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SCALAR AUDIOMAGNETOTELLURIC MEASUREMENTS IN HUNGARY

Antal ÁDÁM*, Pertti KAIKKONEN**, Sven-Erik HJELT**, Juha TIIKKAINEN**

Audiomagnetotelluric (AMT) soundings were carried out in Hungary by the French-made "ECA Résistivimètre" in the frequency range of 4.1–2300 Hz to test AMT method for different geophysical problems (Nagycenk electromagnetic observatory, sedimentary basin, a geodynamic test profile, ore prospecting, etc.).

The main conclusions are the following:

— the most reliable information was obtained at the frequency range of the *harmonics of the Schuman resonance* (7.3–23 Hz).

— the reliability of the apparent resistivity (ϱ_a) values measured on crystalline rocks is higher than that above sediments because in the latter case the much lower amplitude of the electric field essentially worsens the signal-to-noise ratio.

— the noise level caused by power lines of ~ 50 Hz is the highest at 41 and 230 Hz. Near to the sources of the stray (leakage) currents, mainly in villages, the general level of ϱ_a values is increased according to frequency sounding in the "near zone" of the source.

— there is an energy gap between 730 and 2300 Hz which is due to the attenuation of the ELF signals conducted in the Earth—ionosphere cavity and it manifests itself in low ϱ_a values.

Because of difficulties in distinguishing between signal and noise EM fields in scalar measurements without coherence control, there is a need to investigate tensorial data processing and the nature of natural audiofrequency field. For this purpose the design of a digital recording system has been started.

d: audio-magnetotellurics, test surveys, signal-to-noise ratio, time variation, tensorial data processing

1. Introduction

In Hungary the magnetotelluric (MT) method is used by institutes for applied geophysics in the frequency range of 0.01–20 Hz to investigate the relief of the basement at depths of some thousands of metres (see *Fig. 1* section MT_1 of the magnetotelluric sounding curve measured in the Nagycenk observatory, after ÁDÁM et al., 1981). For the geoelectric sounding of the Earth's crust and the upper mantle electromagnetic time variations of much lower frequencies are needed, such as the harmonics of the quiet daily variation (S_q) see section MT_2 in *Fig. 1*). For the determination of the layer structure of the sedimentary cover of a basin, ELF signals of 3–3000 Hz should be used for magnetotelluric soundings. For the geophysical survey of near-surface ore bodies and in various

* Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences, POB 5, Sopron, H–9401, Hungary

** Department of Geophysics, University of Oulu, SF–90570 Oulu 57, Finland

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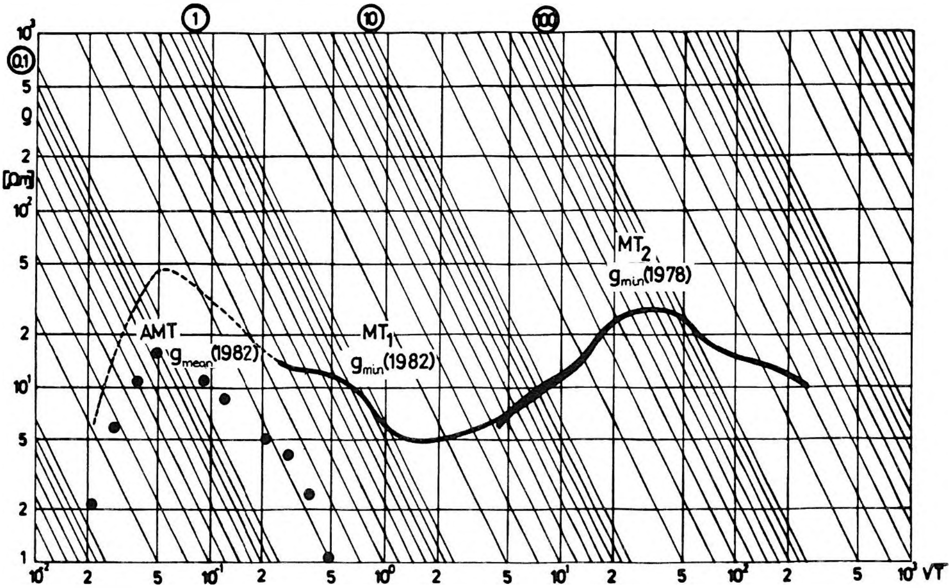

Fig. 1. Magnetotelluric (MT) and audiomagnetotelluric (AMT) sounding curves measured in the Nagycenk observatory. AMT—measured by University of Oulu; MT$_1$—measured by ELGI; MT$_2$—measured by GGRI

1. ábra. A nagycenki obszervatóriumban mért magnetotellurikus (MT) és audiomagnetotellurikus (AMT) szondázási görbék. AMT — Oului Egyetem munkatársainak mérése; MT$_1$ — ELGI munkatársainak mérése; MT$_2$ — GGKI munkatársainak mérése

Рис. 1. Кривые магнитотеллурического (МТ) и аудиомагнитотеллурического (АМТ) зондирования, полученные в обсерватории Надьценк. АМТ — замерены сотругникоми Университета в г. Оулу; МТ$_1$ — замерены сотругниками ELGI ; МТ$_2$ — замерены сотругникоми GGRI

engineering geophysical problems, EM variations in the same frequency range should be analysed. Magnetotelluric sounding using natural ELF signals is called "audiomagnetotelluric" or shortly AMT sounding (see the AMT section in *Fig. 1*).

The measuring group of Oulu University (Finland) carried out AMT soundings between 16 September and 7 October 1982 in Hungary to test the applicability of AMT measurements at middle latitudes for different geophysical problems:

1. in the Nagycenk observatory above 1500 m thick sediments,
2. along a geodynamic profile between the villages of Ukk and Ötvös, in a shallow basin of the Bakony Mts broken into blocks by seismo-active fractures,
3. in the Little Hungarian Plain being a deep basin filled by some thousand metres of sediments,
4. on ore-bearing formations of the Börzsöny Mts.

The AMT instrument, the French-made ECA 542–0, uses a microprocessor to obtain immediately in the field the apparent (scalar) resistivity value (ϱ_a) from the average amplitudes of the electric (E) and magnetic (H) components in perpendicular directions. There are 12 fixed frequencies between 4.1 and 2300 Hz.

2. Geological description

The task of the geophysical surveys in the first three areas was to determine the structure of the sedimentary basin, including the separation of layers of different resistivities, and the tectonics of the basement. The layer sequence in the Pannonian stage can be well characterized by the alternation of more or less resistive sediments (sand or clay). A similar layer sequence was obtained in the Nagycenk observatory but terrace gravel of higher resistivity is embedded into the near-surface layers.

The horizontal anisotropy of the sedimentary layers near the surface of the deep basins is generally less than the anisotropy of the fractured basement.

The AMT sounding curve measured in the Nagycenk observatory is shown in *Fig. 1* as a continuation of MT curves covering together a period range of 8 orders of magnitude. Irrespective of a systematic scale value difference between the AMT and MT ϱ_a values, the AMT curve shifted to the MT_1 curve fits well to it and qualitatively expresses the sedimentary structure described by geoelectric models of the DC soundings. This AMT curve is the geometric mean of 12 measurements. Their mean square errors are shown in *Fig. 2*. Some

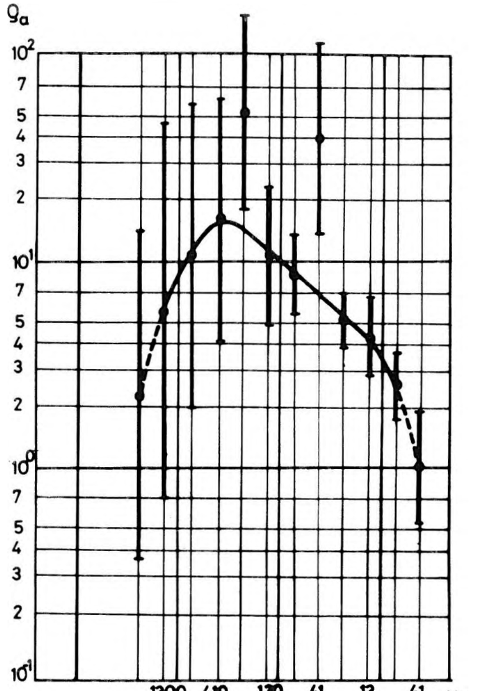

Fig. 2. Mean square errors of the AMT curve in the Nagycenk observatory

2. ábra. A nagycenki obszervatóriumban mért AMT görbe négyzetes középhibái

Рис. 2. Среднеквадратические ошибки кривой АМТ в обсерватории Надьценк.

characteristic features of this curve are briefly mentioned here, with more details being given later on.

- Lowest errors of the ϱ_a values were obtained at the harmonics of the Schuman resonance (7.3, 13, 23 Hz);
- the disturbing fields of power lines of about 50 Hz seriously affect the ϱ_a values at 41 Hz, and at the fifth harmonic possibly at 230 Hz;
- the attenuation between 410 and 2300 Hz in the Earth-ionosphere cavity decreases the amplitudes of the ELF signals, the uncertainty of the ϱ_a values significantly increases.

In the Little Hungarian Plain many factors, such as low electric signals over sediments of low resistivity, high level of disturbances due to the power lines in the villages, etc. decreased the reliability of the individual AMT measurements. Therefore, only an average AMT sounding curve was used for the whole area. Such a curve very much resembles the AMT curve of the Nagycenk observatory measured in a quite similar geological situation *(Fig. 3)*.

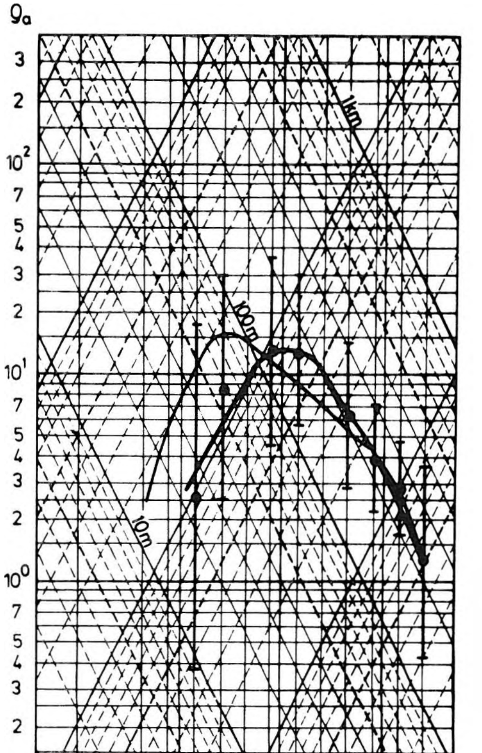

Fig. 3. AMT—measurements at Nagycenk Observatory (thin line) and median of AMT measurements in the Little Hungarian Plain (thick line)

3. ábra. A Kisalföldön mért átlagos AMT görbe (vastag vonal), a Nagycenki Obszervatóriumban mért AMT-görbe (vékony vonal)

Рис. 3. Средняя кривая АМТ, полученная на Малой венгерской низменности (мирной линией), кривая АМТ, полугення в обсерватории Нагьценк (тонкая линия).

Around the villages of Ukk and Ötvös in a shallow basin broken into blocks by deep fractures, the depth of the highly resistive basement varies only some hundreds of meters according to the geological map of *Fig. 4*. The impedance directions Z_{xymax} computed on the basis of the MT soundings are connected with the strike of the fractures. In the villages the AMT curves are generally distorted by stray currents. In view of this, at the measuring site 10 an undisturbed area was chosen to illustrate the information content of the AMT curves (*Fig. 5*). The MTS curve measured at the nearest magnetotelluric point to Ötvös was connected with the AMT curve by a thin line. The anisotropy directions for both of the MT and AMT soundings are assumed to be same. The AMT curve obtained in the direction of 15° E (ϱ_{max}) represents the H polarization case. The currents flowing perpendicularly to the strike cannot penetrate below the Eocene limestone embedded into the sediment cover, and so the curve does not indicate sediments below this resistive layer. The E-polarized AMT curve (direction 285°) however, shows the deeper layer sequence.

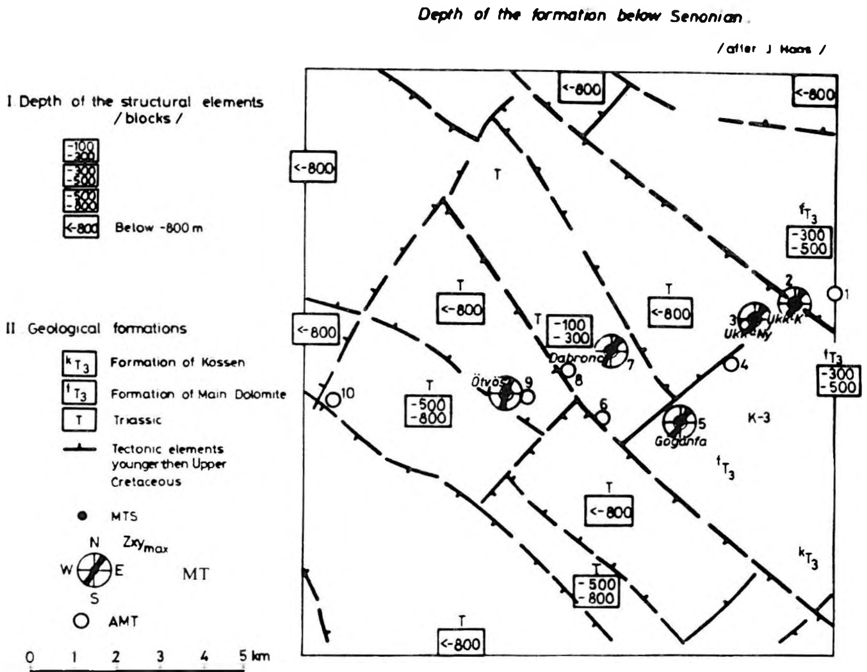

Fig. 4. MT and AMT sites along the Transdanubian geodynamic profile

4. ábra. MT és AMT mérési pontok a dunántúli geodinamikus szelvény mentén

Рис. 4. Места МТ и АМТ зондирования по Задунайскому геодинамическому профилю

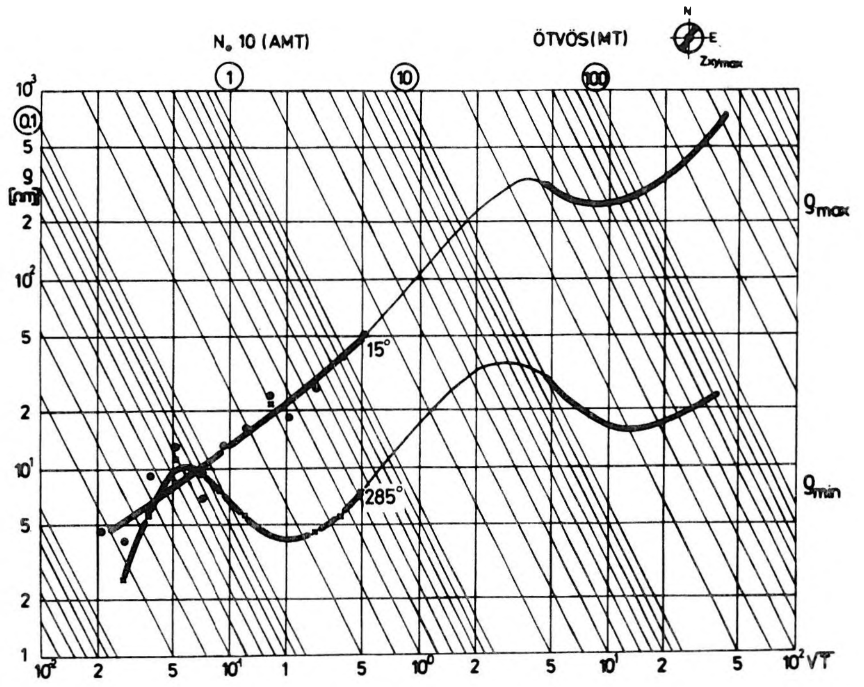

Fig. 5. Connection of MT and the corresponding AMT curve at the measuring site shown in Fig. 4

5. ábra. Az MT és a megfelelő AMT görbe kapcsolata a 4. ábrán bemutatott mérési ponton

Рис. 5. Связь кривой МТ с соответствующей кривой АМТ на месте зондирования, показанном на рис. 4.

The resistivity changes measured at different frequencies by AMT soundings along this geodynamic profile cannot be connected with the MT isoohm profile and the fractures of the area unless the disturbed data are omitted.

Upon comparing the "filtered" AMT isoohm profiles with the original ones *Fig. 6a* and *6b)*, the increase of the values at 41 and 230 Hz in the villages can clearly be seen. On the "filtered" profiles the minimum ϱ_a values appear above the transversal fractures around the villages Ukk and Dabronc. The same can be seen in the residual profiles, which describe the logarithmic behaviour of ϱ_a at each individual measuring point normalized by the regional average of the ϱ_a *(Fig. 7)*.

In the Börzsöny Mts the Eötvös Loránd Geophysical Institute (ELGI) Budapest, carried out ore prospecting using a combination of different geoelectric and IP methods.

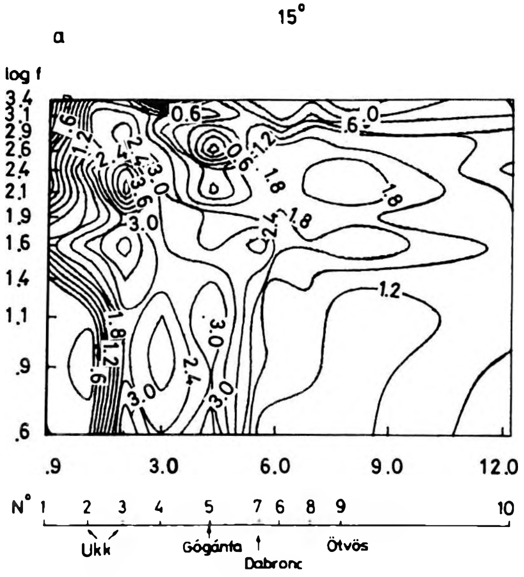

Fig. 6. a. Isoohm section along the Transdanubian geodynamic line

6. a. ábra. Izoohm szelvény a dunántúli geodinamikus szelvény mentén

Рис. 6. а. Разрез изоом по Задунайскому геодинамическому профилю

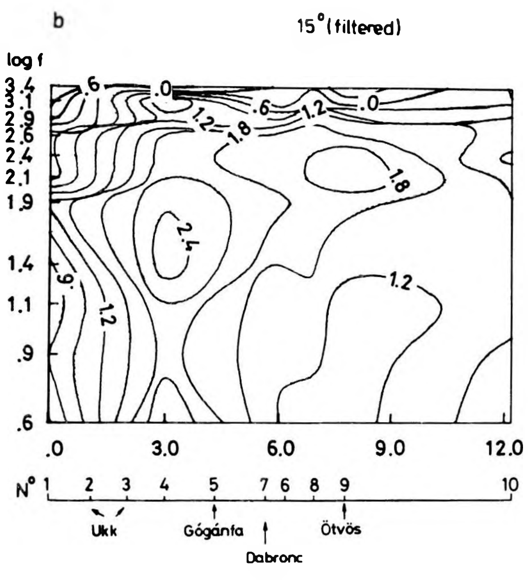

Fig. 6. b. Isoohm section along the Transdanubian geodynamic line omitting data of the disturbed points (2, 3, 5, 7) and the r_a values at 41 Hz and 230 Hz

6. b. ábra. Izoohm szelvény a dunántúli geodinamikus szelvény mentén, a zavarral terhelt pontok (2, 3, 5, 7) és a 41 Hz és 230 Hz frekvencián mért r_a értékek kizárásával.

Рис. 6. b. Профиль изоом по Задунайскому геодинамическому профилю с исключением данных, полученных на точках с помехами (2, 3, 5, 7), и значений ϱ_a на частотах 41 Гц и 230 Гц

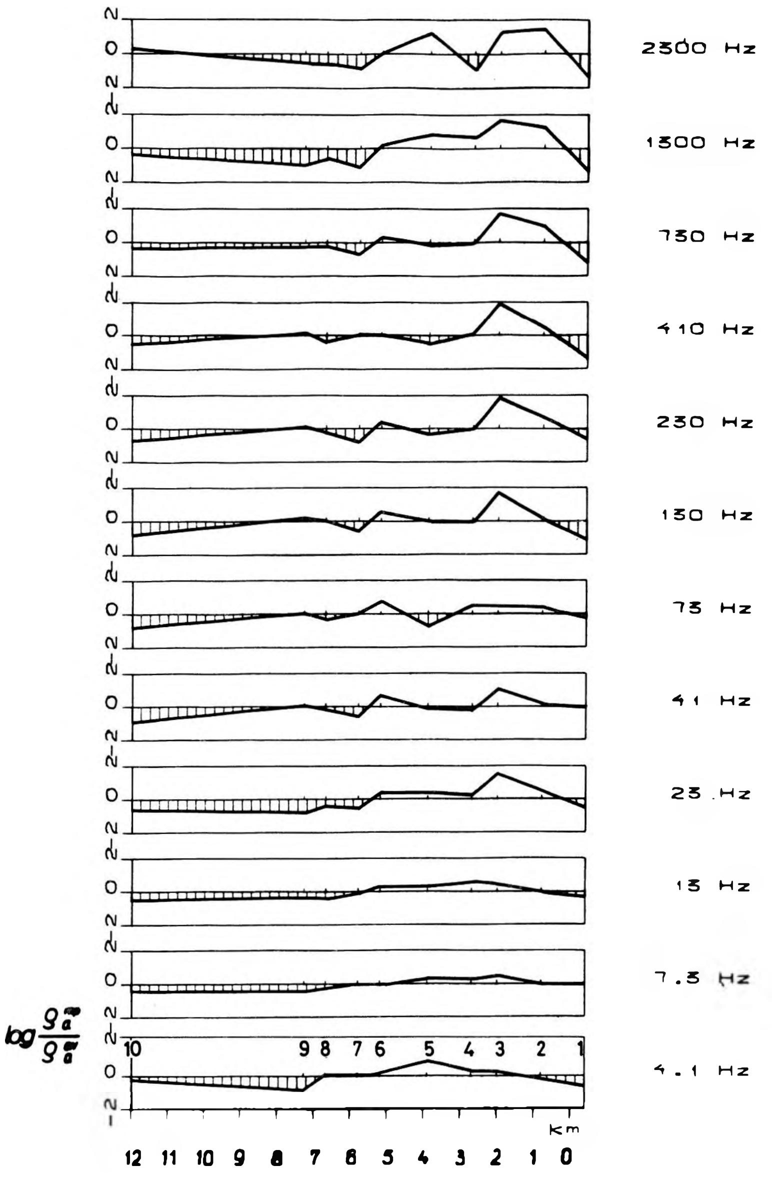

Fig. 7. Residual ϱ_a profiles at each discrete frequency. The direction of the telluric line is 285° (E-polarization)

7. ábra. Maradék ϱ_a szelvények az egyes diszkrét frekvenciákon. A tellurikus vonal iránya 285° (E-polarizáció)

Рис. 7. Профили остаточных значений ϱ_a на каждой дискретной частоте. Направление теллурической линии — 285° (поляризация E)

In *Fig. 8* the AMT ϱ_a-profiles at 4.1 Hz are compared with the resistivity values of a gradient array measured by ELGI above an ore-bearing formation which was verified by a borehole at the point 0.2 km. Irrespective of the different scales, the low resistivity ore formation is well indicated by the AMT profiles in both directions showing its lateral extent, in accordance with earlier experiments of the Oulu group in Finland [PELKONEN ET AL., 1979]. The low-frequency residual profiles in *Fig. 9* delineate laterally fairly accurately the ore formation. This formation pinches out at the left side of the profile between 0.1 and 0.15 km, because both polarizations indicate this pinching out at the same point. The different behaviour of the residual profiles of the E- and H-polarization at the lowest frequencies on the right could be explained by the deepening of the top of the formation to the right.

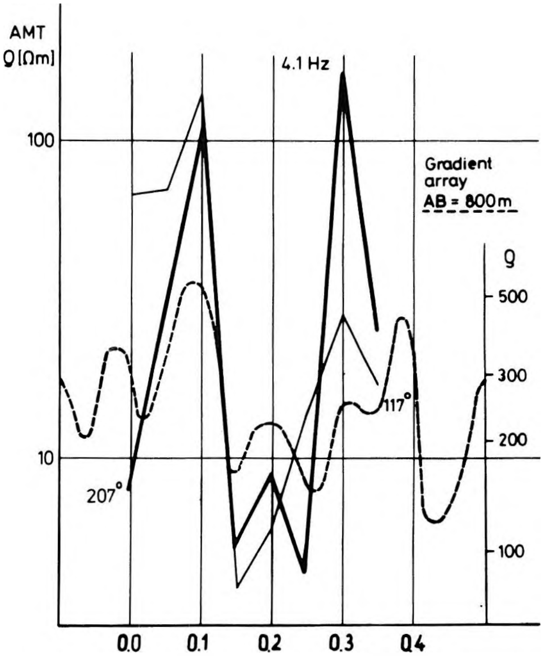

Fig. 8. Geoelectric and AMT profiles measured above an ore-bearing formation in the Börzsöny Mts in the directions of 117° (thin line) and of 207° (thick line)

8. ábra. Geoelektromos és AMT szelvények egy érces formáció felett a Börzsönyben, 117° (vékony vonal) és 207° (vastag vonal) irányban

Рис. 8. Геоэлектрические и AMT профили, полученные над рудной формацией в горах Бёржёнь по направлениям 117° (тонкой линией) и 207° (жирной линией)

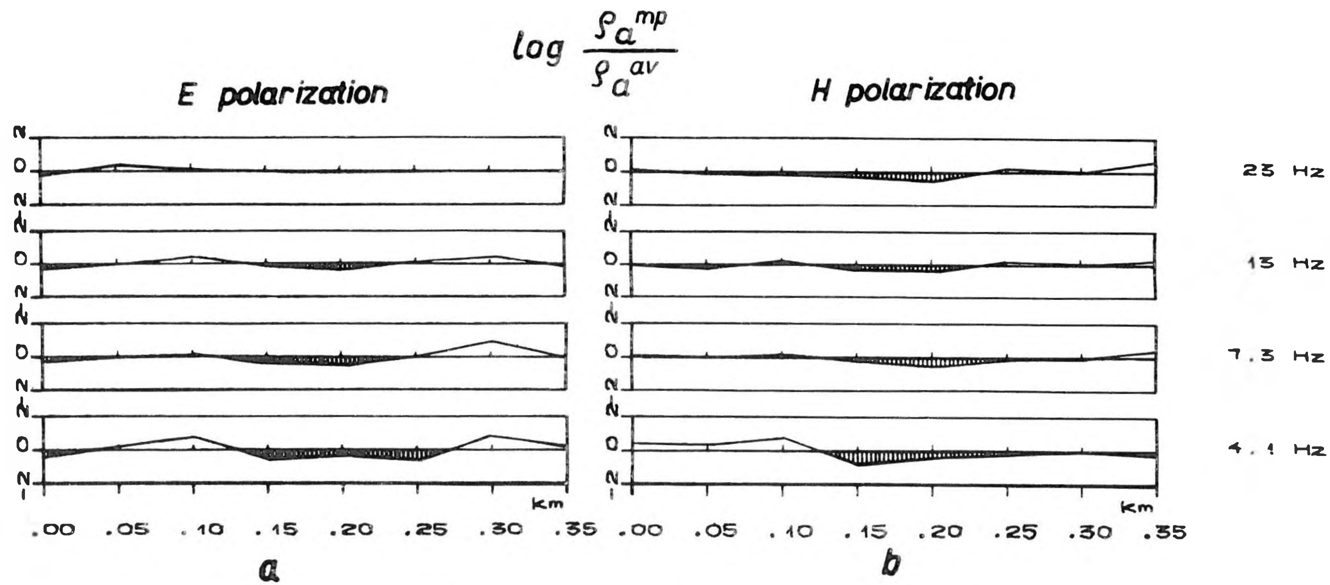

Fig. 9. Residual ϱ_a profiles above an ore-bearing formation in the Börzsöny Mts. The direction of the telluric line is: a) 207° (E-polarization); b) 117° (H-polarization)

9. ábra. Maradék ϱ_a szelvény érces formáció felett a Börzsönyben. A tellurikus vonal iránya a) 207° (E-polarizáció); b) 117° (H-polarizáció)

Рис. 9. Профили остаточных значений ϱ_a над рудной формацией в горах Бёржёнь. Направлсния теллурической линии: а) 207° (поляризация E); б) 117° (поляризация H).

3. Noise level

As is shown in *Fig. 2*, the ϱ_a values at 41 and 230 Hz are significantly increased by stray (leakage) currents caused by power lines ot about 50 Hz and its harmonics. The same conclusion can be drawn from the original isoohm profiles measured along the geodynamic line between Ukk and Ötvös *(Fig. 6a)*, where the signals are increased by about two orders of magnitude at 41 and 230 Hz in the villages. Since the noise mainly appears in the electric components it increases the ϱ_a values. On the basis of the ϱ_a values measured at 41 Hz, 3 noise groups were supposed. The average sounding curve for these groups indicates that the average level of the most noisy sounding curve (group 3) should be much higher than the background given by the other two average curves *(Fig. 10)*:

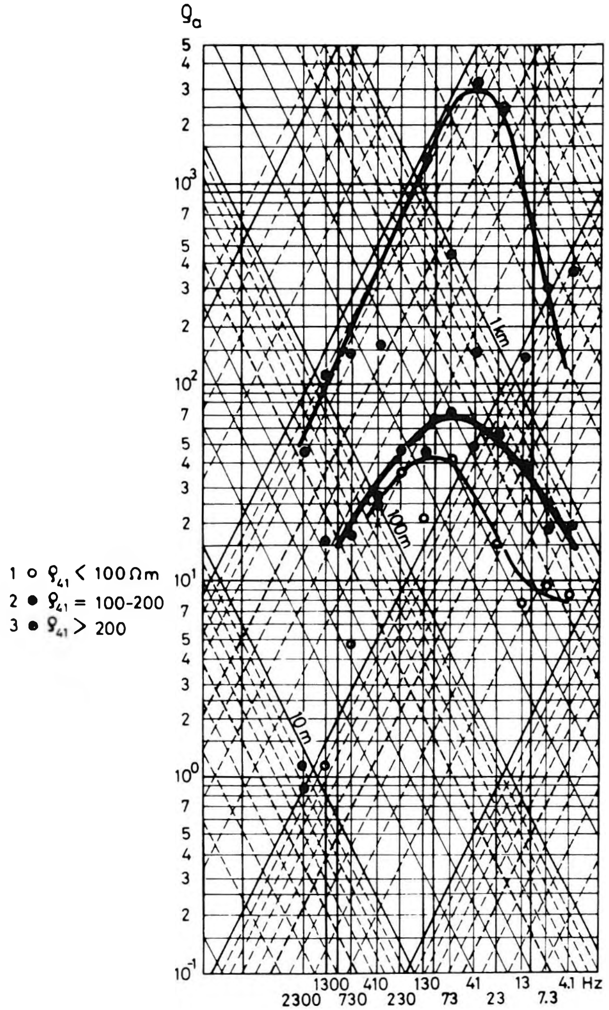

Fig. 10. Median AMT sounding curves of different disturbances

10. ábra. Átlagos AMT szondázási görbék különböző zavarokkal

Рис. 10. Средние кривые АМТ зондирования с разными помехами

These results imply that in the neighbourhood of electricity consumers —mainly in villages—AMT measurements should be processed and interpreted with the greatest care. Also, notch filtering at the power line frequency and around its harmonics should be improved in the instruments.

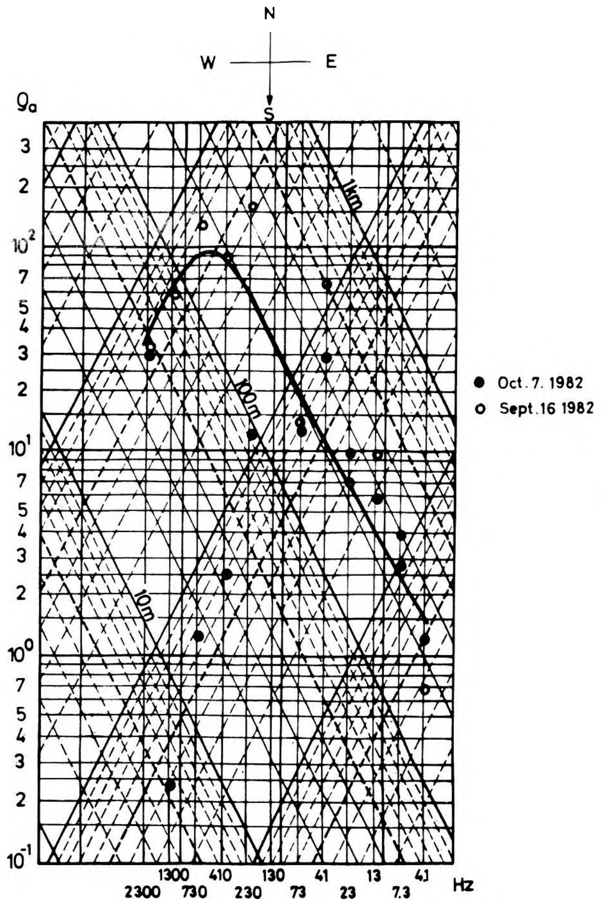

Fig. 11. AMT sounding data measured in the Nagycenk observatory on two different days in N—S direction (the full line indicates the smoothed AMTS-curve obtained on 16 September)

11. ábra. A nagycenki obszervatóriumban két különböző napon É—D irányban mért AMT szondázási adatok (a folytonos vonal a szeptember 16-án mért, simított AMT görbét jelzi)

Рис. 11. Данные АМТ зондирования, полученные в обсерватории Надьценк в два разные дни по меридиональному направлению (сплошной линией проведена выравненная кривая АМТ, полученная 16-го сентября)

4. Signal level

The attenuation of the electromagnetic field is well known from the literature [e.g. STRANGWAY, 1982]. In connection with *Fig. 2* we have already indicated this effect between 410 and 2300 Hz. Due to this attenuation and to the conductive sediments the level of the signal mainly decreases in the electric components. Thus extremely low ϱ_a values were measured in this frequency band.

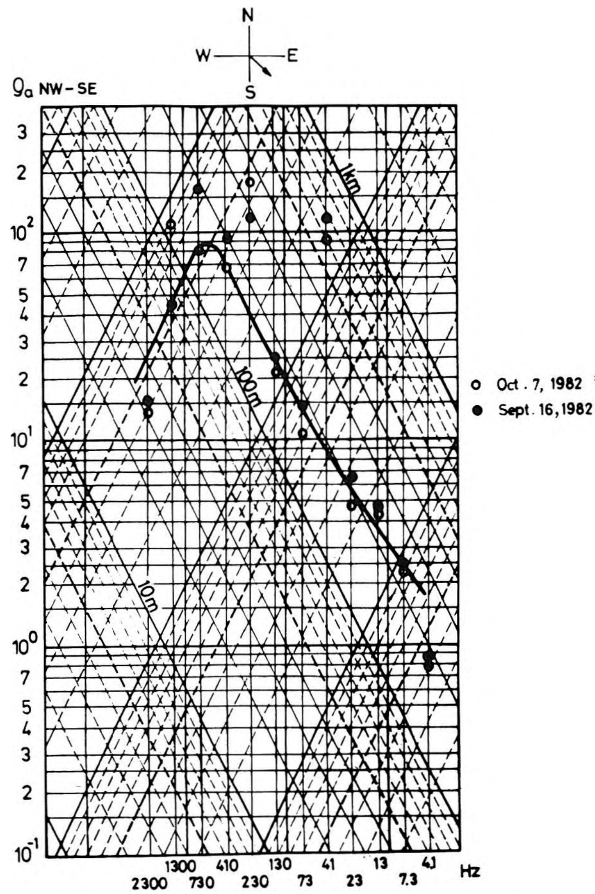

Fig. 12. AMT sounding data and a sounding curve measured in Nagycenk observatory on two different days in NW—SE (i. e. anisotropy) directions

12. ábra. AMT szondázási adatok és átlagos szondázási görbe, melyeket a nagycenki obszervatóriumban mértek két különböző napon, ÉNy—DK (azaz anizotrópia) irányban

Рис. 12. Данные АМТ зондирования и средняя кривая зондирования, полученные в обсерватории Надьценк в два разные дни по направлению СЗ—ЮВ (т. е. анизотропии)

The ELF activity generally increases during the local afternoon; this means that the measuring conditions also improve in this frequency band. The signal intensity, therefore the attenuation, varies considerably from time to time. In Finland experience has shown sudden changes in the high frequency part of the AMT band. Very high harmonics contamination has also caused problems [Hjelt, 1981]. The time variation in Hungary is demonstrated by two sounding curves measured on two different days: on 7 October much lowver ϱ_a values were obtained between 410 and 1300 Hz than on 16 September *(Fig. 11)*.

The scatter of the scalar (two-component) AMT resistivity values can be somewhat reduced, i.e. the reliability of the data improved, for 2-D structured if measurements are made in the main structural (MT anisotropy) directions.

According to the basic relations of the magnetotelluric method, the main impedances Z_{xy} and Z_{yx} can be obtained using the following formulae:

$$\frac{E_x}{H_y} = Z_{xx}\frac{H_x}{H_y} + Z_{xy}, \qquad \frac{E_y}{H_x} = Z_{yy}\frac{H_y}{H_x} + Z_{yx}$$

where the variation of the magnetic polarization H_x/H_y or H_y/H_x can be neglected in the direction where the secondary impedances Z_{xx} and Z_{yy} approximate zero. With 2-D structures these directions correspond to the anisotropy directions. In the Nagycenk observatory the daily scatter of the ϱ_a values is much smaller in certain directions than in other ones (see *Fig. 11* and *12)*. The directions with lower scatter may be just the anisotropy directions.

5. Conclusions

Since signal and noise conditions generally influence first of all the electric components, the reliability of the measurements can be increased only if the ϱ_a values are calculated from well-correlated electric and magnetic variation components, rather than from their average values. The effect of the time variation of the source field and of the 2-D and 3-D structures can obviously be better taken into consideration if the data processing of the AMT method approximates that of the MT.

The frequent occurrence of sufficiently energetic ELF signals and the use of microprocessor techniques, based on the tensorial relations between the EM field components having a great coherence, enable the use of field data processing for the AMT method. Measurements for a better understanding of the time variation and the coherence of the AMT source fields as well as a study of the data processing technique are aims of a joint Finnish-Hungarian project.

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SKALÁRIS AUDIOMAGNETOTELLURIKUS MÉRÉSEK MAGYARORSZÁGON

ÁDÁM ANTAL, PERTTI KAIKKONEN, SVEN-ERIK HJELT, JUHA TIIKKAINEN

Audiomagnetotellurikus (AMT) szondázásokat végeztünk Magyarországon a francia gyártmányú „ECA Resistivimètre" típusú műszerrel a 4,1–2300 Hz frekvenciatartományban, hogy megvizsgáljuk az AMT módszer alkalmazhatóságát különböző geofizikai problémák megoldására (a nagycenki elektromágneses obszervatórium környékén, üledékes medencében, földtani alapszelvényen és az érckutatásban stb.).

A fő következtetések az alábbiak:

— A legmegbízhatóbb információt a Schuman rezonancia harmonikusainak tartományában (7,3–23 Hz) kaptuk.

— A kristályos kőzeteken mért látszólagos ellenállás (ϱ_a) értékek megbízhatósága nagyobb, mint az üledékeken mérteké, mivel az utóbbi esetben az elektromos tér sokkal kisebb amplitúdója alapvetően rontja a jel/zaj viszonyt.

— A ~50 Hz-es távvezetékek által okozott zajszint a legmagasabb 41 és 230 Hz-en. A kóbor (levezetési) áramok forrásának közelében (főleg falvakban) a ϱ_a értékek általános szintje megnövekedett a forráshoz „közeli zóná"-ban végzett frekvenciaszondázás szerint.

— Egy energiahiányos szakasz van 730 és 2300 Hz között a Föld-ionoszféra üregben bekövetkező ELF jel csillapodás miatt, itt a ϱ_a értékek alacsonyak.

A koherencia ellenőrzése híján a skalár mérésekben nehéz különbséget tenni a jelnek, illetve zajnak tekintendő EM terek között, ezért szükséges a tenzoriális adatfeldolgozás és a természetes audiofrekvenciás terek vizsgálata. E célból egy digitális regisztráló fejlesztését kezdtük el.

А. АДАМ, П. КАЙКОНЭН, С. Э. ХЕЛЬТ, Й. ТИКАЙНЭН

СКАЛЯРНЫЕ АУДИОМАГНИТОТЕЛЛУРИЧЕСКИЕ ИЗМЕРЕНИЯ В ВЕНГРИИ

Аудиомагнитотеллурические зондирования (АМТ) были проведены в Венгрии с аппаратурой французского выпуска «ECA Resistivimètre» в диапазоне частот 4,1–2300 Гц с целью изучения возможности применения метода АМТ для решения различных геофизических проблем (около электромагнитной обсерватории с. Надьценк, в осадочном бассейне, по геологическим основным профилям, при поисках и разведке рудных месторождений и т. п.).

По этим работам были сделаны следующие заключения:

— Наиболее надежная информация была получена в диапазоне гармонических резонанса Шумана (4,1–23 Гц).

— Надежность измеренных на кристаллических породах значений кажущегося сопротивления (ϱ_a) выше значений, полученных на осадочных породах, так как в последнем случае значительно более низкая амплитуда электрического поля существенно ухудшает отношение сигнал/шум.

— Уровень шумов ~ 50 Гц, вызываемых линиями электропередачи, является наиболее высоким на частотах 41 и 230 Гц. Вблизи источников блуждающих токов (отвода) (главным образом в деревнях) общий уровень значений ϱ_a увеличивался по частотному зондированию, проведенному в «близкой зоне» источника.

— Наблюдается участок с дефицитом энергии между 730 и 2300 Гц в связи с затуханием сигнала ELF в полости Земля-ионосфера, здесь получаются низкие значения ϱ_a.

В отсутствии проверки сходимости по шкалярным измерениям трудно различить ЭМ поля, рассматриваемые как сигнал или шум, в связи с этим требуются тензориальная обработка данных и исследование естественных полей звуковых частот. Для такой цели начата разработка цифровой регистрирующей аппаратуры.