GEOPHYSICAL TRANSACTIONS 2004
Vol. 44. Nos. 3–4. pp. 301–312

IP Data processing results from using TAU-transformation to determine time-constant spectra

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A generalization of the TAU-transform method [introduced by TURAI 1985] is presented. On combining the TAU transform method and the tools of inverse problem theory a general algorithm for determining the time-constant spectrum of polarizability data (deduced from time-domain IP measurements) is available for the general case of continuous spectra. Some results from interpreting field data collected over Hungarian waste sites are presented and — based on time-constant spectra — the main components of the contaminating material are characterized.

Keywords: IP data, TAU-transformation, time-constant spectra, waste disposal, Weighted Amplitude Value

1. Introduction

The induced polarization method is well known as an effective geophysical method of ore exploration [WAIT 1959; KELLER, FRISCHKNECHT 1966; SUMNER 1976] because both the time-domain and frequency-domain IP measurements are capable of detecting even small amounts of metallic minerals. On the other hand, the metallic content is not the only factor resulting in polarizability of the medium: filtration- and membrane effects as well as electrochemical properties can also lead to similar phenomena. Induced polarization is a very useful geophysical method also in the detection of environmentally hazardous locations, particularly for waste sites.

2. TAU-transformation of time-domain IP curves

By means of time-domain IP data, apparent polarizability curves ($\eta_a(\tau)$) can be constructed. The strictly monotonically decreasing functions

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Manuscript received: 4 November, 2002.

can generally be written as an integral transform of a function $w(\tau)$ [TURAI 1985]:

$$\eta_a(t) = \int_0^\infty w(\tau)\exp(-t/\tau)\,\mathrm{d}\tau, \tag{1}$$

where t is the time and τ is the time-constant.

The function $w(\tau)$ will be called the spectrum of time-constants of the IP measurement, which can be normalized as

$$\int_0^\infty w(\tau)\,\mathrm{d}\tau = 1.$$

Let us define TAU-transformation as a procedure generating the spectrum of time-constants from the polarizability curves:

$$v(\tau) = TAU\left[\eta_a(t)\right] \tag{2}$$

The IP effect of the rock is displayed by the $w(\tau)$ function: it represents all the important information (regarding the medium) contained by the time-domain IP data.

The two algorithms giving the TAU-transform for this case were developed by [TURAI 1985] based on a linear system of equations and Fourier transform.

3. General solution for the TAU-transform

In order to give the TAU-transform (Eq. (2)) for this general case we use the tools of inverse problem theory. In constructing a general algorithm to determine the TAU-transform [TURAI, DOBRÓKA 2001] we write the spectrum function in the form of a series expansion

$$w(\tau) = \sum_{q=1}^{Q} B_q\,\Phi_q(\tau)\ , \tag{3}$$

where Φ_q is the qth base function and B_q is the corresponding expansion coefficient. As base functions, we use Chebishev polynomials and interval-wise constant functions in our investigation. By inserting the discretized spectrum function into Eq. (1) we get

$$\eta_k = \sum_{q=1}^{Q} B_q \, S_{kq} \,, \qquad S_{kq} = \int_0^{\infty} \Phi_q(\tau) \exp(-\frac{t_k}{\tau}) \mathrm{d}\tau \tag{4}$$

where t_k is the time point at which the kth IP data was detected. In the terminology of inverse problem theory Eq. (4) is the (linear) forward modelling formula for calculating theoretical polarizability data which can be written in matrix form as

$$\vec{\eta} = \underline{\underline{S}}\vec{B}.$$

Introducing the deviation between the measured and calculated data

$$\vec{e} = \vec{\eta}^{\,obs} - \vec{\eta}^{\,calc} \tag{5}$$

we can reduce the TAU-transform problem to a simple inverse problem in which the unknown expansion coefficients are determined by minimizing a certain (L_2) norm of the vector given in Eq. (5). This leads to the well-known normal equation

$$\underline{\underline{S}}^T \underline{\underline{S}}\vec{B} = \underline{\underline{S}}^T \vec{\eta}.$$

By solving this linear set of equations, we can calculate the expansion coefficients and, by means of Eq. (3), determine the time-constant spectrum function (or in other words the TAU-transform problem has been solved). Depending on the noise contained by the measured data set, it may be necessary to use a more robust inversion method or to integrate new data sets into a joint inversion algorithm [DOBRÓKA et al. 1991]. The TAU-transform algorithm can easily be formulated also in such a case.

4. Results of time-domain IP measurements using TAU-transformation

TAU-transformation was applied in a TEMPUS project [No. JEP 1553, TURAI et al. 1992] and it was also tested above seven Hungarian waste sites (Nyékládháza—1997–99; Ráckeve—1997; Kecskemét—1997; Győröcske—1999, Pásztó—2000, Tokaj—2001 and Balmazújváros—2002). One of these waste sites (Kecskemét) was an industrial waste site and the others were communal waste sites. Here we show some results of IP data measured above a waste site first near Győröcske, second near Pásztó, and third Tokaj.

Schlumberger electrode arrays were used for IP soundings. At each IP sounding point 16 discrete current electrode spacing points were used, the array parameters were $MN = 1$ m, $AB_{\min} = 3{,}2$ m and $AB_{\max} = 100$ m, where MN was the potential electrode spacing and AB was the current electrode spacing. At each current electrode spacing point the IP apparent polarizability values were measured at 5 discrete points of decay curves ($\eta_a(t = 0.1\text{ s})$, $\eta_a(t = 0.2\text{ s})$, $\eta_a(t = 0.4\text{ s})$, $\eta_a(t = 0.8\text{ s})$, and $\eta_a(t = 1.5\text{ s})$). At each sounding point and at each current electrode spacing point the $w(\tau_n)$ time-constant spectra were calculated using the TAU-transformation described above. (Here τ_n denotes the nth discrete value of the time-constant.)

Let us see the Győröcske area first. Taking our field experiences into account we qualify the main types of polarization mechanisms by the τ_n time-constant values [TURAI, DOBRÓKA 2001]:

filtration polarization	$\tau_n < 0.4$ s,
membrane polarization	$0.2\text{ s} < \tau_n < 0.8$ s,
electrochemical or redox polarization	$0.6\text{ s} < \tau_n < 1.2$ s,
metallic or electrode polarization	$1\text{ s} < \tau_n$.

Table I. shows the sources of polarization:

type of polarization	**source of polarization**
filtration polarization	— porous soil and rocks with conductive fluid,
membrane polarization	— porous soil and rocks with disperse clay and water,
electrochemical polarization	— chemical agent with high reactivity for oxidation or reduction,
metallic polarization	— metallic components in porous rocks with conductive fluid.

Table I. Sources of polarization
I. táblázat. A polarizáció forrásai

The main components of contaminating material on a waste site are connected with the main types of polarization, so we can raise the effect of higher time-constants (connected with dangerous components — chemical and metallic) of the waste site and similarly we can reduce the lower time-constant effect (connected with non-dangerous components — water and disperse clay) using a simple weighting procedure:

$$WAV(\tau_n)=\tau_n w(\tau_n).$$

The *WAV* (Weighted Amplitude Value) section shows the region of the more dangerous components. *Figure 1* presents a vertical *WAV* section. In terms of time-constant spectra, our results show that the polarization on the waste site near Győröcske is mainly of electrochemical *(Fig. 1.1)* and metallic *(Fig. 1.2)* origin. Where *WAV*s are high electrochemical and metallic polarization is to be found.

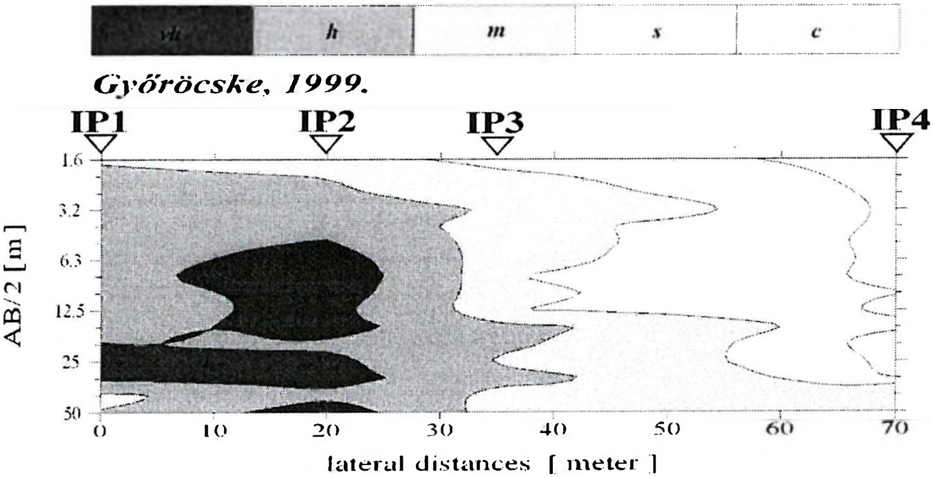

Fig. 1. Vertical *WAV* section near Győröcske. (*vh* — *WAV* is higher than 0.2; *h* — *WAV* is between 0.1 and 0.2; *m* — *WAV* is between 0.05 and 0.1; *s* — *WAV* is between 0.02 and 0.05; *c* — *WAV* is lower than 0.02.)

1. ábra. Vertikális *WAV* metszet Győröcske közelében. (*vh* — a *WAV* nagyobb, mint 0.2, *h* — a *WAV* 0.1 és 0.2 közötti, *m* — a *WAV* 0.05 és 0.1 közötti, *s* — a *WAV* 0.02 és 0.05 közötti, *c* — a *WAV* kisebb mint 0.02.)

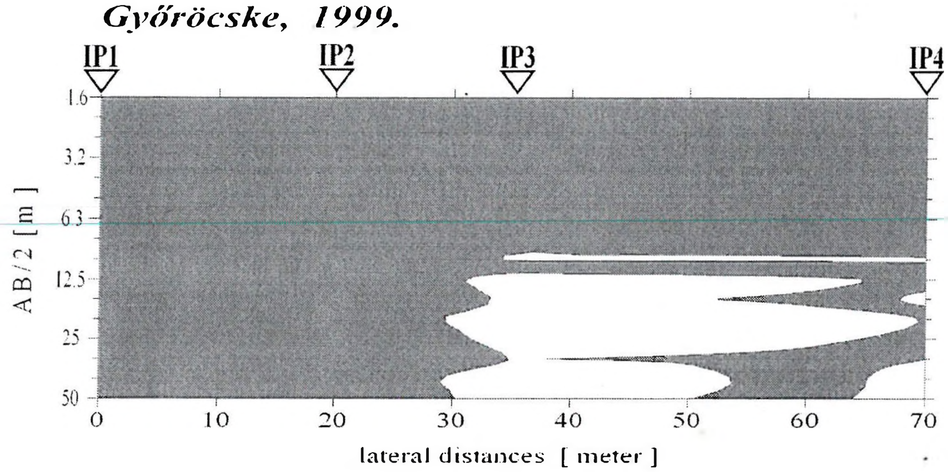

Fig. 1.1. Area of electrochemical polarization (time-constants are between 0.6 and 1.2 s)
1.1. ábra. Az elektrokémiai polarizáció területe (az időállandó 0.6 s és 1.2 s közötti)

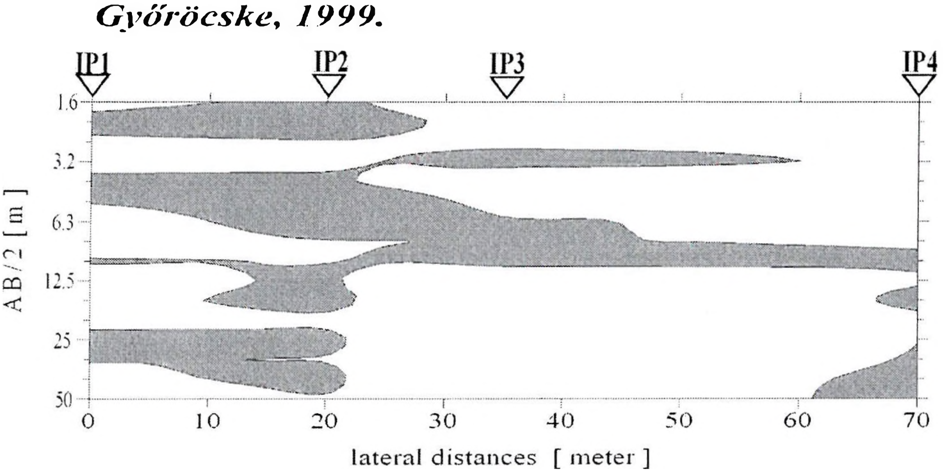

Fig. 1.2. Area of metallic polarization (time-constants are higher than 1 s)
1.2. ábra. A fémes polarizáció területe (az időállandó nagyobb mint 1 s)

The second waste site that was measured was near Pásztó; a *WAV* section from this site is shown in *Fig. 2*. Only small and medium *WAV*s are present near Pásztó. On analysing the type of polarization effect we found mainly membrane *(Fig. 2.1)*, electrochemical *(Fig. 2.2)*, and metallic *(Fig. 2.3)* polarization. *Figure 3* presents a vertical *WAV* section over the Tokaj area. As can be seen, there are only small *WAV*s thereby indicating some dangerous regions under the surface. The polarization components are mainly electrochemical *(Fig. 3.1)* and metallic *(Fig. 3.2)*.

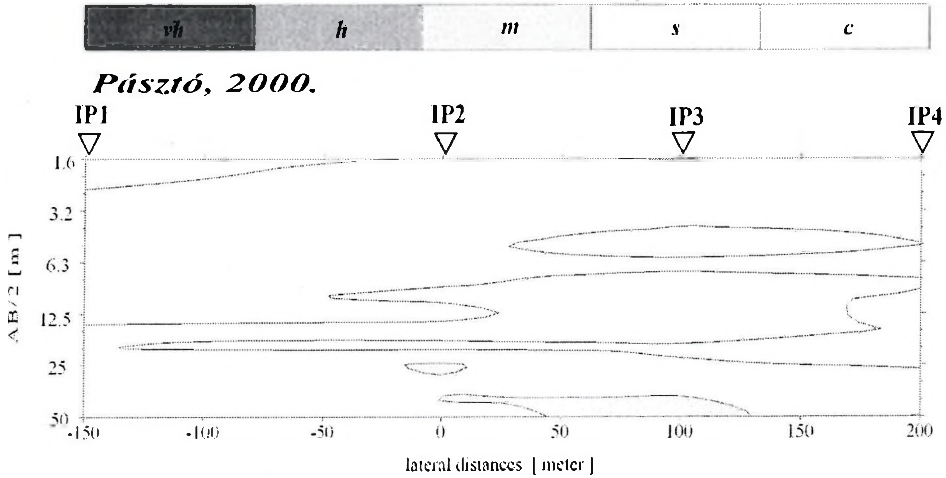

Fig. 2. Vertical *WAV* section near Pásztó. (*vh* — *WAV* is higher than 0.2; *h* — *WAV* is between 0.1 and 0.2; *m* — *WAV* is between 0.05 and 0.1; *s* — *WAV* is between 0.02 and 0.05; *c* — *WAV* is lower than 0.02.)

2. ábra. Vertikális *WAV* metszet Pásztó közelében. (*vh* — a *WAV* nagyobb, mint 0.2; *h* — a *WAV* 0.1 és 0.2 közötti; *m* — a *WAV* 0.05 és 0.1 közötti; *s* — a *WAV* 0.02 és 0.05 közötti; *c* — a *WAV* kisebb mint 0.02.)

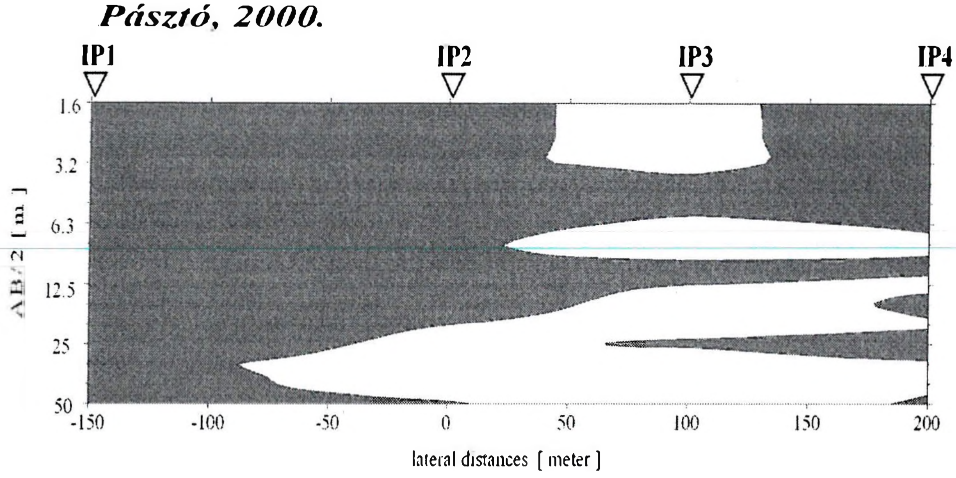

Fig. 2.1. Area of membrane polarization (time-constants are between 0.2 and 0.8 s)
2.1. ábra. A membrán polarizáció területe (az időállandó 0.2 és 0.8 s közötti)

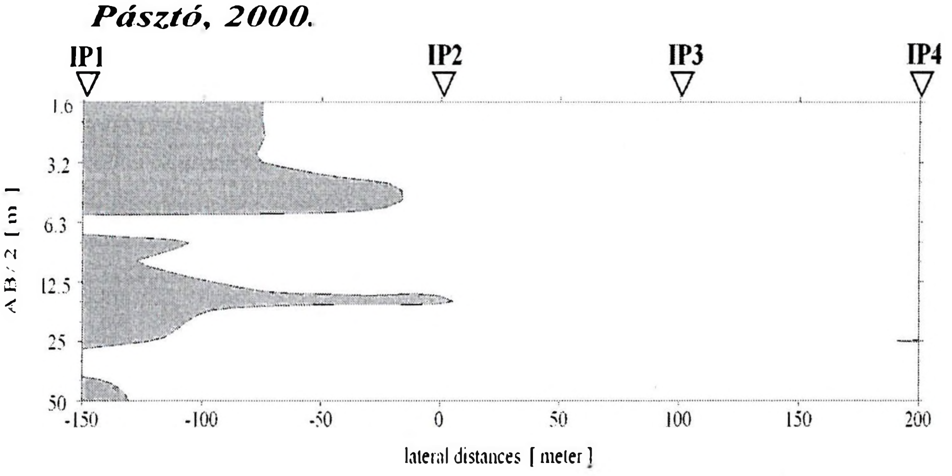

Fig. 2.2. Area of electrochemical polarization (time-constants are between 0.6 and 1.2 s)
2.2. ábra. Az elektrokémiai polarizáció területe (az időállandó 0.6 és 1.2 s közötti)

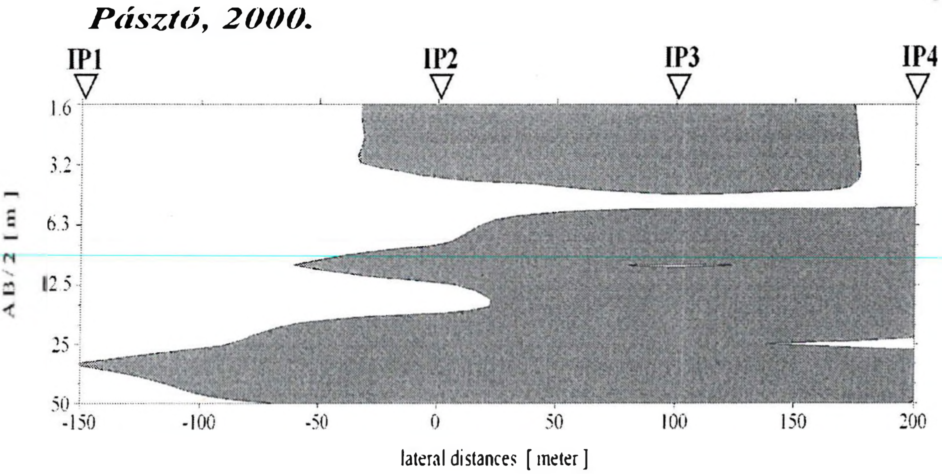

Fig. 2.3. Area of metallic polarization (time-constants are higher than 1 s)

2.3. ábra. A fémes polarizáció területe (az időállandó nagyobb mint 1 s)

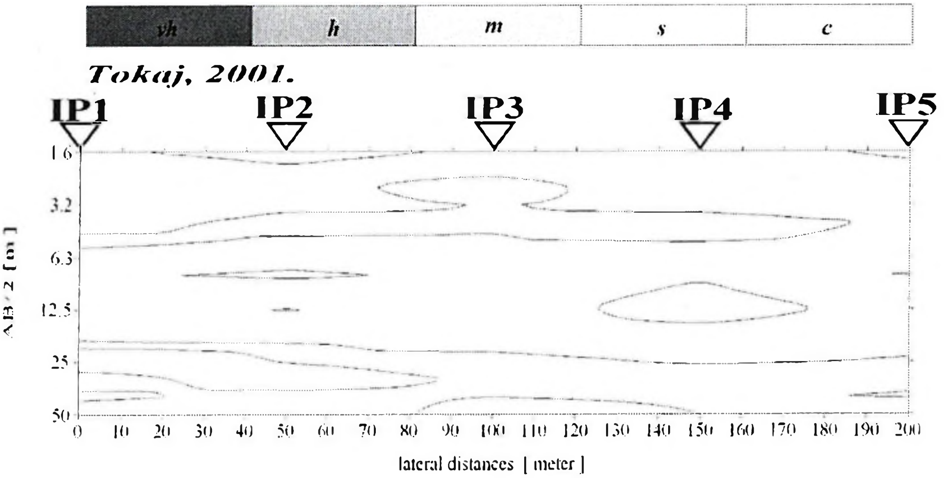

Fig. 3. Vertical *WAV* section near Tokaj. (*vh* — *WAV* is higher than 0.2; *h* — *WAV* is between 0.1 and 0.2; *m* — *WAV* is between 0.05 and 0.1; *s* — *WAV* is between 0.02 and 0.05; *c* — *WAV* is lower than 0.02)

3. ábra. Vertikális *WAV* metszet Tokaj közelében. (*vh* — a *WAV* nagyobb mint 0.2; *h* — a *WAV* 0.1 és 0.2 közötti; *m* — a *WAV* 0.05 és 0.1 közötti; *s* — a *WAV* 0.02 és 0.05 közötti; *c* — a *WAV* kisebb mint 0.02)

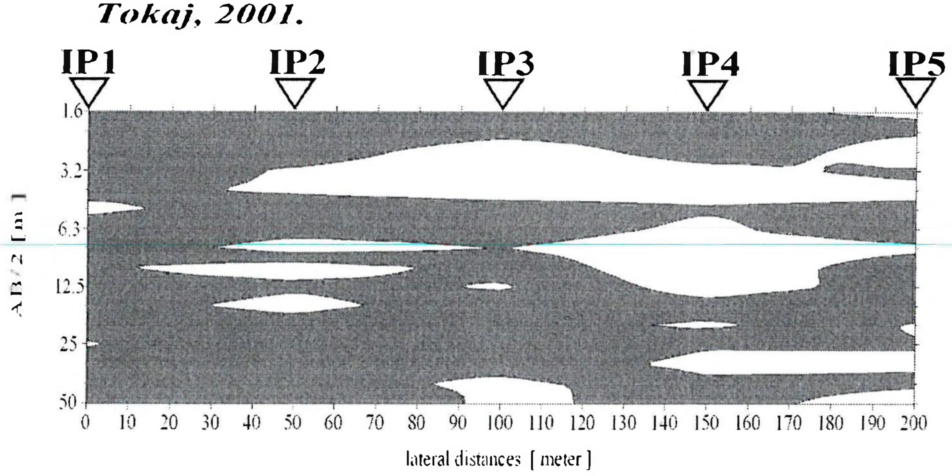

Fig. 3.1. Area of electrochemical polarization (time-constants are between 0.6 and 1.2 s)
3.1. ábra. Az elektrokémiai polarizáció területe (az időállandó 0.6 s és 1.2 s közötti)

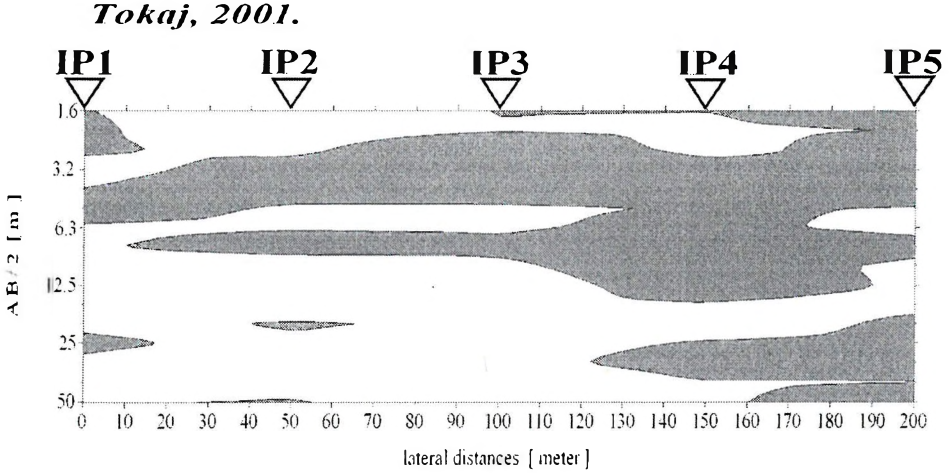

Fig. 3.2. Area of metallic polarization (time-constants are higher than 1 s)
3.2. ábra. A fémes polarizáció területe (az időállandó nagyobb mint 1 s)

Acknowledgements

This research work was supported by the Hungarian Scientific Research Fund (T 046765 and T 037842), FKFP projects (No. 0914/1997 and No. 0277/2000) and TÉT project (No. SF-8/2001), the author is grateful for the support. Thanks are also due to Mr. L. Bucsi Szabó for collaboration in the field work near Győröcske, Pásztó, and Tokaj. As a member of the MTA–Miskolc University Research Group for Geophysical Inversion and Tomography the author wishes to express his gratitude for the support of the Hungarian Academy of Sciences.

, GEOELECTRIC DATA RECORDED IN AN UNDERGROUND COAL MINE.
GEOPHYSICAL PROSPECTING **39**, PP. 643–665

KELLER G. W., FRISCHKNECHT F. C. 1966: Electrical Methods in Geophysical Prospecting. Pergamon Press, Oxford

SUMNER J. S. 1976: Principles of Induced Polarization for Geophysical Exploration. Elsevier, Amsterdam

TURAI E. 1985: TAU-Transformation of Time-Domain IP Curves. ANNALES Univ. Scien. Budapestinensis de Rolando Eötvös Nom., Sectio Geophysica et Meteorologica, Tomus I–II., pp. 182–189

TURAI E., ELSEN R., LIMBROČK K. 1992: Analysis of IP Time-Domain Data Measured above a Waste Site near Offheim using TAU-Transformation of IP Chargeability Curves, JEP 1553–92. TEMPUS project report, DMT-Bochum

TURAI E., DOBRÓKA M. 2001: A New Method for the Interpretation of Induced Polarization Data — the TAU-Transform Approach. 63rd EAGE Conference, Amsterdam, pp. 049/1–049/4

WAIT J. R. 1959: Overvoltage Research and Geophysical Applications, Pergamon Press, London

Az IP adatok feldolgozásának eredményei, a TAU-transzformáció időállandó spektrum meghatározási célú alkalmazásával

TURAI Endre

A dolgozat a TURAI [1981] által közzétett TAU-transzformációs módszer általánosítását mutatja be. A TAU transzformációs módszer és az inverziós elmélet eszközeinek ötvözésével folytonos spektrumok esetére egy olyan általános algoritmust tudunk létrehozni, amellyel az időtartománybeli Gerjesztett Polarizációs (GP) mérések polarizációs adataihoz tartozó időállandó spektrum meghatározása lehetséges lesz. A dolgozat magyarországi hulladéklerakók fölött mért terepi adatok időállandó spektrumon alapuló értelmezésének néhány eredményét mutatja be a főbb polarizálódó összetevők súlyozott időállandókkal történő jellemzésével.

ABOUT THE AUTHOR

Endre Turai received his M.Sc. (1978) in geophysical engineering from the Technical University of Heavy Industry (Miskolc). He obtained his university doctor's degree from the same university in 1984. In 1994 he was awarded his Candidate's degree (C.Sc.) by the Hungarian Academy of Sciences. He graduated as an engineer-economist at the University of Miskolc in 1993, and received his Ph.D. in Applied Earth Sciences from the same university. Currently, he is an associate professor at the University of Miskolc. His main fields of interest are geophysical data processing and interpretation, electric and electromagnetic methods, economics of geophysical explorations, and geoinformatics.