CSEM: A New Vista in Exploration. Case study from Makassar Strait, Indonesia

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Summary

The deepwater Kutei basin is one of the most prolific basins in the Makassar Strait but until recently, the exploration has focused on easy to find structural traps. Basin floor fans often form stratigraphic traps which could be difficult to map on seismic. CSEM, which is not governed by elastic properties but rather electric properties is sensitive to saturation. By imaging resistivity distribution, CSEM helps detect not only the difficult traps like basin floor fan but also help in delineating the trap extent which eventually gives better prediction of net rock volume and hydrocarbon volumes.

2D CSEM data from 2006 acquired in the Kutei basin brought new interpretation when re-processed with updated algorithms. The new CSEM results integrated with other geological and geophysical data successfully validates the outcome of nearby wells and also reveals a new lead.

Introduction

Deepwater exploration in the Kutei Basin has mainly been focused on Pliocene and Miocene age reservoirs with coarse-grained turbidites in slope channels and basin floor fan deposits. However, basin floor fans can be difficult to map using seismic data alone despite often being associated with seismic amplitude events. CSEM combined with other geological and geophysical data can indicate the presence of a hydrocarbon charged reservoir. Moreover it can determine the extent of the deposit and lead to the determination of hydrocarbon-volumes present.

Basin floor fan reservoirs are particularly well suited for CSEM. These deposits are coarse grained sediments encased in shale. When saturated with hydrocarbons, they are more resistive than the surrounding shales, allowing them to be detected using the CSEM method (Filipov et al, 2014). If a basin floor fan within the zone of CSEM detection is saturated with hydrocarbons, a resistive anomaly should be detected. CSEM surveys done worldwide suggest that is an excellent technique not only to determine the existence of a saturated hydrocarbon accumulation but also to define the lateral extent of stratigraphic accumulations.

Methodology

In 2006 EMGS acquired 19 CSEM 2D lines spanning a total of 830 km over several PSC areas in the Kutei Basin (Northern Makassar Strait) as shown in Figure 1. Out of those 19 lines, 11 lines are now in open acreage of previously relinquished blocks. One of these areas is the Oti block, recently announced as part of the 2015 Indonesia Licensing Round. Another open covers the former Papalang block. This paper will focus on the 2.5D inversion result of 2D CSEM data acquired for a NW-SE oriented 2D CSEM line in the relinquished Papalang block labelled as 2D_CSEM in Figure 1.

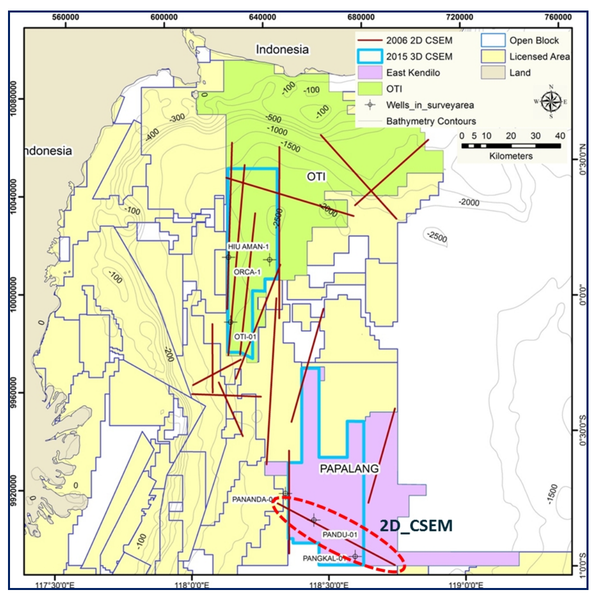

Figure 1: Map of the Makassar Strait showing all survey areas of the 2D CSEM lines (red lines) acquired in 2006.

A. Input data

The bathymetry in this survey area is generally smooth with average water depths of ~2250 m. A total of 22 receivers with a receiver spacing of 2 km were deployed onto the seabed along line 2D_CSEM. The CSEM source was then towed along the line approximately 30 m above the seabed, transmitting a source pulse with a base frequency of 0.05 Hz. The source frequency spectrum for this survey is shown in Figure 2.

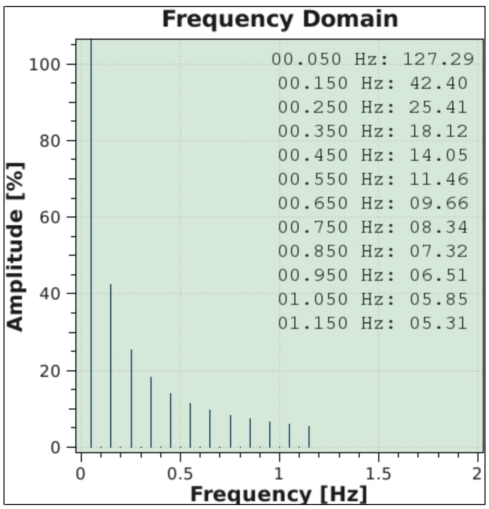

Figure 2: Source frequency spectrum showing substantial source currents (> 5%) for all frequencies at 0.1 Hz intervals between 0.05 – 1.15 Hz. The base frequency is 0.05 Hz.

B. 2.5D Inversion

Unconstrained 2.5D inversion is performed to image the resistivity distribution and reveal resistive anomalies (if any) in the subsurface of the survey area.

In general, a CSEM inversion algorithm attempts to find a model with a resistivity distribution $\rho(r)$, which produces synthetic data $d^{syn}(\sigma(r))$ to match the observed data d^{obs} A cost function $\varepsilon(\rho)$ is defined such that minimizing ε favors a good data fit and chosen regularization. A small value of ε indicates that a model with $\rho(r)$ has a good data fit and preferred structure (for example layered). A Gauss-Newton update algorithm is used to minimize ε.

In 2.5D inversion, it is assumed that the receiver and source positions are located along a line, and that the resistivity is constant in the horizontal direction perpendicular to the towline (i.e. 2D model). The forward modelling of the CSEM source field is done in 3D, hence the term 2.5D (Hansen et al, 2009).

Half-space resistivity model with 2Ωm vertical (Rv), and 1.33Ωm horizontal (Rh) resistivity, was used as initial input to the inversion. The choice of this initial resistivity model was based on the results of the 1D inversion of selected receivers and resistivity logs from nearby wells.

An example of the 2.5D inversion workflow is shown in Figure 3.

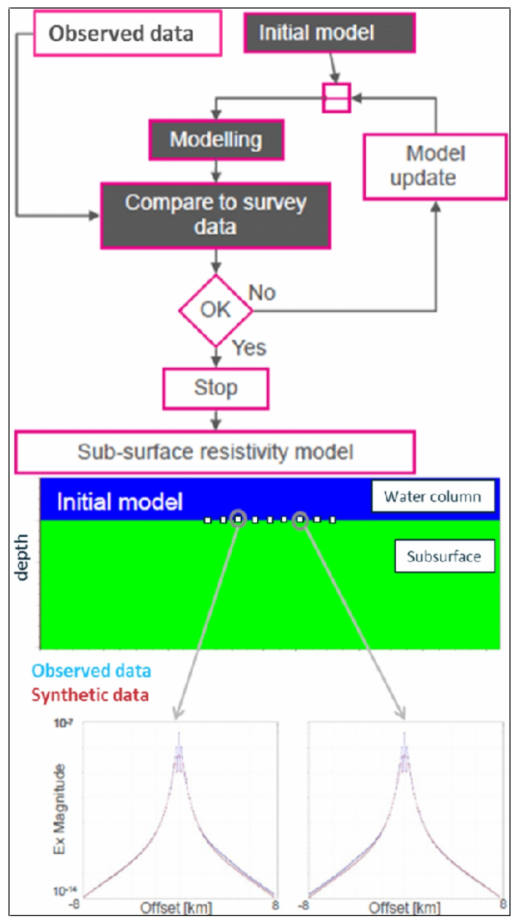

Figure 3: 2.5D inversion workflow taking the acquired electromagnetic field data and a 2D model as inputs. The resulting model will be updated iteratively until a low data misfit is achieved between the modelled synthetic data and observed data.

C. Findings

C1. Resulting Resistivity Models

The resulting resistivity models are shown in Figure 4. Positions of the nearby wells Pandu-1 and Pangkal-1 are projected into the section. The location and an overview of both the wells are shown in Figure 5 and Table 1, respectively.

In general, the resistivity in the survey area increases with depth and the background resistivity ranges from ~1 Ωm – 4 Ωm. A regional resistive feature is observed in the horizontal model which extends from ~5000 m below MSL to the base of the model. In the vertical resistivity model, a localized resistive anomaly is observed at ~4750 m below MSL and extends ~8 km laterally NW side of the 2D_CSEM line.

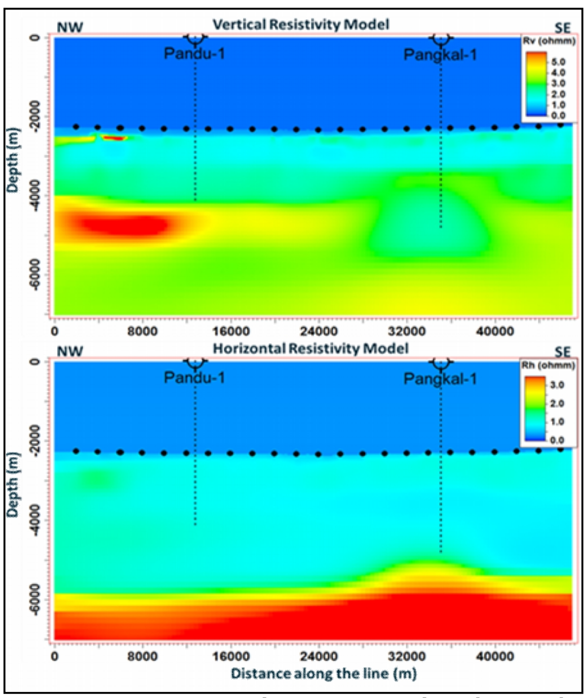

Figure 4: Cross section along 2D_CSEM line showing the resulting vertical and horizontal resistivity models with projected positions of nearby wells. Black spheres are the receiver positions.

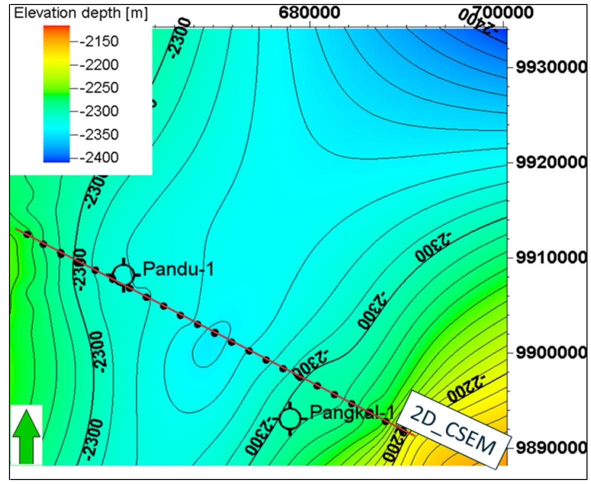

Figure 5: Location of Pandu-1 and Pangkal-1 wells with respect to 2D_CSEM line. The bathymetry is shown in contour.

Well	Pandu-1	Pangkal-1
TD	4100 m	4800 m
Target formation	Upper Miocene	Upper Miocene
Result	Dry	Dry
Status	Plugged and abandoned	Plugged and abandoned
Distance from CSEM line	~400 m	~3000 m

Table 1: Overview of Pandu-1 and Pangkal-1 wells.

C2. Correlation with Seismic and Well Resistivity Logs

As the horizontal component of the electromagnetic field is more sensitive to large-scale structure, CSEM inversion has successfully imaged a pre-Tertiary basement structure exhibiting a good match with 2D seismic along the same line (Figure 5).

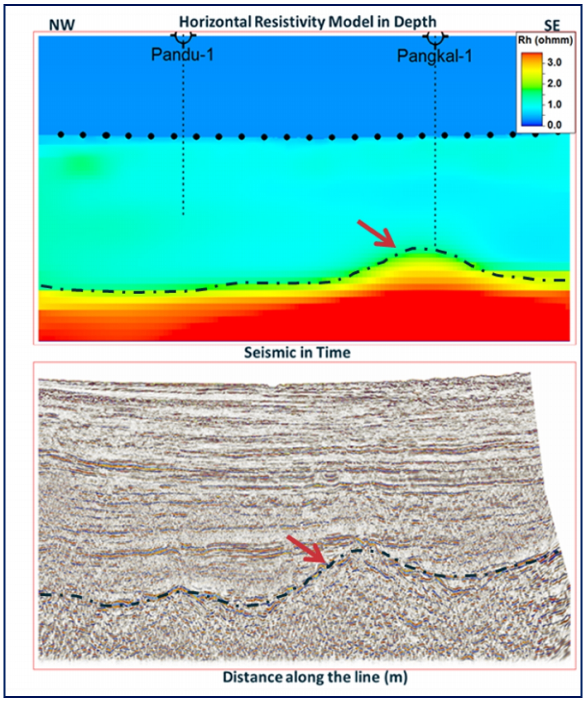

Figure 5: Cross section of the resulting horizontal resistivity model (top) and seismic in time (bottom) along the 2D_CSEM line. The arrow points to the same structure and lateral position in both plots.

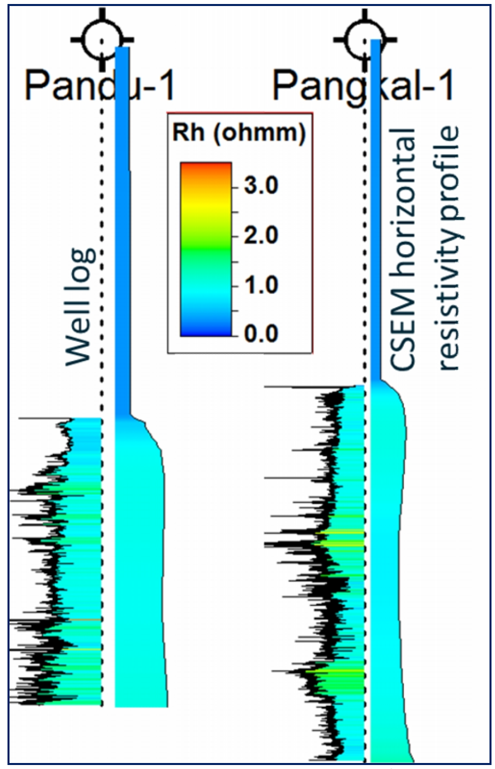

Figure 6: Comparison between resistivity logs from Pandu-1 and Pangkal-1 wells against CSEM horizontal resistivity profile extracted in close proximity to the wells.

Furthermore, the horizontal model from CSEM inversion also correlates well with the resistivity logs from the Pandu-1 and Pangkal-1 wells, see Figure 6. Although vertical resolution of CSEM method is limited compared to the well logs, the background resistivity trend is observed to be consistent.

C3 Evaluation of Localized Resistive Anomaly

Resistive layers that may be associated with hydrocarbon saturation only affect the vertical electromagnetic field component. Therefore they will only be recovered in the vertical resistivity model but not in the horizontal model.

On that basis, CSEM indicates no localized resistive anomalies are resolved in the vertical resistivity model proximal to the well locations Pandu-1 & Pangkal-1 (Figure 7).

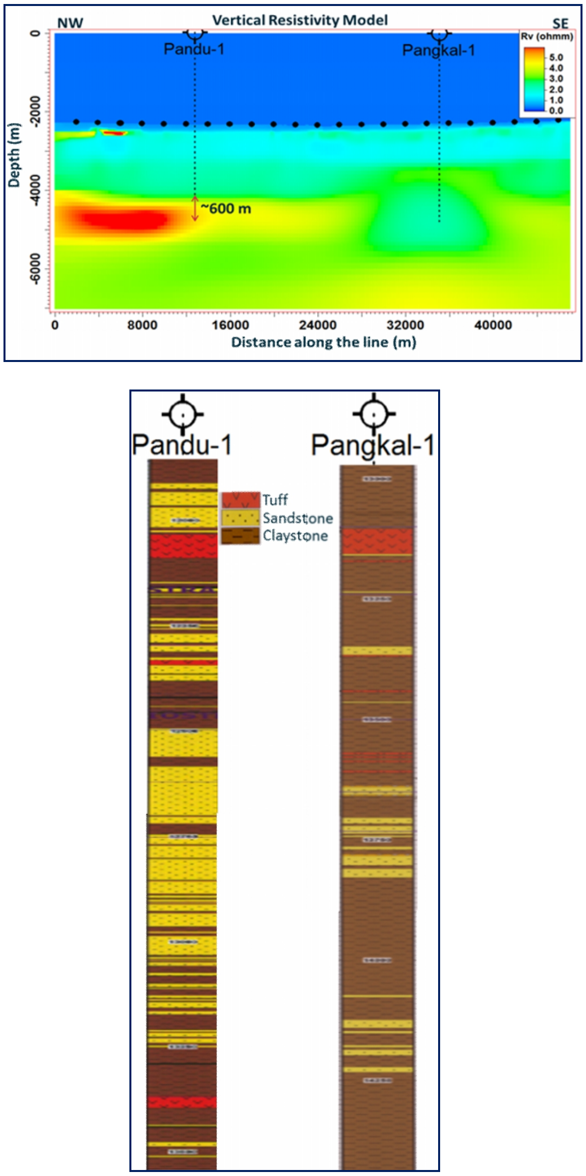

Figure 7: Cross section of the resulting vertical resistivity model (top) with a schematic diagram of the general lithology extracted from the Pandu-1 and Pangkal-1 wells (bottom).

There is however, a prominent resistive anomaly detected in the NW direction, ~600 m deeper than TD of Pandu-1 well. In depth this anomaly falls within the well-recognized play types of the Kutei Basin, targeting deepwater Upper Miocene turbidites, Basin floor fans (Wayne et al, 2009). This has been correlated against the composite well logs. The composite well logs from both wells also reveal that lithology such as carbonates and salt that could produce resistive anomalies are not present in the survey area (Figure 7). This increases the confidence that the resolved anomaly from vertical resistivity model most probably originates from a saturated clastic reservoir.

Conclusion

1. Reprocessing of 2006 2D CSEM lines shows a new, undiscovered lead, based on a high resistivity anomaly as seen on the 2.5D inversion results. CSEM is not a direct hydrocarbon indicator, but based on the integration of the CSEM inversion results with other data such as well-logs, seismic data and information from nearby wells, indicates there is a higher probability of success of this lead.

2. The results of the CSEM inversion is consistent with the dry wells. i.e. there is no resistive anomalies associated with the dry wells.

3. Since the 2006 CSEM data acquisition campaign was 2D in nature, hence the lateral extent of the new lead cannot be properly delineated. However a new 3D CSEM survey in the same area has recently been acquired. The inversion results when available is going to give new insight about the prospectivity of the area.

Reference

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