

Anisotropic CSEM Inversion Near AC818 Well #1 in Alaminos Canyon Block 818, Gulf of Mexico

Cam Kanhalangsy* (ckanhalangsy@emgs.com), Nikolay Golubev (ngolubev@emgs.com), Jurgen Johann Zach (jjz@emgs.com), EMGS Americas, Houston, Texas, USA

SUMMARY

We present data examples from a large CSEM survey conducted in 2008 in Alaminos Canyon, covering part of the Perdido fold belt. The focus is on a part of the survey which is co-located with a recent partially published well, AC818-#1 (“Tiger”). We present anisotropic EM inversion results for different background models. The resulting resistivity sections recover the most prominent features from the well: shallow hydrates at the top of the Oligocene Frio sand as well as resistivity discovered in the Eocene Wilcox formation at the crest of the anticline. Both in terms of depth and structure, the CSEM, seismic and log results agree well, even if the CSEM inversion is not explicitly constrained by a priori horizons. Further, we recover resistors at the flanks of the anticline in an area known for stratigraphic “pinch-out” traps.

INTRODUCTION

The Perdido Fold Belt is a large and prominent structure with northeast-southwest trending anticlines in the ultra-deep water (7,500-10,000 ft) of the Northwestern Gulf of Mexico, with concentric folds cored by autochthonous salt typically bounded by steep reverse faults. The fold belt overlies northeast-southwest basement highs in five parallel folds in Alaminos Canyon (AC), see figure 1 (Trudgill et al, 1999 and Fiduk et al., 1999). Petroleum prospectivity focuses on the crest of the anticline as well as potential stratigraphic pinch-outs on the flanks. The most recent partially published well is AC, block 818 (“Tiger”; Latham et al., 2008; Boswell et al., 2009), drilled by Chevron in 2004. The focus of the latter is on the gas hydrate stability zone at less than 500 m burial depth as well as the crest of the Wilcox formation at about 800 m burial depth, both of which showed enhanced resistive anomalies on the log. The hydrates penetrated by the “Tiger”-well are presumed to originate from deeper Eocene sands, and are located in the shallow regions of the Oligocene Frio sand uplifted during the late Oligocene compressional folding.

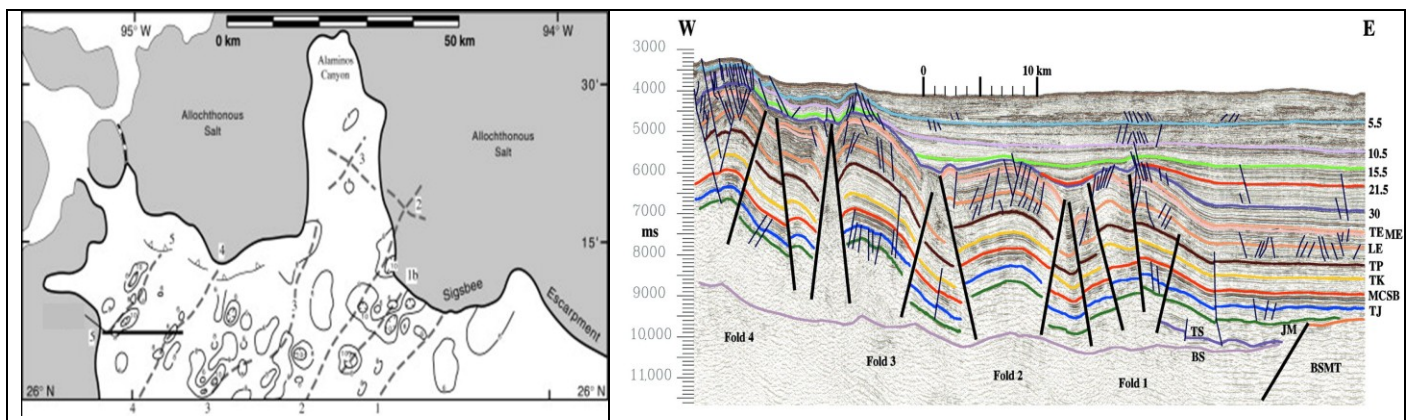


Figure 1, left: isopach map of Upper Jurassic-Cretaceous strata in the around the Perdido fold belt (contour interval 2000 ft). The folds are numbered 1-5, anticlinal axes are shown by dashed lines. Right: interpreted W-E oriented regional seismic profile with some key horizons (e.g., T/M/LE: top/mid/lower Eocene, corresponding to ~3 km burial depth at the Eastern edge; TP: top Paleocene). Sources: Trudgill et al, 1999 and Fiduk et al., 1999).

In 2008, a marine CSEM survey was acquired, covering about 1000 km² of the ultra-deep water (2.4 km - 3.2 km) of Alaminos Canyon, with a dense in-line grid spacing of 0.5 km or 1 km and inter-line spacing of 4 km. In this paper, we co-interpret CSEM inversion results with other geophysical and well data in the immediate vicinity of the “Tiger”-well, see figure 2a. The source waveform was a periodic composite pulse with a base frequency of 0.5 Hz (see figure 2b). All data were inverted using anisotropic 2.5D EM inversion and co-interpreted with existing data, and the present analysis will also be mostly conducted with 2.5D data. Since the acquisition of azimuthal data was not the focus of the survey and due to the large inter-line spacing, 3D inversion was only conducted when a well-defined geological background model based on seismic and well data was available.

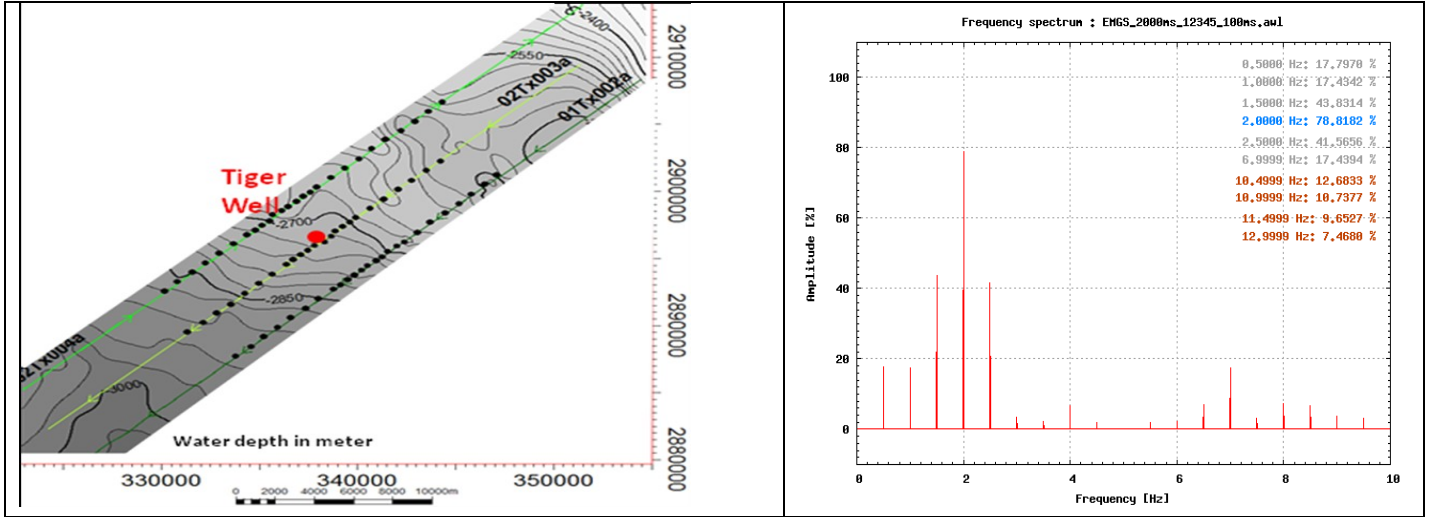


Figure 2: (a, left): survey design of the part of the Alaminos Canyon CSEM survey conducted in the vicinity of the “Tiger”-well with 1.0/0.5 km inline and 4.0 km inter-line spacing. (b, right): source frequency spectrum with $f_0=0.5$ Hz.

METHODOLOGY

In order to tackle the non-uniqueness of geophysical EM inversion, our advanced processing methodology for marine CSEM data is based on inversion schemes with increasing complexity, starting from plane-layer inversion of individual receivers to build background resistivity models for 2.5D and then 3D EM inversion, incorporating seismic & well data as available (see, e.g., Zach, 2010). The 2.5D inversion is based on full 3D modeling using the finite-difference time-domain solver described in Maaø, 2007, but with the assumption of transverse spatial symmetry. The forward modeling code runs on a regular grid, which is remapped onto an arbitrary optimization grid. The update algorithm (described by Hansen and Mitter, 2009) centers on a Gauss-Newton algorithm with line search to minimize a cost function ϵ based on the L2 norm for data, summed over all receivers R_x , frequencies f and field components F :

$$\epsilon = \sum_{R_x, f, F} | \text{Weight}(R_x, f, F) \cdot (F_{R_x, f, F}^{\text{obs}} - F_{R_x, f, F}^{\text{syn}}) | + \lambda \epsilon_{\text{reg}}, \quad (1)$$

where the regularization strength parameter weakens the regularization term ϵ_{reg} during each iteration by typically $\lambda=0.95$ or greater. According to the geological problem investigated, the regularization term can be formulated with a great variety of constraints on the conductivity model σ , penalizing deviation from a priori models, spatial gradients, norms and other variations. In the present case study, we use the L1-norm of the deviation of the model gradient from an a priori model.

$$\epsilon_{\text{reg}} = \beta(x, z) \sum_{R_x, f, F} \left(\nabla_x (\sigma^{0.5}(x, z)) \right)^2 + \left(\nabla_z (\sigma^{0.5}(x, z)) \right)^2, \quad (2)$$

which contains no regularization favoring blocky models. In practice, the a priori models used are mostly flat with discontinuities across discrete seismic or other horizons favoring resistivity horizons.

CASE STUDY

The nearest CSEM line to the “Tiger” well is 02Tx003a with 24 receivers, at about 500 m distance (fig. 2a) with the water depth increasing from about 2550 m in the Northeastern part of the line to about 3,000 m to the Southwest with moderately complex bathymetry. Concentrating on the shallow targets published in the well log by Boswell et al., 2009, relatively short-offset input data were used for the frequencies included with maximum offsets of {6 km, 5.5 km, 5 km, 4 km} for {0.5 Hz, 1.5 Hz, 2.0 Hz, 2.5 Hz}. Results of the 2.5D inversion of the inline electric field for 02Tx003a for two different start models are shown in figure 3b (halfspace start model with $\rho_v=2.25 \Omega\text{m}$ and $\rho_h=1.5 \Omega\text{m}$) and 3c (start model based on geologic horizons obtained through internal analysis; horizons were at the same time tear-surfaces for the conductivity gradient). Comparing figures 3b and 3c shows the inversion being remarkably stable with respect to the start model, indicating a remarkable stability of the inversion result, especially in light of the complete absence of constraints in the halfspace start model case. Comparing the vertical and horizontal resistivities, which are not explicitly constrained relative to each other, further indicate that the shallow hydrates and Wilcox target are thin resistors, which do not give horizontal responses.

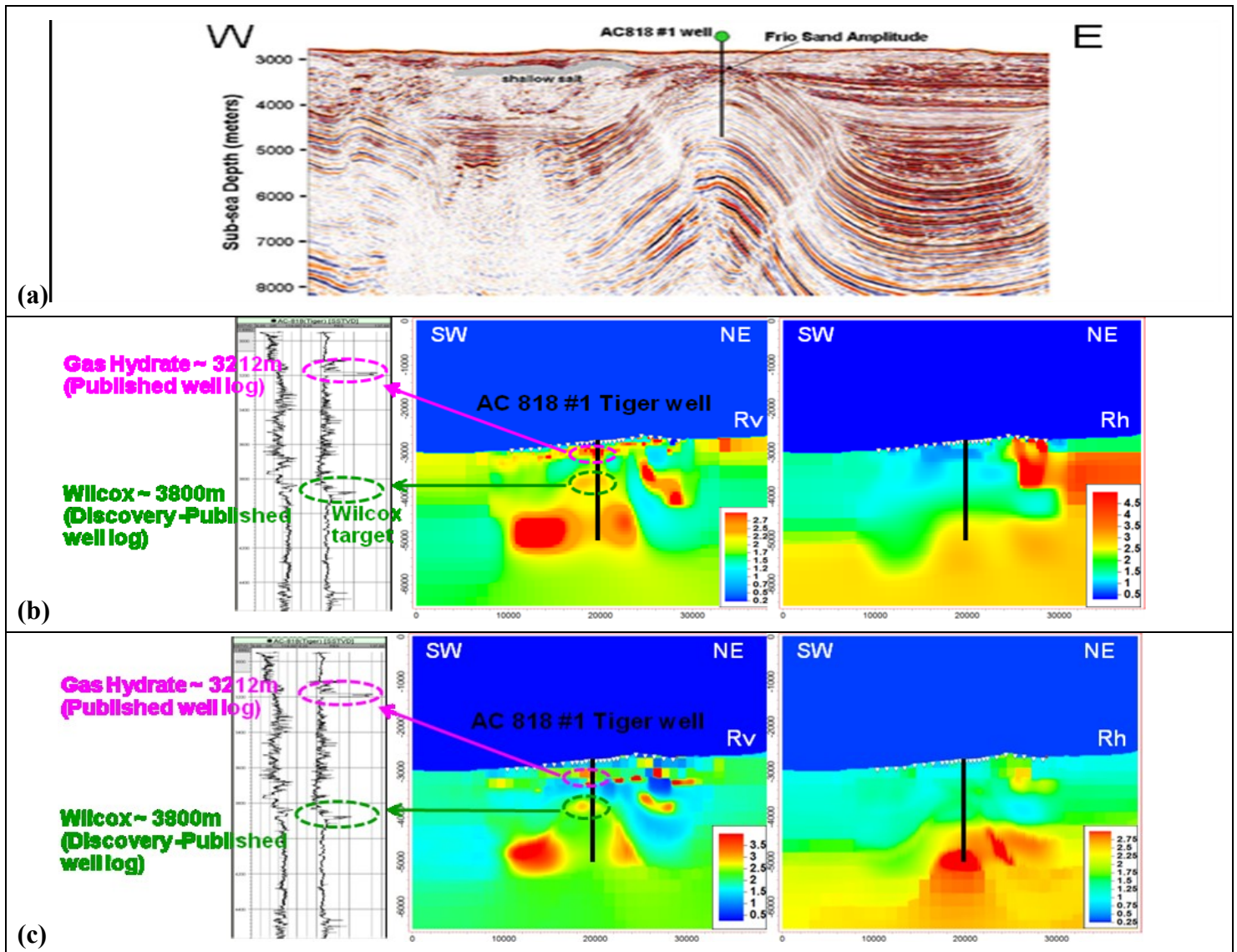


Figure 3, (a): Seismic section across the AC 818 #1 well showing the anticline fold. (Source: Boswell et al., 2009). (b): Vertical (left) and horizontal (right) resistivity profiles for a half-space starting model. (c): Vertical (left) and horizontal (right) resistivity profiles from a start model based on geological horizons.

The CSEM results exhibit high levels of depth consistencies with seismic and log data of the gas hydrates and the Paleocene Wilcox discovery, see figures 3a,b,c. The benchmark data misfit for the final result of 2.5D EM inversion, 10% or less for most receivers and offsets, is met for both results shown, see figure 4. The quality of the results is representative for all frequencies used.

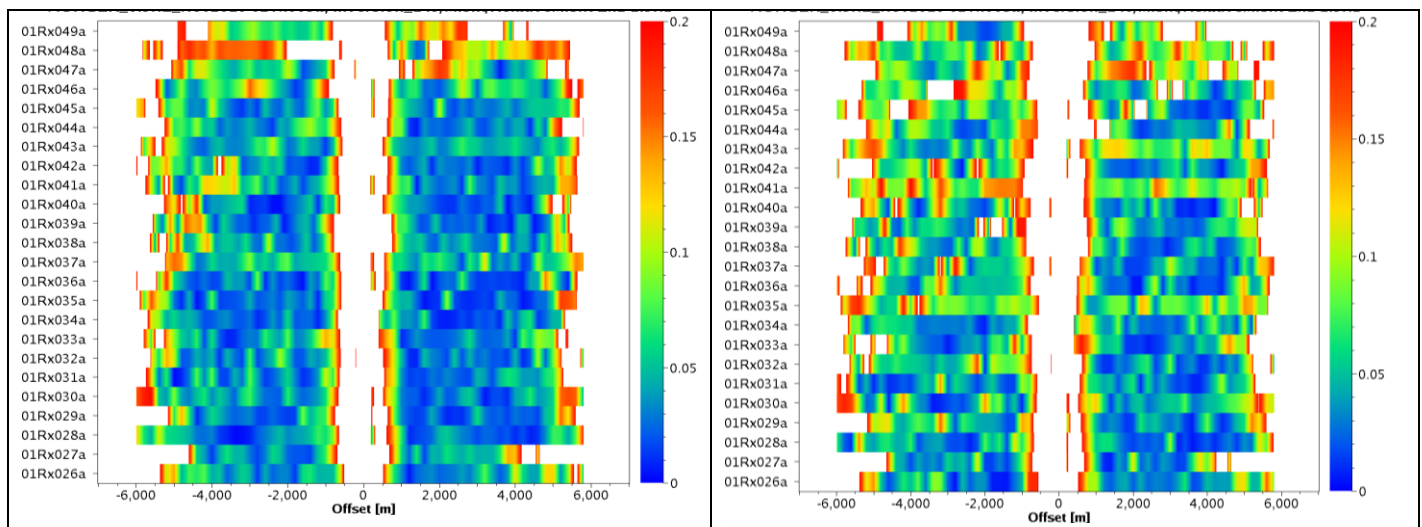


Figure 4: Misfit map: data misfit in the offset domain for line 02Tx003a for all receivers (each horizontal line represents one receiver) and a frequency of 2.0 Hz. Left: halfspace start model. Right: geology-based start model.

CONCLUSION

Anisotropic CSEM inversion was performed near the AC 818 well #1 (“Tiger”). Subsurface CSEM inversion resistivity profiles indicate relatively shallow resistors at approximately 3,200m and 3,800m below MSL, which are highly consistent with the known gas hydrate level (~3212 m below MSL), as well as the Eocene Wilcox discovery (~3800 m below MSL) as comprehensively described from well data. The anticline structure is well represented from CSEM inversion-based resistivity profiles and well correlated with seismic responses. There are also strong indications for resistors at the flanks of the anticline. The inversion results are robust with regard to qualitatively different background models used, and give a data misfit for the final models which is consistent with the sensitivity of the CSEM acquisition and processing for most of the survey data.

ACKNOWLEDGEMENTS

We would like to thank EMGS Multiclient Services in Houston, TX for the opportunity to present these data to the 2011 CSPG/CSEG/CWLS Convention.

References

- Boswell, R., Shelander, D., Lee, M., Latham, T., Collett, T., Gilles, G., Moridis, G., Reagan, M., and Goldberg, G., 2009, Occurrence of gas hydrate in Oligocene Frio sand: Alaminos Canyon Block 818: Northern Gulf of Mexico: *Marine and Petroleum Geology* xxx, 1-14.
- Fiduk, J.C., Weimer, P., Trudgill, B.D., Rowan, M.G., Gale, P.E., Phair, R.L., Korn, B.E., Roberts, G.R., Gafford, W.T., Lowe, R.S. and Queffelec, T.A., 1999, The Perdido Fold Belt, Northwestern Deep Gulf of Mexico, Part 2: Seismic stratigraphy and petroleum systems: *AAPG Bulletin*, **83**, No. 4, 578-612.
- Hansen, K.R., Mittet, R., 2009, Incorporating seismic horizons in inversion of CSEM data: SEG Expanded Abstracts, Houston, TX, USA, 694.
- Latham, T., Shelander, D., Boswell, R., Collett, T., Lee, M., 2008, Subsurface characterization of the hydrate bearing sediments near Alaminos Canyon 818: Proceedings of the 6th International Conference on Gas Hydrates (ICGH 2008), Vancouver, British Columbia, CANADA, July 6-10, 2008.
- Maaø, F. A. [2007] Fast finite-difference time-domain modeling of marine-subsurface electromagnetic problems. *Geophysics*, **72**(2), A19-A23
- Trudgill, B. D., Rowan, M. G., Fiduk, J. C., Weimer, P., Gale, P. E., Korn, B. E., Phair, R. L., Gafford, W. T., Roberts, G. R., and Dobbs, S. W., 1999, The Perdido Fold Belt, Northwestern Deep Gulf of Mexico, Part 1: Structural Geometry, Evolution and Regional Implications: *AAPG Bulletin*, **83**, No. 1, 88-113.
- Zach, J.J., 2010, Using sequential inversion schemes with increasing complexity to tackle the controlled-source electromagnetic imaging problem: Progress in Electromagnetics Research Symposium Abstracts, Cambridge, USA, 424.