APPLICATION POSSIBILITIES OF IP METHOD IN THE FIELDS OF ENVIRONMENTAL PROTECTION, ORE- AND DIRECT HYDROCARBON EXPLORATION

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1. Introduction

From the 1950s the induced polarization (IP) method became well known as an effective geophysical method of ore exploration in the geophysical literature [1-3]. It was applied successfully in ore exploration both in time-domain (TDIP) and frequency-domain (FDIP) measurements, because the metallic polarization phenomenon can occur on the surface of ore showing conductive (free electronic) electric conduction – in a dissociated ionic environment. This type of polarization causes measurable IP anomalies.

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 (redox) properties can also lead to similar phenomena. Due to recognition of this, nowadays the IP method has turned into one of the most efficient geophysical methods for environmental investigations. In electromagnetic geophysical practice [4], however, it is also known that pyrite chimneys may be formed in the roof of productive (containing crude oil, or natural gas) hydrocarbon reservoirs, which causes metal polarization. The ring-like IP anomaly over hydrocarbon reservoirs may be an important feature of productivity in direct hydrocarbon explorations.

Time constant analysis means a novel opportunity of application in all three areas (environmental protection, ore- and direct hydrocarbon exploration). The time constant spectrum of the IP signal can be calculated with TAU-transformation [5]. Anomalies appearing in the interval of the short time constants (smaller than 1 sec) can be bound to less dangerous environmental effects (filtration and membrane), while the larger (higher then 1 sec) time constants connected to dangerous polarizations (redox and electrode) indicate chemical and metallic contamination. Analysis of the interval of high time constants makes it possible to define the types of ores and the pyrite chimney above the borders of productive hydrocarbon reservoirs.

2. TAU-tansformation of time-domain IP data

The strictly monotonously decreasing function $\eta_a(t)$ can generally be written as an integral transform of $w(\tau)$ function

$$\eta_a(t) = \int_0^\infty w(\tau) e^{-\frac{t}{\tau}} d\tau,$$ (1)

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

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In equation (1) the function w(τ) is called the spectrum of time-constants of the IP measurement. It represents all the important spectral information of the polarization. Let us define the TAU-transformation as a procedure generating the spectrum of time-constants from the polarizability curves:

$$w(\tau) = TAU\big[\eta_a(t)\big].$$ (2)

The time-constant spectrum represents all the important information (regarding the medium) of the time-domain IP data. After introducing the concept of the TAU-transform, some approximate solutions [5] and a general inversion solution [6] were developed for continuous time-constant spectra and also for the case of line spectra.

3. Interpretation methods for estimation of type and level of soil and rock contaminations

The TAU-transform method was applied first in a TEMPUS project [7] and was tested above several contaminated areas in Hungary (Nyékládháza – 1997-2008, Ráckeve – 1997, Kecskemét – 1997, Győröcske – 1999, Pásztó – 2000, Tokaj – 2001, Balmazújváros – 2002, Szerencs – 2004, Tiszapalkonya – 2004, Berekböszörmény – 2007, Nagytárkány – 2008, Darvastó – 2008, Miskolc-Hejőpart – 2008, Tiszavasvári – 2008, Nagytétény – 2008, Miskolc-Bedő hegy – 2009, Telkibánya – 2010, Miskolc-Salakbánya – 2010, Miskolc-Gózon L. út – 2010 and Miskolctapolca-Várhegy – 2010). In Felsőtelekes the Háromkő Company measured IP data for the examination of the state of the refuse dump site in 2011.

Based on our field experiences two ways were introduced for the estimation of the type and the amount of soil contamination. According to the first approach the calculation of contamination type comes from the time constant value of the time constant spectra ($w(\tau)$). The estimation of the level of soil contamination is based on the Weighted Amplitude Value (WAV) of the time constant spectra. The second approach estimates the corrected apparent conductivity of the contaminated material (σ_{corr}) as a product of WAV parameter and measured apparent conductivity.

Taking the IP curve $\mu_a(t)$ measured in the field into account we can compute the time constant spectrum based on equation (2) and qualify the main types of polarization mechanisms by the τ_n time-constant values [8].

The main components of the contaminating material in a contaminated site are connected to the main types of polarizations (Table I); thus, we can emphasize the redox and metallic effects with time constants higher than 1 second (connected to dangerous components – chemical and metallic) and similarly we can reduce the lower time constant filtration and membrane effects (connected to non-dangerous components – water and disperse clay) using a simple weighting procedure [8]:

$$WAV(\tau) = \frac{\tau\, w(\tau)}{\big[1\,sec\big]}.$$ (3)

Table I. Geological sources of polarization

Type of polarization	Source of polarization
filtration	porous soil and rocks with conductive fluid
membrane	porous soil and rocks with disperse clay and water
electrochemical or redox	chemical agent with high reactivity for oxidation or reduction
metallic	metallic components in porous rocks with conductive fluid

The WAV (Weighted Amplitude Value) section shows the region of the more dangerous components, thus we can estimate the level of the soil contamination using the following practical scale of the Weighted Amplitude Value (WAV) of time-constant spectra (Table II). In ore and refuse dump exploration this scale is useful for the estimation of polarizable metallic ore concentration.

Table II. Levels of soil contamination

Contamination level or polarizable ore concentration level	WAV
very high (vh)	0.2 (20%) <
high (h)	0.1 (10%) - 0.2 (20%)
medium (m)	0.05 (5%) - 0.1 (10%)
small (s)	0.02 (2%) - 0.05 (5%)
clean (c)	< 0.02 (2%)

Let us define the time constant dependent corrected apparent conductivity of the media ($\sigma_{corr}(\tau)$) as a product of the WAV parameter and apparent conductivity ($\sigma_a = 1/\rho_a$):

$$\sigma_{corr}(\tau) = 1000\,\sigma_a\,WAV(\tau)\left[\frac{mS}{m}\right]. \tag{4}$$

The contamination level of the soil can be estimated based on equation (4) by using the corrected apparent conductivity. If the σ_{corr} value is approximately 50-100 milliSiemens/meter (mS/m) the soil has a medium contamination level.

4. Field results of time-domain IP data measured above contaminated areas

This section presents some field results of IP data measured above the Felsőtelekes refuse dump.

Figure 1 shows the vertical WAV section calculated on the measured profile in the Felsőtelekes area. As can be seen, there are WA values over ten percent, indicating high

and very high contaminated areas under the surface caused by metallic (Fig. 2) and redox polarization effects. When the ore concentration of the waste rock body is relatively high there are high WA values, too.
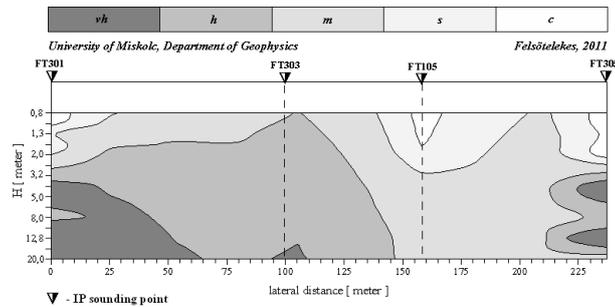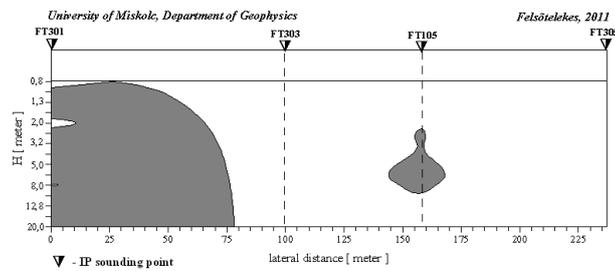

Figure 1. Vertical WAV section

Figure 2. Vertical section of metallic effect (1 sec < τ)

The corrected apparent conductivity vertical section is presented in Fig. 3. The thick black contour line shows the points of the section where the corrected conductivity value is the critical 100 mS/m.
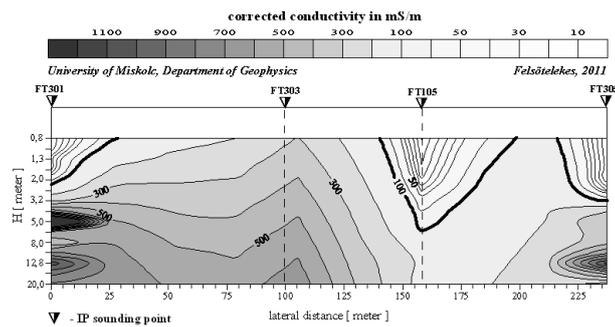
Figure 3. Vertical section of the corrected apparent conductivity

Finally, let us see the WAV map (Fig. 4) and the area of metallic polarization (Fig. 5) calculated at a 10 m reference depth. These maps inform us about the lateral distribution of the polarizable ore concentration in the Felsőtelekes waste rock body.
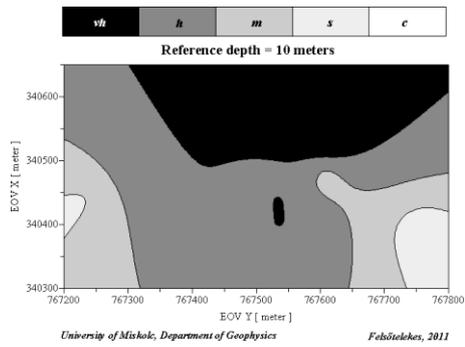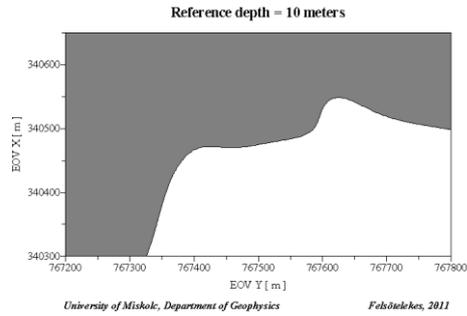

| Figure 4. WAV map at 10 m depth | Figure 5. Area of metallic polarization |

5. Application possibility of IP method for direct surveying hydrocarbon reservoirs

High IP values have been measured over several oil reservoirs [4]. Near the reservoirs the methane (CH_4) and hydrogen sulphide (H_2S) contents can cause the chemical processes visible in Fig 6. The product of this process is an ore mineral (FeS_2–pyrite).
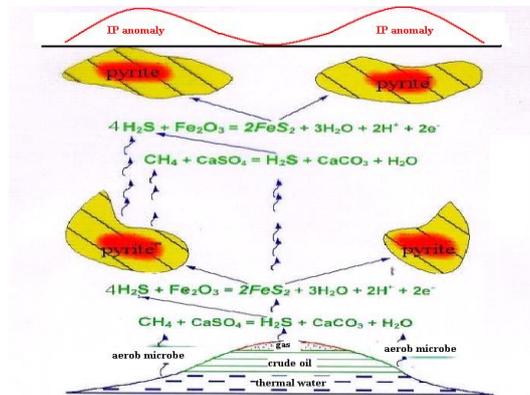

Figure 6. Chemical processes in the roof of hydrocarbon reservoir

The pyrite causes a characteristic metallic polarization, which gives IP values with high time constants. These high time constant values (over 1 sec) show the lateral boundaries of hydrocarbon reservoirs on the surface of measurement. This ring-like IP anomaly correlates well with the lateral boundary of the hydrocarbon reservoir determined from the interpretation of 3D seismic measurements (Fig. 7a), but there are no measured IP anomalies over a reservoir containing only thermal water (Fig. 7b).
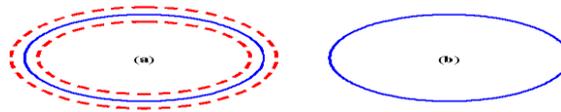
Figure 7. (a) Lateral boundary of hydrocarbon reservoir with ring-like IP anomaly (b) Lateral boundary of thermal water reservoir

6. Conclusions

Two methods were introduced for the estimation of the type and the level of soil contamination and polarizable ore concentration. These methods are useful for identifying ore, assessing possible contamination from refuse dumps, and of course for direct hydrocarbon exploration.

It was shown that the TAU-transformation of time-domain IP data clearly detected polarizable ore content of the refuse dump near Felsőtelekes. The analysis of the IP data shows that there are some very highly contaminated parts in the waste-rock body. The types of the polarization were mainly metallic and redox.

Pyrite causes a characteristic metallic polarization, which gives IP values with high time constants. This ring-like IP anomaly correlates well with the lateral boundaries of hydrocarbon reservoirs.

Acknowledgements

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