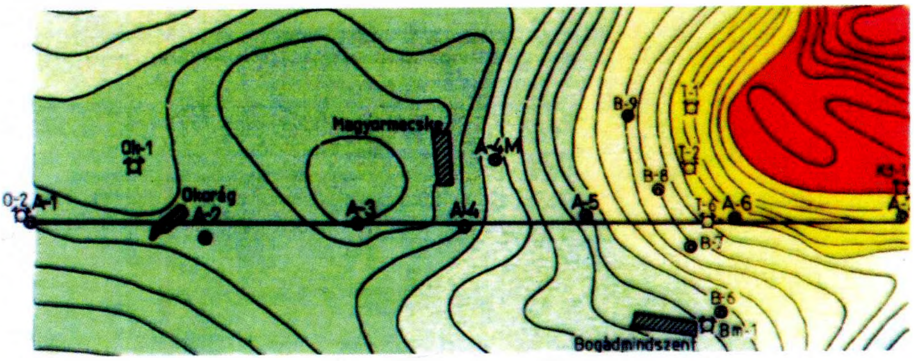
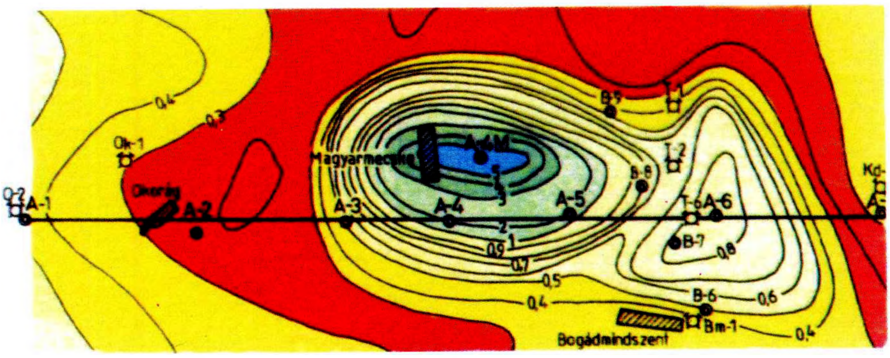


Fig. 6.3.2. Isolines of the equipotential surfaces in the Magyarmecske area at 90° to the primary electric field

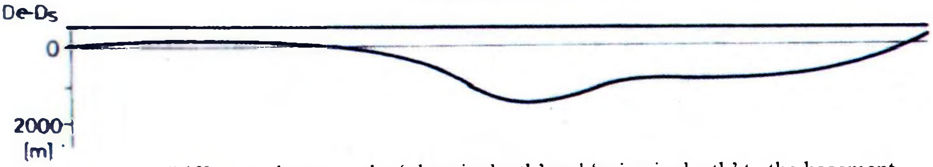
6.3.2. ábra. Az ekvipotenciális felületek izovonalai a Magyarmecske területen 90°-os irányú primér elektromos tér esetén



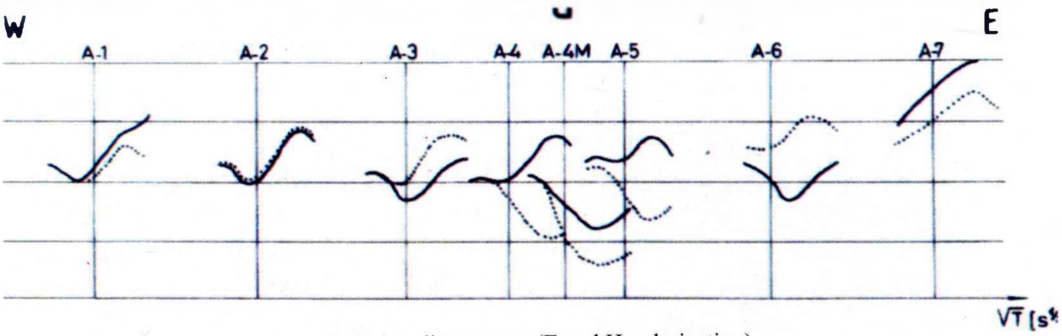
Bouguer-anomaly map
Bouguer-anomália térkép



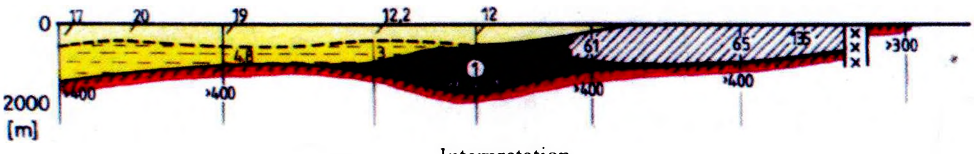
Telluric isoarea map
Tellurikus izoarea térkép



Difference between the 'electric depth' and 'seismic depth' to the basement
Az "elektromos" és a "szeizmikus" aljzatmélység különbsége



MT sounding curves (E and H polarization)
MT szondázási görbék (E és H polarizáció)



Interpretation
Értelmezés

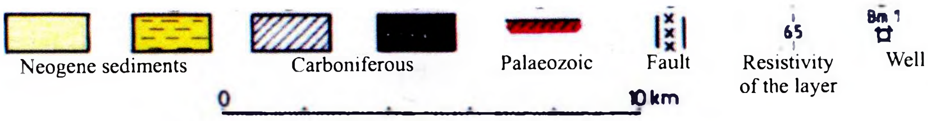


Fig.5.10 Magyarmecske region
5.10.ábra Magyarmecske térsége

a) Some of the triangles, especially those at the boundary of the area, are very elongated. The simplest method to eliminate them is to omit such triangles so that the determination of the potential should remain possible.

b) According to what was said above, in areas where ellipses are very large, determination of the equipotential lines is less reliable. If a more dense network is not possible, and some points strongly distort the result, again the omission of such points is recommended, the deviations being measurement errors or due to near-surface distortions (small area of representativeness for these points). The latter is most often the case.

c) Areas with large absolute ellipses/thin conducting sedimentary cover distort the potentials and currents in a greater area. No solution is possible for this problem without measurements in a greater area.

d) If new measurements are available at the boundary of the original area, the whole computation must be repeated, new points can only be added to the original ones in this way.

The examples presented in Figs 6.3.1– 6.3.3 illustrate the situation in the case of the Magyarmecske area. In addition to certain distortions (which could be eliminated) the deep areas can be identified, whereas the form and the depth of the structure are expressed by the distortion of the primary field in the case of different directions. More exactly, the anomaly is of the same magnitude in the case of all primary current directions, while in the case of 2-D anisotropy, the anomaly disappears in one direction, in the perpendicular direction it is of maximum magnitude, depending on the *E*- and *H*-polarizations, respectively. In the case of a thin sedimentary cover, many random elements play a significant role, and no direction-correct representation is expected. The density of the lines indicates, however, the characteristics of the structures. If a regional field were to be separated, the 2-D representation could even more enhance local, residual anomalies. For this, the determination of the regional field would be a further problem. The density of the lines is in inverse relationship with the horizontal conductance below the station (for equipotential lines), and the relationship is direct for the density of the current threads, being perpendicular to the equipotential lines.

SUPPLEMENT

A) Computation of the potential difference between two points for a (magnetic, or perpendicularly to it) primary electric field

At first each electric field vector is computed at a single point. Geodetic co-ordinates of the point are *x, y,* the data of the absolute ellipse *A, B,* α. We use a system of co-ordinates with the axis *X* pointing north, *Y* to east, and the rotation is clockwise. The vector of the primary electric field is a unit vector in the φ direction.

Computation of the coefficients *a, b, c, d* of the transfer function from the parameters *A, B,* α of the absolute station ellipse takes place in the following way supposing no direction distortion in the directions of the axes (this is a necessary condition; it is perhaps necessary to use weights in the following so that more eccentric ellipses have lower weights).

The co-ordinates of the endpoints of a vector having the length of the semi-major axis (*A*) and pointing in the α direction are X_A, Y_A, those of a perpendicular vector having the length of the semi-minor axis (*B*) are X_B, Y_B (*Fig. 6.3.4*).

$$X_A = A\cos\alpha; \qquad Y_A = A\sin\alpha$$

$$X_B = B\cos(\alpha+90°) = -B\sin\alpha; \qquad Y_B = B\sin(\alpha+90°) = B\cos\alpha$$

X_0, Y_0 is a unit vector in the direction of the major axis,

X'_0, Y'_0 of the minor axis.

$$X_A = a\,X_0 + b\,Y_0 = a\cos\alpha + b\sin\alpha = A\cos\alpha$$

$$Y_A = c\,X_0 + d\,Y_0 = c\cos\alpha + d\sin\alpha = A\sin\alpha$$

$$X_B = a\,X'_0 + b\,Y'_0 = a\sin\alpha - b\cos\alpha = B\sin\alpha$$

$$Y_B = c\,X'_0 + d\,Y'_0 = c\sin\alpha - d\cos\alpha = -B\cos\alpha$$

From the solution of these four equations:

$$a = A\cos^2\alpha + B\sin^2\alpha; \qquad d = B\cos^2\alpha + A\sin^2\alpha$$

$$b = \frac{A-B}{2}\sin 2\alpha; \qquad c = \frac{A-B}{2}\sin 2\alpha$$

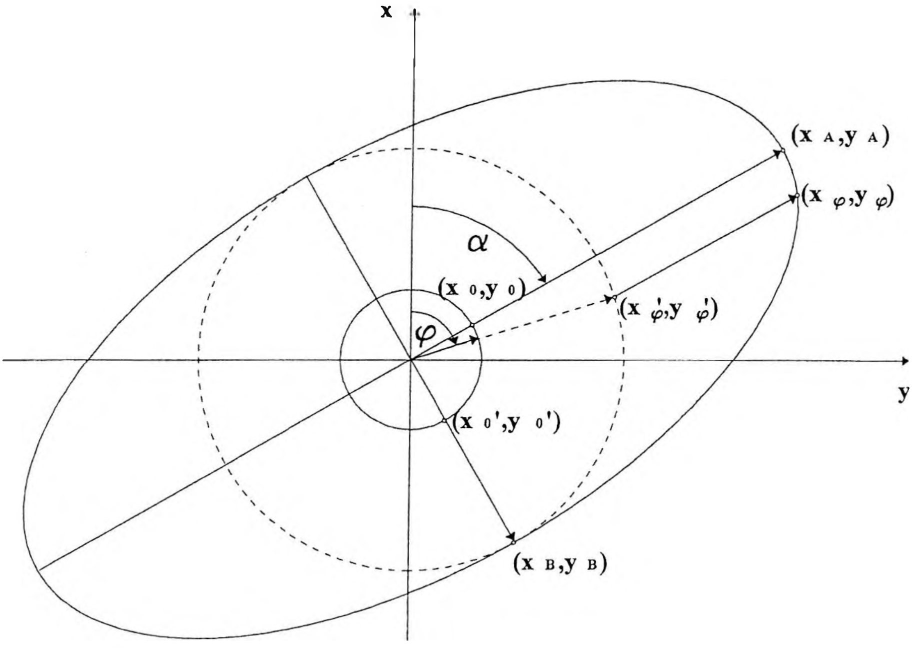


Fig. 6.3.4. Identification of the point belonging to the unit vector in the direction φ on the station ellipse. Point (X_φ', Y_φ') is the point on the circle with the radius b projected in direction φ, this point is then projected in direction α of the major axis to the ellipse. The point (X_φ, Y_φ) obtained so has the direction ψ (not plotted in the figure). Point (X_A, Y_A) in the direction of the major axis is exactly the projection of the unit vector (X_0, Y_0) in the same direction, while the endpoint (X_B, Y_B) of the minor axis corresponds to the unit vector (X_0', Y_0') in the same direction, thus no direction distortion is supposed in these directions

6.3.4. ábra. A φ irányú egységvektorhoz tartozó pont keresése az állomásellipszisen. A φ irányban megkeressük a kistengely b sugarával húzott körön fekvő (X_φ', Y_φ') pontot, majd ezt a nagytengely α irányában vetítjük az ellipszisre. A kapott (X_φ, Y_φ) pont irányszöge, ψ nincs az ábrán feltüntetve. A nagytengely α irányában fekvő (X_0, Y_0) egységvektornak éppen a nagytengely (X_A, Y_A) végpontja, a kistengely irányában fekvő (X_0', Y_0') egységvektronak pedig a kistengely (X_B, Y_B) végpontja felel meg, tehát ezekben az irányokban iránytorzulást nem tételeztünk fel.

Now the gradient can be computed in an arbitrary φ direction always supposing that there is no distortion in the directions of the axes (*Fig. 6.3.5*):

$$X_{\varphi,1} = a\cos\varphi + b\sin\varphi$$

$$Y_{\varphi,1} = c\cos\varphi + d\sin\varphi$$

$$G_{\varphi,1} = \sqrt{X_{\varphi,1}^2 + Y_{\varphi,1}^2}$$

The direction of this vector is:

$$\tan\psi_1 = \frac{Y_{\varphi,1}}{X_{\varphi,1}}$$

This computation is to be carried out for each corner point of the triangle, then the lengths l and the directions (β) of the sides are also to be computed — being for example P_1P_2:

$$\tan\beta_{1,2} = \frac{y_2 - y_1}{x_2 - x_1}; \qquad \tan\beta_{1,3} = \frac{y_3 - y_1}{x_3 - x_1}; \qquad \tan\beta_{2,3} = \frac{y_3 - y_2}{x_3 - x_2}$$

$$l_{1,2} = \sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} \quad \text{etc.}$$

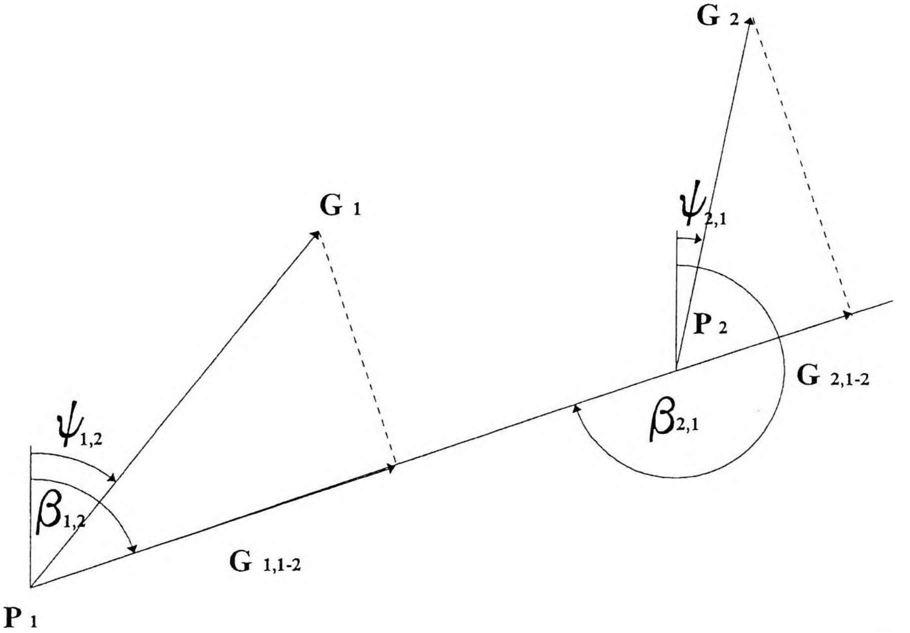


Fig. 6.3.5. The potential difference between the two points (P_1, P_2) in the direction $\beta_{1,2}$ and $\beta_{2,1}$ respectively is computed with the corresponding gradients $G_{1,1-2}$ and $G_{2,1-2}$, respectively, which are projections of the gradient vectors having the directions $\psi_{1,2}$ and $\psi_{2,1}$ respectively

6.3.5. ábra. A $\beta_{1,2}$ illetve $\beta_{2,1}$ irányban lévő két pont (P_1, P_2) közötti potenciálkülönbség számítása. A $\psi_{1,2}$ illetve $\psi_{2,1}$ irányú gradiensvektorokat a β irányra vetítve kapjuk meg a kérdéses irányú gradiensek $G_{1,1-2}$, illetve $G_{2,1-2}$ értékét a végpontokban

The projection of $G_{\varphi,1}$ can now be computed in the $\beta_{1,2}$, direction and also the projection of $G_{\varphi,2}$ in the opposite direction $\beta_{2,1}$

$$G_{1,1-2} = G_{\varphi,1} \cos(\beta_{1,2} - \psi_1)$$
$$G_{2,1-2} = G_{\varphi,2} \cos(\beta_{2,1} - \psi_2)$$

If $G_{1,1-2}$ and $G_{2,1-2}$ are known, the electric potential can be computed between points 1,2 (s is the distance along the actual side, s_{max} its end-point):

$$E(s) = p s^2 + q s + E_1$$

$$\frac{dE(s)}{ds} = 2p s + q; \qquad \frac{dE(1)}{ds} = q = G_{1,1-2}; \qquad \frac{dE(2)}{ds} = 2p\, s_{max} + G_{1,1-2} = G_{2,1-2};$$

$$p = \frac{G_{2,1-2} - G_{1,1-2}}{2s_{max}}$$

$$E(s) = \frac{G_{2,1-2} - G_{1,1-2}}{2s_{max}} s^2 + G_{1,1-2}\, s + E_1$$

The potential difference between the two points is thus the same from this computation as if the average of the two gradients would be multiplied by the length of the distance between the two points, and this value would be added to the potential of point 1. This can immediately be seen from the last equation by substituting $s = s_{max}$.

B) Interpolation along the sides of a triangle

The electric potential between the three points of a triangle are:

$$E_1(s) = e_1 + q_1 s + p_1 s^2 \qquad E_2(s) = e_2 + q_2 s + p_2 s^2 \qquad E_3(s) = e_3 + q_3 s + p_3 s^2$$

The derived functions are:

$$\frac{dE_1(s)}{ds} = q_1 + 2p_1 s \qquad \frac{dE_2(s)}{ds} = q_2 + 2p_2 s \qquad \frac{dE_3(s)}{ds} = q_3 + 2p_3 s$$

Continuity equations at the node points (1,2) and (2,3) of the triangle can also be written as follows:

$$E_1(s_{12}) = E_2(0)$$

and

$$E_2(s_{23}) = E_3(0)$$

From the previous formulae it follows that

$$e_1 + q_1 s_{12} + p_1 s_{12}^2 = e_2 \qquad e_2 + q_2 s_{23} + p_2 s_{23}^2 = e_3$$

Thus the potential differences are along the sides of the triangle:

$$E_1(s) = e_1 + G_{1,1-2}s + \frac{G_{2,1-2} - G_{1,1-2}}{2s_{12}} s^2 \qquad 0 \le s \le s_{12}$$

$$E_2(s) = E_1(s_{12}) + G_{2,2-3}s + \frac{G_{3,2-3} - G_{2,2-3}}{2s_{23}} s^2 \qquad 0 \le s \le s_{23}$$

$$E_3(s) = E_2(s_{23}) + G_{3,3-1}s + \frac{G_{1,3-1} - G_{3,3-1}}{2s_{31}} s^2 \qquad 0 \le s \le s_{31}$$

The contradiction is on the periphery of the triangle:

$$E_3(s_{31}) - E_1(0)$$

In detail, the following formula is obtained:

$$\frac{G_{1,3-1} + G_{3,3-1}}{2} s_{31} + \frac{G_{3,2-3} + G_{2,2-3}}{2} s_{23} + \frac{G_{2,1-2} + G_{1,1-2}}{2} s_{12}$$

The contradiction is zero only if

$$(\overline{\mathbf{G}}, S) = 0$$

where $\overline{\mathbf{G}}$ is the average electric field vector

$$S = (s_{31}, s_{23}, s_{12})^T$$

The program computes in its present form the average of the contradiction in the triangle fitting to this point.

As this method computes the electric potential along the sides of the triangle and a linear interpolation is carried out within the triangles, the isolines of the potential are broken. This can be avoided if a surface is fitted to the triangles where the gradients are given. Moreover it can be prescribed that parts of the surface should continuously join to each other along the sides.

C) Interpolation of a function with two variables

A second order polynomial in the variables *x, y* is fitted to each triangle.

$$f(x,y) = a_{20}x^2 + 2a_{11}xy + a_{02}y^2 + 2a_{10}x + 2a_{01}y + a_{00}$$

The gradient of the function *f(x, y)* is to be deduced:

$$\begin{bmatrix} f_x \\ f_y \end{bmatrix} = \begin{bmatrix} a_{20}x & + a_{11}y & & + a_{10} & \\ & a_{11}x & + a_{02}y & & + a_{01} \end{bmatrix}$$

The gradients are known at each corner point of the triangle, thus the following equations can be written:

$$\begin{pmatrix} X_{9,1} \\ Y_{9,1} \\ X_{9,2} \\ Y_{9,2} \\ X_{9,3} \\ Y_{9,3} \end{pmatrix} = \begin{pmatrix} x_1 & y_1 & 0 & 1 & 0 \\ 0 & x_1 & y_1 & 0 & 1 \\ x_2 & y_2 & 0 & 1 & 0 \\ 0 & x_2 & y_2 & 0 & 1 \\ x_3 & y_3 & 0 & 1 & 0 \\ 0 & x_3 & y_3 & 0 & 1 \end{pmatrix} \begin{pmatrix} a_{20} \\ a_{11} \\ a_{02} \\ a_{10} \\ a_{01} \end{pmatrix}$$

In matrix form:

$$\mathbf{g} = \mathbf{A}\mathbf{a}$$

The adjustment theory yields for the coefficients of the polynomial the following equations:

$$\mathbf{a} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{g} = \mathbf{N}^{-1}\mathbf{n}$$

where

$$\mathbf{N} = \begin{pmatrix} \sum_1^3 x_i^2 & \sum_1^3 x_i y_i & 0 & \sum_1^3 x_i & 0 \\ & \sum_1^3 x_i^2 + y_i^2 & \sum_1^3 x_i y_i & \sum_1^3 y_i & \sum_1^3 x_i \\ & & \sum_1^3 y_i & 0 & \sum_1^3 y_i \\ & & & 3 & 0 \\ & & & & 3 \end{pmatrix}$$

$$\mathbf{n} = \begin{pmatrix} x_1 X_{9,1} & + x_2 X_{9,2} & + x_3 X_{9,3} & & & \\ y_1 X_{9,1} & + y_2 X_{9,2} & + y_3 X_{9,3} & + x_1 Y_{9,1} & + x_2 Y_{9,2} & + x_3 Y_{9,3} \\ y_1 Y_{9,1} & + y_2 Y_{9,2} & y_3 Y_{9,3} & & & \\ X_{9,1} & + X_{9,2} & + X_{9,3} & & & \\ Y_{9,1} & + Y_{9,2} & + Y_{9,3} & & & \end{pmatrix}$$

This method enables us to determine 5 coefficients out of the 6 of the polynomial. In order to determine the sixth coefficient let us consider the triangle which contains the centre of gravity of the data set. At the corner point lying nearest to the gravity centre we set $f(x, y) = 0$. This condition can be fulfilled for each triangle containing this corner point. Thus, all parameters can be computed for these triangles. In the neighbouring triangles the sixth parameter can be computed from the condition that $f(x, y)$ has at the common corner point the value which was determined from the already known triangles. All triangles can be included by looking for neighbouring triangles.

6.3. FEJEZET

Ekvipotenciális vonalak és áramfonalak tellurikus mérésekkel sűrűn befedett területen

VERŐ József és ZÁVOTI József

A soproni Akadémiai Intézet kutatói kidolgoztak egy eljárást az ekvipotenciális vonalak és az ezekre merőleges áramfonalak megszerkesztésére, tetszőleges irányú primér áramteret feltételezve. A jelentős matematikai probléma megoldása után a magyarmecskei anomália ekvipotenciális vonalait és áramfonalait szerkesztették meg 30 fokonként elforgatott primér áramirányt feltételezve. A megszerkesztett ekvipotenciális felületek rendkívül szemléletes, mintegy 3D leképezését mutatják az anomáliának.

ABOUT THE AUTHORS

József Verő for a photograph and biography, see this issue, p. 133

József Závoti (1949) graduated in applied mathematics from the Eötvös Loránd University of Sciences. Since 1975 he has been working at the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences in Sopron. At present he is the director of the Institute. The topic for his thesis was digital terrain modelling and its application in geodesy. His present field of research relates to the application of robust estimation methods for various problems in geodesy. He holds a D.Sc. awarded by the Technical University of Budapest. Since 1998, he has been a professor at the University of Western Hungary lecturing in mathematics.

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CHAPTER 7
Comparative study of the telluric map with geological and other geophysical investigation results

László NEMESI*

There are cases when a certain geological exploration task or a specific raw material prospecting problem can be prepared or solved by a given geophysical method and there is absolutely no need to apply other methods. A well can be located, mine opening can start, etc. Such target-oriented explorations can be designed based on already known geology and earlier gained local experience.

For instance raw material investigations might utilize geomagnetic measurements in prospecting for magnetite-bearing iron ores, induced polarization for the exploration of sulphide ores, various direct and alternating current geoelectric measurements in groundwater prospecting, or the seismic method for hydrocarbon exploration in deep sedimentary basins.

Some 50–80 years ago such methods were gravity-based, then later the telluric method was used in hydrocarbon investigation; such methods were capable of providing a qualitative image of the sedimentary basins, of the buried structures in their basement, based on which anticline structures could be found. Today, these so-called mapping or potential field geophysical methods have a preparatory role in regional basic investigations. If we omit these well-tried methods l' orders of magnitude cheaper than seismics l' in the hope of quick raw material discovery, we might well end up paying a very high price.

It should not be forgotten that regional investigation results of gravity, geomagnetic and telluric–magnetotelluric methods providing infor-

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mation covering several km, or even several 10 km depth intervals can be used to solve a whole variety of tasks, e.g. geothermal energy investigation, safety studies before constructing nuclear power plants, barrage systems or other large facilities.

A vast amount of experience has proved that certain geological information can be obtained just from a comparative study of the results of different methods. When anomaly maps obtained from measuring two different physical parameters show different images, this has at least such importance in the understanding of basins and their basement structure as if we saw an ideal agreement.

Complementation or comparison of the results of telluric measurements with other methods have been performed since the very beginning with the aim of narrowing the reasons for the ambiguity of the anomalies. On the one hand, we can learn from comparative studies whether or not we have reached the basic objective of the study and, on the other hand, the comparative studies have sometimes led to unexpected, previously unknown results. (Some such results can already be understood today but there are items of information that cannot as yet be interpreted unambiguously l' though it is to be hoped that we can benefit from these results some day.)

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CHAPTER 7.1
Depth to the basement and the telluric conductance

László NEMESI*

The author compares the basement depths from wells penetrating the pre-Tertiary basement with the conductance measured (interpolated) there. He states that as a first approximation the telluric map of Transdanubia is proportional to the basement depth, disregarding some smaller or larger sub-areas. Changes in the physical parameters of sedimentary sequences lying deeper than 2500 m, e.g. higher resistivity, are remarkable.

Keywords: tellurics, conductance, basement

Similarly to all geophysical methods, in tellurics as well, the first experimental telluric measurements were carried out in the 1950s between wells penetrating the basement, mostly along refraction seismic profiles to decide the usefulness of the method (Ernő Takács, András Erkel). Initial research showed at that time that basins filled with young (Palaeogene, Neogene and Quaternary) sediments and their basement can qualitatively be investigated with this method, but imaging was known to be inaccurate as it is not proportional to depth. More exactly, over smaller areas the relationship between the basin depth and conductance of sediments is linear, but larger areas can be characterized either by separated straight lines, or the linearity might even completely deteriorate. Because of this and other factors already mentioned, telluric measurements in Hungary have never been applied exclusively, without corrections and checking with results obtained from other methods.

In spite of this, it is of interest to see the extent to which the telluric method alone was suitable for investigating basins filled with low resistivity sediments. The simplest way to decide this is to compare the basement

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depth data determined from wells with the corresponding conductance data of our telluric map.

To demonstrate the general situation the comparison was made at about 120 wells (also shown in the enclosed telluric map). Their location, depth to the basement and basement quality data were taken from the Pre-Tertiary Basement Contour Map of the Carpathian Basin beneath Austria, Czechoslovakia and Hungary [KILÉNYI et al. 1991].

There are orders of magnitude more wells in Transdanubia penetrating the basement than used by us in our study, but of basin parts deeper than 3000 m there are relatively few and even fewer are those deeper than 5000 m. It is also characteristic that wells can be found strongly concentrated in smaller areas, while in certain parts of Transdanubia we have absolutely no well data, although just based on the telluric results it would be justifiable to drill on the anomaly, e.g. at Magyarmecske.

Because of the above facts, we do not consider it necessary to make a comparison between tellurics and many wells in the whole of the basin, and on the other hand, no data are at our disposal from concession blocks. It is, however, emphasized that not one of the important regions explored with wells was omitted from our limited study.

On the basis of *Fig. 7.1.1* we can state the following:

a) If we consider the complete set of points, even though the scattering is rather high, it is true as a first approximation that higher conductance means greater basin depth. Therefore the qualitative telluric investigation of Transdanubia should be qualified as fruitful and successful considering the starting goal, even without having checked it with deep direct current and magnetotelluric soundings.

b) The set of points can be divided (somewhat arbitrarily) into three groups:

The major part of the areas with a basin depth less than 2500 m belongs to the *first group*, these are represented by blue and red squares in Fig. 7.1.1; the first section of the line. In spite of the ±20% error limit it is true in these areas that almost twice as high conductance belongs to a twice as great depth. In these areas telluric imaging of the basin can be called good in itself as well.

Basins deeper than 2500 m can be ranked into the *second group* (points indicated with green triangles). Scattering is significantly higher here but the relationship between the basin depth and conductance is also linear, only the slope of the straight line is not so steep as in the shallower basin

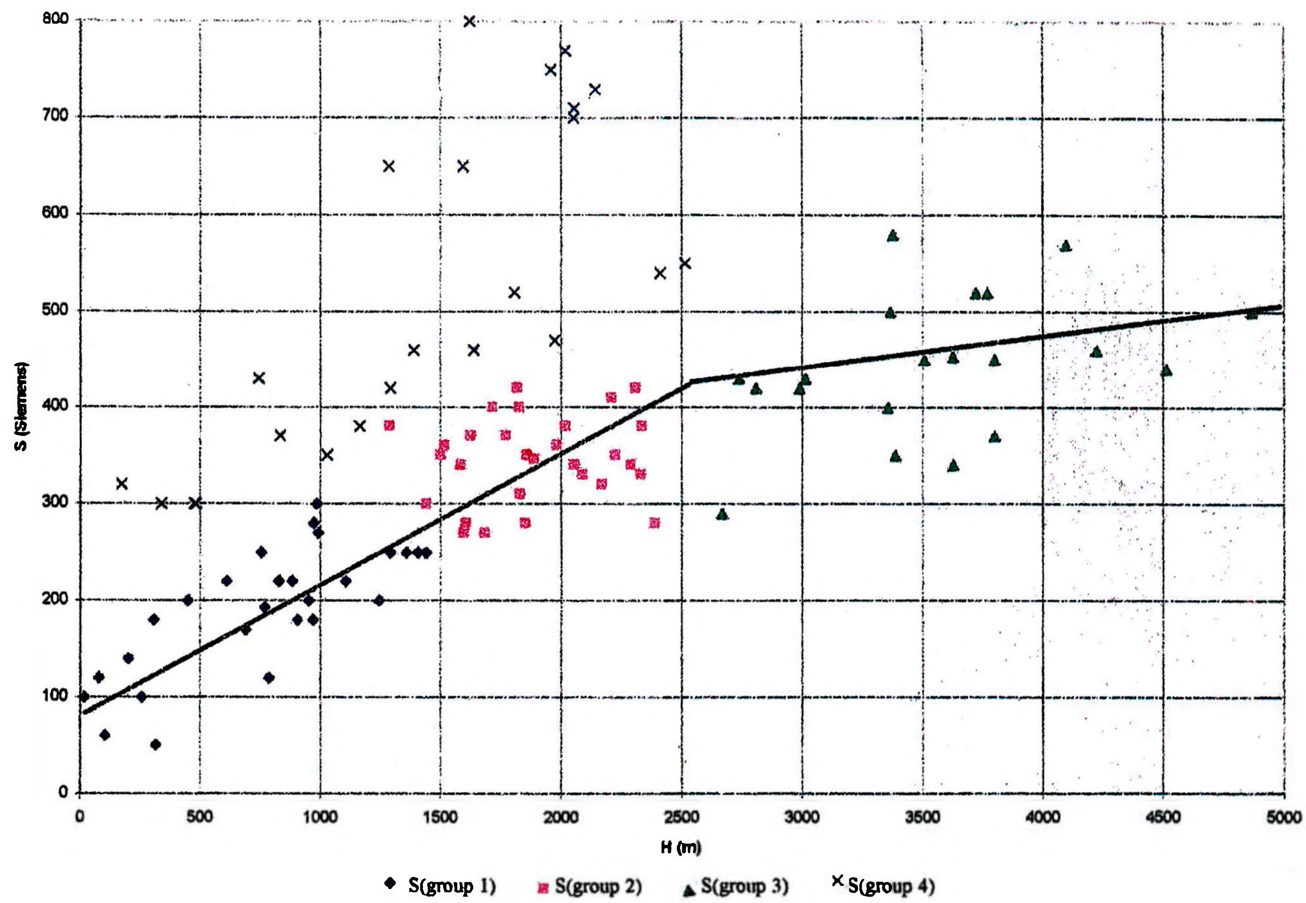

Fig. 7.1.1. Telluric conductance vs. depth to the pre-Tertiary basement (determined in wells)
7.1.1. ábra. A tellurikus vezetőképesség a pre-tercier aljzat (fúrásokban) meghatározott mélységének függvényében

parts. This has an interesting physical explanation that was recognized a long time ago. From direct current and magnetotelluric sounding curves it is unambiguous that the resistivity of Early Pannonian fine-grained marine sediments decreases to 2–5 Ωm down to a depth of 2000–2500 m. Deeper than that the resistivity starts to increase even if the formation's material, grain size, age and conditions of accumulation do not change. This can be explained by the decrease in water content due to the load of layers. In the whole Carpathian Basin, in the deepest parts where the 'A' type geoelectric section (where the resistivity of layers lying one below another increases monotonically) can unambiguously be observed both on the direct current and magnetotelluric sounding curves, a 'layer boundary' in the 2000–2500 m interval is obtained.

The second section of the line (after the break), on the right of Fig. 7.1.1 explains why the deepest grabens in the basement do not appear with sharp anomalies as in first approximation might be expected from the basement contour map. Graben parts deeper than 2500 m are always filled with sediments of higher resistivity than the shallower parts.

Those basin parts can be ranked into the *third group* where there are formations of considerable electric conductivity within the pre-Tertiary basement as well, these are verified by magnetotelluric measurements, too. These areas occur in that part of the Kisalföld that is adjacent to the Transdanubian Central Range and south of the Lake Balaton, in a few km wide strip of the so-called Balaton Line. Points from these areas are marked (with x) in Fig. 7.1.1 and were omitted when the points belonging to the first two groups were averaged out.

c) Finally, it is stated that the adjusted lines do not go through the origin. An approximately 100 siemens conductance belongs even to the 0 basement depth. The reason for this is that the resistivity of the basement is infinitely high neither on the areas of outcrops nor elsewhere. Even under resistivity conditions of the order of magnitude 100–1000 Ωm characterizing the basement the pulsation penetrating down to a depth of several 10 km senses the conductivity of the basement, too, and this is obvious just at the outcrops.

After studying the global relationships between the conductance determined using the telluric method and the basin depth it is pointed out that although depth-proportional imaging of the basement structures leaves much to be desired, we consider it a fundamental result that all elements of the basement structure known up to now and explored with wells or other methods can be found on the telluric map which could theoretically be found based on the station density. The possibility of finding a promising structure from the point of view of raw material prospecting is probably a more significant, more useful result than accurate depth data. These are, however, not negligible results because for the planning of seismic measurements in hydrocarbon prospecting in Hungary the gravity maps were used which, however, in contrast to the telluric map gravity maps show a slight relationship with the structural elements of the basement in the southeastern part of the Carpathian Basin not discussed here (because of density inhomogeneities within the crust and mantle).

We are of the view that telluric measurements calling attention to basement inhomogeneities that could not be detected by non-geoelectric methods an advantageous feature of the telluric-magnetotelluric method, this in itself proves the necessity of applying a number of geophysical methods together: in other words, integrated investigations.

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7.1. FEJEZET

Aljzatmélység és a tellurikus vezetőképesség

NEMESI László

A szerző a pre-tercier aljzatot ért fúrások aljzatmélységét hasonlítja az ott mért (interpolált) vezetőképességgel. Megállapítja, hogy a Dunántúl tellurikus térképe kisebb-nagyobb részterületektől eltekintve első közelítésben az aljzatmélységgel arányos. Feltűnő azonban a 2500 m-nél mélyebb üledékes összlet fizikai paramétereinek megváltozása, pl. nagyobb fajlagos ellenállása.

ABOUT THE AUTHOR

Nemesi László for a photograph and biography, see this issue, p. 120

GEOPHYSICAL TRANSACTIONS 2000
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CHAPTER 7.2
Separation of the young sediments' and pre-Tertiary formations' conductance

András MADARASI* and Géza VARGA*

The authors determined from magnetotelluric soundings and electrical well-logs the conductance of the strictly Cenozoic sediments and subtracted it from the telluric conductance map. In the residual map obtained in this way the 6–8 km deep Kisalföld sub-basin can clearly be seen where oscillations of 25 s period time did not reach the basement, but an even more interesting result is the map-like representation of the electrically conductive sequences within the pre-Tertiary basement. It is remarkable that these conductivity anomalies can be outlined with lines of NW–SE direction in the middle of Transdanubia.

Keywords: tellurics, magnetotelluric surveys, well-logging, conductance

As described in Chapters 5.3 and 7.1 in the case of the telluric measurements in Transdanubia, the condition that the period range of the measurements is everywhere in the so-called *S*-interval where the measurable conductance does not increase any more with increasing period time is not fulfilled. The main reason for this is that over a large part of the survey area the pre-Tertiary basement cannot be considered a non-conductor; in the penetration range of electromagnetic waves of the 25 s average period time used in telluric measurements, formations of significant conductivity occur within the basement. This finding is not of recent origin: researchers had already encountered this phenomenon at the beginning of the deep structural investigations in Transdanubia (Transdanubian conductivity anomaly, Antal ÁDÁM [1977]; Magyarmecske anomaly, József HOBOT [1964]). Some of the anomalous areas were discussed in detail in Chapter 5.2.

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When the relative conductance values related to different telluric base stations were transformed into telluric conductance in the way described in Chapter 5.1 the possibility opened to quantify the conductance values associated with formations within the basement and to represent them in the form of a map. This process is remarkably simple, the conductance of the young sediments (calculated value) should be subtracted from the telluric conductance value (measured data). The creation of this latter data set was the principal problem.

Two ways present themselves. One of them is that in addition to the depth map of the area — which was constructed using wells, seismic lines, gravity measurements and telluric measurements in the Kisalföld — we create the resistivity distribution model of sediments filling the basin which is based on well logs and magnetotelluric soundings. This way was finally rejected because estimation of the reliability of the results seemed to be uncertain in relation to the amount of work required.

The other and simpler way is to use the conductance values calculated from 1-D inversion results of magnetotelluric soundings utilizing the following known formula:

$$S = \sum h_i / \rho_i$$

This calculation was carried out at about 500 magnetotelluric sounding stations measured by ELGI, this was complemented with magnetotelluric soundings taken over from the MOL Co. and cumulative conductance values calculated from well logs (25 magnetotelluric soundings and 65 wells). The summarized conductance map of the Cenozoic sediments shown in *Fig. 7.2.1* was constructed using these data. It can be seen that the spatial distribution of data is uneven, the bulk of the stations can be found along profiles and the separation between the profiles is rather large. Therefore, for interpolation into a 2x2 km grid, a parameter (radius of search) had to be applied which yielded a relatively smooth surface. Variability in conductance of sediments filling the basin is certainly stronger than this, therefore the difference map to be described in what follows should be treated with caution with regard to the smaller anomalies.

In *Fig. 7.2.2* the difference between the telluric conductance and the conductance of the Cenozoic sediments is shown. This parameter covers a range of 1000 siemens in Transdanubia. A part of the values is negative, which means that the measured telluric value is smaller than that calculated

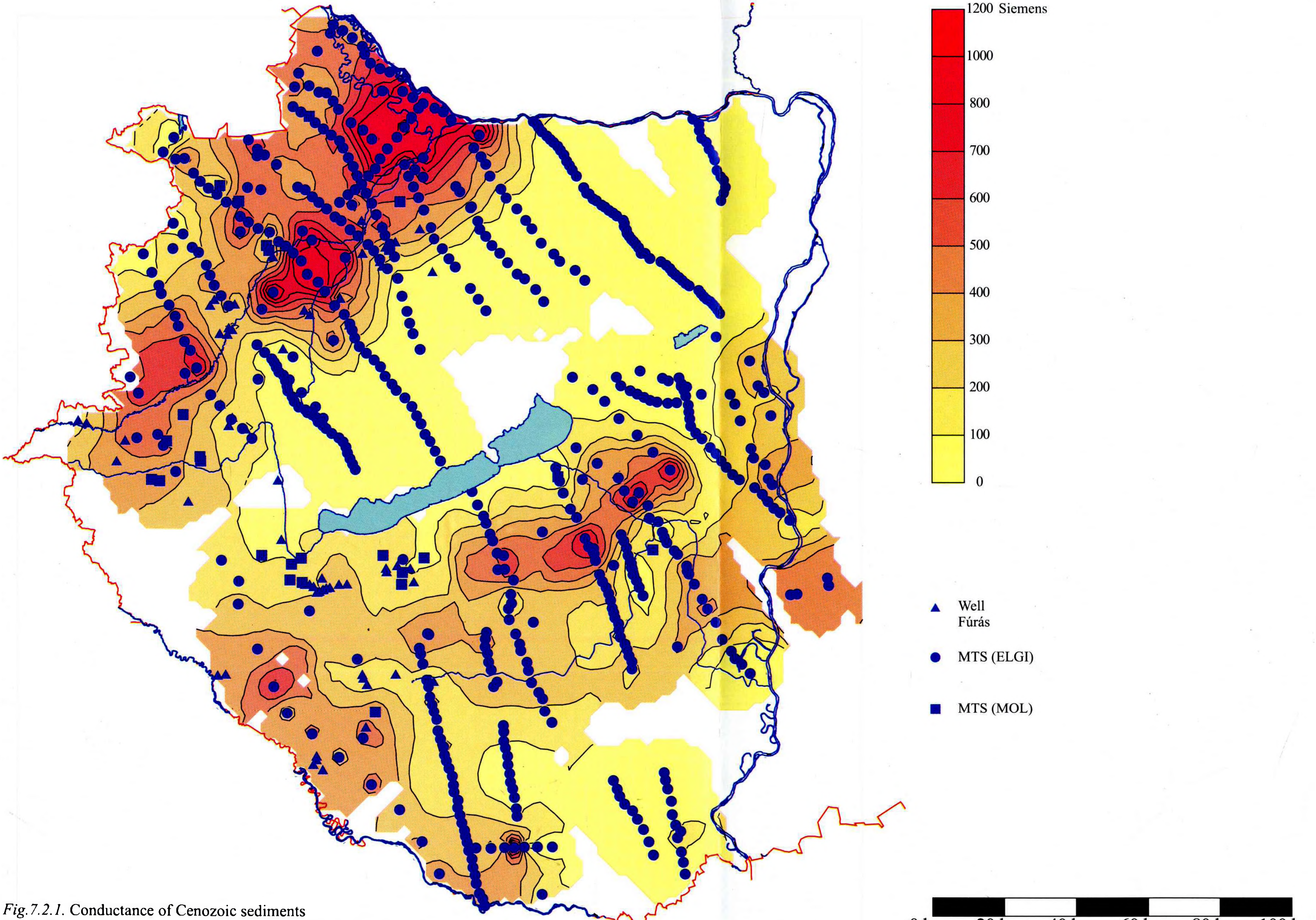

Fig.7.2.1. Conductance of Cenozoic sediments
7.2.1. ábra A kainozoós üledékek összegzett vezetőképessége

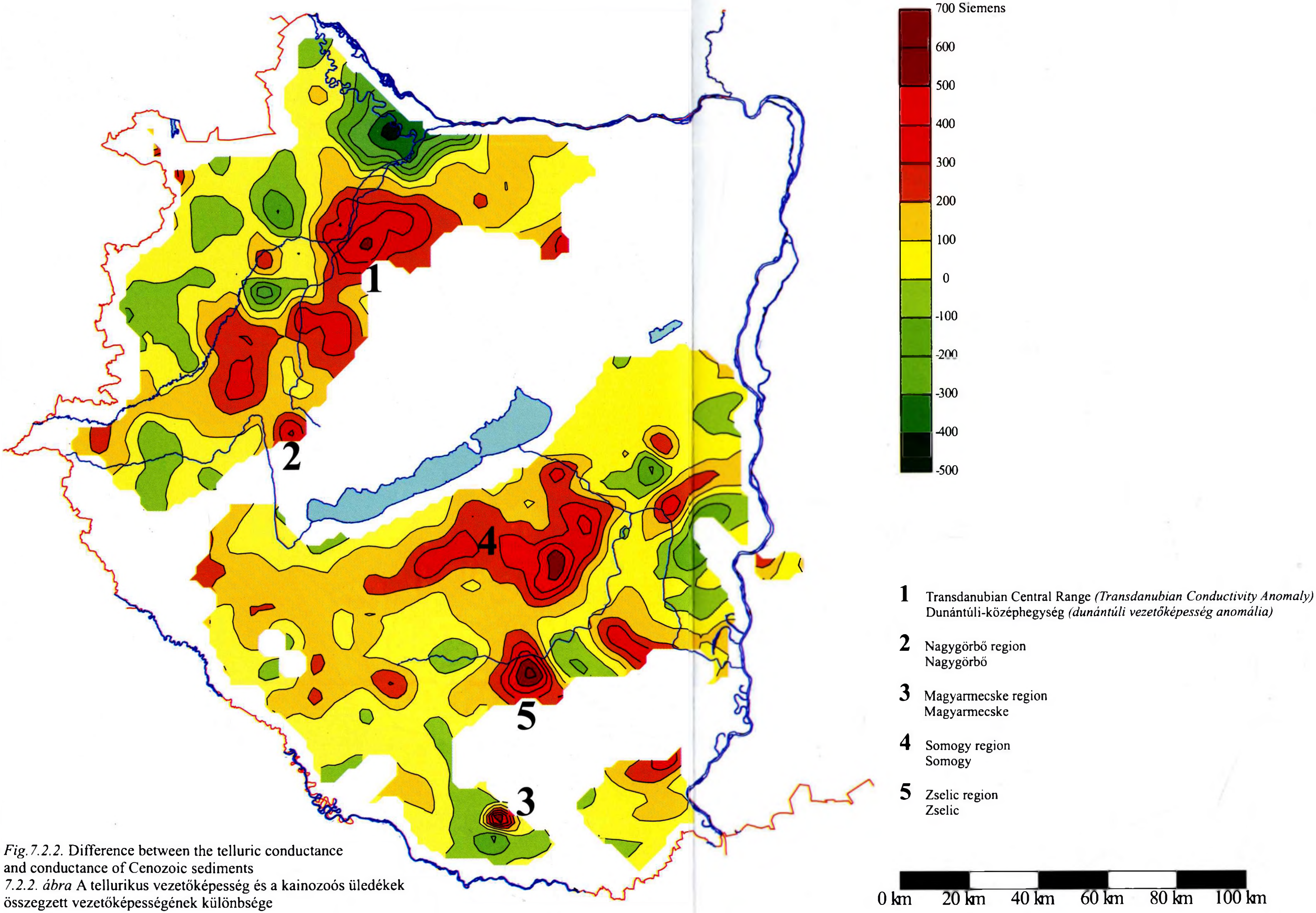

Fig. 7.2.2. Difference between the telluric conductance and conductance of Cenozoic sediments
7.2.2. ábra A tellurikus vezetőképesség és a kainozoós üledékek összegzett vezetőképességének különbsége

from the magnetotelluric sounding. The reason for this is that we used the formula given above in our calculations; the measured telluric value, on the other hand, is commensurable with the apparent conductance that can be deduced from the 1-D magnetotelluric transfer function calculated with the given layer parameters, assuming a non-conducting basement. Therefore, in the case of a high resistivity basement, the lack of a conductor within the basement means that the difference is always negative.

Particularly high negative values are obtained if the period range of telluric measurements is smaller than the period time of the S-interval derived from the model. This situation appeared in the Kisalföld, in the vicinity of Győr, where the thickness of the sediments filling the basin is so large that the telluric measurements did not reach the basement, therefore a difference of about –400 siemens was obtained.

In those areas where the thickness of young sediments is small and the resistivity of the basement is a few hundred m, this difference is in any case positive, although not very high, because the waves of 25 s period time on average penetrate down to a depth within the basement so that the product of the small conductivity and the large thickness can result in a surplus of about +100 siemens.

From among the anomalies exceeding the value of +200 siemens and covering a relatively large area, the following are pointed out in Fig. 7.2.2 (also see Chapter 5):

- The Transdanubian conductivity anomaly (1). A group of anomalies at the N and NW edges of the Bakony Mountains.
- Nagygörbő (2). A small-sized, isometric anomaly, in volcanic surroundings.
- Magyarmecske (3). Telluric anomaly whose value is the highest in Hungary; it is supposedly associated with graphitic, anthracitic formations.
- Somogy (4). The source of the anomaly of large extension south of Lake Balaton is not exactly known but it supposedly lies in the area of the occurrence of Late Palaeozoic, Carboniferous formations.
- Zselic (5). Late Palaeozoic sequences are also known here below the Triassic carbonates, but no wells at nearby Gálosfa hit the particular source. It is assumed here, too, that the maximum is associated with the occurrence of Carboniferous anthracitic formations.

We do not intend to deal with the smaller anomalies because these are frequently extreme cases based on only one magnetotelluric measuring station, where — in addition to the telluric results processed with manual methods from analogue photorecords — the less sophisticated (frequently analogue) magnetotelluric instruments of the last decades and the earlier processing programs that were unable to filter out the industrial noise also spoilt the reliability of the results.

As we do not consider the difference map to be a final one, we should like to ensure a more accurate calculation of the sediments' effect using further data.

At the same time we deem it justifiable that there should be a detailed investigation of the smaller anomalies and anomaly groups.

Finally, we should like to call attention to the fact that the highs associated with electrically conducting objects within the basement delineate a wide zone of NW–SE strike (in the difference map); it would be desirable to include this in the tectonic model of the Carpathian Basin.

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7.2. FEJEZET

A fiatal üledékek és a pre-tercier képződmények vezetőképességének szétválasztása

MADARASI András és VARGA Géza

Magnetotellurikus szondázásokból és elektromos karotázs szelvényekből meghatározták a szigorúan vett kainozoós üledékek vezetőképességét és ezt levonták a tellurikus vezetőképesség térképből. Az így kapott "maradék" térképen jól látszik az a 6–8 km mélységű, kisalföldi medencerész

is ahol a 25 s periódusidejű oszcillációk nem érték el az aljzatot, de ennél értékesebb eredmény a pre-tercier aljzatban levő elektromosan vezető összletek térképszerű elterjedésének bemutatása. Feltűnő, hogy ezek a vezetőképesség-anomáliák a Dunántúl közepén ÉNy-DK irányú vonalakkal lehatárolhatók.

ABOUT THE AUTHORS

András Madarasi for a photograph and biography, see this issue, p. 204

Géza Varga for a photograph and biography, see this issue, p. 204

GEOPHYSICAL TRANSACTIONS 2000
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CHAPTER 7.3
Correlation between the telluric conductance values and the Bouguer anomaly values

László NEMESI*

Based on a more detailed comparative analysis of gravity and telluric measurements in the middle part of southern Transdanubia five different major and within these several smaller — but spatially separable — basement types can be detected. Between the clearly outlined blocks both the pre-Tertiary basement's NE-SW megastructural directions and the almost perpendicular (Balkan) directions can be drawn.

Keywords: correlation, conductance, Bouguer anomalies, Transdanubia

In the area to be presented here the surroundings of Magyarmecske discussed in detail in the description of the telluric map (Chapter 5) and the Zselic area can also be found, where the deviation between the gravity and telluric maps is especially striking in these critical regions. KASSAI [1980] realized that in areas close to the Drava Valley the basin depth map determined by geoelectric methods is systematically deeper over an area of about 1000 km^2 than the map based on the seismic method. Wells drilled in the region of Szigetvár–Barcs–Nagyatád hit mostly basement of Carboniferous age; the resistivity of those formations is equal or is very close to the resistivity of the Pliocene (Pannonian) sediments according to well-logging studies. Thus, tellurics did not regard as 'basement' the Carboniferous sequence.

These particular items of information induced us to study somewhat more thoroughly the correlation between the gravity and telluric measurement results over the middle part of southern Transdanubia, over an area of about 4500 km^2. According to the results (see *Fig. 7.3.1)* there are areas which can be well delineated and where there is a linear relationship be-

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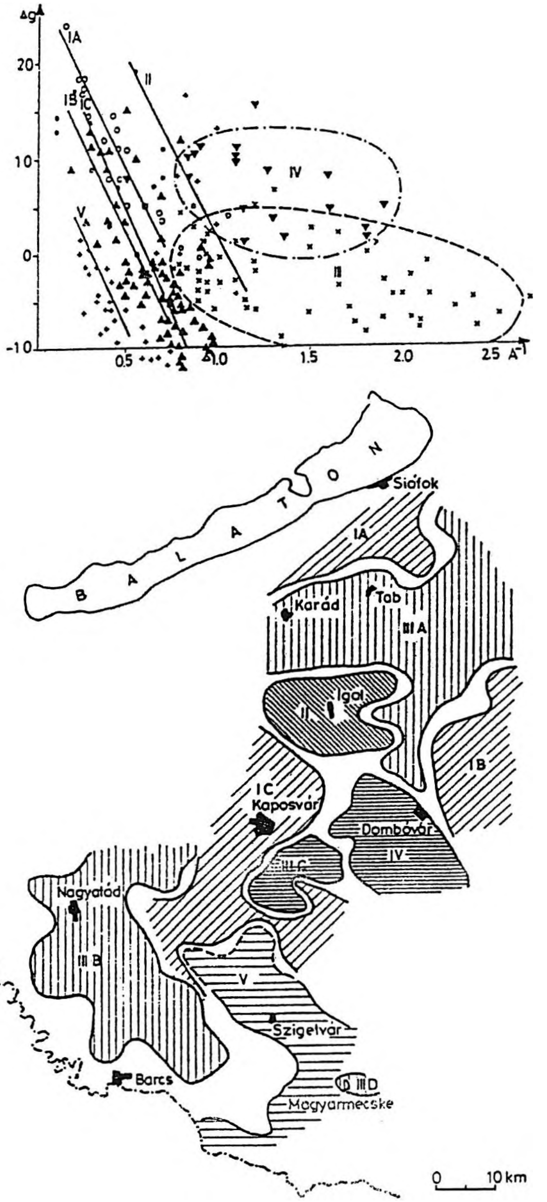

Fig. 7.3.1. Different types of areas according to their Bouguer anomalies (Dg) *and* relative telluric conductance (A–*l*) in the central part of southern Transdanubia

7.3.1. ábra. A Bouguer anomália (Δg) és a relatív tellurikus vezetőképesség (A^{-1}) kapcsolata alapján elkülönülő területtípusok a D-Dunántúl középső részén tween the two data sets (Bouguer anomaly and telluric conductance), although it would not be appropriate to average out the set of points with only one line. In areas I/A, I/B and I/C the wells hit Early Palaeozoic crystalline formations below the Neogene sediments. In area II, Mesozoic carbonates underlie the Neogene rocks. The data series characterized by function V came from the area with a Permian basement.

There is no linear connection between the data sets of areas III and IV. The reason is obvious: although the density of the basement is significantly higher than that of the sediments filling up the basin, this is not valid for the resistivity of basement. We have concrete knowledge, however, only from the area marked III/B, where the above mentioned Carboniferous basement lies below the Neogene (even Pliocene) rocks.

We have only few data from area III/A but our magnetotelluric measurements detected a deep fracture (penetrating down to a depth of 9–12 km) which causes a conductance anomaly in the northern part of this area, and in the southern part of the area which is less known from wells and seismics Palaeogene sediments were also found in addition to the Neogene ones. It is also important that the resistivity of the basement of unknown age and petrological composition is only a few times higher than that of the sediments based on the magnetotelluric measurements.

The Gálosfa well drilled in the III/C area hit the high resistivity Triassic carbonate basement at a depth of –753 m. According to its logs the resistivity of the sediment is not lower than the Transdanubian average and the resistivity of the basement is orders of magnitude higher. Thus, the high telluric conductance can be explained by high density, high velocity and deeper (older?) formations than those penetrated by the well, therefore they are unknown.

We have even fewer data from area IV but it can be assumed that we should provide an explanation, on the one hand, similar to that in area III/C, and/or such fracture lines can be assumed, on the other hand, to which a significant conductance anomaly is connected. In the discussion of the telluric map (in Chapter 5) these two neighbouring sub-areas were therefore not separated.

In connection with this relatively small area and this simple comparative study it is worth referring back to the geological facts discussed in Chapter 3 where, on the one hand, we are aware [KERTAI 1957] that 'the Mesozoic and Palaeozoic blocks are hidden below the Neogene basement in the form of a chessboard formed of irregular polygons and the strike directions of the individual blocks are different'. Our small map completely backs up this statement. On the other hand, a further comment is valid: Viktor Scheffer in the 1960's [SCHEFFER 1960], then later Elemér NAGY [1968] and Miklós KASSAI [1980] also draw geological structural and occurrence maps in which it is not the NE–SW structural lines that are dominant as in the pre-Tertiary basement map attached to Chapter 3, but the perpendicular 'Balkan directions'. It is probably not difficult to see that in our small map (Fig. 6.3.1), it is not these directions but rather the NE–SW megastructural directions that can also definitely be recognized at the borders separating the individual blocks.

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7.3. FEJEZET

A tellurikus vezetőképesség értékek és a Bouguer anomália értékek korrelációjának vizsgálata a Dél-Dunántúl középső részén

NEMESI László

A D-Dunántúl középső része gravitációs és tellurikus méréseinek részletesebb összehasonlító elemzésével 5 különböző fő és ezeken belül még néhány kisebb, területileg is elkülöníthető aljzattípus mutatható ki. A jól lehatárolható blokkok közé egyaránt behúzhatók a pre-tercier aljzat ÉK–DNy-i nagyszerkezeti irányai és az ezekre közel merőleges (balkáni) irányok is.

ABOUT THE AUTHOR

Nemesi László for a photograph and biography, see this issue, p. 120

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CHAPTER 7.4
Statistical analysis of the geophysical parameters

Sándor KOVÁCSVÖLGYI* and Péter OCSENÁS*

The authors study the gravity Bouguer-anomaly, the magnetic anomaly, the telluric anomaly and pre-Tertiary basement contour maps using cluster analysis. They state that the three other maps show almost no correlation with the magnetic map. By means of detailed analysis of the basically similar 'other three', however, Transdanubia can be divided into four major units: the Kisalföld, the Somogy, the Dráva, and the Villány unit. Within these there are smaller, separable units. Separation can be recognized in the overlying layers as well, but primarily within the basement (crust) based on physical parameters.

Keywords: statistical analysis, Bouguer anomalies

7.4.1. Data and methods

Four parameters suitable for regional statistical studies are at our disposal from the Transdanubian area that was studied. The Bouguer anomaly, the magnetic anomaly and the telluric conductance values are measured (or calculated from direct measurements by means of corrections) parameters, while the depth to the pre-Tertiary basement is a derived parameter. We have calculated the Bouguer anomaly values based on the data of the National Gravimetric Database [KOVÁCSVÖLGYI 1994, MILÁNKOVICH 1995]; the source of the magnetic anomaly values is the countrywide reconnaissance measurements carried out in the 1950s and 1960s [HAÁZ, KOMÁROMY 1966]; the telluric data set has been described in this paper (an isoline map of all three parameters can be seen attached to this publication); depth data of the pre-Tertiary basement's surface were obtained from the map of KILÉNYI, ŠEFARA [1991] by reading the average values for

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2x2 km squares (concerning Transdanubia, this map is identical with the KILÉNYI–RUMPLER map[1984] shown in Fig. 3.6).

The known parameter values constitute a homogeneous data set without considering their spatial distribution, or their reliability. To make this data set more homogeneous, data sets of the three parameters were interpolated into a 2x2 km grid and the grid points coincided with the midpoints of the squares used in constructing the depth data set. In connection with the reliability of this formally homogeneous data system the following should be mentioned:

— The density of gravity stations significantly exceeds the density of grid points, therefore at the level of the estimated accuracy of the measurements — 0.1 mGal — the data in the grid are reliable.

— The countrywide reconnaissance magnetic measurements were carried out in a fairly uniform 1.5x1.5 km quasi-grid, thus the interpolated values are also reliable.

— The locations of the original measuring stations of the telluric data grid can be seen in the attachment; according to this the interpolated values are reliable.

— The above-mentioned contour map was constructed from well, seismic, telluric data and — where even the latter were missing — from gravity data. Unfortunately, from among the sources of real data the map indicates only the location of the wells, therefore in the case of parts explored poorly with wells we do not know where the data came from (geophysical measurement, projection, interpolation, etc.). In view of this the reliability of depth data from such areas cannot even be estimated.

Cluster analysis was used for the spatial classification of data, correlation analysis for studying the relations within the individual classes.

Cluster analysis considers standard values (of 0 average and 1 scattering) of n parameters belonging to the individual grid points as co-ordinates of an n-dimensional spatial point. The procedure determines the co-ordinates of the so-called core centres, their number corresponds to the number of clusters (classes) and then each point of the data set is included in the cluster corresponding to the core centre lying closest to it. Because the determination of the clusters' number is a subjective decision, clarification of the reason for belonging to the individual clusters, and the statistical and geological interpretation of the results represent a special task.

In that the study area is very large, it might be assumed that our geophysical parameters are charged with different regional effects, which might be the primary causes of inclusion in clusters. Because delineation of the known regions was not the objective, the data set was divided into four smaller areas (*Fig. 7.4.1*) and cluster analysis was performed only on them.

In the course of the first experimental series it turned out that areas of high (positive or negative) magnetic anomalies get into a special cluster. This confirms the finding of Chapter 5.2, according to which no similarity can be revealed between the telluric conductance map and the magnetic anomaly map, even on a general scale, and this is also in agreement with the results of earlier, countrywide statistical analyses [KOVÁCSVÖLGYI 1999]. Based on this we omitted the magnetic data in our further experiments. In some cases (e.g. the Magyarmecske conductance anomaly) we have obtained local clusters covering a small area, these points — because they suggest known features — were also omitted from the further studies.

Thus, theoretically, effectiveness of the following relationships might be expected:

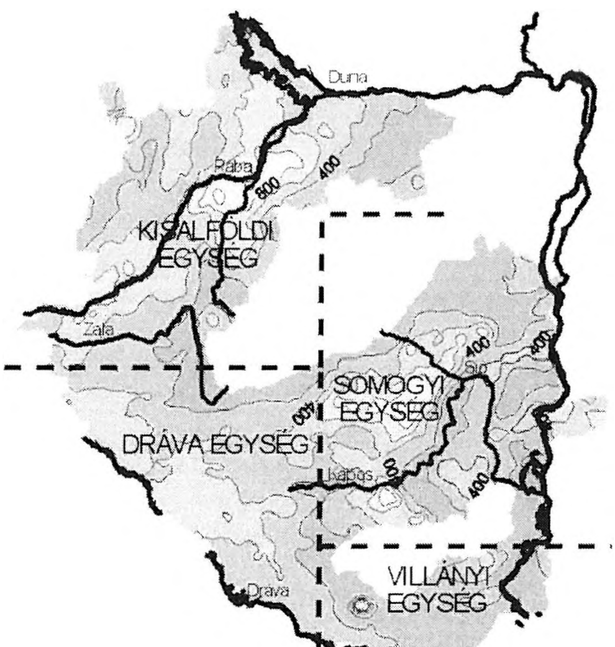
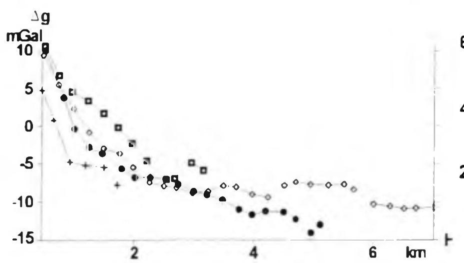


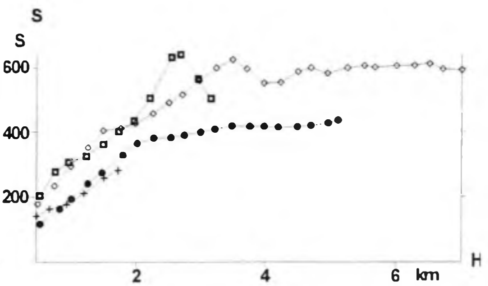
Fig. 7.4.1. Location of the studied sub-areas on the conductance map
7.4.1. ábra. A vizsgált részterületek elhelyezkedése a vezetőképesség térképen

— By increasing the depth to the basement the Bouguer anomaly values decrease — because the high density horizon gets further from the measuring station.
— By increasing the depth to the basement the telluric conductance increases — because the low resistivity sediment is thicker.

7.4.2. General relations between the depth to the surface of the basement and the values of geophysical parameters

Depth data of the data set, separately for the four sub-areas, were divided into 500 m wide strips and the average values of all three parameters *were calculated for these strips, then the results obtained were plotted as* curves illustrating the dependence on the depth to the basement (*Figs.* *7.4.2* and *7.4.3*). The presumable inaccuracies of the depth map together with the low number of data falling into the individual strips would have made the utilization of narrower strips illusory; resolution, however, has been made finer by changing the midpoint of the strips by 250 m, thus all strips overlap by a half-width the corresponding half-width of the neighbouring strips. At the ends of the plotted curves belonging to large basement depths there remain some still — individual strips but due to the small number of data they were omitted as being unsuitable for drawing conclusions of statistical character. The curves start with the strip of the 250–750 m basement depth because in the case of smaller depth due to the





Legend: • Dráva ◦ Kisalföld ▫ Somogy + Villány

Fig. 7.4.2 Dependence of Bouguer anomalies on depth to the basement surface
7. 4. 2. ábra. A Bouguer-anomáliák függése az aljzatfelszín mélységétől

Fig. 7.4.3. Dependence of telluric conductance on depth to the basement surface
7.4.3. ábra. A tellurikus vezetőképesség függése az aljzatfelszín mélységétől

local changes in the basement relief the average values read out cannot be considered representative.

Based on the dependence of Bouguer anomalies on the depth to the basement surface (Fig. 7.4.2) the following can be pointed out:

— The starting level of the curves belonging to the 0.5 km depth significantly differs in the Villány area from the other three sub-areas (later, in the analysis of the area we will see that it does not hold true for the whole area). The phenomenon cannot be explained by the low density of the basement formations because neither the Bouguer anomaly map nor the density data [SZÉNÁS 1965] suggest this. Thus, the only possible explanation might be the larger than the Transdanubian average thickness of the Earth's crust, because in this case the lower crust–upper crust boundary and the Mohorovičić discontinuity — boundaries that can be characterized by a jump in density — get further from the level of observations thereby causing a smaller positive effect, i.e. a negative anomaly. Assumption of a thicker crust is in contradiction with the map of the Mohorovičić discontinuity's surface published in 1991 [POSGAY et al. 1991]. It should be noted, however, that on the one hand this area lies at the periphery of the map and, on the other hand, it does not refer to the source of real data (e.g. location of seismic lines). At the same time this map still indicates deepening of the Mohorovičić boundary in the case of the Békés Basin, while the profile PGT–1 measured later unambiguously shows elevation of the Mohorovičić surface in the area in question [POSGAY et al. 1995], and puts the position of the Mohorovičić discontinuity about 6 km higher. Based on this it can be assumed that the map of the Mohorovičić discontinuity published in 1991 does not reflect the real situation, not even qualitatively. The Mohorovičić discontinuity map of SZABÓ and PÁNCSICS [1999a] based on seismic and gravity data estimates the depth to the Mohorovičić boundary as being about 31 km in the Villány area, in contrast to the 28–29 km which can be considered as an average in the Transdanubian areas studied by us. Bearing in mind the deepening of the Mohorovičić discontinuity in question and assuming a 2500 m thick infinite Bouguer slab a density difference of 600 kg/m^3 between the basement formations and mantle formations below the Mohorovičić discontinuity which is accepted in the literature, –6 mGal is obtained as the gravity level of the Villány area, this is in accordance with the data of Fig. 7.4.2.

— Similar considerations indicate that the position of the deep structural levels should be considered balanced within each area of the Somogy, Kisalföld and Drava areas because the average Bouguer anomaly values belonging to the 0.5 km basement depth differ from each other by hardly 2 mGal. This statement may seem to be surprising because thinning of the crust is known in the middle of the Kisalföld [NEMESI et al. 1997], the area of the Transdanubian Central Range which can be characterized by a larger crust thickness; however, this is not part of our studies. According to the map of SZABÓ and PÁNCSICS [1999a], however, elevation of the mantle beneath the Kisalföld is compensated by the depression which can be found along the western border of the country and is connected with the structure of the Alps while in the Somogy and Drava areas the Mohorovičić discontinuity shows only small variations.

— The slope of the curves in Fig. 7.4.2 shows a connection primarily with the density of sediments. In the 0.5 km–1.0 km range two types can be distinguished: the decrease on the curves from the Villány and Drava areas is steeper than on the curves from the Kisalföld and Somogy. In the course of studying the density data from well-logging SZABÓ, PÁNCSICS [1999b] distinguished two types of Late Pannonian sediments in Hungary: the density of the so-called Hegyfalu type sediments is higher on the surface and increases faster with depth than that of the sediments belonging to the Pálmonostora type. Based on the location of the studied wells it can be identified that the Hegyfalu type is characteristic of the Kisalföld, while the Pálmonostora type is characteristic of the Drava Valley in our survey area (there are no data for the Somogy and Villány areas). The sediment types are in harmony with the data in Fig. 7.4.2 because the slower decrease of the Bouguer values is a consequence of the tendency to higher density of the Kisalföld (Hegyfalu type) sediments. Based on the above facts it can be assumed that the young sediments of Somogy also belong to the Hegyfalu type whereas the sediments of Villány belong to the Pálmonostora type. This assumption practically completes the areas of Szabó and Páncsics where data are missing and it makes it likely that the Pálmonostora type characterizes the southern part of the country, and the Hegyfalu type the northern one. It is mentioned that this statement by no means includes the consequence that two separated basins should be assumed during the Late Pannonian in the northern and southern parts of the country. Density of sediments shows a connection with the history of their vertical movements since their origin rather than with the place of their origin [MÉSZÁROS, ZILAHI-SEBESS 2001]. Based on this the assumption is more likely that in the northern part of the area which can be characterized by the Hegyfalu type sediments the general tendency of sinking in the recent geological past was more frequently interrupted by periods during which some blocks became elevated by a smaller degree.

— The curves in Fig. 7.4.2. run furthest from each other in the 1–2 km interval. A characteristic of all curves is that their steepness decreases and the curves of the Somogy, Drava and Kisalföld areas run practically parallel over a large part of the interval (it is difficult to draw conclusions concerning the Villány curve because the data practically come to an end at the basin depth of 1.5 km).

— The curves of the three areas converge at the depth of 2.5 km. Because we have seen that these curves started from practically identical levels, this means that at such sediment thickness the density of sediments statistically equalizes, and the effect of the differences observed at higher levels is counterbalanced by the changes of opposite direction at deeper levels.

— Below 2.5 km the behaviour of the three curves deviates. At the descending sections the steepness of the curves decreases due to the further decrease in density contrast and takes similar values in the different curves. In addition to the decreasing sections, however, there are increasing sections as well; the important differences between the curves derive from the actual places where they can be found.

— The Kisalföld curve increases from the depth of 3 km, slightly decreases in the interval of 3.5–4.2 km and after another increase the decreasing section begins at 5.5 km, then from 6 km the curve becomes straight, there is no statistically provable connection between the Bouguer anomaly values and the depth to the basement. It is not effective to deal with the interpretation of the decreasing interval between 3.5 and 4.2 km, the hardly 1 mGal decrease is not significant and might be the consequence of numerous local phenomena. Therefore the curve is considered as if it were a depth-independent horizontal line in the 3.5–5.5 km interval, similarly to the 6–7 km interval, only at a higher level. The reason for the ascending interval between 3 and 3.5 km should be looked for in the deep structure. Our earlier studies [KOVÁCSVÖLGYI 1999] showed that it is generally characteristic in the area of the Pannonian Basin that at larger (above 4 km) sediment thickness instead of the natural inverse correlation between the Bouguer anomalies and depth to the basement a direct correlation can be experienced. According to our assumption the reason for this is that the deeper sub-basins in the Pannonian Basin came into being where the mantle is in an elevated position, the formation of the basin itself took place as a consequence of the contraction associated with the cooling of the hot mantle material in its elevated position. This phenomenon was demonstrated by gravity modelling in the case of the deep basin of the Kisalföld [NEMESI et al. 1997], while in the case of the Békés Basin with seismic profiles and gravity modelling [POSGAY et al. 1995]. For the 5.5–6 km interval the descending section is thought to be due to the intensive sedimentation taking place in the geological recent past. Comparing HRUSECKY et al.'s [personal communication] pre-Tertiary basement contour map with DRASKOVITS et al.'s Quaternary thickness map [1997] it can be stated that the Quaternary sediments of significant thickness (more than 200 m, in some places exceeding 600 m) are unknown just where the total sediment thickness exceeds 5–6 km. According to the data of SZABÓ and PÁNCSICS [1999b] the horizontal sections of the curve are caused by the fact that after reaching a certain depth the density of the sediments is practically identical with the density of the basement formation as a consequence of compaction.

— According to the curve of the Drava area the ascending section begins from a depth of 4 or 5 km; marking of the limit cannot be done with certainty because of the rapidly decreasing number of data with depth. It is fact, however, that the natural inverse correlation between the Bouguer anomaly values and the depth to the basement ceases to exist at 4 km and somewhere the ascending tendency also appears. According to our assumption the reason for this is, similarly to the Kisalföld, the elevated position of the mantle beneath the area of the deep basins. This assumption is in agreement with the data of the Mohorovičić discontinuity map of SZABÓ and PÁNCSICS [1999a]. From the above mentioned map it can be seen that the mantle elevation in the vicinity of the Drava is of much more moderate size than that in the Kisalföld; this might explain the uncertainties indicated in the section of the curve showing the dependence of Bouguer anomalies on the depth to the basement.

— The ascending section begins already at 2.5 km in the curve of the Somogy area. In view of the fact that the curve of the telluric conductance (Fig. 7.4.3) also shows irregularities at this section, an explanation for the phenomena will be given later.

Based on the comparison between the telluric conductance and depth to the basement (Fig. 7.4.3) the following can be stated:

— It is a characteristic feature of all curves that after a steep initial section, starting from a certain depth they become horizontal or nearly horizontal, i.e. after a certain limit the telluric conductance does not depend on the depth to the basement. The individual curves differ from each other primarily in the value of the starting level, and at the depth where the horizontal section begins.

— In the 0.5–1.5 km interval the steepness of the Somogy, Kisalföld and Drava curves is roughly equal, whereas the Villány curve is significantly less steep.

— The steepness of the Drava curve which shows the above mentioned characteristic features most clearly decreases significantly below a depth of 2 km, it is practically horizontal in the 3.5–5 km interval. Below 5 km an ascending section begins; it is assumed that this is due to the appearance of conductive formations within the basement.

— The Kisalföld curve shows only roughly the above characteristics in the 1.5–4.5 km section. Based on the results of cluster analysis (see below) this behaviour deviating from the general one characterizes only one part of the area and not the whole of it. Below a depth of 4.5 km the depth dependence of the conductance ceases to exist, the curve is horizontal.

— The Somogy curve shows irregularities from the depth of 2.5 km similarly to what we have seen for the depth dependence of Bouguer anomalies. Bearing in mind that the gravity anomalies characterize first of all the basement formations whereas the telluric conductance primarily characterizes the sediments, the possibility is that the irregularity appearing in the same interval stems from the inaccuracy of the depth map. In Fig. 3.6 it can be seen that in the Somogy area those parts which are deeper than 2.5 km are connected to a graben whose strike direction is approximately parallel with the line of Lake Balaton. This graben, however, lies about 5–10 km south of the maximum which can be seen in the attached telluric conductance map, and of the corresponding minimum of the Bouguer anomaly map, in an area west of the River Sió. In the graben's area the map of KILÉNYI and ŠEFARA [1991] does not indicate wells penetrating the basement, thus taking into account the location of the graben there are no real data in contradiction with the situation indicated qualitatively by the two geophysical parameters which would support the depth map's data. As a check we studied the seismic section MK–2/73 which crosses the graben in the NNW–SSE direction [CSÖRGEI et al. 1979], its data justified our conception: they detected the graben precisely where it can be assumed based on the Bouguer anomaly map and the telluric conductance map.

— The connections found between the telluric conductance and the depth to the basement agree with those presented in Chapter 7.1 where these connections were directly deduced from well data. The curves of Fig. 7.4.3 provide a finer resolution than that of Fig. 7.1.1 as a consequence of the orders of magnitude higher data number.

— The characteristic features revealed in the curves of Fig. 7.4.3 are connected with the resistivity conditions of sediments and basement formations. In contrast with the analysis of the curves of the Bouguer anomalies we make no conjectures about the geological interpretation of these features because up to now no analyses summarizing the results of resistivity well-logging have been prepared for this area which could serve as a basis for interpretation.

Based on the above results it can be stated that division of the Transdanubian area into sub-areas was a correct conception because our parameters frequently show different characteristics in different sub-areas.

7.4.3. Results obtained with cluster analysis

Cluster analysis was performed on all four areas by ranking our data into each of 4 clusters. Generally speaking, it can be said that in three of the four clusters the connections between the depth to the basement, the values of Bouguer anomalies and the value of telluric conductance are reflected, whereas areas showing features different from these got into the fourth cluster.

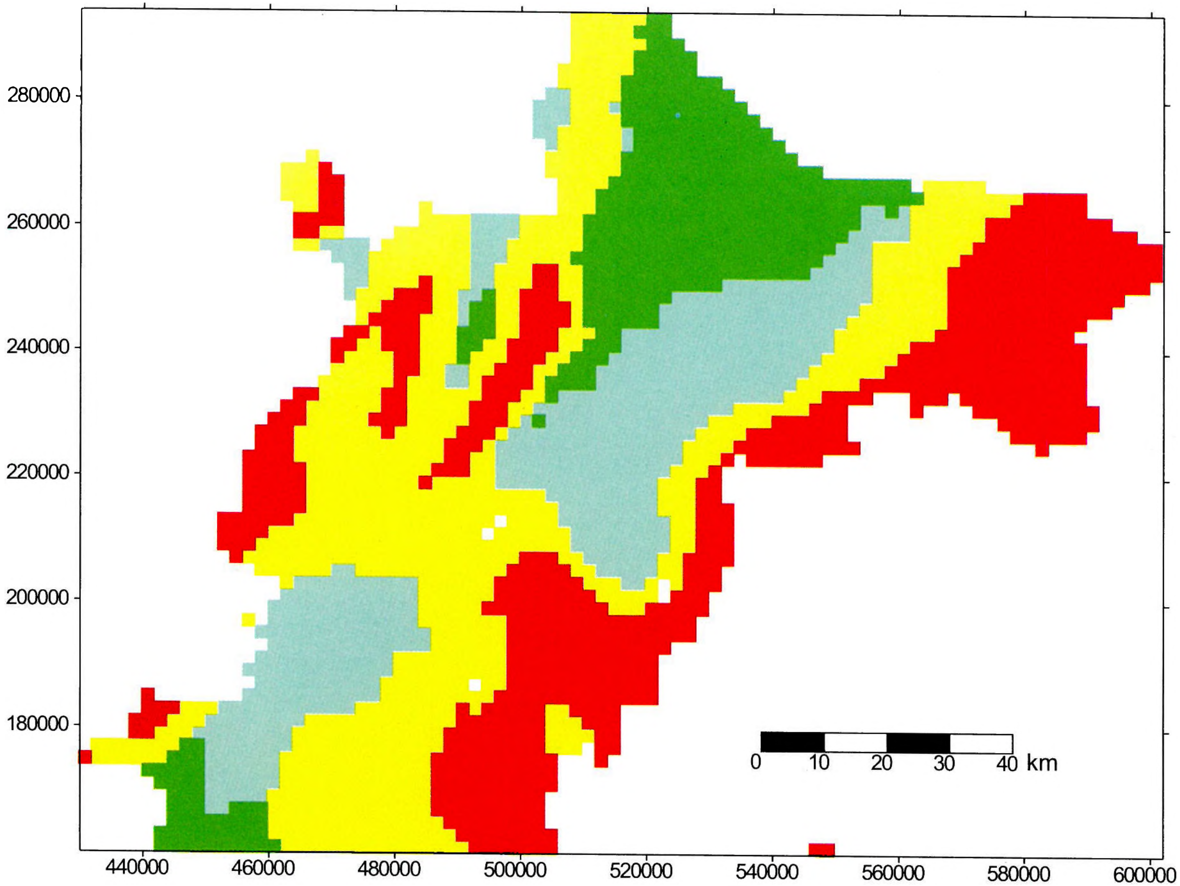


Fig. 7.4.4. Cluster map of the Kisalföld area
7.4.4. ábra A Kisalföld klaszter-térképe

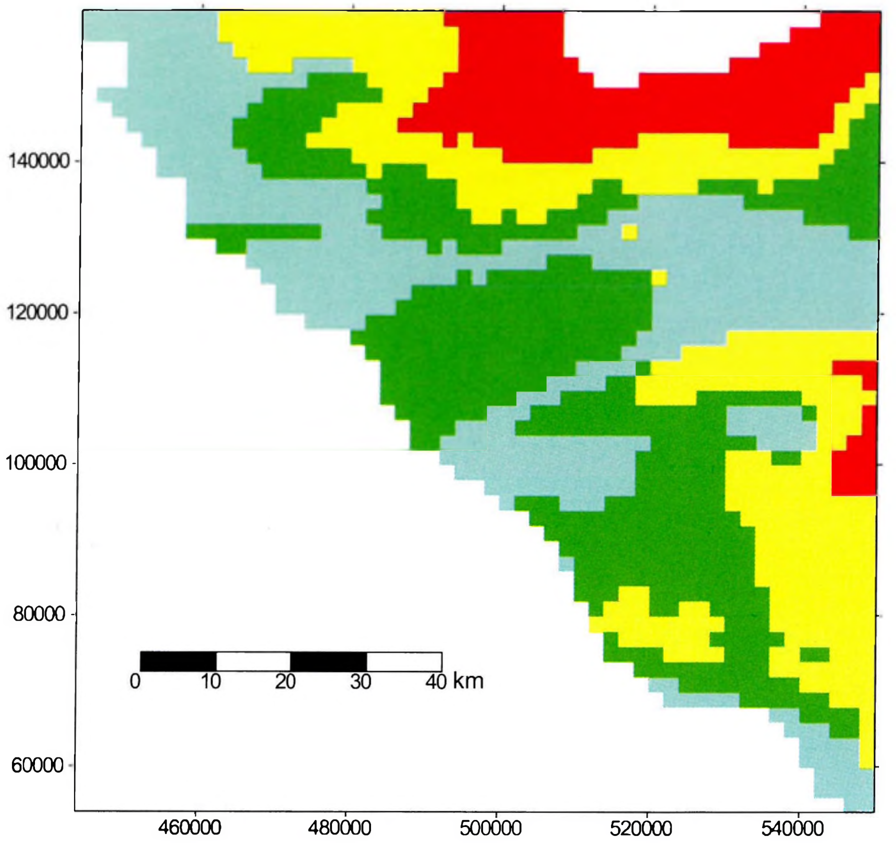


Fig.7.4.5. Cluster map of the Dráva area
7.4.5. ábra A Dráva-vidék klaszter-térképe

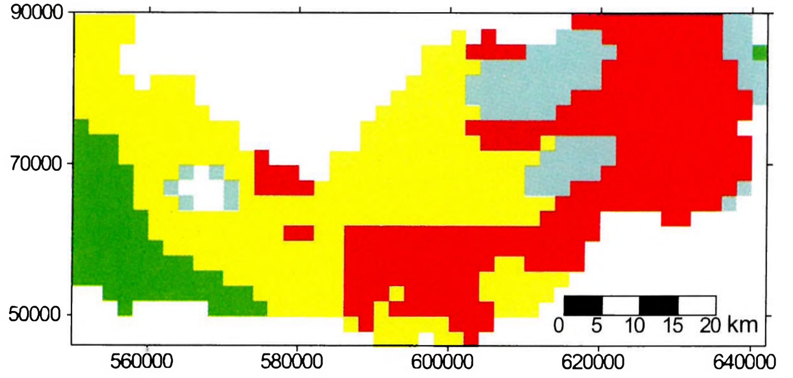


Fig.7.4.6. Cluster map of the Villány mountains region
7.4.6. ábra A Villányi-hegység vidékének klaszter-térképe

In the Somogy area the error in the depth map discussed above appears in two clusters, these represent about 60% of the whole area. Therefore the result of clustering cannot be a real one, and there is no point in analysing it.

Maps were constructed illustrating the spatial distribution of data ranked among the different clusters for the other three areas (*Figs. 7.4.4–7.4.6*). In each map, red indicates the clusters belonging to the shallow basement depths, yellow the medium and green the (relatively) large basement depths, and the points belonging to the fourth cluster, showing irregular behaviour are plotted in blue.

We constructed the curves illustrating the basement depth dependence of geophysical parameters separately for the clusters of all three areas (Figs. 7.4.7– 7.4.12). Curves for each cluster were constructed similarly to those described in Figs. 7.4.2 and 7.4.3, based on the average values of the depth strips and those strips were omitted where the number of data was low. In the figures, numbers 1, 2 and 3 refer to the clusters showing normal depth dependence, while 4 refers to the irregular cluster.

Our results are presented by areas.

Kisalföld

The cluster map is Fig. 7.4.4, the depth dependence of parameters is shown in *Figs. 7.4.7* and *7.4.8*.

Analysis of the curves makes it obvious that formation of the irregular cluster 4 is the consequence of the anomalously high conductance in some areas of medium depth. The majority of these areas in question (marked in blue in Fig. 7.4.4) fall into the zone of the Rába Line [NEMESI et al. 1994]. (The smaller patches appearing in the vicinity of the border are unsuitable for interpretation.) The most recent magnetotelluric results [VARGA 1999] indicate the very low resistivity of basement formations in this zone, therefore they are in agreement with our statistical results. The spatial location of cluster 4 allows the magnetotelluric results to be extended to areas not covered by this method.

According to Fig. 7.4.7 the character of changes in Bouguer anomalies in cluster 4 is the same as in cluster 2 representing a similar depth interval, only the Bouguer anomalies in the former belonging to the same depth are about 5 mGal smaller. Our earlier studies [NEMESI et al. 1997] showed that change in the depth to the Mohorovičić discontinuity and to the lower

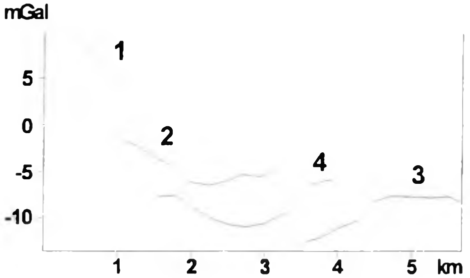


Fig. 7.4.7. Dependence of Bouguer anomalies on depth to the basement in the clusters of the Kisalföld area
7.4.7. ábra. A Bouguer-anomáliák függése az aljzatfelszín mélységétől a kisalföldi terület klasztereiben

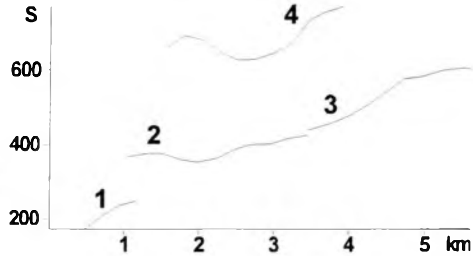


Fig. 7.4.8. Dependence of telluric conductance on depth to the basement in the clusters of the Kisalföld area
7.4.8. ábra. A tellurikus vezetőképesség függése az aljzatfelszin mélységétől a kisalföldi terület klasztereiben

crust–upper crust boundary takes place just along the Rába Line, thus the lower level of Bouguer anomalies in cluster 4 cannot be explained by the position of these interfaces. Based on these we may assume that the density of the low resistivity basement formations is also low.

Another characteristic feature of Fig 7.4.7 is that at the boundary between clusters 2 and 3, at a depth of 3–3.5 km the depth dependence of Bouguer anomaly values shows a 'break' of about 10 mGal. The reason for this should very likely be sought in the spatial position of cluster 2. Figure 7.4.4 shows that these areas are adjacent to the dominantly shallower areas of cluster 1, thus it can be assumed that the higher Bouguer anomaly values are caused by the side effect of the neighbouring areas of the elevated basement. In the case of cluster 3 the basement of the adjacent areas is also deep; moreover, the Bouguer anomaly values increasing with depth reflect a regional deep structural effect, too, thus we cannot reckon with any side effect that would significantly increase the anomaly values.

Drava region

Figure 7.4.5 shows the spatial location of the clusters, the relations within the clusters are shown in *Figs. 7.4.9* and *7.4.10*.

Clusters in the area have developed on the basis of being partly overlapping but still separating depth strips. An interesting feature of Fig. 7.4.9 is that the Bouguer anomaly values of cluster 3 are about 7 mGal higher than those in cluster 4 belonging to the same depth. In the section in ques-

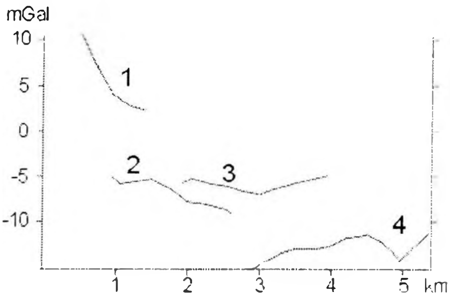


Fig. 7.4.9. Dependence of Bouguer anomalies on depth to the basement in the clusters of the Drava region
7.4.9. ábra. A Bouguer-anomáliák függése az aljzatfelszín mélységétől a Dráva-vidék klasztereiben

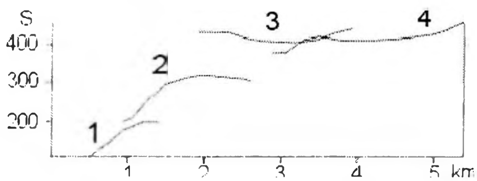


Fig. 7.4.10. Dependence of telluric conductance on depth to the basement in the clusters of the Drava region
7.4.10. ábra. A tellurikus vezetőképesség függése az aljzatfelszín mélységétől a Dráva-vidék klasztereiben

tion both curves show an ascending tendency with depth. The depth map does not create doubts because in the course of the exploration in the hydrocarbon fields of the area numerous wells penetrating the basement were drilled and a large number of seismic lines were located, therefore it is very likely that here the map is significantly more accurate than in general in Transdanubia. The side effect assumed in the Kisalföld cannot be used to explain the phenomenon because the points of cluster 4 fell primarily in the area of narrow grabens, thus the side effect appears in just the opposite direction, increasing the Bouguer anomaly values. According to Fig. 7.4.10 the telluric conductance also behaves in these two clusters differently in this depth strip. In cluster 3 the conductance unambiguously increases with the depth to the basement, in cluster 4 it is practically independent of depth. We see, however, an unambiguously decreasing tendency in the section belonging to the smaller basement depth in cluster 3, this suggests anomalous behaviour. Based on these it can be assumed that in the area of cluster 3, in the depth interval of about 2–3 km, high resistivity and high density formations can be found at the level of basin sediments, their effect causes a decrease in telluric conductance, at the same time it increases the level of Bouguer anomalies.

An increase in Bouguer anomalies in correlation with basement depth can equally be observed in clusters 3 and 4 in the 3–4.5 km interval. This phenomenon can be explained by the elevated position of the Mohorovičić discontinuity and/or of the lower crust. The reversal of the tendency taking place at 4.5 km — similarly to the Kisalföld — is explained by the intensive sinking and sediment accumulation taking place in the recent geological past. This is supported by Fig. 7.4.10 as well because from 4.5 km onwards the values of telluric conductance show an ascending tendency again.

Villány

The spatial location of clusters is shown in Fig. 7.4.6, the relations within the clusters are given in *Figs. 7.4.11* and *7.4.12*.

Both figures (7.4.11 and *7.4.12)* show that the data belonging to clusters 1, 2 and 3 refer to depth strips complementing each other, within these both the Bouguer anomalies and the values of telluric conductance vary as expected; unified curves could be constructed from the data of the three clusters as well.

It should be noted that in cluster 1 (shallow = red in Fig. 7.4.6) the level of Bouguer anomalies corresponds to the Transdanubian average (Fig. 7.4.2), smaller values than the Transdanubian average observed in the Villány average curve are characteristic of areas of clusters 2 and 3 only.

With regard to cluster 4 the behaviour of data is significantly different for both the characteristic values and the tendencies as well. Although ac-

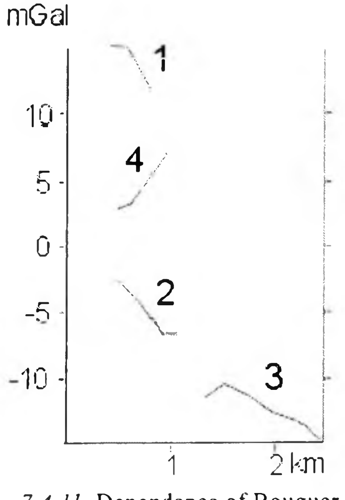


Fig. 7.4.11. Dependence of Bouguer anomalies on depth to the basement in the clusters of the Villány area

7.4.11. ábra. A Bouguer-anomáliák függése az aljzatfelszín mélységétől a villányi terület klasztereiben

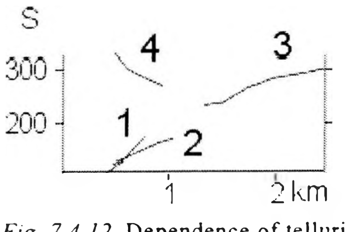


Fig. 7.4.12. Dependence of telluric conductance on depth to the basement in the clusters of the Villány area

7.4.12. ábra. A tellurikus vezetőképesség függése az aljzatfelszín mélységétől a villányi terület klasztereiben cording to Fig. 7.4.11 the Bouguer anomaly values seem to fill the gap between clusters 1 and 2, in contrast with the expectation the anomaly values increase proportionally with depth. According to Fig. 7.4.12 the value of telluric conductance is anomalously high in the cluster's area and in contrast with the expectation the values decrease with increasing depth to the basement. Both phenomena suggest that low resistivity and low density formation build up the pre-Tertiary basement in the cluster's area. This interpretation is supported by the fact that the zone surrounding the Magyarmecske conductance anomaly (see Chapter 5.2) belongs to this cluster (the area of the intensive anomaly itself was excluded from the analysis). By analogy it can be assumed that in the case of further patches that can be found in the eastern part of the area and belong to this cluster the situation interpreted in Chapter 5.2 is found.

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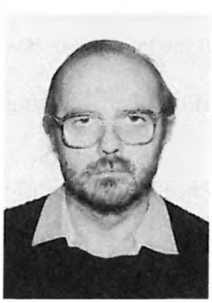
7.4. FEJEZET

A geofizikai paraméterek statisztikai vizsgálata

KOVÁCSVÖLGYI Sándor és OCSENÁS Péter

Klaszter analízissel vizsgálják a gravitációs Bouguer-anomália, a mágneses anomália, a tellurikus anomália és a pre-tercier aljzat mélységtérképét. Megállapítják, hogy a földmágneses térképpel a másik három gyakorlatilag alig korrelál. Az alapvetően hasonló "másik három" részletes elemzésével azonban a Dunántúl négy nagyobb egységre bontható: a Kisalföld-, a Somogy-, a Dráva- és a Villány- egységre. Ezeken belül is vannak kisebb elkülöníthető egységek. Az elkülönülések a felépítményben is, de főként az aljzatban (kéregben) ismerhetők fel a fizikai paraméterek alapján.

ABOUT THE AUTHORS



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.

Péter Ocsenás (1966) received his diploma in geophysics from the Eötvös Loránd University of Sciences; then, in 1999, a diploma in environmental protection engineering from the Technical University of Budapest.
From 1991 onwards he dealt with groundwater exploration and geostatistical studies in the Eötvös Loránd Geophysical Institute of Hungary. Since 1999 he has been involved with environmental statistical studies in the Hungarian Central Office of Statistics.

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CHAPTER 8

Summary of the results of telluric exploration from the viewpoint of a geophysicist

László NEMESI*

Funds from the National Scientific Research Foundation (OTKA) enabled a dozen geophysicists to summarize the telluric explorations carried out over a period of several decades in Western Hungary, in Transdanubia. The telluric method was elaborated by geophysicists of the French firm Schlumberger; the concept is originally due to Geza Kunetz, a geophysicist of Hungarian origin. One of the most important workshops for its further development was in Sopron, Hungary. In the original form tellurics is no longer utilized anywhere in the world including Hungary.

Since the initiation of the project three years ago, we have had two principal aims. The first of these was documentation. Several chapters of the present work belong to this category, such as the history of research, the description of instruments and processing methods, and — to some extent — the geological models behind the early exploration aims some decades ago. The latter support our decision to include a short description of the geological setting of the Carpathian Basin, particularly of Transdanubia with reference to the development of this knowledge in phases corresponding to the different phases of the exploration which determined the actual tasks of the telluric method.

The second aim was to construct a uniform telluric map of the area together with its interpretation. Three institutions carried out telluric measurements in Transdanubia: ELGI (Eötvös Loránd Geophysical Institute), the geoelectric team of the Hungarian Oil Industry, and the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences.

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(The latter two changed their names several times during the lifetime of the telluric method in Hungary.) Relative conductance maps of smaller areas constructed in the framework of contracts were based on data relating to the electric parameters of base stations, where the corresponding actual electric parameters were mostly unknown. It was sometimes not known whether pulsations used to interpret the measurements actually reached the basement depth and, if they overshot the basement depth, whether the basement contained electric conductive formations. If it did contain them then the telluric map reflected not only the conductance of the Tertiary and Quaternary formations to be mapped but it also reflected the inhomogenecities of the basement. The two effects, however, cannot be separated by the telluric method alone.

A further difficulty in interpreting the telluric measurements was that the relative conductance (isoarea) maps of adjoining areas referred to different base stations are independent of each other, thus partial maps could not be combined. Therefore maps of greater areas, or parts of the whole region selected on the basis of new points of view could not be compared with other data and, correspondingly, the geological interpretation was also difficult.

The most important task in the framework of the three years of the OTKA contract was the construction of the unified map.

The first step was to produce a unified database. This had to include all relevant telluric data. We succeeded in performing this by no means spectacular but very time consuming task. Thus, most of the important data of all telluric measurements carried out in Transdanubia have been included in the database of the Hungarian Geological Survey.

The second task was to carry out comparative measurements at the telluric base stations, this being a precondition for the construction of a unified telluric map. From several variants of such comparative measurements tested over a period of some decades the most effective method was selected, namely magnetotelluric soundings at the 30 Transdanubian base stations. These measurements were carried out by the ELGI crew in the years 1997 and 1998, in intervals thought to be most favourable from the point of view of the geomagnetic activity, using ELGI's GPS system with an instrument pair adapted for synchronous measurements for carrying out the processing of the data immediately in real time. Financial support was obtained from two OTKA contracts. The most important result of these measurements was that previous relative conductances could be transformed into absolute conductances and by this the major obstacle to constructing the unified map disappeared. The second not negligible result was the possibility to study the position of pulsations with periods of 20 to 30 s with respect to the *S*-interval. Judging from these MT measurements, these pulsations were mostly within the *S*-interval. Nevertheless, there were certain areas where this was not true — either due to too low penetration depth or due to conductive formations in the basement. Therefore a remark is in order here in relation to the unified conductance map: viz. it is coherent for a period of 25 s. The conductance was determined at the base stations for a period of 25 s and these values were used in the transformation of the relative telluric values. The choice of the period 25 s is supported by the fact that this period is in the middle of the range 20 to 30 s used in about 90 percent of the stations. Moreover, the peak of the occurrence frequency of pulsations is just at that period at Hungary's latitude according to statistical observatory data. The telluric map included in this issue is, on the basis of what has been said, a coherent map of the absolute conductance for a quasi-25 s period.

The final task is — like the main task of all types of geophysical exploration — the interpretation of this telluric map, of the geologic information implied in it.

These investigations have been carried out by two methods since the very beginning of telluric explorations: the first of these was comparison with the results of other geophysical methods, with borehole data and with geological information; the second was a continuous methodological study of the theoretical principles of the method. Some chapters in this work cover both fields.

Methodological analyses and direction dependent information are treated mainly in Chapter 6. It is to be emphasized here that the telluric–magnetotelluric complex belongs to the few geophysical methods which bring information not only about the geological structure below the measuring station but also on the environment, on the structural setting. Temporal absolute ellipses, directions of the major and minor axes of the polar diagrams are connected to structural directions, to the directions of dip and strike (*E* and *H* polarizations). These latter, viz. the temporal absolute ellipses, the direction of the axes, as well as the surfaces of equipotential lines, provide us with spectacular imaging of 2- and 3-D structures in zones of quick conductance-changes; otherwise — in areas of changes of the conductance by some ten-twenty-thirty percent — the regional effects and not any local peculiarities of the primary electromagnetic and of the geological characteristics govern the directional statistics.

In the framework of the comparative studies, in the first place we prefer comparison with mapping (potential field) methods carried out with the aim of preparatory exploration; in addition, we would utilize comparisons with magnetotellurics as being a method yielding more quantitative results. A further preference is to analyse regional geological maps in that the scale of the telluric maps and the density of measurements just corresponds to them.

On this basis it is evident that the telluric conductance map reflects in a first approximation the conductance of Tertiary and Quaternary sedimentary (sandy-clayey) rocks in the Carpathian Basin, qualitatively their thickness, too. Even so, there are areas of about hundred square km where obviously significant conductance anomalies have no counterpart in other geophysical and geological maps (Magyarmecske, Zselic, Paks, Nagygörbő). The source of these anomalies is to be looked for in older formations, eventually perhaps in tectonically stressed zones. In some cases Upper Cretaceous and Carboniferous formations are supposed there based on analogies confirmed by borehole data (Paks and Magyarmecske), in other cases we have no information about the source of the anomalies and we can only make suppositions.

Geophysical and geological maps and data can be interpreted by more exact physical-mathematical methods, e.g. by magnetotelluric sounding and by cluster analysis. The imaging can be improved, the resolution increased and major areas can be split into smaller ones with different physical properties. The differences between these minor areas are often also reflected in the younger sediments covering them; nevertheless, these differences do not mean absolutely new, surprising facts in most cases. This means that these zones have already been detected by reflection seismics, boreholes and well logging.

Anomalies in the less explored basement, however, are of a much higher value. In particular, the conductance map of the basement (see Chapter 7.2) should be mentioned here being the difference of the telluric conductance and the conductance of the Tertiary-Quaternary complex. One of the obvious anomalies in this map is the Transdanubian Conductivity Anomaly discussed several times by Antal Ádám. Another significant feature is a conductive zone in the centre of Southern Transdanubia striking N–S which had been less known and which was treated and analysed in more detail in Chapters 7.3 and 7.4. Young Palaeozoic sediments found or supposed here have tectonic directions nearly perpendicular to the directions of the present surface and basin structures. We consider this information as significant for the exploration of mineral resources, especially for coal and hydrocarbon deposits. Wells in this area discovered a Carboniferous meta-anthracitic complex. New tectonic information is added to basic knowledge in geology, too; such information proves or disproves suppositions made several decades ago by well-known geologists. Depending on whether the earlier suppositions are proved or disproved earthquake hazard investigations, geothermal energy investigations and other exploration problems (at present not yet outlined) may be influenced.

The telluric map included here means that much of the Hungarian basin areas are covered not only by gravimetric and geomagnetic maps, but also by maps of the conductance. (In the area between the rivers Danube and Tisza, some ten thousand square km has remained without telluric measurements.) Based on experience obtained from maps of the basins in Eastern and Northern Hungary and from other basin areas (e.g. in the Gobi Desert in Mongolia) it is to be stressed that: (i) telluric measurements imaged basin areas with a 6 to 8 km thick sedimentary cover (e.g. Békés Basin, Makó Graben, the basement high between them at Pusztaföldvár–Battonya) which remained undetectable from gravimetric–geomagnetic maps and even filtering could not enhance them; (ii) a comparative analysis of the three maps yielded geological information which could not be obtained just by one method alone. Cluster analysis carried out on traditional maps helped us to divide Transdanubia into three big geological units: viz. the Little Plain, the Somogy region, and the Villány region. Where measurements are dense enough, the units can be further split into even smaller areas with surfaces of a few thousand or even a few hundred square km.

These facts mean important information for the development of exploration conceptions. The cost of the three traditional methods is by orders of magnitude less than that of the seismic method and by many orders of magnitude less than that of borehole exploration. Their application is therefore advantageous and well founded in all areas of the world covered by sediments of several km thickness. Fracture zones and certain types of rock cause additional conductance anomalies which can only be explored by electric methods. In such cases the telluric method is an inseparable part of the detailed target exploration.

Nowadays magnetotelluric–telluric measurements with many stations are recommended as conductance measurements. This possibility was observed by big instrument manufacturing firms, too. In other words such measurements (magnetotelluric measurements at the base station and the measurements of only the telluric components at many roving stations) put into practice the method, earlier used by us, that rapid and inexpensive telluric measurements at many stations should be coupled with quantitative magnetotelluric measurements.

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Nemesi László for a photograph and biography, see this issue, p. 120

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CHAPTER 9

A few reflections on the telluric conductance map of Transdanubia

György MAJOROS*

Construction and publication of the 1:500 000 scale telluric conductance map prepared from the telluric measurements in Transdanubia represents an enormous amount of work which rightly deserves recognition and praise. Without a shadow of doubt, it is of immense benefit to the domestic geosciences.

In some areas, connected with certain raw material prospecting projects — as is also evident from the introduction to this work — we might learn about earlier telluric measurement materials and maps, too, and a goodly number of publications about this topic have been published. Together with colleagues I myself also took part in the one-time uranium exploration and the objective determination and geological interpretation of the telluric and magnetotelluric measurements carried out in the environs of the Villány Mountains in the early 1980s (László Nemesi, Géza Varga). In spite of this, up till now I have had no possibility to study a sufficiently detailed telluric map of a larger area, of a geological unit. Therefore I looked forward with great interest and pleasure to this new kind of regional geophysical parameter map. I should here like to thank the Editor for having given me this flattering opportunity.

Lack of space and time means that I cannot undertake a more detailed analysis with a geological approach of this parameter map — which taking into account the precedents was a new kind to me — covering such a large area of variegated geology. The following few reflections and remarks are, however, probably not completely without benefit for those who intend to

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use and further interpret this map. However, I should like to point out that not for a moment do I wish to give any guidance or instruction regarding the interpretation of telluric maps, I do not have enough knowledge and experience for that; I mention — as a geologist dealing with the structural study of the area — some of my observations.

With regard to a comprehensive evaluation of the attached telluric conductance map of 1:500 000 scale I agree in general with the findings of the authors described here, especially with those concerning the very striking similarity between the Bouguer anomaly maps and contour maps of the pre-Tertiary basement. They provide a technically sound explanation for that. The choice of the colour code for the telluric maps can be considered an ingenious solution, assisting in the most obvious visualization of similarity.

It is fully evident from a joint study of pre-Tertiary basement and telluric maps — as the authors also point out — that the above mentioned similarity frequently does not exist in the case of small, few hundred m basement depth or for large pre-Tertiary basement depths exceeding 2500–3000 m.

There are, however, cases when a considerable difference presents itself between the two maps in areas with so-called 'medium' depth to the pre-Tertiary basement. This may stem from several natural reasons, but most frequently it may be a consequence of the necessarily inaccurate construction due to few well data, especially where the density of wells is substantially lower than that of telluric measuring points. To support my idea I would bring up the case of the detection of the S–SE edge line of the so called Balaton crystalline range, south of Lake Balaton.

The relevant detail of the morphologic map of the pre-Tertiary basement in the area south of Balaton constructed in the early 1980s (Fig. 3.6) does not show much similarity with the telluric map. I myself — as a member of the editorial working team — constructed this detail in question of this map based on fairly few data. Then, I elaborated a new construction based on a much greater amount of data that had accumulated in the meantime (wells, geoelectric, seismic data) of Balaton's environs, in this the sharp, step-like pattern of the southern edge of the Balaton crystalline range appears. Comparing this non published morphologic map of more recent construction with the telluric map the similarity is almost breathtaking.

It follows quite obviously from the foregoing that the telluric map, taking into account its discussed limits, generally reflects the pattern of the pre-Tertiary basement covered with sediments, it maps their morphological features, frequently without close quantitative relations between the sediment thickness and telluric anomalies. In this way, this map shows the morphology of the descending basement starting from the basement outcrops on the surface, as though it 'transilluminates' the overlying sediments.

This attribute of the telluric map makes it suitable for comprehensive study of structural pattern, structural style of areas covered with sediments, and to mark out the boundaries of areas of different structural pattern and style. The environs of the Mecsek Mountains serve as an excellent example for that, where, for example, the system of long ridges and depressions of NW–SE orientation obviously manifests itself based on the telluric maps and the area of this basement structural style's validity can also be easily outlined. The area outlined in this way can be analysed in even more detail, utilizing other information available from the area, too. But observations of this kind and structural analysis based on the telluric maps can be made on almost the whole area of the map — with sometimes unambiguous or sometimes less clear manifestation — serving as a useful contribution to the structural analysis of both the basement and the sediments filling up the basin. Such observations can be made based on gravity maps, too, and though we make the best of this possibility my preliminary experience is that the telluric maps unambiguously reflect the basement topography.

The telluric map's editors also attempt to interpret some of the characteristic telluric conductance anomalies. From among these I should like to comment primarily on the Magyarmecske and Nagygörbő anomalies. In my opinion, these two anomalies are of similar character and represent a special type. One of the fundamental characteristics of both anomalies is that they are of small extension and almost isometric shape characterized by high siemens values in a low conductance (150–200 siemens) background. A gravity minimum, approximately similar to the telluric image falls on the area of both anomalies. As the authors also point out a funnel- or bay-like depression of the pre-Tertiary basement characterizes the area of both anomalies. In the case of the Nagygörbő anomaly the geological section (*Fig. 9.1*) that can be constructed from the wells drilled in the anomaly's area or in its vicinity clearly shows this as well. In other words we should see that these telluric anomalies can mostly be connected to the

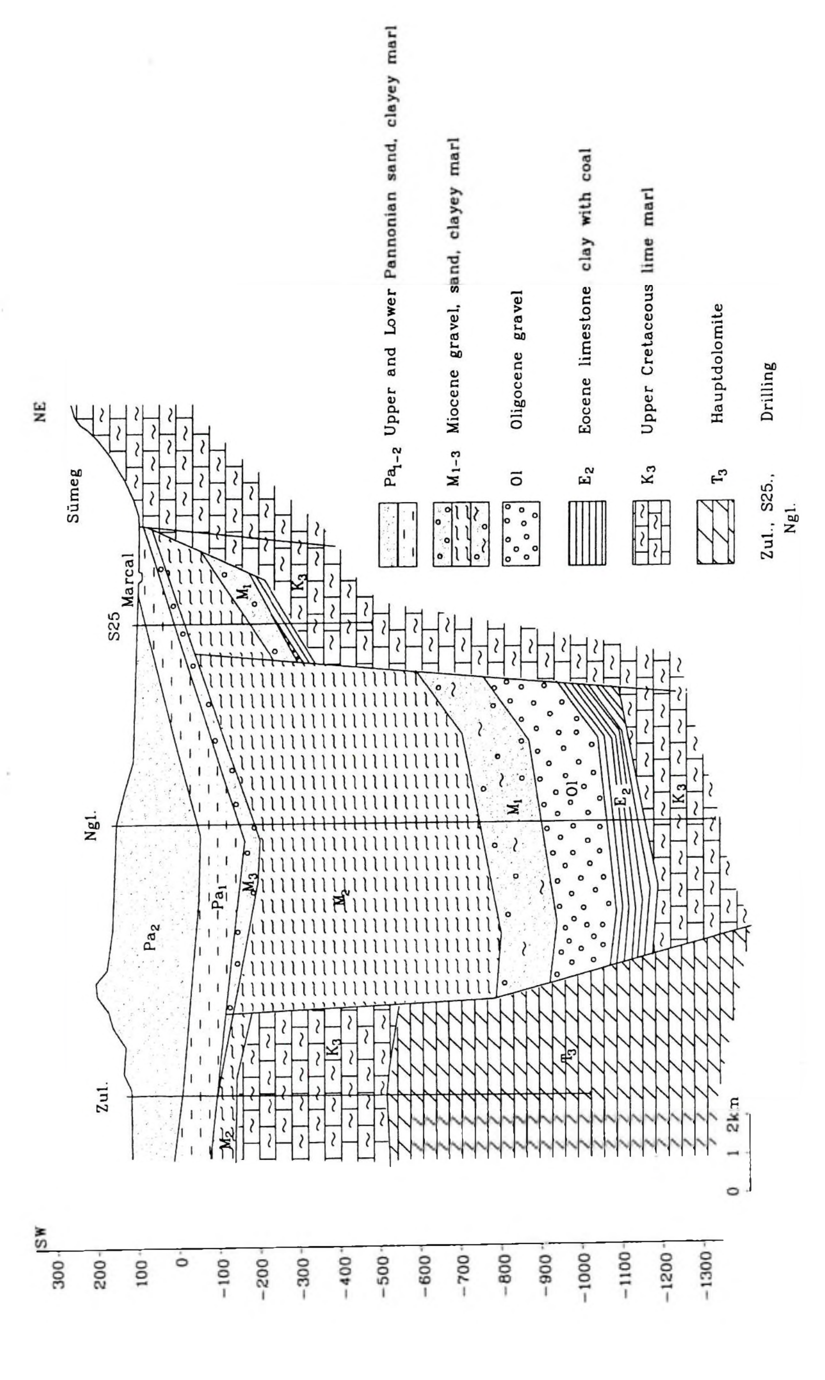


Fig. 9.1. Geological cross-section between Zalaudvarnok and Sümeg
9.1. ábra. Földtani keresztszelvény Zalaudvarnok és Sümeg között

very deep basins sunk along faults of steep walls into the basement that is in a relatively high position at the mountain edge and it is not absolutely necessary to look for low resistivity rocks to explain them. In the vicinity of these collapse type basins significant strike slip zones can be detected in both cases, this supports our idea, i.e. these basement depressions can be considered basins of pull-apart character, where the limiting steep faults penetrate deep into the basement and might give rise to a telluric anomaly of significant amplitude and depth.

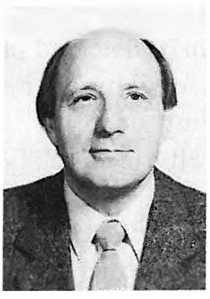
I would mention one more phenomenon to complete the potential explanation to these telluric anomalies. The temperature measurement performed in the Nagygörbő–1 well drilled in the Nagygörbő depression suggests that there is a significant negative temperature anomaly in the depression. A rock temperature of 49°C was measured even at the bottom of 1500 m. In other words, it seems that there is an intensive infiltration in these depressions of pull-apart type with steep walls at the mountain edges and this cools down the rocks. I cannot form an opinion whether this intensive water flow, infiltration can generate this significant increase in telluric conductance.

To summarize, my opinion is that the obviously detected small basins, the associated steep faults penetrating deep into the basement are more likely to cause the above sharp anomalies of small extension than high conductivity rocks within the deep basement occurring isolated in an area of few km^2. In other words, similarly to the other telluric anomalies the large sediment thickness generates them, only due to the small basin size the effect of faults penetrating deep into the basement is added to this.

In the case of Magyarmecske, the presence of coal-bearing Carboniferous in the pre-Tertiary basement can undoubtedly contribute to forming the anomaly image. What is required is a satisfactory explanation as to why there is no significant telluric anomaly in further neighbouring areas, where the presence of coal-bearing Carboniferous is also known from wells (even black shale of high organic content was found in a well (Szava–1)).

Finally, though up to now I have limited experience concerning the telluric map, I already think that the editors' intention (i.e. to provide by means of constructing the telluric map another regional geophysical parameter map in addition to the gravity and magnetic maps), has been fully realized and it can successfully be used together with the already existing ones in the study of the deep geology and structure of the represented areas.

ABOUT THE AUTHOR



György Majoros completed his studies in geology at the Eötvös Loránd University of Sciences. Since his graduation, he has worked for the Mecsek Ore Mining Co. (MÉV). From 1968 onwards he was head of the geology department of MÉV's Exploration Division; later, as chief geologist, he was the technical supervisor of uranium and other raw material prospecting in the Transdanubian Central Range, Northern Middle Range and Mecsek Mountains. Since his retirement he has become a consultant in geology. He received his doctorate in 1963. From 1986 onwards he was a part-time senior lecturer and, from 1995, an invited lecturer in geology, environmental geology and palaeontology at the Janus Pannonius University of Sciences. He is a member of the Hungarian Stratigraphy Committee and, at present, head of the Palaeozoic Working Team. He served several terms as a member of the Geological Scientific Committee of the Hungarian Academy of Sciences.

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Finally, with this publication the authors wish to commemorate the late András Erkel. In the mid 1950s, together with Antal Ádám and Ernő Takács, he pioneered the introduction of the telluric method in Hungary. His activities were of determining character in ELGI, and he played an important part in establishing the telluric team of the oil industry.

A DUNÁNTÚL TELLURIKUS VEZETŐKÉPESSÉG TÉRKÉPE

25 s periódusidőre (f=0.04 Hz) számolt látszólagos vezetőképesség értékek felhasználásával

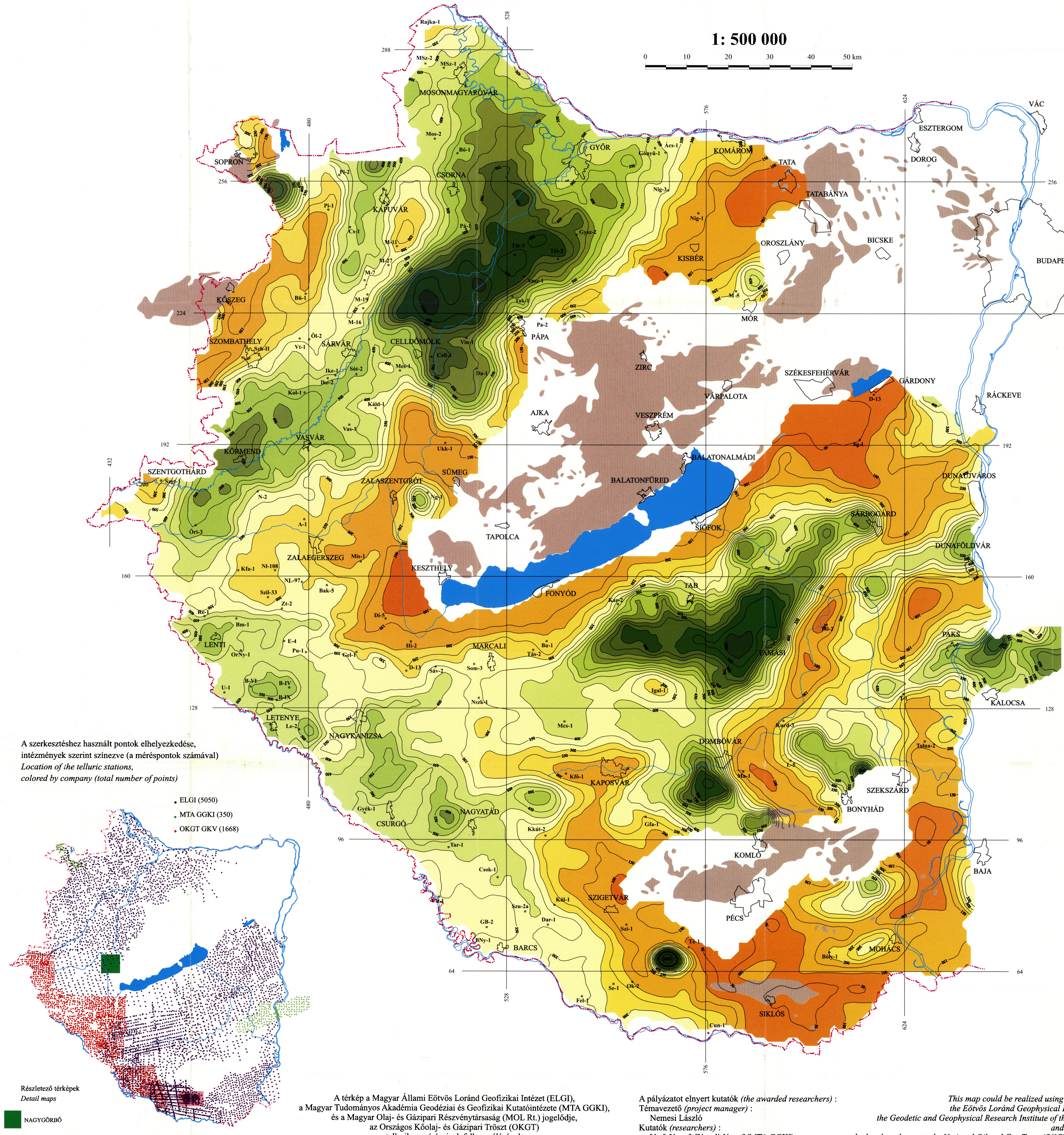
TELLURIC CONDUCTANCE MAP OF TRANSDANUBIA

Based on apparent conductance, calculated for 25 s period (f=0.04 Hz)

Alapítva 1919

1: 500 000

0 10 20 30 40 50 km



Jelmagyarázat
Legend

Pre-tercier képződmények a felszínen
Outcrops of pre-Tertiary basement

Mélyfúrás
Well

EOV koordináták [km]
EOV coordinates in km

Színskála
Color scale

1000 siemens
800
700
600
500
400
300
200
100

Szerkesztette Madarasi András
Constructed by András Madarasi

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

ELGI (5050)
MTA GGKI (350)
OKGT GKV (1668)

Részletező térképek
Detail maps

NAGYGÖRBŐ
MAGYARMECSKE

A térkép a Magyar Állami Eötvös Loránd Geofizikai Intézet (ELGI),
a Magyar Tudományos Akadémia Geodéziai és Geofizikai Kutatóintézete (MTA GGKI),
és a Magyar Olaj- és Gázipari Részvénytársaság (MOL Rt.) jogelődje,
az Országos Kőolaj- és Gázipari Tröszt (OKGT)
tellurikus méréseinek felhasználásával,
az Országos Tudományos Kutatási Alapnál (OTKA) elnyert
T 024 097 számú pályázat révén valósulhatott meg.

A pályázatot elnyert kutatók *(the awarded researchers)* :
Témavezető *(project manager)* :
Nemesi László
Kutatók *(researchers)* :
Verő József, Závodi József (MTA GGKI)
Madarasi András, Varga Géza (ELGI)
Nagy Zoltán, Landi Kornélné (MOL Rt.)

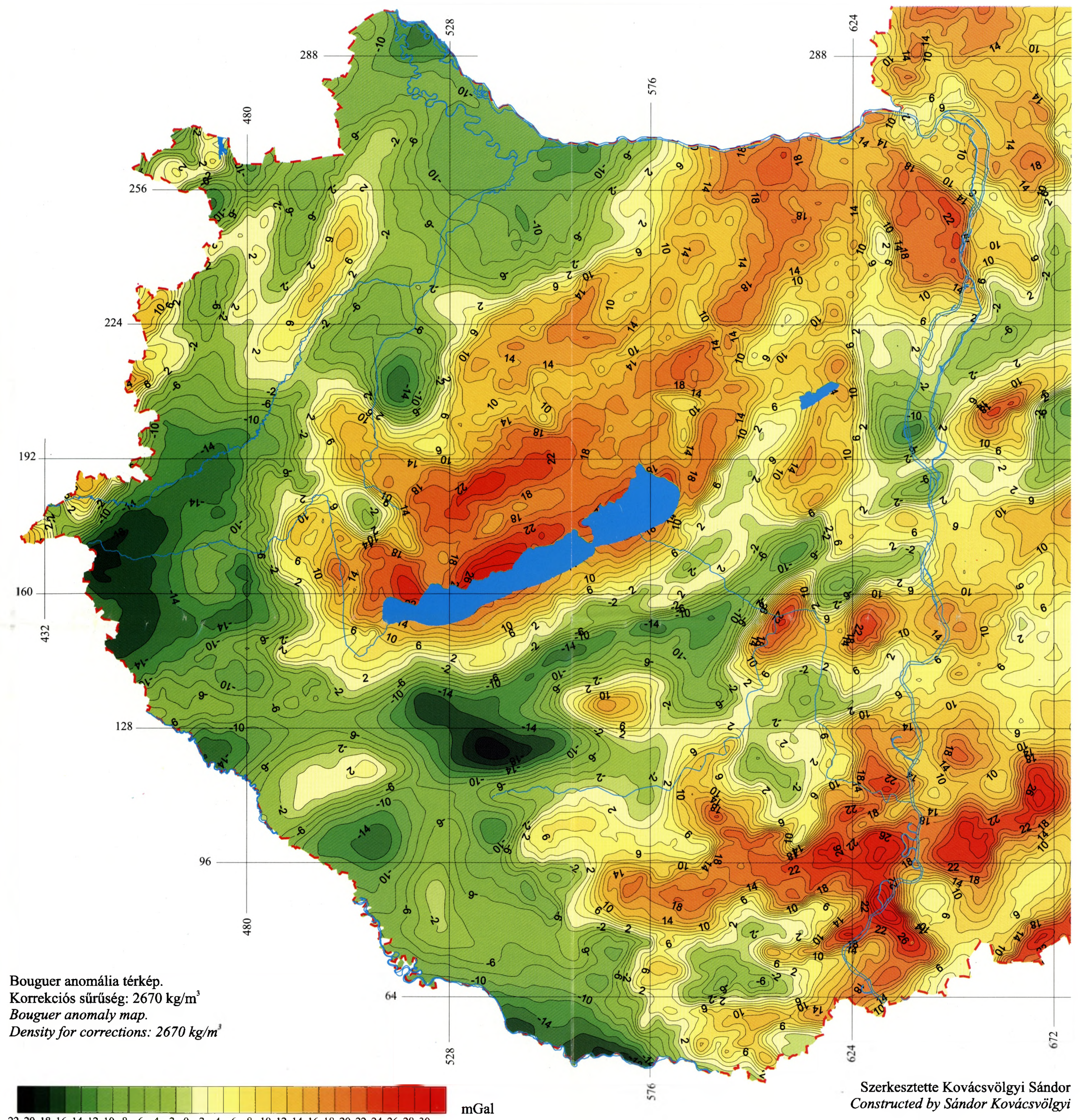
This map could be realized using the telluric measurements of the Eötvös Loránd Geophysical Institute of Hungary (ELGI), the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (MTA GGKI), and the legal predecessor, the National Oil and Gas Trust (OKGT) of the MOL Hungarian Oil and Gas Company (MOL) through the support obtained from the National Scientific Research Fund N° T 024 097

A DUNÁNTÚL GRAVITÁCIÓS ÉS MÁGNESES TÉRKÉPE

GRAVITY AND MAGNETIC MAP OF TRANSDANUBIA

1 : 1 000 000

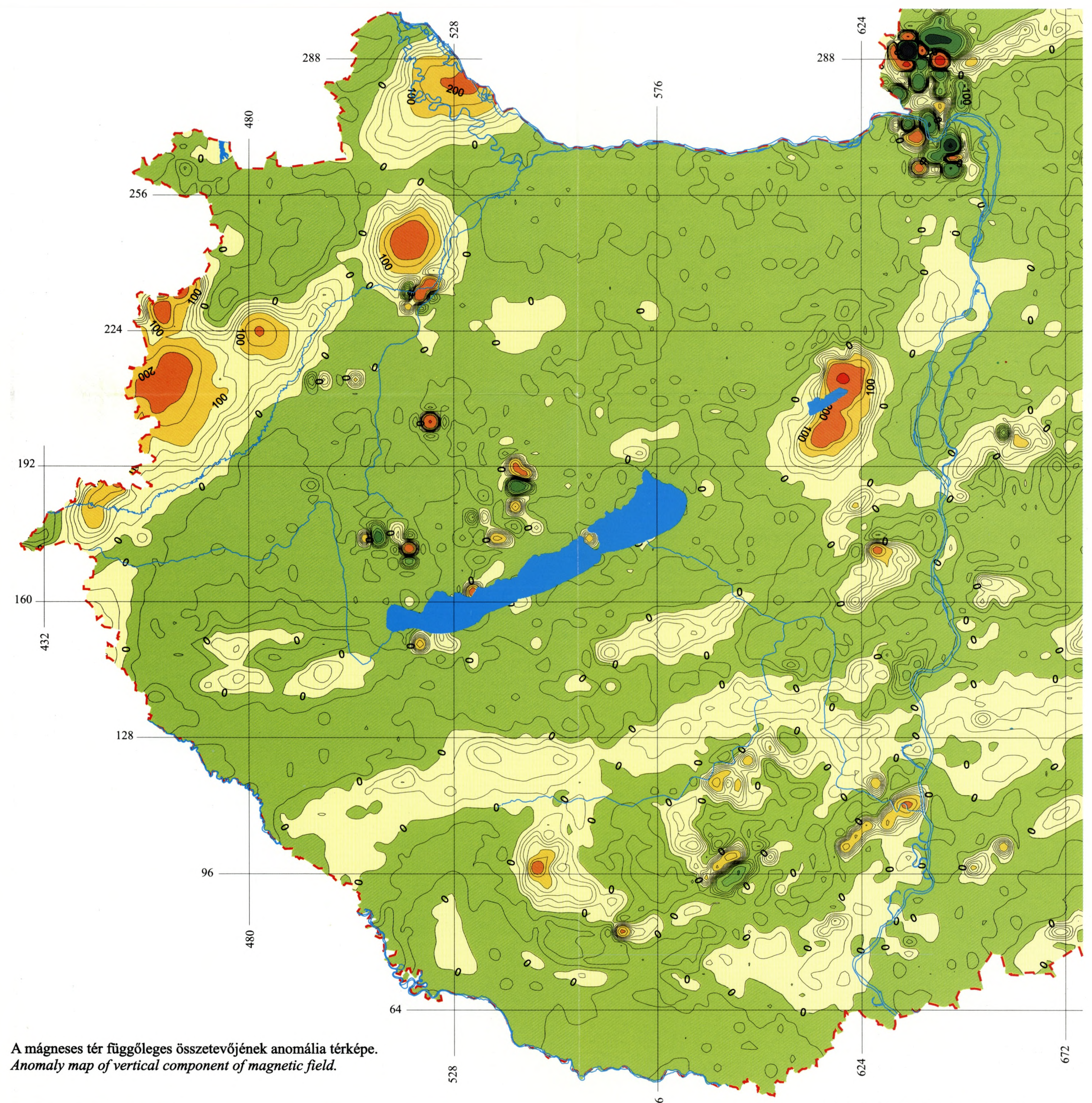
0 10 20 30 40 50 km



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

-22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 mGal

Szerkesztette Kovácsvölgyi Sándor
Constructed by Sándor Kovácsvölgyi



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

-2000 -1000 -500 -200 -150 -100 0 100 200 500 1000 nT

Haáz István és Komáromy István nyomán.
After István Haáz and István Komáromy.

A TÉRKÉP A MAGYAR ÁLLAMI EÖTVÖS LORÁND GEOFIZIKAI INTÉZETBEN KÉSZÜLT BUDAPESTEN, 1999-BEN.
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