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Reservoir monitoring with CSEM

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Reservoir monitoring with CSEM

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Summary

The economic value of reservoir monitoring technology resides in its ability to uniquely detect the property that both changes over time and can be attributable to reservoir production performance. Fluid typing is a key element in this and electromagnetics is the prime choice of method. Recent advances in electronics now make it possible to combine surface and borehole electromagnetic (EM) measurements with 3D seismic and link fluid changes and porosity distribution monitoring with an exact location in the three-dimensional space. The value of the EM method lies in its ability to measure and understand the fluid content in a pore space. Physically, the detection of a reservoir is based on the resistivity contrast of the resistive reservoir fluid. EM sensors can be placed both in the borehole and at the surface to optimize resolution and spatial coverage. These systems can be either permanently emplaced or utilized in a time lapse fashion. The goal is to now integrate electromagnetics into the exploration life cycle and leverage its strengths in reservoir characterization, production monitoring and ultimately optimized abandonment.

Introduction

For greater than 40 years the seismic method has been the geophysical workhorse of the oil industry. While it offers the best description of the reservoir shape and stratigraphy, it falls short on describing the fluid properties of the pore space as elastic waves predominantly travel through the rock matrix. In particular, many of the changes that take place the during production life of a reservoir do not exhibit a detectable change in acoustic properties. Electromagnetic methods can measure and understand the fluid content in a pore space. They are based on detecting the resistivity contrast of the resistive reservoir fluid to its conductive surrounding. Time variant electromagnetic fields of either natural or artificial origin cause eddy currents within the conductive sediment layers. These eddy currents cause a secondary EM-field that can be sensed with magnetic or electric sensors placed on the sea floor or in the wellbore. Integration with seismic is particularly important, as the EM method is based on the physics of diffusion and is of much lower natural vertical resolution than that of seismic which is based on wave propagation.

Surface EM

Our choice of electromagnetic method is in time-domain, or transient EM. In time-domain CSEM one transmits a broadband current into the Earth and charges the subsurface. The current is then switched off and the charge drains from the Earth. (Strack, 1992) Transient responses to this artificial electric field are then measured by sensors that record both the electric and magnetic field components. Like seismic, which synchronizes the recorded response with its impulsive source, transients have a start and finish timing that correlate to current changes in the source. For each source receiver offset, we obtain a unique transient and we can leverage this time-offset relationship in our processing and interpretation of the data. As time-domain CSEM is collected in a style similar to seismic it can be robustly integrated with seismic data and utilize the processing strengths of seismic where one can apply noise suppression, signal enhancement and imaging algorithms.

Borehole EM

Understanding the movement of water-floods and steam-floods has historically been recognized as the largest prize in reservoir monitoring. With proper measurements, one can potentially determine sweep patterns, sense pressure depletion, or identify residual or by-passed pay and also optimize production performance on a predictive basis. Placing sensors in the wellbore and not only at the surface is critical to providing the reservoir-scale resolution needed for an effective reservoir monitoring program. A study of single-well deep reading technologies concluded that a combination of seismic and EM offers the optimal combination of sensors to monitor reservoir production changes. Borehole EM tools operate in a fashion similar to other time domain techniques as they generate a magnetic field in the surrounding rock and record the induced voltages that are generated when the current is switch off. Perturbations in the recorded voltages are indicative of changes in resistivity. Figure 1 provides an example of the type of resistivity changes that can be seen following a steam flood. Borehole to surface modeling, as shown in Figure 2, demonstrates that these reservoir changes can be detected with EM methods.

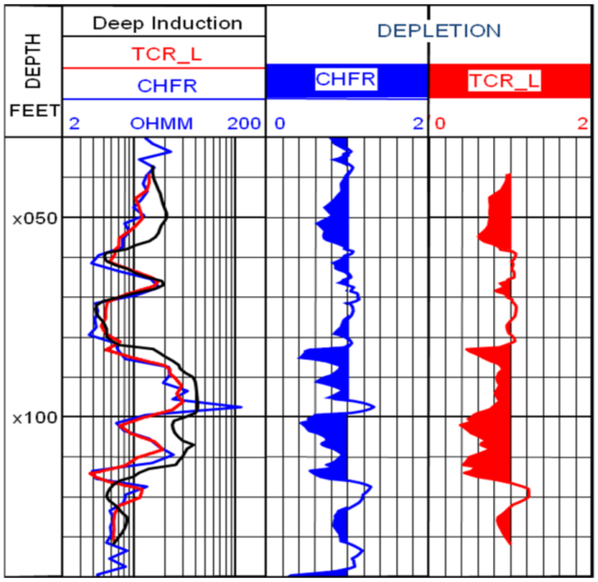

Figure 1: Steam flood has reduced 80 Ω-m reservoir resistivity to 40 Ω-m, black curve represents pre-flood resistivity and red curve represents post-flood resistivity. After Zhou et al., 2002.

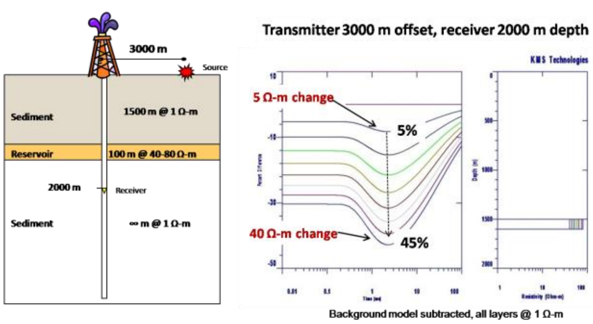

Figure 2: Surface to borehole time-domain CSEM 1D modeling conducted to evaluate sensitivity to changes in reservoir resistivity. A change from 80 Ω-m to 40 Ω-m, similar to the steam-flood example in Figure 1, yields a 45% change in recorded electric field data.

Linking the surface and borehole

Integrating borehole and surface EM measurements with seismic will give the reservoir engineer a dynamic monitoring tool that utilizes the imaging strengths of seismic and the fluid detection capabilities of EM. Repeatability of the measurement is the key to successful monitoring efforts. Permanent emplacement of EM and seismic sensors in the field, OBC deployed marine EM & seismic, and concurrent acquisition of seismic and EM offer solutions to this problem.

Numerous feasibility studies have shown that surface resolution is in many cases not sufficient and borehole data must be include. In fact, the best system would be a deep reading single well EM system with deep reading capabilities.

Conclusion

The application of electromagnetic methods has increased in the past two decades because of an improved understanding of the technology, improved availability of the services, and higher quality of the EM measurements. Robust integration with seismic, well log data and other geophysical measurements (gravity, magnetic, etc.) will further increase the reliability and precision of the EM method. The expectation now is that electromagnetics will become a routine part of the exploration life cycle and will play a significant role in reservoir characterization, production monitoring and ultimately optimized abandonment.

We have learned from many feasibility studies that borehole information is needed to obtain sufficient resolution of the target.

References

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