The Use of CSEM within an Integrated Exploration Project "Best of EAGE"*

Andrea Lovatini[1], Elena Medina[1], Tracy Campbell[2], and Keith Myers[3]

Search and Discovery Article #40866 (2012)
Posted January 17, 2012

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG International Conference and Exhibition, Milan, Italy, October 23-26, 2011

[1]WesternGeco, Milan, Italy (alovatini@slb.com)
[2]WesternGeco, Baku, Azerbaijan
[3]WesternGeco, Perth, WA, Australia

Abstract

We discuss the integration of multiple geophysical methods in a single project basin study in the offshore Potiguar basin, located in northeastern Brazil, where there is production from the nearshore area, but no production and limited exploration from the deepwater portion.

The existing 2D seismic dataset, initially available only as prestack time migrated data, underwent prestack depth migration using new tools for noise attenuation and multiple removal. The results showed significant spectral content improvement at shallow depths and fault and reflector definition and continuity in the deeper section. The dataset was interpreted to provide regional scale horizons and used as input with other geological and geochemical data for a petroleum system model of the whole basin. Satellite images were processed to provide a map of sea-surface oil slicks.

The CSEM method was applied at a different stage than its more common utilization in exploration workflows, which is as a tool to evaluate known prospects. It was applied together with other methods to provide further information on the geology of a poorly explored basin. Oil slicks and seismic interpretation structural and stratigraphic features were used to identify possible areas for CSEM acquisition. 1D modeling was preliminarily used to identify which features were detectable. Approximately twelve targets were prioritized using the 1D modeling results, their seismic characteristics, their level of complexity for CSEM interpretation and

also their areal distribution within the entire basin. 2.5D and 3D modeling was used to investigate more complex targets. To cover as broad a range of depths as possible, a spectrum with high energy at multiple frequencies was designed.

To include as many targets as possible in the basin in a cost-efficient way, without losing 3D illumination, a hybrid approach between 2D and 3D layouts was followed in survey design. Within the basin five separate datasets were acquired. The interpretation workflow included: qualitative interpretation, 1D anisotropic inversions, up-scaling to 2D and 3D resistivity volumes, background model forward modeling assessment. 2.5D and then 3D anisotropic inversions. All the 3D inversions used multiple frequencies to improve both sensitivity and resolution.

The resistivity volumes were then integrated with the seismic data, the interpreted horizons, the oil-slicks and the petroleum system modeling predicted accumulations in a single 3D earth model.

Introduction

The controlled-source electromagnetic (CSEM) method has not yet reached the status of other geophysical methods that are routinely included in exploration workflows. At its commercial launch, in fact, it was presented as an almost binary method that could be used by itself for decision making. As expertise and knowledge grew in the exploration community, and more complete interpretation techniques were developed, the method gained a more relevant role, providing complementary information about rock properties.

The word integration has been largely used when referring to the interpretation of electromagnetic (EM) data, probably because certain limitations such as lack of structural resolution can be reduced, thereby exploiting other geophysical methods with complementary strengths.

The Potiguar Integrated Exploration Project

In 2009, WesternGeco decided to integrate multiple geophysical methods available in its portfolio in a single project: a basin study that was not simply the sum of the different data types, but the result of simultaneous or iterative use of each method with respect to the others.

The offshore Potiguar basin selected for this project is located in northeaster Brazil (Figure 1). Its onshore counterpart is the second most productive basin in Brazil. Offshore there is production from the nearshore area, but little exploration and no production from the deepwater portion.

The existing 2D seismic dataset, available at the beginning of the project only as prestack time migrated data, underwent prestack depth migration utilizing new tools for noise attenuation and multiple removal. The results showed a significant spectral content improvement at shallow depths and fault and reflector definition and continuity in the deeper section.

The dataset was interpreted to provide regional scale horizons and used as input with other geological and geochemical information for a petroleum system model of the whole basin. An additional project task was satellite image processing to provide a map of sea-surface oil slicks.

The CSEM Workflow

In this project, the CSEM method was applied at a different stage than its more common utilization in exploration workflows, which is as a tool to evaluate prospects, where target position and depth are known or at least likely. It was, instead, applied together with other methods to provide further information on the geology of a poorly explored basin.

Sea-surface oil slicks and seismic structural and stratigraphic features, highlighted by the interpretation, were used to identify possible areas for CSEM acquisition. 1D modeling was used to identify which features were detectable in terms of depth, modeling laterally-infinite targets. Approximately twelve targets were prioritized using the 1D modeling results, their seismic characteristics, their level of complexity for CSEM interpretation and also their areal distribution within the entire basin. 2.5- and 3-D modeling was used to investigate more complex targets.

Synthetic modeling showed how several frequencies were sensitive to different target depths. To cover as broad a range of depths as possible, a spectrum with high energy at multiple frequencies was designed, using least square approach to meet the desired spectrum, fulfilling at the same time the source hardware requirements.

To cover as many targets as possible in the basin in a cost-efficient way, without losing 3D illumination that is beneficial for target extent delineation and anisotropy information, a hybrid approach between 2D and 3D layouts was followed during survey design.

Purely broadside receivers were adopted together with standard inline receivers, thus providing increased sensitivity (Bhuyian et al., 2009) at minimal extra cost (Figure 2 and Figure 3).

Within the basin five separate datasets were acquired in June 2009; each dataset was followed by an interpretation workflow that included:

- Qualitative interpretation (i.e., normalization of observed data with respect to synthetic background model responses) to assess the data quality and indicate the main data trends;
- 1D anisotropic inversions, constraining the thicknesses with the seismic horizons to derive both horizontal and vertical background resistivities;
- Up-scaling to 2D and 3D resistivity volumes (Figure 4 and Figure 5);
- Forward modeling to assess the background model validity with respect to the observed data;
- 2.5D anisotropic inversions;
- 3D anisotropic inversions including both inline and broadside data;
- Integration of seismic and other data using seismic-to-simulation software.

All the 3D inversions utilized multiple frequencies in the inversion process (0.25, 0.5, 0.75 and 1.5 Hz) because to improve the sensitivity of the inversion itself (Figure 6), thereby increasing the resolution with both low and high frequencies. Higher frequencies, mostly sensitive to the shallower part of the model, drove the resulting resistivity in the overburden and provided better definition of shallow features. Synthetic studies as well as observed data analyses with known target depths showed that the inversion of data including multiple frequencies with respect to a single frequency gave much better depth resolution, even without other constraints.

Conclusions

Integration of the resistivity volumes obtained through 3D anisotropic inversions of the five CSEM datasets provided a different approach to better understand the earth model in analysis (Figure 7). Further or new interpretation of the seismic data could then be performed using this additional value to characterize seismic features not previously defined. The same information could be used in an exploration workflow with other tools, e.g., petroleum system models and seismic attribute analysis, simultaneously or iteratively to better understand a sedimentary basin.

Reference

Bhuyian, A. H., B.P. Thrane, M. Landrø, and S.E. Johansen, 2009, Controlled source electromagnetic three-dimensional grid-modelling based on a complex resistivity structure of the seafloor: effects of acquisition parameters and geometry of multi-layered resistors: Geophysical Prospecting, v. 58/3, p. 505-533.

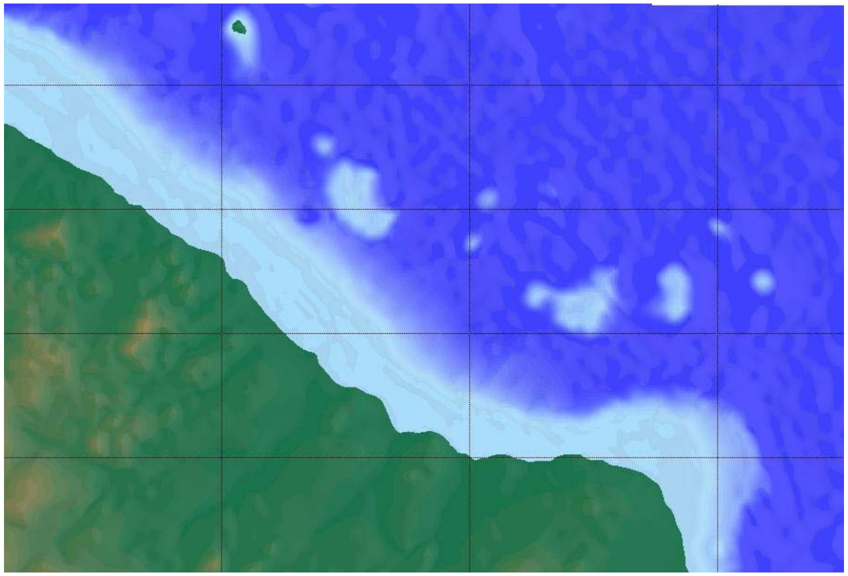

Figure 1. The Potiguar Basin, northeastern Brazil.

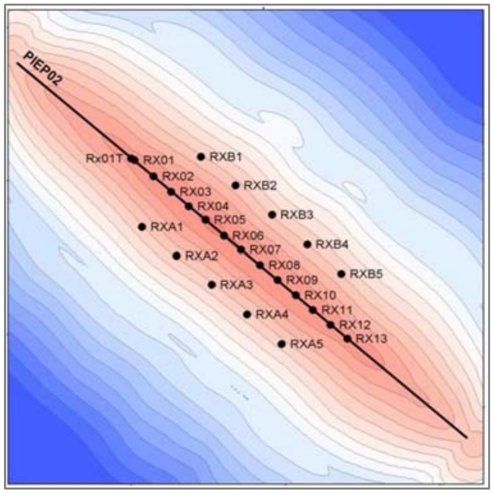

Figure 2. Inline data only 3D inversion cumulative sensitivity between mid-Eocene level and 300 m below. The reddish part corresponds to higher sensitivity.

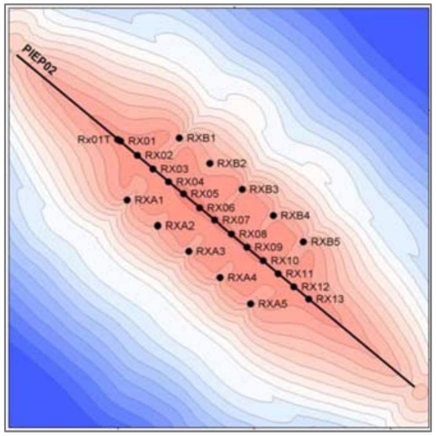

Figure 3. Inline and broadside data 3D inversion cumulative sensitivity between mid-Eocene level and 300 m below. Same colour scale as figure on the left.

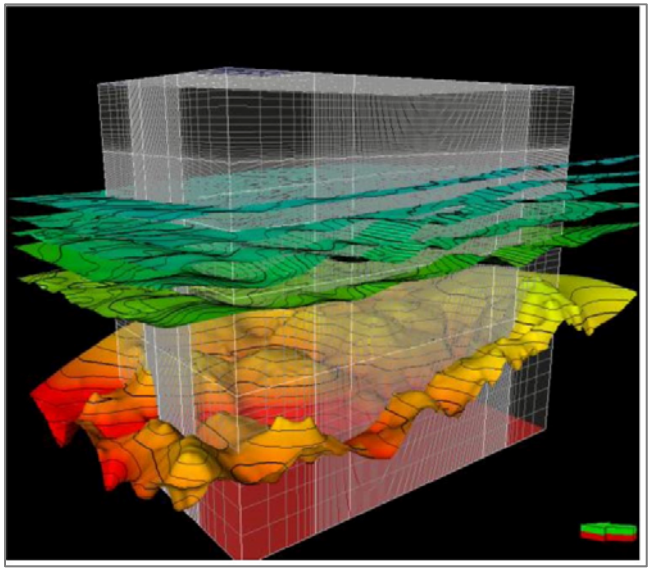

Figure 4. Example of 3D inversion mesh generation using the horizon surfaces to define the vertical gridding.

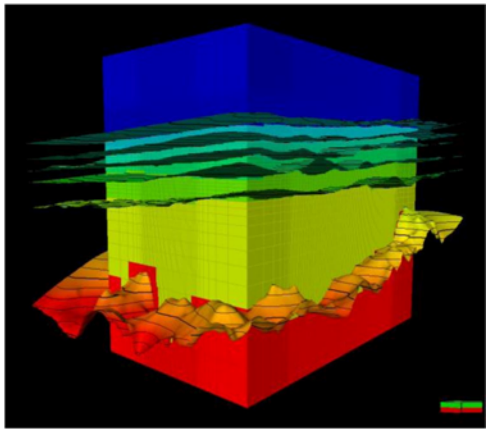

Figure 5. Example of 3D inversion mesh populated with resistivity values uniformly between the horizons.

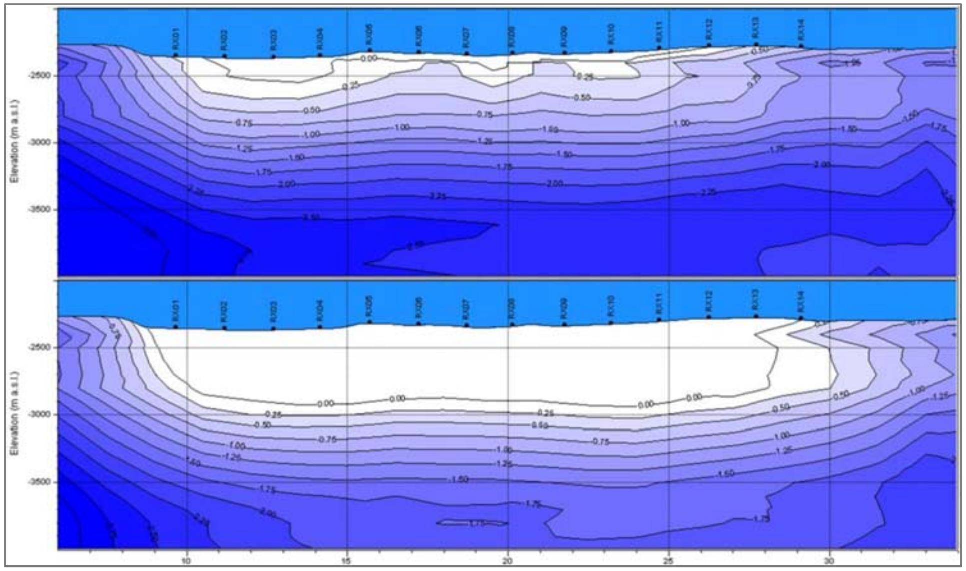

Figure 6. 3D inversion sensitivity (A^TA) sections (lighter colours indicate higher sensitivity): inverting only 0.25Hz (above) and (below) inverting four different frequencies (0.25, 0.5, 0.75 and 1.5 Hz).

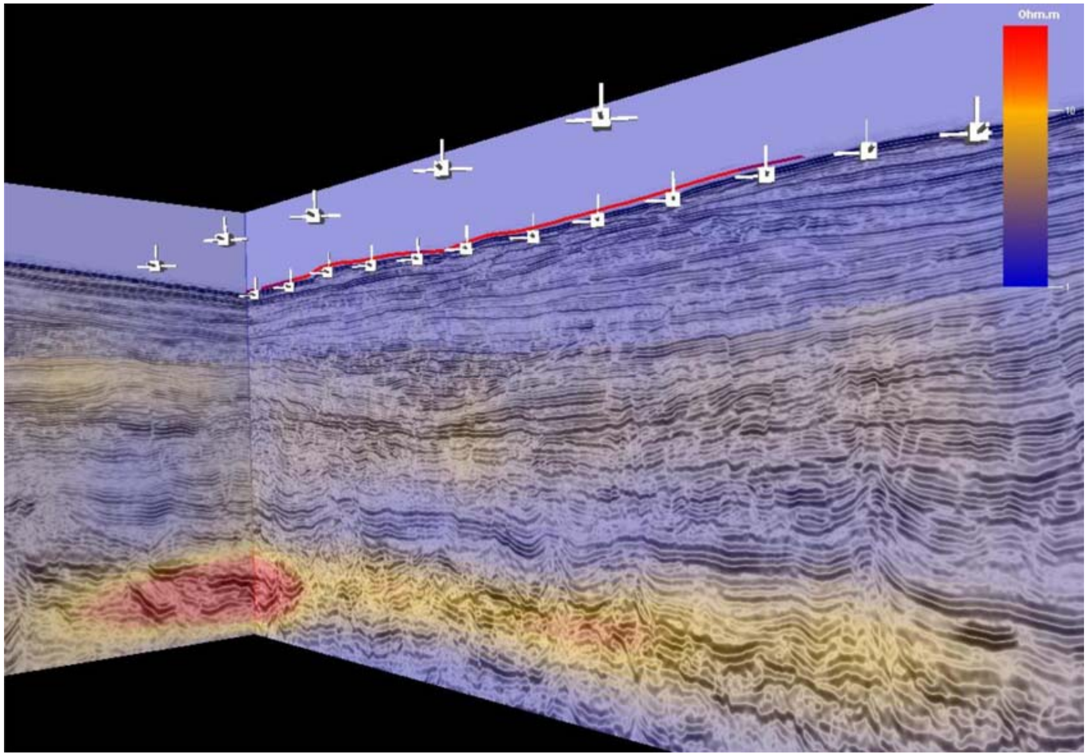

Figure 7. Vertical resistivity output volume co-rendered with seismic sections (white symbols indicate receivers and the red line the source path)