TIME-DOMAIN INDUCED POLARIZATION AS A TOOL FOR TRACING CONTAMINANTS

VYZVANÁ POLARIZACE V ČASOVÉ DOMÉNĚ PRO SLEDOVÁNÍ KONTAMINACE

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Abstract

Investigation of contaminants appearance in geological environment is usually carried out only by "indirect" surveying, i.e. for instance localizing contaminants preferential pathways, typically in form of tectonic lines, which one can map out via classic direct current methods such as resistivity profiling or ERT. Direct indication of, for example crude oil products connected to the pore space, can be viable by investigating electrochemical properties of these products for instance. In particular, we can measure weak natural induced polarization (IP) potentials caused by interaction between a contaminant and mineral grains. This paper will briefly introduce the theory and limitations of the IP in time-domain, mainly for solving environmental problems, and will present three typical case studies of such problems in the Czech and Slovakian Republic.

Abstrakt

Průzkum výskytu kontaminace v geologickém prostředí je obvykle prováděn pouze za pomocí „nepřímých" metod, tzn. například pomocí vyhledávání preferenčních cest kontaminace, kdy se typicky obvykle jedná o tektonické poruchy, jež lze vymapovat například pomocí klasických stejnosměrných geofyzikálních metod jako jsou metody odporového profilování nebo multielektrodová odporová metoda ERT. Přímá indikace takových látek, jako jsou například rozložené ropné produkty navázané na pórový prostor, může být možná pomocí měření elektrochemických vlastností těchto látek. To znamená, že jsme schopni měřit slabé přírodní potenciály vyzvané polarizace, vzniklé interakcí mezi kontaminantem a minerálním zrnem. Tento článek krátce představí teorii a možné limity metody vyzvané polarizace v časové doméně, především v kontextu řešení úkolů zátěží životního prostředí, a představí tři ukázky řešení podobných úkolů v České a Slovenské republice.

Keywords

induced polarization, contaminants, IP, remediation, ERT

Klíčová slova

vyzvaná polarizace, kontaminace, VP, sanace, ERT

1 Introduction

Time-domain IP became very popular in recent years, mainly due to relatively simple field procedure. Another positive aspect is that one can use standard multielectrode systems for such measurements. On the other hand, time-domain IP measurements can bring some difficulties, which are well described in the paper (Dahlin et al., 2002). A lot of these limitations are not present while using frequency-domain (or spectral = SIP) induced polarization – many examples of such research can be found for instance in Lee Slater`s publications ((Placencia-Gomez et al., 2015) as an example) or in (Abdelal et al., 2013), when authors deal with oil products contamination using the SIP. Unfortunately, the spectral IP is far more difficult regarding instruments and field procedure. Therefore one can use simpler multielectrode procedure and suitably surpass limitations connected with the time-domain IP.

The inception of the induced polarization method goes back to 1910th when Conrad Schlumberger had firstly used the method for the sulfidic deposits prospection – the strength of the signal (anomalies) is typically very strong in this case. A rise of the method in the Czechoslovakia is connected with 1950th when it had become very popular due to increasing needs for ore resources. After 1980th a decline of the method had come, mainly due to closing of ore deposits in the country. Recently (approximately last decade), new applications have arisen, mainly in the fields connected with environmental issues – landfills, remediation projects, water contamination etc. In this case one cannot expect such strong anomalies as for the ore prospection but the method is still viable.

2 The Method

According to (Sumner, 1984), we can carry out IP measurements either in frequency or time-domain. In time-domain a time-decay of voltage between two potential electrodes is being measured right after switching-off the current pulse. Then we measure so-called apparent chargeability, which can be expressed for instance in mV/V (usually equals to ms too) or in %. Time-dependent decay is measured in time windows of varying length (typically microseconds to first seconds). There are several origins of IP signals, which are generally connected with the induced electrochemical processes phenomena. Such processes can produce IP potentials when current is introduced, typically on the contact between solid and liquid phase. There are two primary causes of chargeability. In both cases the redistribution of charges takes some time to occur when an external DC electric field is applied. Equivalently, it takes the same time to revert to a balanced charge distribution once the electric field is removed. "Charging" is hard to measure in practice. "Discharging" is measured using time domain IP survey techniques. The two types of polarization are called "membrane polarization" and "electrode polarization". Membrane polarization occurs when pore space narrows to within several boundary layer thicknesses. Charges cannot flow easily, so they accumulate when an electric field is applied. The result is a net charge dipole which adds to any other voltages measured at the surface. Electrode polarization occurs when pore space is blocked by metallic particles. Again, charges accumulate when an electric field is applied. The result is two electrical double layers which add to voltages measured at the surface.

Anyway, one should always take possible difficulties of time-domain IP in account. Main problems and questions of it mainly are:

- differences due to used electrodes material (more in (LaBrecque et al., 2008));

- occurrence of noise due to electrode polarization in multielectrode protocols (more in (Dahlin, 2000) and (Aizebeokhai et al., 2014));
- occurrence of so-called electromagnetic coupling when the potential and current wires are not separated (more in (Dahlin et al., 2012));
- appearance of negative chargeability values (more in (Dahlin et al., 2015));
- high RMS inversion errors as typical constraints of time-domain IP, in comparison with apparent resistivity.

3 Case Studies

3.1 Ivachnová site

Ivachnová site lies eastern from the Žilina city in mid-Slovakia. The site was affected by old environmental burden after the Soviet army. Originally the garages were at the area of interest and therefor this area is strongly contaminated by, among others, crude oil products relicts. Geologically, the site is composed of quaternary sediments and backfill, bedrock is in the form of Carpathian flysch. Due to heavy snowing just prior to the field works it was necessary to manually uncover the geophysical profiles (see Fig. 1). A network of eight geophysical profiles was set at the site. Four of them went from the north to the south; the other four were perpendicular to previous ones. Profiles going from the north were approximately one hundred meters long while the other ones approximately fifty meters (these ones went partly out of the garages area as well, see results). The ARES instrument (GF Instruments) was used here – it allows simultaneous measurements of the apparent resistivity and polarization. Because of the IP method we decided to use one-second long current pulse, the IP-windows were set to 0.02 s – 0.04 s – 0.06 s – 0.08 s – 0.1 s – 0.15 s – 0.2 s – 0.25 s – 0.3 s – 0.35 s.

Several IP anomalies in range of 2.5 – 6 % were discovered (Fig. 2). Results of the IP together with ERT survey were crucial for placing the remediation wells. In this case, original data (not inverted) are displayed – depth of points was approximated by 1/5 of current electrodes spacing.

One can clearly distinguish "clean" parts with values of chargeability around 0 – 2 % while the values up to approximately six percent are considered as contaminated. We can also see values higher than ten percent – in this case we consider them as artefacts of the measurements in deeper parts of the cross-section or a result of an iron body buried underground. Results of ERT show very diverse material at the site.

Fig. 1 ARES at the Ivachnova site

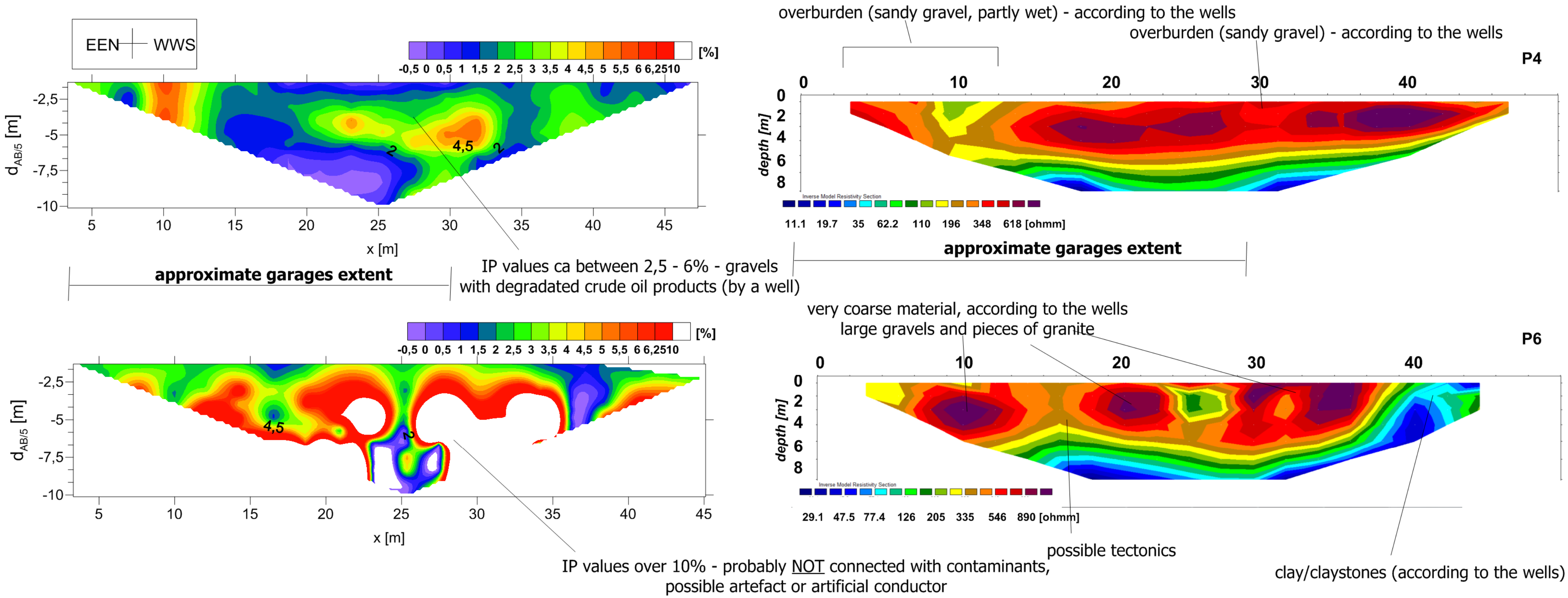

Fig. 2 Values of induced polarization and apparent resistivity at two profiles at the Ivachnova site

3.2 Pohnánec site

The Pohnánec village lies in the hilly terrain of mid-Bohemia, close to the city of Tábor. Approximately one kilometer away a landfill, under operation of the ČEPRO ltd., lies. The landfill (mainly composed of solid waste, ashes products, pond mud etc.) was settled in a depression (bedrock consists of migmatite, with overlying claystone and alluvial sediments), which was excavated by mining-off the brick clay. The aim of the project was a complex assessment of the landfill, i.e. presence of tectonics, contaminants or old iron bodies (such as barrels or drums). As the customer wanted us to reach as much details about the landfill as possible, we used wide portfolio of geophysical methods, including magnetometry (iron material in the landfill), DC resistivity profiling (presence of tectonics that could work as a preferential pathways for waste contaminants to the nearby village) and ERT together with IP.

Geophysical works discovered IP anomalies (Fig. 3) that could equal to weak contamination from waste, which probably will remain in the landfill, as no remarkable tectonic line was discovered. In this case we are using inverted data, which, especially in greater depths, can produce non-realistically high values (up to first hundreds of percent). RMS inversion errors were relatively high, roughly tens of percent. Physical units of the IP measurements here are called “count” and equal to ms. Comparing to the Ivachnova site´s results, which are in percent, we can do the recalculation via rule 10 ms = 1 %. Unfortunately, inverted IP results (especially in greater depths) are probably artefacts caused by the method´s limitations and high RMS error.

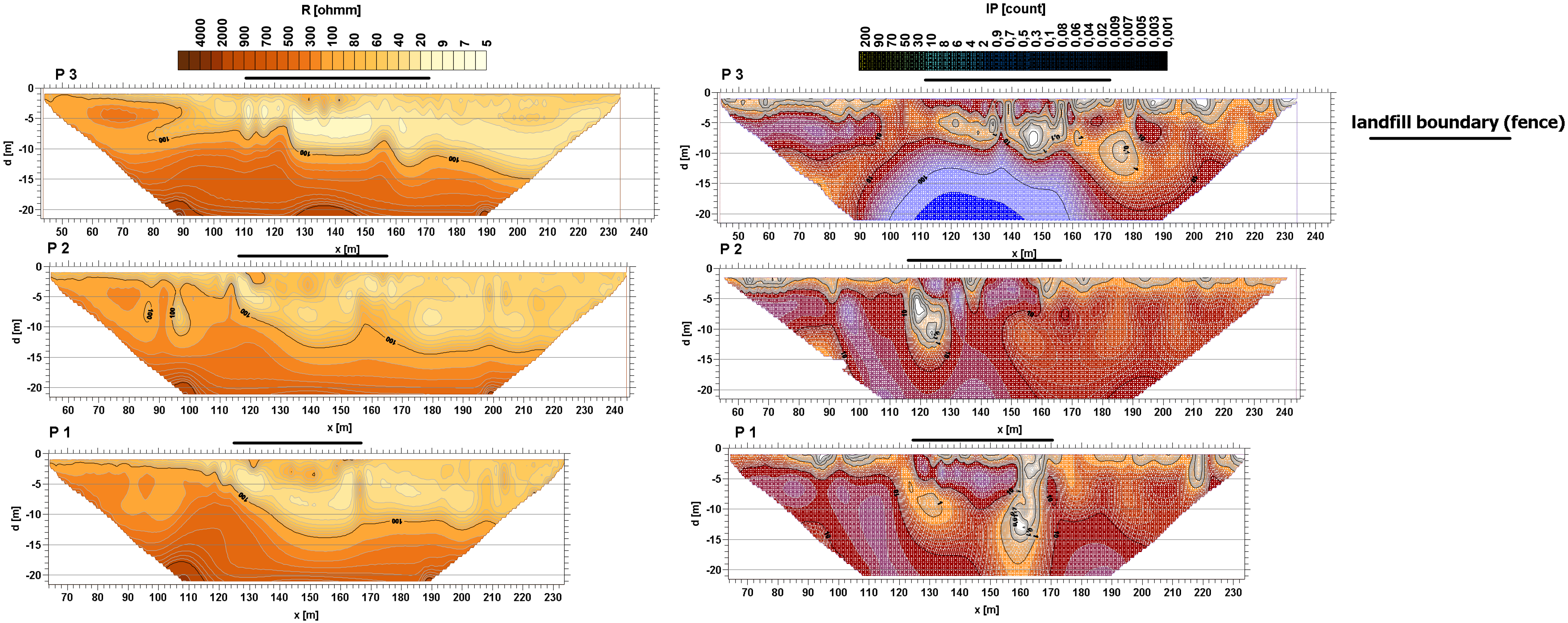

Fig. 3 Values of induced polarization and apparent resistivity at three profiles at the Pohnanec site

3.3 Smyslov site

According to a contract between our company and Vodni zdroje Chrudim ltd., we carried out a geophysical survey in the city of Smyslov, nearby so-called Pike pond ("Stici Rybnik"). The aim of the survey was to check possible preferential pathways for contaminants (crude oil products, gas etc.) between old industrial park and nearby pond and stream. We used methods of ERT, SP (self-potential) and IP at six geophysical profiles. Overall geological situation consisted of alluvial sediments over the migmatite bedrock.

Geophysical survey clearly showed overburden – bedrock boundary and identified zones with higher streaming potentials (i.e. zones with higher infiltration or exfiltration). Results of our IP measurements (again in *ms*, recalculation formula to % is stated in the previous chapter) showed an interesting phenomenon – appearance of negative chargeability values (see Fig. 4). These values were classically interpreted as an erroneous measurement, however, in couple of last years (Dahlin et al., 2015) new theories have arisen. One of the explanations, which was successfully confirmed by modelling, says that negative chargeability values can be connected with sudden changes of zones with high and low resistivity – just like in our case here. At Smyslov these anomalous zones are generally connected to the interface between the alluvial sediments (conductive) and migmatite bedrock (resistive).

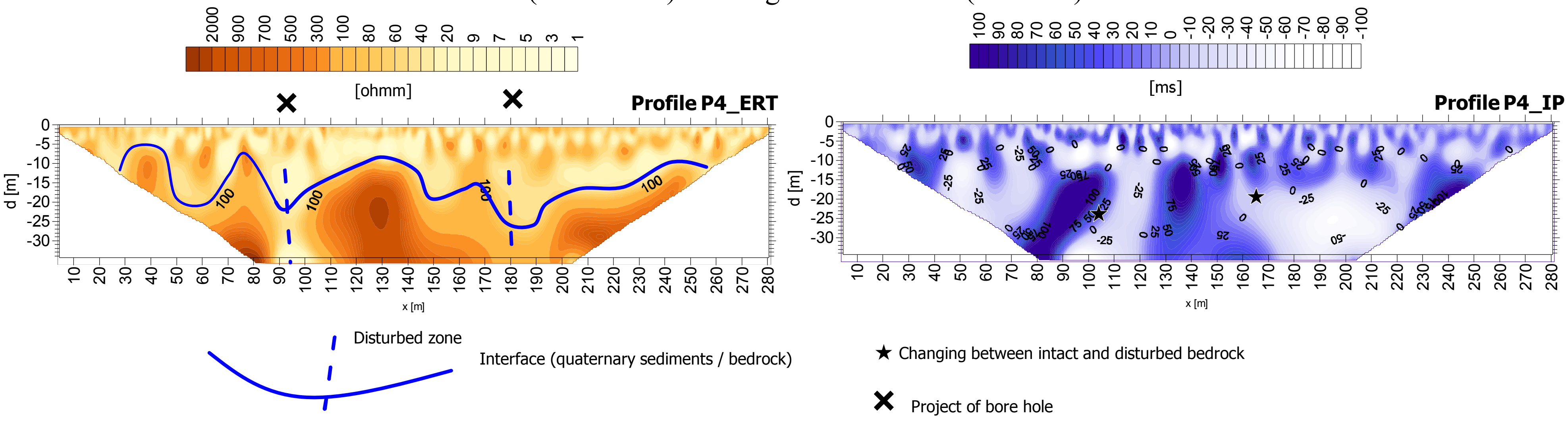

Fig. 4 Values of induced polarization and apparent resistivity at the Smyslov site

4 Conclusions

Time-domain IP looks like a very profitable method for potential direct indication of contaminants in geological environment, ideally in combination with ERT. Comparing to apparent resistivity inversions, high RMS errors can occur. Due to this fact, working with original (apparent) data, can bring better (more reliable) results. Similarly, time-domain IP is more sensitive to the noise caused by used technologies and materials. One can surpass these problems especially by using state-of-the-art instruments, which can deal with them. Additionally it is necessary to keep grounding resistance low as it is a crucial parameter that influences good data quality. Anyway, we have to realize that as the method of IP technically charges up the environment, it can charge up everything that lies underground – including things like barrels, which can produces non-realistically high chargeability values. Additionally, zones with negative chargeability can appear as a result of two geological structures contact, where high resistivity gradient is.

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