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## Geo-electric Analysis Based on Quantitative Separation between Electro-magnetic and Induced Polarisation Field Response

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### SUMMARY

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The geo-electric method allows mapping of resistivity and induced polarization effects in the subsurface. It permits detection of diagenetic alteration zones with micro-pyrite crystals, situated some distance above hydrocarbon accumulations due to leakage from a non-perfect top seal. Geo-electric surveying (DNME) uses special parameters for monitoring the electric earth response in time. Inversion of relaxation curves is done to establish a depth model, whereby non-uniqueness of the solution is a well known problem. Additional constraints are needed for a plausible scenario. Two basic components are measured: the electro-magnetic and induced polarisation response. A synthetic model illustrates their contributions in spite of the non additive character. The inversion is done in a 1D mode with a Cole-Cole simulation. The modelled response at a recording station has been compared with that of the known 3D model. The discrepancy is better than 0.1 %, illustrating the validity of the inversion modelling. A considerable amount of successful study cases has been performed in Russia, like the Severo Guljaevskaya study in the Barents Sea. The geo-electric technique reduces risks attached to drilling of new hydrocarbon prospects and provides a better ranking at a reasonable cost.

## 1. The geo-electrical investigation method

The response of the subsurface is analysed with an electrical transmitter-receiver setup (Fig. 1). A powerful current is introduced into the earth via two input electrodes (100-2000 metres apart). The receiver assembly is located 1 to 10 km further away along the survey line.

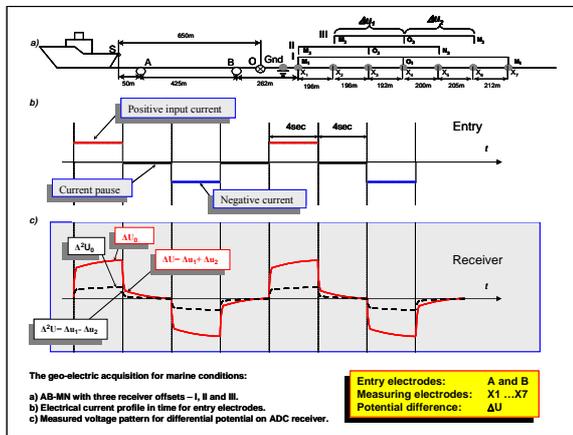


Figure 1: Set up of a geo-electric acquisition survey

Several electrical potential differences ( $U_1$ ,  $U_2$ ) are measured simultaneously with a 0.25 ms time sampling rate (Davidenko et al 2008). A differentially normalized approach is adopted with several diagnostic parameters (patented DNME method, Legeydo et al 1996).

$$\begin{aligned} \Delta U &= \Delta U_1 + \Delta U_2 & DU &= \Delta U / \Delta U_0 \\ \Delta^2 U &= \Delta U_1 - \Delta U_2 & D^2 U &= \Delta^2 U / \Delta U_0 \\ P_0 &= \Delta^2 U_0 / \Delta U_0 & P_1 &= \Delta^2 U / \Delta U \\ P_S &= (\Delta^2 U - \Delta^2 U_0) / (\Delta U - \Delta U_0) \\ I_t S &= \Delta_t (\Delta^2 U - \Delta^2 U_0) / \Delta_t (\Delta U - \Delta U_0) \approx (\Delta_t \Delta^2 U) / (\Delta_t \Delta U) \\ D_\phi S &= I_t S - P_S \end{aligned}$$

The current is transmitted during a four second period and then turned off during 4 seconds (or up to 8 seconds). The decay of the potential difference in the receiver electrodes is registered during the current turn-off stage of the experiment. Several parameters are measured on the decay function that may reveal anomalies in the subsurface behaviour. Inversion techniques result in an earth model, whereby chargeability and resistivity depth sections are generated at the same time. Anomalous response in the decay function is often observed when hydrocarbon accumulations are present (e.g. Sternberg 1991) caused by a diagenetic alteration zone with micro-pyrite crystals (Davydycheva et al 2006). These crystals get polarized and retain their polarization when the current is turned off. Afterwards the crystals go slowly back to their neutral state. This phenomenon results in a change in differential potential characteristics as measured in the receiver assembly. A more detailed description is given by Veeken et al (in press).

## 2. Two earth models that have similar electrical response.

Two simple models are given that represent a high resistivity body in a high conductive background (model 1) and a high chargeability body (model 2), but at distinctive depth. Simulation is done with the 3D electric modeling program Geoprep. The time domain outputs for the electrical response is actually the same and this example shows the non-uniqueness of the inversion problem (Figure 2). Complications in inversion occur when dealing with carbonate reservoirs (little contrast between oil reservoir and water-filled surrounding) and when many high resistivity layers (salt, anhydrite, dolomite etc) are encountered. An additional parameter like chargeability will reduce the uncertainty in the retained solution.

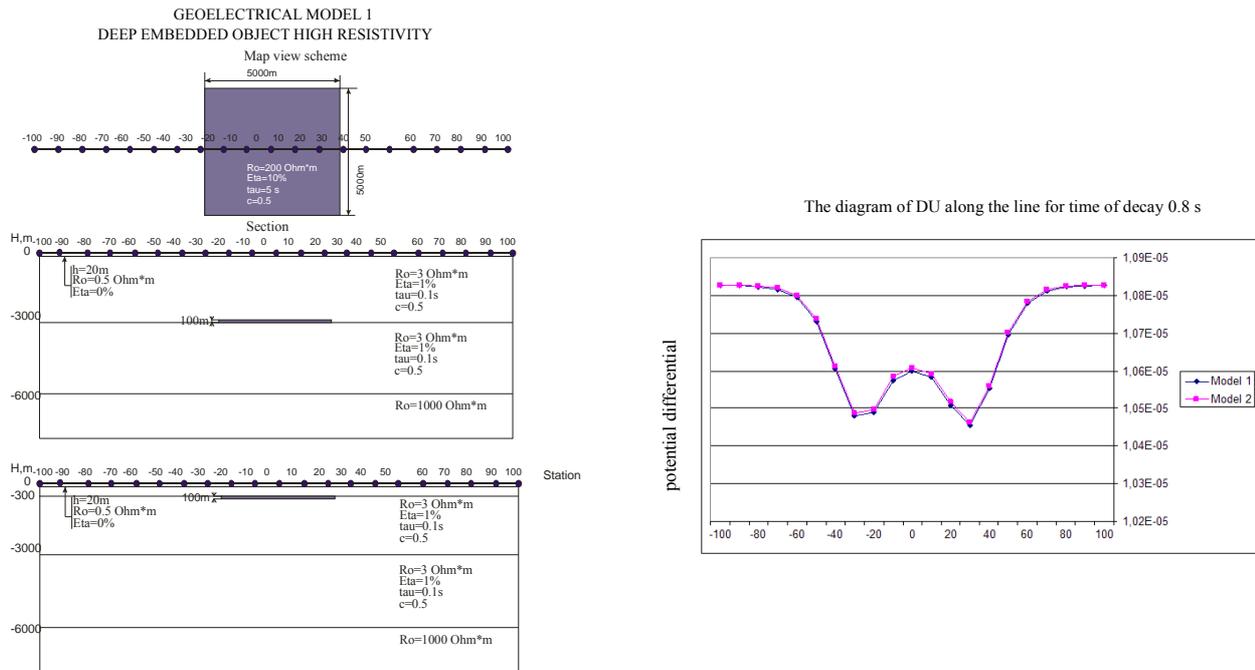


Figure 2: Two distinctive earth models that generate a similar potential difference response

## 3. Separation of electro-magnetic and induced polarization components.

The field response consists of two contributions: an electro-magnetic and an induced polarization component. The geo-electric DNME parameters have different functional dependencies towards induced polarisation and electro-magnetic. They have been chosen so that a more optimal IP/EM ratio is obtained. A method is presented to restore the components of the total field notwithstanding that these processes are not additive. For this purpose different space-time representations of induced polarization and electro-magnetic fields are examined. The electro-magnetic eddy-current fields tend (with increasing decay time) to have an uniform distribution in a medium and propagates in time,

whereas induced polarisation fields are always spacially inhomogeneous but more stationary in time (Figure 3).

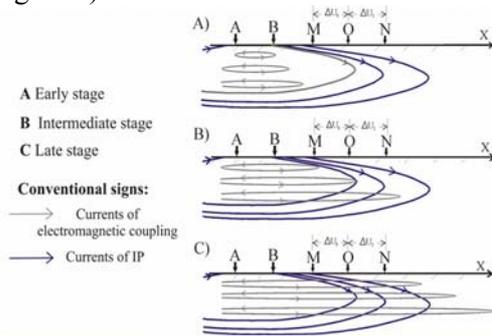


Figure 3: Space distribution of eddy currents and IP in different stage of transient field response

Let's now consider transformants of the transient electrical field, which were recorded in one station point. The most natural solution is to involve, in addition to the transient fields, their normalized space derivatives (to be more precise – the finite differences), since the space-time structure is different. The rate of temporal decay of the electro-magnetic field is not the same in different points in space. The decay is slower at further distance from the source. As a consequence, the spatial inhomogeneity of electro-magnetic induction field decreases and, within the boundaries of the measuring equipment, eddy currents are distributed evenly at sufficiently great decay time. The transient equation in non-polarizable medium is given by the diffusion equation. As time goes by, the IP field decays steadily from the initial value to zero. This depends only on medium properties (in terms of Cole-Cole model-relaxation time), without regard to the location of source and receiver. The use of differentially normalized parameters reduces the number of degree in freedom in the inversion problem and also allows to separate the electro-magnetic and induced polarization fields. Chargeability and resistivity distribution depth sections are useful to consider. An earth model is assumed and the forward 3D modeling response is computed for this case (Figure 4).

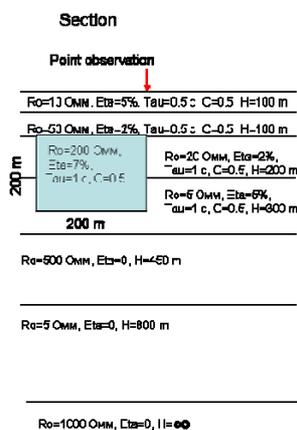


Figure 4: Resistivity and chargeability earth model

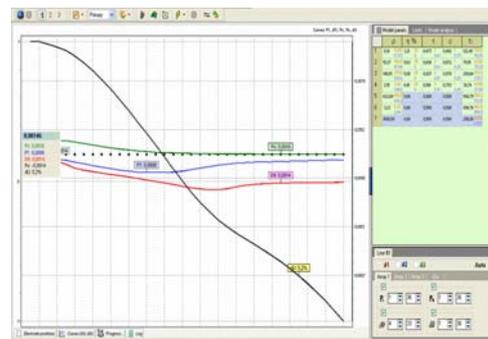


Figure 5: Comparison inverted response and delay curves

For the center point of the setup the DNP parameters were simulated using Cole-Cole formula. The chargeability in each point of the model can be set zero and then the electro-magnetic component is computed. When the wavenumber is set to zero, than the induced polarization is calculated. This modeling step quantifies their contribution to the total field measurements. The decay curves (thick line) are computed for the center point in the setup (red point Figure 5). Then a 1D inversion has been run on the data from the same spot and the modeled decay curves (thin lines) are compared. The discrepancy between the 3D and 1D approach has been determined and it is better than 0.1%. It shows the validity of the inversion procedure. The DNME approach has reduced the number of degrees in

freedom for the inversion and simultaneously separates the electro-magnetic from the induced polarization effect.

#### 4. Severo-Guljaevskaya oil-and-gas field (Barents Sea, Northern RF)

Calibration of the dataset is provided by resistivity logs in the 1-SG well. Reservoir contour maps allow to construct an input model for evaluation of the GE dataset. The polarisation coefficient section illustrates the anomalous high values concentrated in a specific zone. The map view of the GE inversion results shows a sharp increase of  $\eta$  (polarisation coefficient) in the 4<sup>th</sup> layer, from 2—6% to 11—13%, in the area above the hydrocarbon accumulation. Also the polarisation for the 5<sup>th</sup> layer depicts a closed contour area with high values up to 9% or more. The other parameters don't change so rapidly when crossing the same area and are therefore of less diagnostic value. The zone with increased resistivity for layer 5 is confined to where hydrocarbon deposits are present on the deeper level of layer 6. Diagenetic processes, like local calcitisation, could explain this high resistivity. The mapped anomalies correspond to the zone of structural closure and a direct relation is evident. A better match might be obtained when the depth conversion parameters are adjusted. The study illustrates the benefits of the geo-electric analysis for hydrocarbon prospect ranking.

#### 5. Conclusions

Electric potential differences help to identify and rank hydrocarbon prospects in sedimentary rocks. Local anomalies are often caused by the presence of diagenetically altered rocks overlying a hydrocarbon accumulation. Leaking of hydrocarbons from a deeper level is postulated as cause of such typical alteration zone. Several DNME geo-electric attributes are monitored in time, that have different functional induced polarisation and electro-magnetic dependencies. The components of the measured field can be restored notwithstanding the fact that these processes are not additive. A different space-time structure of induced polarization and electro-magnetic fields is used – eddy-current fields tend (with increasing the decay time) to have a more uniform distribution in a medium, whereas induced polarisation fields are always inhomogeneous in space. The synthetic modelling indicates a discrepancy up to 0.1%, thus illustrating the validity of the inversion modelling adopted in the DNME workflow. Inversion of the geo-electric dataset gives access to a depth model of the polarisation coefficient and resistivity distribution. An integrated approach enhances the reliability of the output. Geo-electric surveying provides an additional means for outlining prospects, helping to refine depth conversion with a better grip on the volumetrics. It is a useful tool in the exploration phase of projects, but also may indicate existence of bypass areas and/or justifies more daring outsteps in existing fields (strat trap delineation).

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