Dealing with the complexity of the interpretation of marine Controlled Source Electro-Magnetic surveys

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Subsurface resistivity mapping based on Controlled Source Electromagnetic (CSEM) measurements are attractive for Shell because they offer the possibility to distinguish between hydrocarbon and brine bearing reservoirs where conventional seismic methods are sometimes inconclusive. Indeed, the resistivity of a reservoir rock is directly related to the amount and type of fluid filling the pores while its acoustic properties are rather insensitive to it. CSEM can therefore be a valuable tool to compliment seismic data for prospect evaluation. In Shell, we have applied the CSEM method on a worldwide scale since 2003 to both de-risking and portfolio polarization in a marine settings.

In this paper, we will share the learning of our past experiences in interpreting CSEM data. Soon we realized that the analysis of CSEM data by comparing on- and off prospect responses (so-called normalized plots) and the techniques inspired by seismic processing methods were insufficient if not misleading in complex geological settings. Indeed, to properly interpret the CSEM data, it is important to keep in mind that:

- Electromagnetic waves diffuse in the earth. This limits the spatial resolution of the technique, in particular at depth;
- The resistivity of a formation is related to the rock type, its porosity and fluid in the pore space. Porosity variations are therefore equally important as saturation varies. So, the CSEM technique is not only sensitive to hydrocarbon bearing resistive bodies but also to low porosity resistive bodies like tight sands, carbonates or volcanics. Therefore, this technique can at most provide a resistivity map of the Earth that needs to be carefully calibrated and interpreted;
- The electrical structure of the Earth can be more complex that we manage to image it with conventional geophysical techniques. Three-dimensional and anisotropic effects must therefore be taken into account in complex geological settings.

We will show that advanced 3D interpretation techniques that incorporate information gathered from other measurements, especially seismic measurements, are often required to value the CSEM measurements. To handle the complexity of the diffusive nature of the electromagnetic waves at respective CSEM frequencies, we have developed our own 3D anisotropic forward modeling and inversion algorithm. Its efficiency not only allowed us to image subsurface resistivity variations in complex geological settings but also to perform geologically based scenario testing and assess the uncertainty in the CSEM results in a timely manner. This extends to survey design. Indeed, successive modeling and inversion of synthetic data can help designing surveys that allows answering univocally the geological question(s) we wish to address and to assess what a-priori information is required. A survey is considered adequate when its outcome is insensitive to expected external and acquisition related noise but also to various subsurface scenarios and uncertainty ranges. Similarly, when a survey is or has been acquired, modeling and inversion of synthetic data simulated with the actual acquisition geometry and noise conditions allow a rapid assessment of the overall survey quality in terms of meeting the geophysical objective. We will demonstrate these aspects with actual or synthetic data in this paper.