Modeling and Inversion of Marine CSEM Data

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The principle of the marine controlled-source electro-magnetic (CSEM) technique used for remote detection of hydrocarbons (HC), is described by Ellingsrud et al., (2002). A horizontal electrical dipole (HED) emits an ultra-low frequency (0.1–5 Hz) electromagnetic (EM) wavefield into the underlying seabed and downwards into the subsurface. EM energy is rapidly attenuated in the conductive seafloor sediments. In high resistive layers such as HC-filled sandstones and at a critical angle of incidence the energy is guided along the layers and attenuated less. The detection of this guided and refracted energy is the basis of marine CSEM in HC exploration.

Before interpretation of the CSEM data is possible, extensive data processing is required. Important processing steps include: (1) window-based Fourier transform from time to frequency, (2) separation of down-going and up-going (scattered) fields, (3) depth migration, and (4) full inversion, estimating subsurface conductivity. Here we will focus on the last two processing steps; depth migration and inversion, and the use of forward wavefield simulations as part of the necessary workflow.

Zhdanov et al., (1996) introduced frequency-wavenumber (fk) and finite-difference depth migration methods for CSEM data, based on familiar ideas from seismic imaging (Claerbout, 1985). There are, however, important differences in migration of CSEM data, compared to seismic data: First, the attenuation of EM-fields in a conducting subsurface is very strong, and ultra-low CSEM data suffer significantly from dispersion. Second, the conductivity contrast at the sea floor is usually significant. Third, the horizontal and vertical conductivity can differ significantly, which leads to strong anisotropy.

The migration methods mentioned above does not handle EM-wavefield amplitudes correctly. In fact their seismic counterparts, were never assumed, nor designed, to do so. Hence, the result of depth migration is only a structural image of conductivity contrasts. To compute estimates of the subsurface conductivity, full inversion must be used. In steepest-decent and conjugate-gradient inversion schemes (Newman et al., 1997), the gradient in the first iteration provides a structural image of the subsurface. In seismic imaging the gradient calculation is referred to as reverse-time migration (Mittet et al., 2005).

A subsurface conductivity anomaly is not a unique hydro-carbon indicator. It may be due to other resistive bodies or layers in the subsurface, such as salt and igneous intrusions (sills) or regional trends (e.g., basin thickening). In the interpretation of marine CSEM data for HC exploration, these anti-models must be considered. In a typical workflow, numerical forward modelling is used to simulate and evaluate all realistic scenarios. The EM results are used, together with other information, e.g., seismic data, to risk exploration prospects before drilling decisions are made. In the presentation we will show examples from marine CSEM field data, and discuss some of Statoils experience using this technology.

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