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GEO-ELECTRIC ANALYSIS BASED ON QUANTITATIVE SEPARATION BETWEEN ELECTROMAGNETIC AND INDUCED POLARISATION FIELD RESPONSE.

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Summary: The geo-electric method allows mapping as resistivity as induced polarization effects in the subsurface. The method permits detection of diagenetic alteration zones with micro-pyrite crystals, situated some distance above a hydrocarbon accumulation due to leakage from a non-perfect top seal. Geo-electric surveying (DNME) makes use of special parameters for monitoring the electric earth response in time. Inversion of the registered relaxation curves is done to establish a depth model, whereby non-uniqueness of the solution is a well known problem. Additional constraints are needed to establish the most plausible scenario. The recorded field consists of two basic components: an electromagnetic and induced polarisation response. A synthetic model is compiled to illustrate their contributions in spite of the non additive character. The inversion is done with the aid of a Cole-Cole simulation in a 1D mode. The modelled response at a recording station has been compared with that of the known 3D model. The discrepancy is shown to be better than 0.1 %, illustrating the validity of the inversion modelling. The effectiveness of the workflow has been demonstrated already by a substantial amount of case studies. The Severo- Guljaevskaya study in the Barents Sea provides an example of a successful application. The geo-electric technique helps to reduce risks related to drilling new hydrocarbon prospects and provides a better ranking at a reasonable cost.

1. Introduction. The geo-electrical investigation method

The response of the subsurface is analyzed with an electrical transmitter-receiver setup (Fig. 1). A powerful current is introduced into the earth via two input electrodes (100-2000 meters apart). The receiver assembly is located 1 to 10 km further away along the survey line. Several electrical potential differences ($U_1, U_2$) are measured simultaneously with a 0.25 ms time sampling rate (Ivanov et al 2008). A differentially normalized approach is adopted with several diagnostic parameters (patented DNME method, Legeydo et al 1996).

\[
U = U_1 + U_2 \quad DU = \frac{U}{U_0} \\
^{2}U = \frac{U_1 - U_2}{U_0} \quad D^{2}U = \frac{^{2}U}{U_0} \\
P_0 = \frac{^{2}U_0}{U_0} \quad P_I = \frac{^{2}U}{U_0} \\
PS = \frac{(2U - 2U_0)}{(U - U_0)} \\
IS = \frac{(2U - 2U_0)}{(U - U_0)} \\
DS = IS - PS
\]

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 behavior. 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 model 1) and a high chargeability body (in model 2) in a high conductive background, but at distinctive depth. Simulation is done with the 3D electric modeling program Geoprep. The time domain output 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.

3. Separation of electromagnetic and induced polarization components.

The field response consists of two contributions: an electromagnetic and an induced polarization component. The geoelectric DNME parameters have different functional dependencies towards induced polarization and electromagnetic. 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 electromagnetic fields are examined. The electromagnetic eddy-current fields tend (with increasing decay time) to have a uniform distribution in a medium and propagates in time, whereas induced polarization fields are always spacially inhomogeneous but more stationary in time (Figure 3). 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 electromagnetic 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 electromagnetic 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 electromagnetic 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 (Figure 4). For the center point of the setup the DNP parameters were computed using Cole-Cole formula. The chargeability in each point of the model can be set zero and then the electromagnetic component is calculated. 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 electromagnetic from the induced polarization effect.

3. 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 \( \eta \) (polarization coefficient) in the 4th layer, from 2—6% to 11—13%, in the area above the hydrocarbon accumulation. Also the polarization for the 5th 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.

4. Conclusions

The 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 and have different functional induced
polarization and electromagnetic dependencies. The components of the measured field can be restored notwithstanding that these processes are not additive. For that purpose a different space-time structure of induced polarization and electromagnetic fields is used – eddy-current fields tend (with increasing the decay time) to have an uniform distribution in a medium, whereas induced polarization 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 volumetric. It is a very 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).

References

Figure 3

Figure 4

Figure 5