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Pitfalls in reservoir monitoring with CSEM

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Some aspect of pitfalls in reservoir monitoring with CSEM

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ABSTRACT

Reservoir monitoring is gaining increasing importance for hydrocarbon and geothermal reservoirs to improve recovery factors and understand fluid movement including fluid induced reservoir changes. Similar, it can be applied to monitoring volcanoes' magna movements and aid for volcano eruption prediction.

In order to see variations at percentage level much more detailed attention is required at all data handling stages. During acquisition, more effort is required to obtain long term stable transmitter and receiver site including not only daily monitoring of contact resistance but also controlling them during the acquisition process to better than 1%. Because of the large dynamic range of the signal highly accurate reference level with active adjustment before the transmitted signal is necessary. When processing the data, a feedback loop between filter selection and noise suppression in the reservoir signal band allows you to optimize the filter and to reduce their effect on the anomaly itself. When modeling for a sedimentary environment, anisotropy is the biggest cause for error and misinterpretation. It can be derived before the survey from exiting logs using end members derived from the log based on the interaction of the layers on reservoir scale. We are using real field measurements for feasibility and as potential misinterpretation examples to illustrate the severance of these issues.

INTRODUCTION

For reservoir monitoring, electrical property changes appear in the reservoir fluid boundaries. The larger the contrast, the larger is the electromagnetic (EM) response. Thus, EM methods provide unique opportunities to track fluid movements and flow. They are important parameters in reservoir management, especially for high value targets such as unconventional (shale) reservoirs or steam/water/CO_2 flood EOR. Thus, the EM data and interpretation could yield considerably more value than traditional seismic interpretation alone. At the same time, technology has progressed such that it is now routine recording virtually an unlimited number of channels at lower cost (than in the past) and interpreting data in 3D.

Surface-to-surface Controlled Source EM (CSEM) applications using a grounded electric dipole in time-domain (Strack, 1992; 2004, 2014; Strack& Aziz, 2013) are more promising for land applications than frequency domain CSEM (Johansen et al., 2005; Constable, 2010), since it is advantageous to record once the transmitter is off, after the airwave has passed (Kumar & Hoversten, 2012).

Reservoir monitoring is a time-lapse exercise with measurements that link downhole and surface-to-surface data enable critical calibration and increasing sensitivity to fluid variations in the reservoir. The wealth of EM information tied to 3D surface and borehole seismic data also permits to extrapolate fluid movements and seal integrity away from a given well bore (Passalacqua et al. 2016).

To date, EM applications for reservoir monitoring are in an early stage of development. Presently, only limited monitoring applications have been reported (Hoversten et al. 2015, Tietze et al. 2014; 2015; Thiel, 2016).

Over the past 10 years we have be developing an array system concept that includes the combination of surface and borehole measurements (Strack, 2004). When realizing that the existing geophysical system did not meet our requirements, we developed an integrated borehole, marine and land concept with the survey layout shown in Figure 1. From borehole measurements and the recent 3D induction logging tools, it became apparent that borehole resistivity logs in anisotropic formations (most basins) are underestimating hydrocarbon reserves by more than 25% (Yu et al., 2001; Barber et al., 2004). Figure 2 shows two log examples with the one from Yu et al. (2001) on the left and from Barber et al. (2004) on the right. In both case the increased reserved that were estimated from the 3-component induction log was more than 35%, more than from the normal induction log that only measures horizontal resistivity and it is dominated by shales. We experienced similar effects for marine controlled source electromagnetics when ignoring transverse-isotropic anisotropy (Thomsen et al., 2007). This results in the requirement of measuring full tensor resistivities in the borehole and on the surface.

As novel contribution we derived a methodology and additional measurements where the information content can be focused below the receivers using either Focused Source EM (FSEM) (Davydycheva & Rykhlinski, 2009; 2011) or vertical electric field measurements. This will overcome the issue with not knowing the image point where the information comes from that we measure at the receiver site.

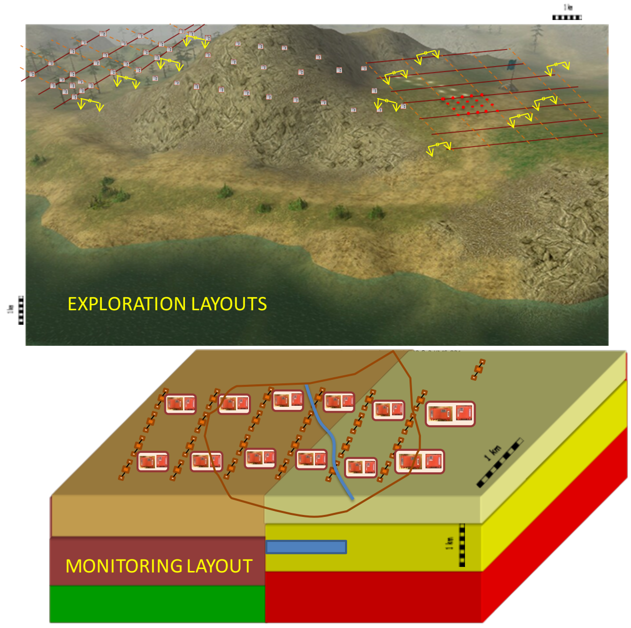

Figure 1: Field layout for carrying out CSEM land surveys (top) and monitoring measurements (bottom).

IMPROVED IMAGING

The biggest error is coming from the inherent inaccuracy of image focus related to the receiver location. In borehole logging this is handle by focusing the injected current to a narrow bed. We apply these principles described by Davydycheva & Rykhlinski (2009; 2011). Instead of using many sources we can also use multiple receiver by applying the principle-of-reciprocity. Figure 3 shows sensitivity plots for time and frequency domain on the left and on the right for focused source EM (also for time and frequency). The FSEM on the right shows that by build the differences between receivers we get the vertical current from below.

ACQUSITION ISSUES

From the acquisition side, for reservoir monitoring, the main issue is source stability, high power and accurate synchronization between transmitter and receiver. Since we use a grounded dipole the latter also depends on the inductance and resistance of the source. When addressing this correctly in the hardware, we experienced that – with active current control – this can be kept at below 0.5% source repeatability over long periods of time.

SUMMARY

Applying controlled source EM to reservoir monitoring require accuracy from the instrumentation beyond what we used before. We need to reconcile surface tensor with borehole measurements to calibrate the data against actual reservoir fluid production. In addition, we need to correct the by measuring in a focused way similar to what is being done in the logging industry. Further, accuracy and time consideration need to be applied to get proper reliable repeatability.

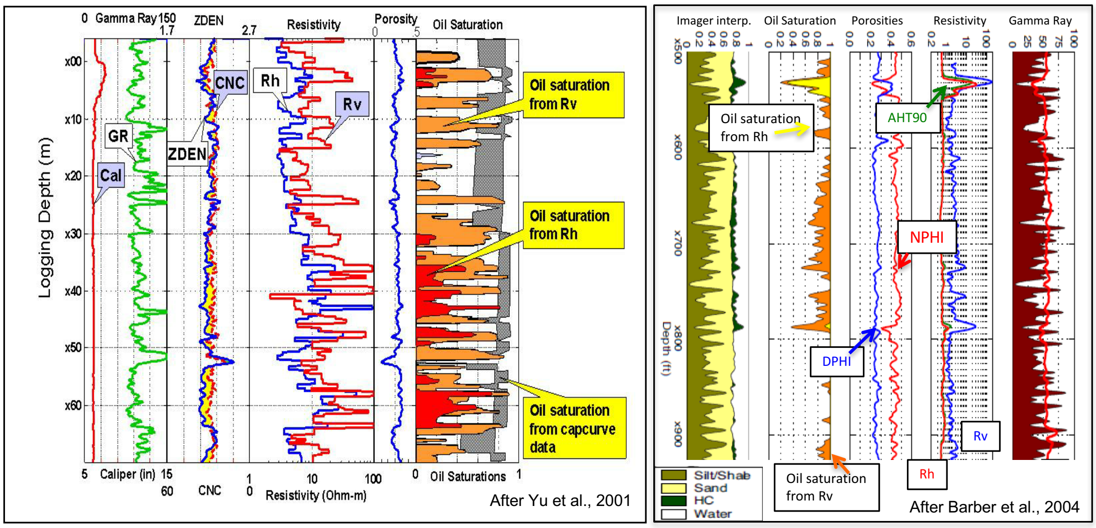

Figure 2: Two examples of interpreted 3D induction logs using 3-component transmitter and receivers. In both cases the improved oil saturation is shown in the orange shaded track.

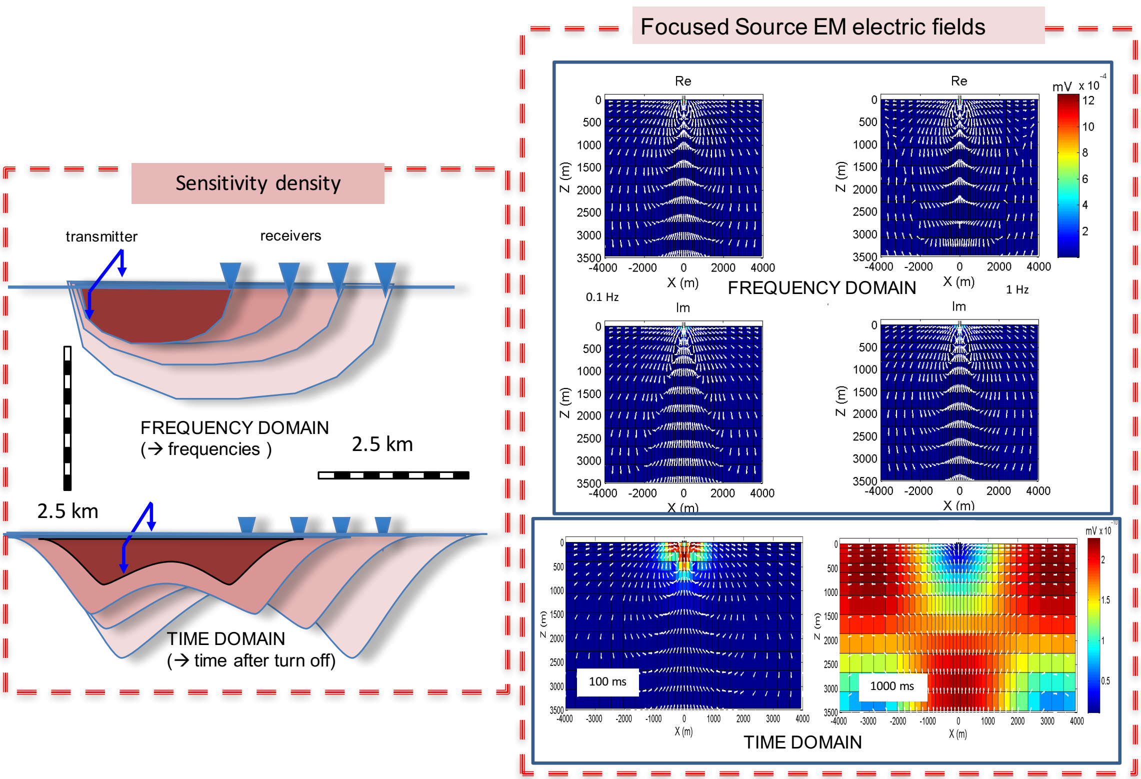

Figure 3: Sensitivity plots for frequency and time domain CSEM on the left and on the right for FSEM.

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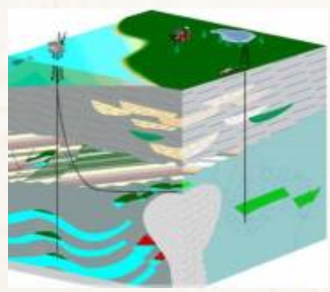

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