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Looking Through the Haze - How CSEM can Improve Reservoir Imaging Where Seismic Struggles - A Case Study from Malaysia

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SUMMARY

We present a CSEM survey case in offshore Sarawak, Malaysia showing how CSEM can help reservoir imaging where seismic struggles due to poor seismic reflection. The Seismic data at the prospect depth shows poor reflection due to low saturated gas seepage The CSEM data was acquired in 2008 along two receiver lines assuring azimuth data coverage between the lines.. EMGS performed 2.5D inversion along both the tow lines and the result showed resistive anomalies in one of the structures in each lines. In 2009 Newfield drilled a well in one of the structure which resulted in a gas discovery. Pre-drill 2.5D inversion result matches well with the well log. In early 2012, Newfield drilled a second well a few Km off the CSEM line in the other structure, which was believed to be oil charged but was dry. CSEM inversion did not show any anomaly in that structure. Unconstrained anisotropic 3D inversion was performed in 2012 and the results were then correlated with the well logs. The result of 3D inversion matches very well with the well logs and also laterally with the structure.

Introduction

In Malaysia, poor subsurface imaging through seismic due to gas seepage is a common problem. Low saturation gas causes reflectivity loss and it can be challenging to interpret hydrocarbon prospects with conventional methodology (Ghazali et al., 2008). Controlled Source Electromagnetic (CSEM) measurements map a different sediment property, namely the electrical property rather than the acoustic (Eidesmo et al., 2002). According to Archie's Law, the resistivity of a clean sand increases exponentially with increasing hydrocarbon saturation (Archie et al., 1942). Consequently, low saturated gas, which could be destructive for seismic imaging, will have little effect on the resistivity imaging of the overburden and the target.

CSEM is a low frequency method (0.1-10Hz) so obviously the vertical resolution of unconstrained CSEM inversion cannot match that of seismic tuning. It has become standard practice, to include seismic information in the form of horizons in EM inversions in order to place resistivity at correct depth. However, delineating the lateral extent of HC- saturated rocks using CSEM has proven to be more reliable also for unconstrained inversion. Therefore, in areas where the structural imaging is uncertain due to gas seepage, the lateral extent of HC-saturated rocks can still be mapped by CSEM. By excluding seismic information, there will inherently be an uncertainty related to the depth placement of the EM anomaly, but assuming the laterally defined anomaly is associated with HC-saturation, one can thereby build better P10/P90 estimates. In a more complex geological setting with compartmentalized reservoir rocks, CSEM can help in prioritizing compartments to reduce risk of appraisal well location. We will show an example from Malaysia where the above is discussed.

Geology background

The tectonic development of the area is linked to the rifting of the South China Sea. Exploration initiatives in the area are focused on the structures formed during the rifting phase, targeting the under-explored Paleogene play. This area is affected by zones of high seismic attenuation in the overburden that are thought to be related to pockets of shallow gas. These anomalous pockets of shallow gas deteriorate the quality of the seismic imaging of the underlying rifted fault blocks and hamper any possible reservoir and fluid qualitative analysis.

2009 CSEM 2.5D inversion results

In 2008 EMGS acquired CSEM data along two receiver lines for Newfield with 3km line spacing. All receivers were deployed prior to towing the EM-source, assuring azimuth data coverage. The azimuth data later helped us in 3D imaging and interpretation of the 2D survey. *Figure 1* shows the survey layout and seismic intersections along the two main CSEM lines.

Seismic data along CSEM line 01Tx001 reveals two compartments while the seismic line along CSEM line 01Tx002 shows no amplitude in the target area due to gas seepage (*Figure 1*). Anisotropic 2.5D inversion was performed along both towlines. The results of the 2.5D inversion along line 01Tx001 show that the SW compartment is associated with an EM resistivity anomaly (*Figure 2*). The second compartment in the NE shows a low to no resistive build up along the line. In 2009, Newfield drilled **''Well-1''** at the south western compartment which resulted in a gas discovery which matches well with the results of the 2.5D Inversion. The second compartment along the same line in the north eastern part of the survey area was believed to be oil-charged. In early 2012, a second well **''Well-2''** was drilled a few km away from the line in the north- eastern compartment, which was dry. The results of the 2.5D inversion on line 01Tx002 did not reveal any high resistivity build-up at shallow depth but imaged a resistive anomaly at the target depth (*Figure 2*).

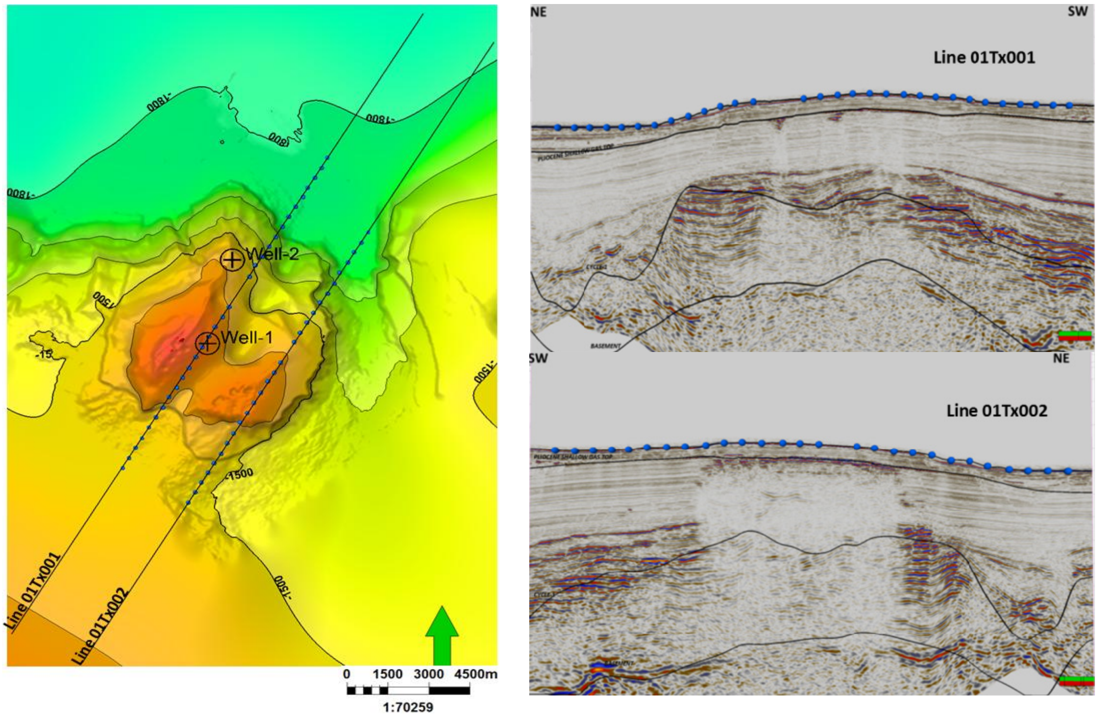

Figure 1 *Survey layout with bathymetry map and drilled wells (left). Seismic cross section along line 01Tx001 (top right) and line 01Tx002 (bottom right).*

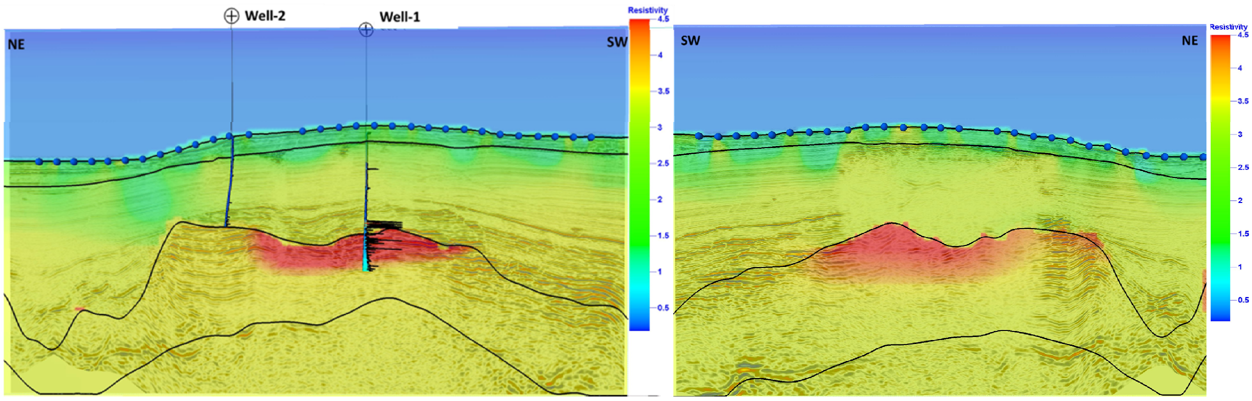

Figure 2 *Pre-drilling 2.5D inversion result displayed with seismic and the post drilling well logs along line 01Tx001 (left) and 01Tx002 (right).*

2012 3D CSEM inversion and well Calibration

To fully account for 3D effects and to better map anisotropy it is necessary to run full anisotropic 3D inversion. Unconstrained anisotropic 3D inversion was performed on this 2D survey in 2012 and was then correlated with the results of the two wells. Since the initial 2009 inversion work, the seismic has been reprocessed and the new horizons have been incorporated into the start model of the 3D CSEM inversion. As seen in *Figure 3*, where the vertical-resistivity model from 3D CSEM inversion are displayed over seismic and well log along both the lines, only the south-western compartment is associated with an electrical resistivity anomaly, which was also observed in the pre-drill 2.5D inversion result.

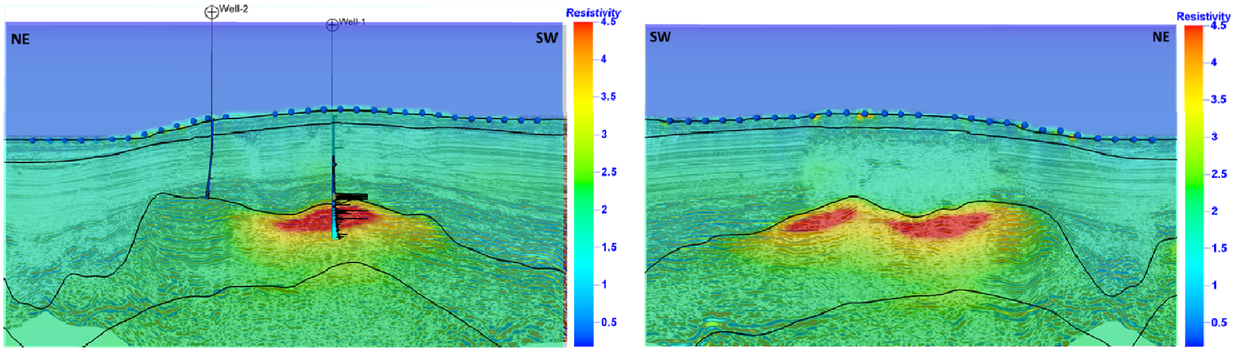

Figure 3 *The vertical-resistivity model from 3D CSEM inversion displayed along with seismic section along line 01Tx001 (left) and 01Tx002 (right).*

Figure 4 shows the inverted result overlaid on arbitrary cross section perpendicular to the CSEM lines and passing through the wells. One can observe that the well-log coincides very well with the resistive anomaly in the unconstrained inverted result. Due to lack of data coverage, the subsurface resistivity between the two towlines cannot be ascertained.

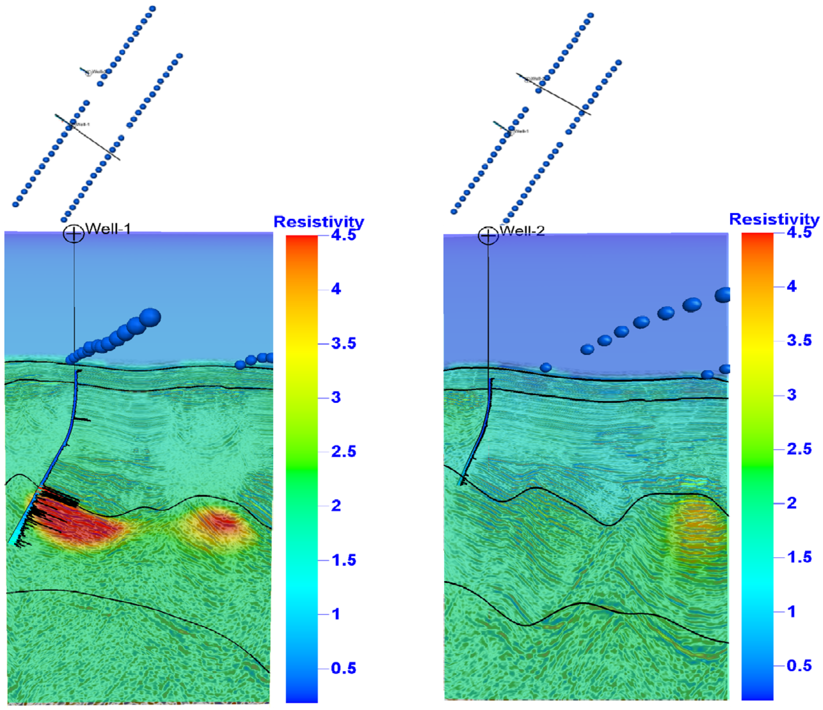

Figure 4*The inverted vertical-resistivity model from 3D CSEM inversion overlaid on seismic through arbitrary cross lines passing through the wells Well -- 1(left) and Well – 2 (right).*

The calculated apparent anisotropy ratio (inverted vertical-resistivity model divided by inverted horizontal-resistivity model) in *Figure 5* shows a clear high electrical anisotropic layer above the reservoir level, which is generally observed in shaley rocks (Ellis et al., 2010). This higher anisotropic layer coincides very well with the higher values of gamma ray logs measured in both wells. Apparent anisotropy is also associated with the mapped resistivity anomalies at target level. This can be explained by CSEM being mainly sensitive to vertical resistivity and not horizontal resistivity, resulting in an apparent anisotropy (Ramananjaona et al. , 2008; Fanavoll et al. , 2012). This observation therefore can be used as an indicator for thin resistors despite the low vertical resolution of CSEM. Some of the observed anisotropy may also be attributed to anisotropy generated from sand-shale sequences as encountered at the reservoir level in Well-1.

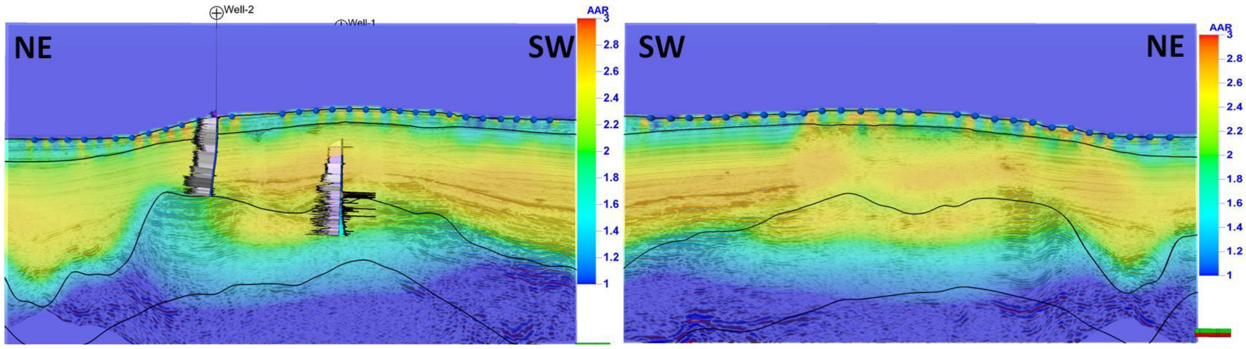

Figure 5 *The apparent electrical anisotropy ratio displayed over seismic along with Gamma Ray logs from both the wells through line 01Tx001 (left) and 01Tx002 (right).*

Conclusions

The CSEM survey and inversion work undertaken here has shown that it can be used as a tool to reveal the presence of electrical resistive anomalies in the subsurface where conventional methods such as seismic imaging struggle due to gas seepage. The inversion result shows the absence of a high-resistive body in the shallow overburden, which suggests that the interpreted shallow gas anomaly is made up of low-saturated gas in shale/silt sequences. Calibration with well data shows a very good match of the resistivity distribution from CSEM and well-log. The high apparent anisotropy observed in the CSEM inversion results above the reservoir, generally observed in shaley rocks correlates well with the gamma ray logs of both wells.

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