Experience with the Three-dimensional Imaging of Marine Controlled Source Electromagnetic Data for Hydrocarbon Exploration

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Experience with the three-dimensional inversion of frequency domain, controlled, multi-source, electromagnetic data collected in the deep water marine environment suggests that the derived resistivity images can, under appropriate conditions, play a useful role in commercial hydrocarbon saturation predictions. Significant technical challenges exist in the simulation and inversion of these data.

The Marine Controlled Source Electromagnetic (MCSEM) surveys conducted by ExxonMobil beginning in 2002 provide data for which electromagnetic imaging offers a significant potential due to the relatively high spatial density of the electric field recordings, the low level of anticipated noises and the excellent electrical coupling provided by the marine environment. Unfortunately, significant technical issues are presented by the large subsurface volume probed by low frequency electromagnetic recordings, the large dynamic range of the recorded data, the large number of source positions, and the three-dimensional nature of the anticipated targets. Inversion results at locations offshore of West Africa illustrate the progress made in confronting these technical difficulties and progress toward the goal of establishing a new class of hydrocarbon exploration tools.

Electromagnetic soundings in conductive sediments are heavily constrained by the skin-depth phenomena to a very narrow range of frequencies which must both successfully penetrate to maximum target depth and also resolve significant conductivity variations between the sea bottom and the target zone. The implied frequency range for targets of practical interest varies from approximately 1/16 Hz to 2 Hz and the skin depth from 2 km to no less than 0.2 km. On these scales reservoir targets are unquestionably three dimensional objects for which two dimensional approximations are either inappropriate or unnecessarily restrictive. Sediments and seawater are assumed to exhibit conductivity values ranging from about 6 s/m to values in the range of 0.01 s/m in well saturated hydrocarbon reservoirs. Only three general techniques for simulation and, therefore, inversion of Maxwell's equations (in the frequency domain) are available for three-dimensional models: integral equations (IE), finite difference (FD), and finite element (FE). Weak scattering approximations, particularly of the distorted wave type, may have some domain of application (yet to be shown) due to the limited range of subsurface conductivity values anticipated. However, these methods may face difficulties associated with the large size of the domain of unknown subsurface resistivities sought by the inversion process. The availability of a massively parallel FD approach dictated its selection for this undertaking versus a more sophisticated FE approach restricted in scope to a single processor platform. Inversion results reported in this presentation use both amplitude and phase information derived from the ocean bottom electric field recordings.

Application of inversion technology to MCSEM datasets from offshore of West Africa over both hydrocarbon reservoir and non-reservoir locations shows that hydrocarbon data signatures, particularly for the electric field component parallel to the applied transmitter current, can be effectively imaged into three dimensional resistive bodies which are often broadly consistent with existing seismic structures. Carefully processed MCSEM data has repeated been found to fit likely three dimensional models to a very high percentage of electric field energy, frequently exceeding 95%. Inverted resistivity images displayed against the more conventional dense seismic depth images illustrate the potential for the new MCSEM tool in hydrocarbon exploration.