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Classification of Induced Polarisation Anomalies Using Relaxation Time Attributes

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SUMMARY

New algorithms are used to determine a classification of induced polarization anomlies as registered by the DNME geoelectric investigation method. Using time filters during the inversion of the measured data is of great significance. Small relaxation time τ values are suited for the exploration of hydrocarbon prospects. Comparison of temporal and amplitude of the IP field characteristics allow to determine with more confidence IP anomalies caused by HC accumulations. The calculation range of τ relaxation time is a good indicator for the occurrence of destroyed or breached oil and gas traps. In this case, the pyrite crystals at a shallow level are submitted to an oxidizing environment and their oxidized rim causes a change in resistance that can be detected in the electric discharge behaviour when the power is turned off.

Introduction

The differentially-normalized geoelectric investigation method (DNME) is specifically designed for use in oil and gas exploration. The identified Induced Polarisation (IP) anomalies can be good indicators for attractive HC-bearing prospects (Veeken et al. 2009). The cause of an IP anomaly lies in the typical reducing medium above a hydrocarbon accumulation, characterized by an enrichment zone with fine-grained epigenetic pyritization, accompanied by a shift in electrokinetic potential to smaller values (cf. Pirson, 1982; Komarov, 1980; Rokityanskiy, 1957). The quantitative division of electromagnetic induction (EM) and IP (Patent EP1876473A1; Legeydo et al., 2008) is inherent to the method and allows to evaluate the intensity of field components with different nature under different geological and geophysical conditions.
Of course not all IP anomalies are connected with hydrocarbon accumulations. In most cases other causes can be accounted for. IP field characteristics (intensivity, delay velocity) depend on multiple factors (formation water salinity, shaliness, porosity, electron-conductive inclusion content etc). This article presents a set of new algorithms that allow an increased prediction reliability. The latter is achieved by adopting a special procedure in the allocation and sorting of the identified IP anomalies.

DNME work procedure

DNME measurements are conducted on land as well as in off-shore regions (Legeydo et al., 2009; Figure 1). A sequence of rectangular bipolar current impulses proceeds from the input electrode line A - B to the medium. First and second potentials differences are registered both in the inducing field and at the transient processes. Both known (robastic and narrow-band filtration, method of principal components, wavelet-analysis and other) and proprietary algorithms are used for the receiver signal processing, whereby the accuracy of the measurement is kept better than 0.5%.

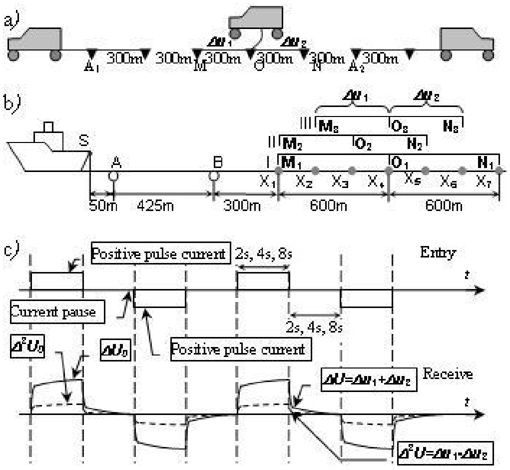

Figure 1 The principles of the DNME method a) Land A1B1-MON-A2B2 setup with opposite power dipoles position b) Marine AB-MN setup with three offsets – I, II и III c) Electrical current profile in time for entry electrodes and measured voltage pattern on ADC input.

Theoretical justification of time characteristics use at estimation and interpretation of IP field

It is well known, that high chargeability of electronic conductors is accompanied by a slow induced polarization discharge. It so happens that the velocity of the IP discharge after the electric current cut-off for small electron-conductive spheres is proportional to the sphere's radius (Komarov, 1980). Two practical conclusions can be drawn from this basic observation.
First of all, the influence of large electron-conductive bodies (for example, zones of more intense mineralization in basalts) on increasing of IP response can be filtered out. Only a few formulas, describing temporal (or frequency) IP dependence, are used in the inversion of geoelectric data and observed curve modeling. They comprise propositions as made by Cole and Cole (1941) and Komarov (1980). In the Cole-Cole model the chargeability features are described by η, τ and c parameters (Cole and Cole, 1941; Pelton et al., 1978), and in the Komarov model – A, G and H

parameters are used. The time parameter G characterizes slow processes of IP discharge (Komarov, 1980). Since the anomalous IP response over hydrocarbon accumulations is mostly determined by presence of fine pyrite, it is likely that in the region of hydrocarbon accumulations values of time parameter G will be lower than in the volcanic basalt region.
Secondly, during the data inversion a variation in τ relaxation time will influence the retained solution. The use of time filter is of great significance. In certain conditions the use of smaller times (less than 0.1 sec) does allow to get a reasonable match and to allocate IP anomalies connected with HC accumulations.

Estimation of τ is also used for identification of IP anomalies that appear above breached hydrocarbons accumulations. Presence of reducing conditions above hydrocarbons accumulations is required for epigenetic pyrite mineralization formation. If at a later stage in the geologic history these reducing conditions change into oxidizing or a neutral one, then the outer surface of pyrite grains may be exposed to oxidation. During the power-up stage of the DNME experiment, charges are accumulated on the border of the electronic and ionic conductor where a double electrical layer occurs. Discharging is taking place during the power shut-in phase. Speed of discharging depends on capacitance of double electrical layer C and environment resistance R in the space between charges ($\tau = R * C$). The oxidized rim of the pyrite crystal is not an electronic conductor and therefore a double electrical layer is formed on the border of the oxidized and non-oxidized parts of the grain. Discharging occurs after the power is turned down. Speed of discharging changes as a dampening resistance R_0 is felt from the oxidized rim. Capacitance of double electrical layer is changed according to the depth of oxidation rim ($\tau=(R+R0)*C$). This process is correctly described by a complicated integral - differential equation, which was established by prof Dr O. Putikov (Ivanov et al., 2008). Output of the computations is shown in Figure 2. Time of relaxation should increase with the increase of oxidized rim resistance and size of pyrite crystals or clots. This conclusion is effectively confirmed by laboratory experiments (Figure 3).

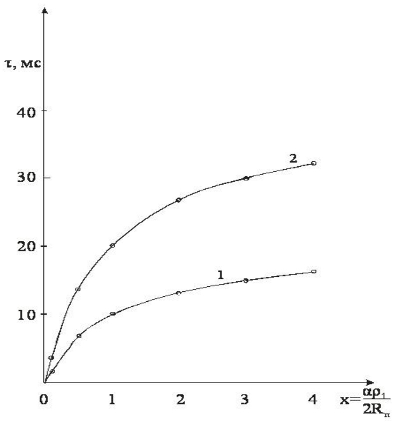

Figure 2 Graphs of theoretically obtained dependence of relaxation time of spherical clot (radius **a**) upon surface oxidation level of shell.

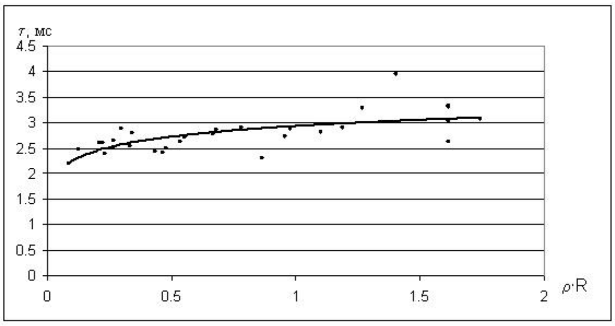

Figure 3 Graph of experimentally obtained dependence of relaxation time upon surface oxidation level of crystal rim.

Field study examples

Let's give an example of IP anomaly ranking based on the use of the time parameter G for a region in Siberia. The distribution map of this G parameter shows increased values close to the outline of the trap. Most IP anomalies, including the reference object near the productive well, correspond to areas with low values (Figure 4). Comparison of 'anomalous zones' contours, allocated by IP and the contour displayed by time parameter G, allows to separate with the more confidence anomalies stemming from volcanic origin and those caused by a deeper seated HC accumulation. IP field and the A parameter anomalies are very similar, which testifies the correctness of the calculation method.

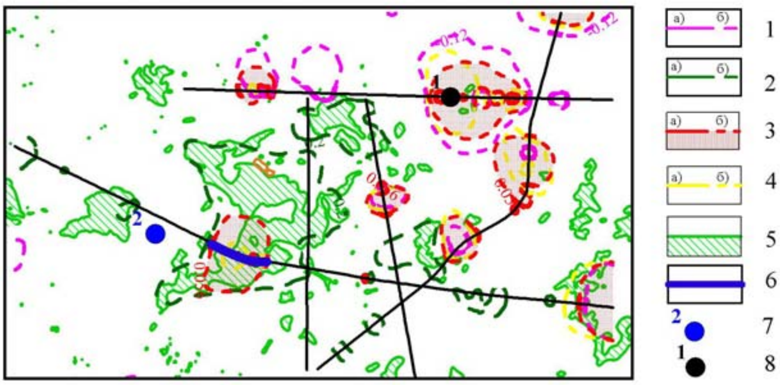

Figure 4 Comparison of anomalous areas allocated by amplitude parameter A and IP field with areas of maximum and minimum values of time parameter G (1 – logG boundary value isoline contouring regions with relatively fast IP discharge, 2 – logG boundary value isoline contouring regions with relatively slow IP discharge; 3 – IP boundary value isoline, 4 – logA boundary value isoline: a – reliable, b – obtained by means of extrapolation; 5 – regions of traps exposion; 6 – IP anomalies that can be connected with traps; 7 – well with water inflows; 8 – well with gas inflow).

Example of influence of different time filters on the results of data inversion is given for the conductive section in the Prichernomorskaya-Severo-Kavkazskaya oil and gas province (Figure 5). The sections demonstrate that small values of time of relaxation τ are optimal for exploring hydrocarbon prospects in these conditions.

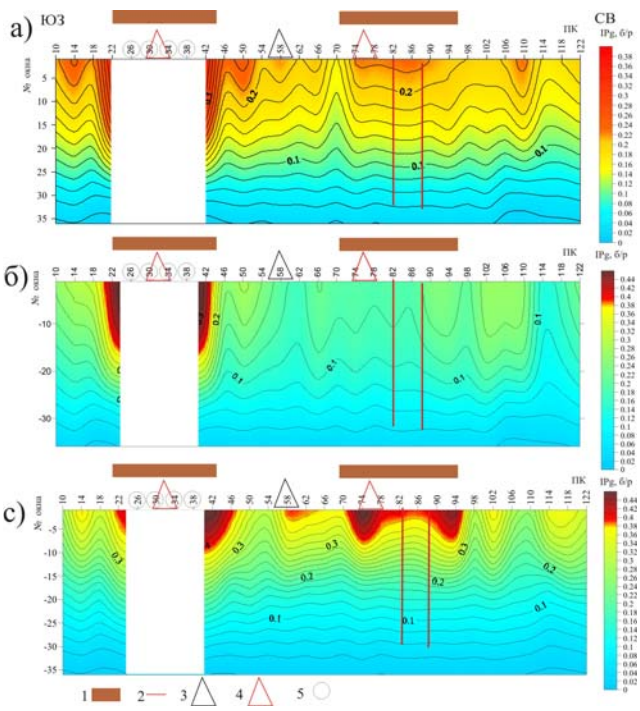

Figure 5 Comparison of polarization fields IPg distribution at different time filters' usage: a)0.01sec≤ $\tau \leq$ 5sec;b) 0. 1sec≤ $\tau \leq$ 5sec; c) $\tau <$ 0.1sec (1 – HC deposits confirmed by drilling; 2 – faults according seismics; 3 – empty wells; 4 – productive wells.

One area on shallow shelf of the Caspian Sea serves as example to illustrate the benefits of the relaxation time determination to the interpretation of geoelectric results (Ivanov et al., 2008). DNME acquisition permits to outline IP anomaly in this offshore area. A borehole, drilled within the outlining contour of the IP anomaly, revealed only water-saturated clastic reservoirs. Cutting description indicated clots or single traces of pyrite minerals in numerous intervals of the well trajectory. Detailed modeling was carried out to investigate the reason for getting these negative drilling results. It was determined that the time of relaxation within the outline of the IP anomaly near the borehole exceeded a few times similar parameters obtained in IP anomaly limits above known hydrocarbon accumulations on this shelf.
The following conclusion can be drawn from this study: epigenetic pyrite mineralization is the most probable cause of the IP anomaly. This epigenetic pyrite mineralization occurs either due to the earlier presence of a hydrocarbon accumulation that was destroyed in a later phase by seal breach. An other possibility is that there is not a vertical leaking effect but there once existed a powerful lateral drift of scattered hydrocarbon resulting in a shift of the geochemical alteration zone (halo). The latter points to an existing accumulation laterally away from the borehole. An alternative explanation is that the hydrocarbons are coming from stratigraphic level deeper in the section than penetrated by the borehole.

Conclusions

Algorithms have been proposed that can be used in DNME data inversion scheme and allow interpretation of IP field response. It permits determination and contouring of IP anomalies connected to HC accumulations. The new approach is based on the inversion using small values of relaxation time (i.e. stable time filtration of data). The variation range of time relaxation τ supports the subdivision of IP anomalies into two categories: undestroyed still present HC accumulations and structures destroyed by later seal breach. The time parameter G for allocation target IP anomaly is particularly useful in sections with intensive volcanism and magmatism. This more sophisticated approach to the inversion modeling of geoelectric data exhibits a real improvement for the interpretation and allocation of anomalies attached to the presence of oil and gas bearing reservoirs.

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