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Seismic-EM Integration Tackles Deep Water E&P Challenges

A. Zerilli* (Schlumberger), M.P. Buonora (Petrobras GEO/MNS), P.D.L. Menezes (Petrobras GEO/MNS), J.L. Crepaldi (Petrobras GEO/MNS) & T. Labruzzo (Schlumberger BRGC)

SUMMARY

Deep water is a complex high-risk environment with no shortcuts to success. Joint interpretation of seismic and deep reading electromagnetics (EM) can provide a powerful tool for the risk mitigation process. This work focuses on the advances and challenges in seismic-EM integration and gives case examples of imaging improvements that are consistently proving to lower exploration risk while maximizing knowledge of the prospects in the deep Brazilian offshore where challenges, logistics, and costs can be formidable.

Introduction

Today, workflows are being developed to integrate technologies that reduce the exploration risk in demanding deep water environments. The approach is to develop geologically sound earth models consistent with all of the available data types, then integrate the measurements until exploration risk is reduced to acceptable levels. While the latest developments in high-tech seismic vessels, ‘mega’ channel counts and in the post-processing and interpretation tools (TTI Reverse Time Migration (RTM), Full Waveform Inversion (FWI)) tell a large part of the exploration story even in complex geology, many information gaps may be filled in with deep reading Electromagnetic (EM) methods.

Seismic may predict the presence of hydrocarbons in a formation, but one of the biggest pre-drill knowledge gaps is formation resistivity. Formation resistivity is one of the most reliable indicators of hydrocarbon saturation levels within a formation structure. Previously this information has only been available through well logs, but now deep reading EM (specifically Controlled Source EM (CSEM)) is providing subsurface resistivity information before drilling.

Using models developed from seismic, CSEM data are used to help prioritize prospects. The combination of seismic and CSEM clearly delineates the resistive structures within the prospects enabling to prioritize regions of interest and assist in the task of ranking potential drilling leads.

Multimeasurements Constrained Imaging - clearer delineation of prospects

Several approaches can be adopted to exploit the electrical properties for: a) deep water prospect identification; b) building velocity models that bridge the gap between the low frequencies and long offsets acquired in the data c) evaluation of prospect’s petrophysical properties in terms of porosity and water saturation.

In a cooperative joint inversion (CJI) approach, seismic and EM model building is carried out in parallel and the results mutually utilized in an iterative fashion to constrain both datasets. Another approach is the so called simultaneous joint inversion (SJI). Here with respect to the cooperative approach, two datasets, seismic and EM, are inverted jointly: The inversion process will minimize the misfit between observed and model predicted synthetic data for both sets as well minimizing the differences between different properties of a single multi-property earth model, according to geometrical or petrophysical relationships between the geophysical properties [Zerilli (2002), Colombo, De Stefano (2007), De Stefano et al., (2011)].

In simultaneous joint inversion, each inverted data is used to stabilize the others. In fact all the methods illuminate the same subsurface formations but they are characterized differently in terms of penetration and resolution, and more importantly in terms of noise. Therefore a particular portion of the subsurface that may be scarcely recovered by one method may be on the other hand recovered reliably by another. Combining the complementary information from the various methods allows recovering of an underlying earth model with reduced uncertainty.

Seismic-EM CJI, SJI at work – The Brazilian offshore

Seismic-EM integration through CJI and SJI has been applied extensively by Petrobras over several distinct geological settings of the deep Brazilian offshore. In this work we present the potential of this integration over selected case histories and demonstrate the value of the integrated interpretation based on the joint inversion of seismic and CSEM data (*Figure 1*).

We show that these new integrated workflows lead to locate the most promising deep water prospects then minimizing the technical and economic risks. Specific challenges and limitations such as: ambiguities in reconstructing prospects depth, resolving stacked objectives, imaging uncertainties for

prospects in the proximity of salt or in rough bathymetry are addressed. Models with remarkable structural resemblance and improved estimates of electrical resistivity and seismic properties are reconstructed, significantly reducing the artifacts observed in the resistivity and seismic models obtained from the standalone interpretation. The most promising deep water prospects are accurately delineated showing more geometrical similarity between the resistivity images and the seismic images as well as reproducing the true features electrical resistivities and seismic properties.

Figure 1 (Left) 3D Cooperative ‘Hybrid’ Inversion of seismic - CSEM data from the Espirito Santo Basin. Vertical resistivity depth section co-rendered with seismic. Seismic interpretation used to structurally constrain the inversion. Resistivity features are correctly located in depth and indicate the presence of hydrocarbon within the structures helping improve drilling decisions; **(Right)** 3D cooperative inversion of seismic - CSEM data from the Potiguar Basin. Resistivity features are correctly located in depth and indicate the presence of hydrocarbon within the structures helping improve drilling decisions.

Conclusions

We have shown case examples for the application of seismic-CSEM integration to locate the most promising prospects in the deep Brazilian offshore, to reduce uncertainties and minimizing timescale and costs. We have underlined the ability of ‘state-of-the-art’ cooperative and simultaneous joint inversion to leverage seismic and accommodate complex geologies, ensuring robust and reliable models and improved property modeling.

State-of-the-art’ joint inversion of seismic and EM data is defining new strategies for deep water prospect identification and evaluation, thereby enhancing the role of non-seismic methods. Applications relevant for the later stages of petroleum operations are being addressed by a joint Petrobras-Schlumberger R&D project in quantitative reservoir characterization studies on real data and in feasibility studies for reservoir monitoring.

References

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