Introduction

There is a range of physical parameters we can use to investigate the earth and properties of fluids within it. Well logs provide a high resolution measurement of the properties of a reservoir and the surrounding strata, however properties can only be determined in a small area local to the well. Often a measurement of reservoir properties across the extent of a field is desirable for reservoir management or production optimization and for this we must turn to remote sensing methods. In the well logging industry both electric and acoustic properties are routinely collected and analysed to study lithology, reservoir properties and the properties of fluids within them: it would be almost unthinkable to collect one data type without collecting the other, since this would result in an incomplete dataset that left gaps in our understanding of the reservoir and surrounding strata.

Until recently the same logic has not been applied in geophysical surveying and data analysis. Seismic methods, sensitive to elastic properties only, have been the primary tools used in exploration, reservoir appraisal and monitoring. These methods are extremely powerful. Seismic data are commonly used to provide images of the sub-surface, and develop high resolution geological models of structure and stratigraphy. Amplitude variation with offset (AVO) and inversion for acoustic and elastic impedance may also be used to constrain properties such as elastic moduli and density. However seismic data alone in many situations cannot give a complete picture of the reservoir.

The controlled source electromagnetic (CSEM) method provides a method of determining the distribution of electrical resistivity from the seafloor. In recent years CSEM has been applied globally, used primarily as a technology to de-risk the exploration process. A high powered horizontal electric dipole source is used to transmit a low frequency electromagnetic field through the earth to an array of seafloor receivers. Analysis of the resulting data allows remote mapping of the electrical resistivity structure beneath the seafloor.

All three approaches to determining the structure and properties of the earth have strengths and weaknesses. For example, 3D seismic data can be used to obtain high resolution structural images of the sub-surface in many situations, but not all. As an illustration, the presence of high velocity layers such as a basalt or salt can mask deeper, potentially prospective, sedimentary structure. Although electromagnetic methods lack the fine scale structural resolution of seismic approaches, they have been used successfully in such situations to constrain the base of the high velocity region and improve the interpretation of seismic data (MacGregor & Sinha, 2000; Key et al., 2006).

Similar problems may be encountered when the object of the survey is to map the properties (rather than structure) of the seafloor. AVO anomalies, for example, may be caused by fluid or lithological changes, which are difficult to distinguish on the basis of acoustic data alone. A high resistivity zone imaged by analysis of CSEM data may indicate the presence of a hydrocarbon accumulation. However other materials, for example tight carbonates or volcanics, will also result in high resistivity zones, which cannot be distinguished on the basis of electric properties alone. Just as in well logging, an integrated approach to data analysis, utilising the full range of earth properties available, is required.

Case study

We illustrate this using a modelling study from the Luva gas discovery, which lies on the Nyk High in the Voring Basin of the Norwegian Sea. The water depth in the area is 1274m. Well 6707/10-1 encountered gas in an interval approximately 150m thick at a depth of 1680 m below the seafloor. In 2006, OHM Ltd collected a CSEM dataset over the Luva field. Analysis of this showed a clear high resistivity zone coincident with the known position of the gas sand, which also has a clear expression in seismic data. In this study we use electric and elastic models constructed from the well log data to examine the sensitivity of both data types to hydrocarbon properties.

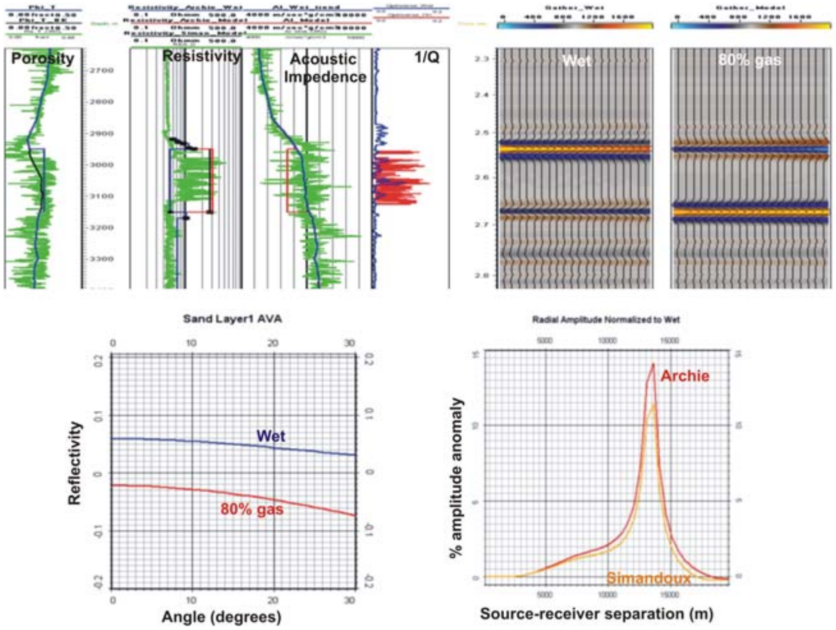

Figure 1: Effect of 80% gas saturation on the seismic and CSEM response. The porosity is 26%. Top left: well logs from the Luva gas discovery. These were used to construct electric and elastic models of the reservoir. Top right: Synthetic seismic gathers show a strong difference between the wet and gas saturated cases (orange colours indicate a positive amplitude, blue colours a negative. Bottom left: Reflectivity versus angle of incidence for the wet case (blue line) and gas saturated case (red line). Bottom right: the normalised CSEM anomaly, showing the difference in response between the wet and gas saturated cases. The transmission frequency is 1Hz. Note that the inclusion of shale in the model alters the measured response.

As a starting point we calculate the seismic and electromagnetic response to a baseline water saturated case, using Biot-Gassman to compute the seismic velocity changes, and calculating the electrical resistivity changes for clean sand and shaley cases using Archie and Simandoux models respectively (Mavko et al, 2003).

Figure 1 shows the CSEM anomaly (calculated as the difference between the amplitude response between the gas saturated and wet reservoirs) and seismic response for the case of an 80% gas saturation, which is consistent with the average in-situ gas saturation in the reservoir. The presence of the gas results in a significant negative amplitude anomaly (in contrast to a positive anomaly in the wet case) in synthetic gathers. In the CSEM anomaly we see a large increase in the strength of the measured signal resulting from the reservoir.

In figure 2 we decrease the gas saturation from 80% to 20%. Although this is a large change in gas saturation, the seismic response changes little. Indeed given a survey dataset it would be hard to distinguish the commercial 80% gas saturation from a lower saturation accumulation which is commercially not viable. However the CSEM response changes dramatically: the bulk resistivity decreases smoothly with gas saturation. The CSEM data are sensitive to the change in this property, and for the low gas saturation accumulation the effect on the CSEM response is small. Thus in this example by including the CSEM data in the analysis, a commercial gas reservoir could be distinguished from a non-commercial accumulation, which would not have been possible on the basis of seismic data alone.

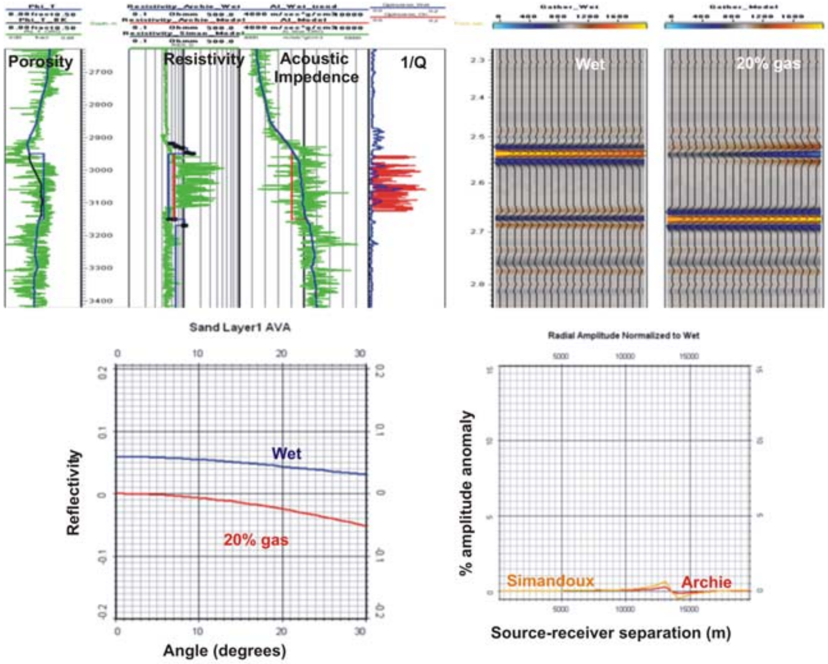

Figure 2: Effect of 20% gas saturation on the seismic and CSEM response. The porosity is 26%. See figure 1 caption for other details. Although the gas saturation is dramatically lower, the seismic response is similar: this non-commercial saturation could not be distinguished from the commercial case in figure 1 on the basis of seismic data. However, the CSEM anomaly, sensitive to the bulk resistivity in the reservoir, is significantly decreased.

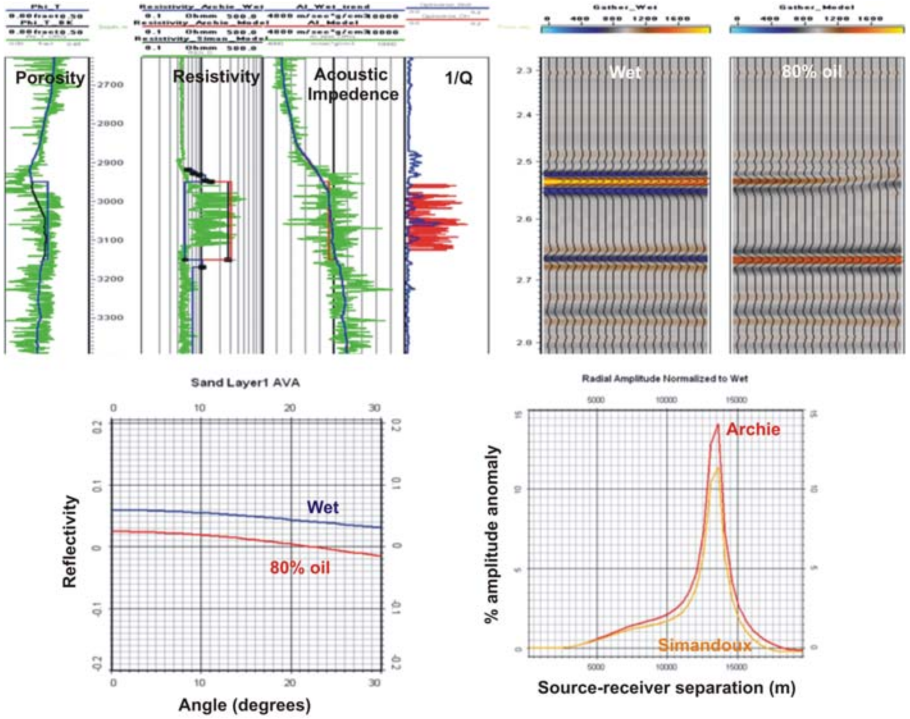

Figure 3: Effect of 80% gas saturation on the seismic and CSEM response. The porosity is 26%. See figure 1 caption for other details. The CSEM response is similar to that from a gas saturated reservoir. In this example the seismic response can be used to distinguish the hydrocarbon type in the reservoir.

The final example is shown in figure 3. In this case we look the effect of hydrocarbon type on the seismic and CSEM response, by replacing the gas in the reservoir with oil. In this case the CSEM anomaly is large, as in the gas saturated case. Both gas an oil produce an increase in the bulk resistivity of the reservoir. The CSEM data can map this high resistivity but are not sensitive to the difference between gas and oil. However because gas and oil have significantly different acoustic properties, the seismic response is significantly different. In this example by combining the results of seismic and CSEM surveys we can differentiate between different hydrocarbon types.

Conclusions

This simple example highlights the importance of intelligently integrating disparate geophysical data types in the interpretation process. In the first example, if only seismic data were available, then although the presence of a gas accumulation could be established, since the saturation cannot be constrained, no assessment of commercial viability could be made prior to (potentially costly) drilling. CSEM provides the information which when integrated with the seismic data can resolve this ambiguity.

In the second example we show that although the CSEM technique can determine the presence of a high resistivity zone, which may indicate the presence of hydrocarbons, it cannot distinguish between gas and oil. Here the seismic data, integrated into the interpretation, can provide this information.

Of course the earth is complex, and many fluid and lithological changes can affect both seismic and electrical properties, and hence the geophysical techniques that are sensitive to them. Gathering and using a wide range of geophysical data, sensitive in different ways to the physical properties of the earth, is therefore essential.

Acknowledgements

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