Marine Controlled-Source Electromagnetic Response: Campos Basin Experience

The marine controlled-source electromagnetic (MCSEM) response of known reservoirs yields anomalies that, although considered marginal, can be imaged with new processing and interpretation procedures. There is evidence of correlations between the anomalies and reservoirs. A proposed workflow enhances the ability to interpret weak anomalies accurately and gain benefit from the additional MCSEM data.

Introduction

The Campos basin MCSEM data were acquired on a rectangular grid with a line spacing of approximately 5 km. Three-component electrical-field and two-component magnetic-field data were recorded. All fields at each receiver location were processed and interpreted through a novel workflow. The main objective of the survey was to calibrate the MCSEM technology over known reservoirs and quantify anomalies associated with those reservoirs, with the expectation that a new prospective location(s) could be found. A further objective was to establish an industry-standard workflow.

In recent years, MCSEM technology has drawn the attention of major oil companies with its sensitivity in mapping resistive structures (such as hydrocarbon reservoirs) beneath the ocean bottom. Many surveys have been carried out on a variety of prospect scenarios in marine environments of northwest Europe, Africa, the Mediterranean, Southeast Asia, and offshore Brazil, and many have been verified with wells. MCSEM technology is in the early stage of application to real E&P problems, and a great deal of R&D is needed to improve its efficiency and reliability in acquisition hardware, accurate survey engineering, data processing, multidimensional modeling, and inversion. The success of MCSEM technology will depend on integration with seismic, geologic, and petrophysical data for the area under investigation.

*This article, written by Technology Editor Dennis Denney, contains highlights of paper OTC 18003, "Marine Controlled-Source Electromagnetic: The Campos Basin Experience," by **M.P.P. Buonora,** Petrobras S.A., and **R. Reddig** and **A. Zerilli,** AGO Schlumberger, prepared for the 2006 Offshore Technology Conference, Houston, 1–4 May.*

Offshore Brazil

Petrobras has acquired approximately 1600 km of MCSEM data offshore Brazil, encompassing 36 towed lines as shown on **Fig. 1.** Data were acquired over three major sectors: southern sector covering a small portion of the Santos basin (339 km), central sector on portions of the Campos basin (1121 km), and northern sector on the Espirito Santos basin (153 km of towed lines). The Campos basin survey used two distinct tow patterns: star-like shape (green lines on Fig. 1), and 5-km rectangular grid (red lines on Fig. 1). This study focused on data acquired from the 5-km rectangular-grid tow pattern.

The reservoir is a rectangular thin sheet 3 km wide, 10 km long, and 50 m thick with resistivity of 10 $\Omega\cdot$m buried 1 km below the seafloor. The reservoir is illuminated by an electrical horizontal-dipole source (transmitter). Resisitivities for the 1.5-km water layer and for the surrounding background were set to 0.3 and 0.8 $\Omega\cdot$m, respectively. The model parameters were derived from a nearby well that encountered the reservoir at the same depth.

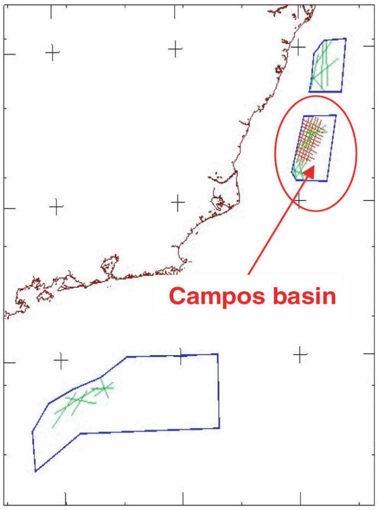

Fig. 1—MCSEM-survey location.

Campos Basin Survey

The receivers were placed at grid crossings. Data from each receiver were processed with an advanced workflow that uses instantaneous dipole length, moment, altitude, feather angle, and dip. Processed electrical-field data from each receiver then were normalized by use of a ratio method. The method is based on compartmentalizing the survey area into selected sectors and then generating the corresponding reference background fields from the well logs selected for each sector. The very detailed layering from the borehole measurements was combined into a much simpler geoelectrical section, representative of that resolved with the MCSEM method and constrained by the seismic-depth model. The objective was to build a model with the minimum number of layers necessary to provide the same MCSEM response as a full-layer model derived from well logs. To determine where the boundaries should be placed for a several-layered model, both the cumulative resistance and cumulative

The full-length paper is available for purchase from the OTC Library: www.otcnet.org. The paper has not been peer reviewed.

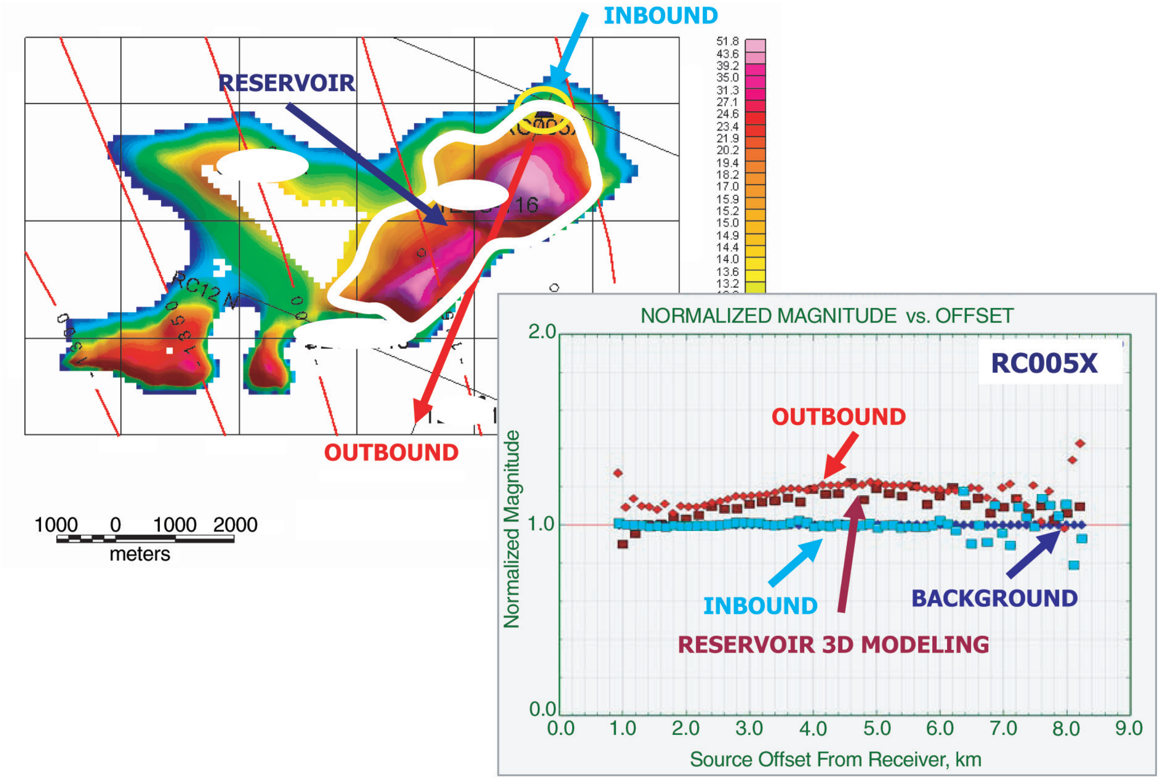

Fig. 2—3D normalized radial-electrical-field response of a known oil reservoir (left). Outbound processed data (red diamond) vs. computed response (brown square) normalized to background (right).

conductance were calculated from the well logs. This method enabled establishing locations of the layer breaks and determining the resistivities and the anisotropies of the layers.

Data at each receiver location were normalized to the background model to produce a ratio map. The ratio map showed two distinct areas of anomalies: the southwestern sector showing values less than 1.45 and the northern sector showing values greater than 1.45. The southwestern sector shows an anomaly on the order of 20% above the background. This anomaly was correlated with a known Eocene reservoir.

Advanced 3D depth imaging was based on blocked well-log resistivities and model geometry derived from seismic and reservoir-structure data. The reservoir was imaged as a body idealized in a finite-difference mesh **(Fig. 2)** for multitransmitted frequencies. Fig. 2 shows a good match between the processed and normalized outbound real data (red diamonds) and the response of the idealized reservoir (brown squares) computed at 0.25 Hz. The background was constructed from the layer breaks derived from the cumulative resistance calculated from a nearby well log and the seismic-depth model.

Anomalies on the order of 20 to 30% have been considered marginal and risky in current MCSEM-data-interpretation practice. However, application of a workflow that uses true-geometry processing and advanced depth imaging may increase the ability to map prospective hydrocarbon reservoirs that produce weak but detectable anomalies because of their size and resistivity contrast. The workflow detailed in the full-length paper was effective and was used to image several MCSEM anomalies in the southwest sector of the Campos basin.

The forward solution uses an optimal-grid technique based on an anisotropic material-averaging formula to scale up fine structure to a coarser computational grid. The algorithm allows solving the problem for multiple transmitter positions simultaneously and does not confine the sources and receivers to a single plane that is perpendicular to the invariant direction, and thus realistic acquisition geometries can be simulated.

The inversion is based on a Gauss-Newton minimization scheme in which the inverted parameters are forced to lie within user-defined bounds by use of a nonlinear transformation procedure. To provide a stable solution, either an L2-normal or a pseudo-L1-normal constraint was used on the gradient of the model parameters to produce either a smooth or sharp image, respectively.

Starting models were created on a set of surfaces derived directly from the seismic interpretation. Resistivities were constructed from the layer breaks derived from the cumulative resistance calculated from selected well logs.

Conclusions

The MCSEM response of known hydrocarbon reservoirs in the Campos basin yielded anomalies that could be imaged clearly, and there was evidence of correlations between the anomalies and the reservoirs at several locations in the basin. It was shown that applying the new workflow based on true-geometry processing and advanced depth imaging increased the ability to map prospective hydrocarbon reservoirs that have less resistivity contrast and are laterally smaller and thinner. There are many aspects that must be considered to develop MCSEM methods further for successful hydrocarbon exploration. A critical need will be establishing an advanced integrated-interpretation workflow. **JPT**