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3D Inversion-Based Interpretation of Marine CSEM Data

J.J. Zach and M.A. Frenkel, EMGS

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Abstract

The Marine Controlled-Source Electromagnetic (CSEM) method has been evolving into a geophysical imaging tool for increasingly complex geological settings, in which multiple resistive bodies can be resolved. An advanced subsurface imaging workflow for 3D CSEM surveys is presented, which reproduces the subsurface to within a spatial resolution determined frequencies included. The performance of our advanced processing workflow is demonstrated using a case study from the Gulf of Mexico, where a dense 3D grid was acquired over an area where high-quality seismic data, as well as well log control was given.

At the heart of our 3D workflow is an inversion methodology with approximate Hessian-based optimization and a fast finite-difference time-domain forward operator. The optimization matches the synthetic to the measured field within 100-200 iterations and is sufficiently robust in 3D to avoid expensive regularization schemes. The sensitivity of the gradient-based inversion to the starting model is addressed by investing considerable effort in building 1D inversion-based starting model. At the same time, 3D inversion algorithms for survey layouts including azimuthal data demand high quality data conditioning, for which we present a processing sequence from time-domain electromagnetic data acquired by seabed receivers to frequency domain data and weights for inversion.

Detection and delineation of reservoirs in the presence of salt is recognized as a major challenge to CSEM methods. In order to accurately interpret 3D data in such a complex environment, the true resistivity cube is built from a sequence of constrained inversion-based interpretation steps. Using a dataset acquired in 2008 in the Gulf of Mexico, we demonstrate the ability of our 3D-technology to resolve small (2km x 2km), low resistivity pay ($\Delta\rho < 5\Omega m$) targets with in the vicinity (< 1km) of large salt bodies. In this case study, the 3D method converged within 1 week running on 150 parallel nodes.

Introduction

Marine controlled-source electromagnetic (CSEM) methods for hydrocarbon detection, which rely on a horizontal electric bipole emitting a predefined extremely low frequency spectrum, and the recorded electromagnetic fields by ocean bottom receivers, have been used in hydrocarbon exploration on a commercial scale since 2002 [1, 2]. The hydrocarbon detection mechanism is the relative enhancement of the transverse magnetic component of the received electromagnetic signal through a partial waveguide effect by resistors buried in the subsurface. These resistors can be either hydrocarbon deposits or other resistive bodies.

Advances in hardware and operations have resulted in a vast improvement in data quality, permitting the acquisition of well-defined and repeatable grids of seabed receivers with complex towing patterns including the acquisition of wide-azimuth data. Thus, marine CSEM has become a method for 3D imaging of complex geological settings, which is increasingly adopted by the industry, either as a standalone method or in conjunction with other geophysical probes, such as seismic [3] or MT [4]. Recent published case studies include [5-7].