PS Gas Hydrate Mapping using 3D CSEM*

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Abstract

The presence of gas hydrates in deep water Rakhine Basin, offshore Myanmar is widely acknowledged. Their identification is based on seismic attributes and relevant gas hydrate indicators. Saturation within the gas hydrates and the underlying associated free gas at a regional scale is however still poorly understood. In this paper, we would like to show how Controlled Source Electro-Magnetic (CSEM) derived resistivity can provide a better guidance to mapping saturated hydrates and free gas at a regional scale. Natural gas hydrates form in deep waters (> 500 m) under certain pressure-temperature conditions where gas molecules (usually methane) are trapped within the crystal structure of water to form a solid, crystalline compound. The zone that provides favorable conditions for the hydrates to form is termed as the gas hydrate stability zone (GHSZ). Solid hydrates are considered as a potential natural resource as well as a drilling hazard. In both cases, it is crucial for oil companies to accurately locate and map these shallow accumulations, either to estimate their volumes or to avoid them while drilling.

Hydrate mapping usually relies on the seismic amplitude variations that occur within the GHSZ and the free gas beneath. The base of GHSZ is termed Bottom Simulating Reflector or “BSR”, a seismic event that occurs where low-velocity gas underlies higher-velocity hydrate-bearing strata, giving it a characteristic soft kick. Present dogma naturally equates a pronounced BSR with the presence of free gas with an overlying gas hydrate. However, given that acoustic impedance responds to a wide range of saturation, it is not always possible to detect variation in saturation of free gas and/or gas hydrates using seismic data alone. Electrical resistivity is more dependent on gas saturation as described by Archie’s law. Significant changes in resistivity are not achieved until the majority of the conductive fluid (i.e. brine) is replaced by non-conductive fluids such as gas (Constable, 2010).

CSEM measures electrical resistivity at a regional scale. CSEM has been proven to be very effective tool in mapping and quantifying shallow (400 m BML) conventional hydrocarbon accumulations (Morten et al, 2017) and hydrates being shallow, are ideal targets for the CSEM method. The lower operational frequency range (0.05 to 50 Hz), limits the vertical resolution of CSEM and its ability to differentiate resistive response of a saturated gas hydrate from the underlying saturated free gas. Hence one might need to rely on BSR from a seismic and CSEM co-rendered image in order to differentiate the hydrate from underlying free gas. The lateral resolution of the resistive geobody however, is well

constrained due to 3D receiver grid coverage and the available azimuthal information. This makes it possible to map the areal extent of saturated hydrate/free gas accumulations more accurately.

3D CSEM has been acquired and inverted in various gas hydrate provinces around the world. The results show a clear correlation between resistive anomalies seen on CSEM resistivity volume and strong reflective events identified on seismic. The results also show that these resistive anomalies do not always follow the seismic BSR. Average resistivity map produced from CSEM resistivity volume provides an overview of resistivity variation (and hence the saturation variation) within the hydrates. Information derived from these maps can be used to identify locations that could be a potential drilling hazard. The areal extent of resistivity anomaly derived from these maps, combined with the thickness information derived from seismic can give a more accurate estimation of saturated hydrate volume in place. In this paper, we would like to share our experience of mapping hydrates with case examples from around the world where 3D CSEM data has been acquired. Through CSEM synthetic modeling and inversion studies we try to demonstrate how the CSEM signal would image some of the more common gas hydrate-free gas scenarios.

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Abstract

The presence of gas hydrates in deep water Rakhine Basin offshore Myanmar is widely acknowledged, their identification is based on seismic attributes and relevant gas hydrate indicators; However, saturation within the gas hydrates and the underlying associated free gas at a regional scale is still poorly understood. This paper describes how Controlled Source Electromagnetic (CSEM) derived resistivity can provide a better guidance to mapping saturated hydrates and free gas at a regional scale using an analogue dataset from a similar setting.

Hydrate mapping usually relies on the seismic amplitude variations that occur within the gas hydrate stability zone (GHSZ) and the free gas beneath. The base of GHSZ is termed Bottom Simulating Reflector or "BSR", a seismic event that occurs where low-velocity gas underlies higher-velocity hydrate-bearing strata, giving it a characteristic strong seismic response. Present dogma naturally equates a pronounced BSR with the presence of free gas and an overlying gas hydrate. However, given that acoustic impedance responds to a wide range of saturation, it is not always possible to detect variations in the saturation of free gas and/or gas hydrates using seismic data alone. CSEM measures electrical resistivity at a regional scale, since it gives a definitive response between a low saturated and saturated reservoirs it has been proven to be a very effective tool for mapping and quantifying conventional hydrocarbon accumulations (Morten et al., 2017). Hydrates, being shallow, are ideal targets for the CSEM method. The lower operational frequency range (0.05 to 50 Hz) of CSEM limits the vertical resolution and its ability to differentiate the resistive response of a saturated gas hydrate from underlying saturated free gas; Hence, one might need to rely on BSR from seismic and a co-rendered with a CSEM image to differentiate the hydrate from underlying free gas. The lateral resolution of the resistive geobody however, is well constrained due to azimuthal information available from 3D receiver grid coverage. This makes it possible to map the areal extent of saturated hydrate/free gas accumulations more accurately. Average resistivity maps produced from CSEM resistivity volumes provide an overview of resistivity variation (and hence the saturation variation) within the hydrates. The areal extent of a resistivity anomaly derived from these maps, combined with the thickness information derived from seismic, can provide a more accurate estimation of saturated hydrate/free gas volumes in place.

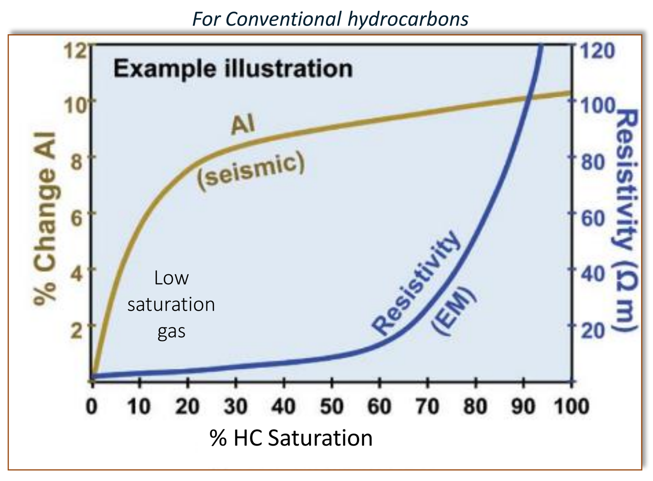
CSEM has been acquired and inverted in gas hydrate provinces around the world. The results show a clear correlation between resistive anomalies on the CSEM resistivity volume and strong reflective events identified on seismic. The results also show that these resistive anomalies do not always follow the seismic BSR (effect of saturation variation). The resistivity values in most of these hydrate anomalies range between 4Ωm and 10Ωm, however, in certain locations resistivity values have been observed to increase by an order of magnitude (~100 Ωm) above hydrates, possibly indicating the presence of saturated free gas below hydrates.

One such case example from Makassar Strait, offshore Indonesia has been discussed here. 3D CSEM dataset acquired in this area has been inverted and the average resistivity map derived from the inverted resistivity model shows 3 distinct resistivity ranges which could be categorized into no-hydrate, hydrate and possible free gas related anomalies. The resistivity variations within the anomalies and the areal extent of these anomalies are likely indications of the saturation variation and the areal spread of the possible free gas in this area. Through synthetic inversions, the depth of the free gas related anomalies has been evaluated further.

Acoustic and resistivity response to fluid saturation

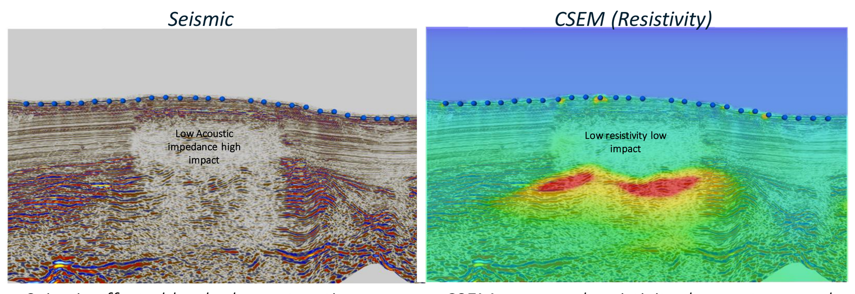
Panel 1

For Conventional hydrocarbons



Correlation between saturation vs Acoustic impedance and resistivity for a porous sandstone (Hesthammer et al., 2010)

- Acoustic impedance response cannot distinguish between low and high HC saturation
- Resistivity can differentiate between low saturated hydrocarbon accumulation and a saturated hydrocarbon accumulation



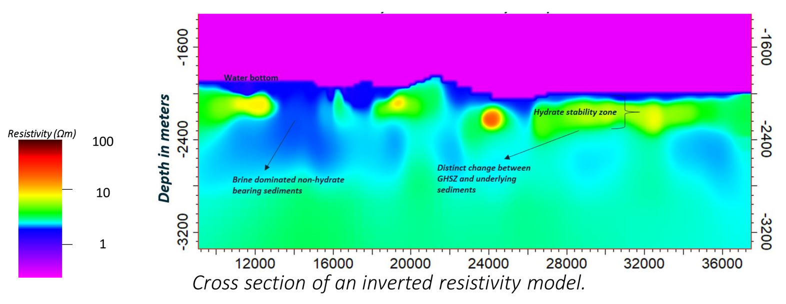
Seismic effected by the low saturation fizz gas

CSEM measured resistivity does not respond to the low saturation fizz gas but responds to the deeper gas-saturated accumulations Chakroborty. S et al., (2013)

Resistivity response to gas hydrates

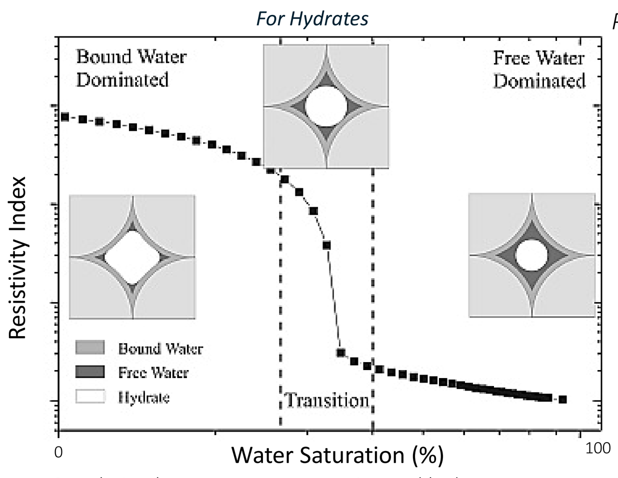
Panel 2

- Laboratory studies shows a resistivity index - saturation relationship which again depends on capillary effect and grain size.
- *Would BSR be visible in CSEM?* BSR is a purely elastic interface usually caused by high/low saturated gas beneath hydrate. In a resistivity domain, the variation in resistivity response is seen only if sufficient brine is replaced by hydrates with in the sediments in and below the GHSZ.



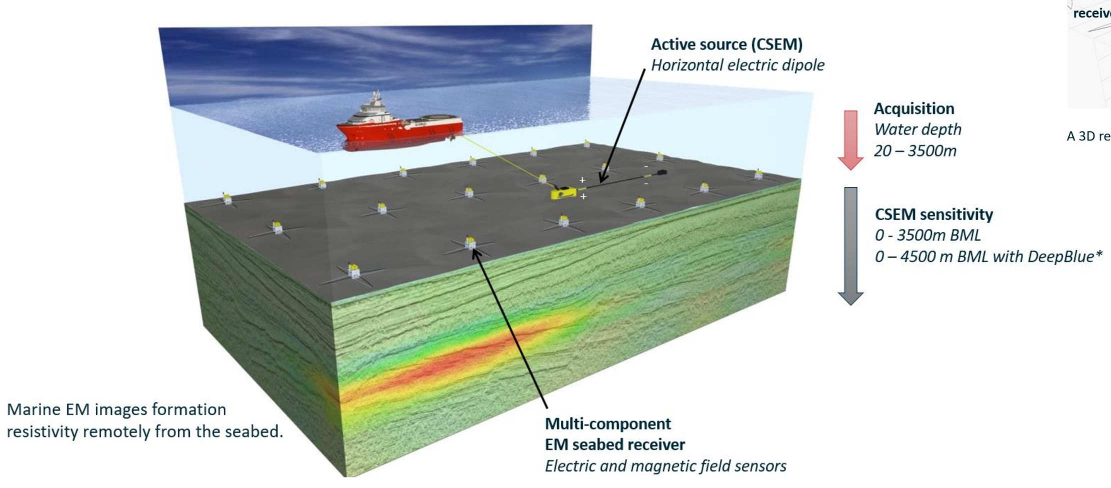
Cross section of an inverted resistivity model.

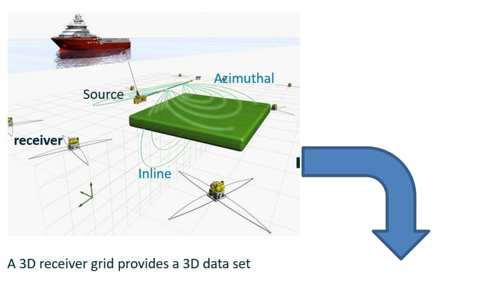
For Hydrates



Correlation between water saturation and hydrates (Spangenberg and Kulenkampff, 2006)

CSEM Acquisition in a nutshell





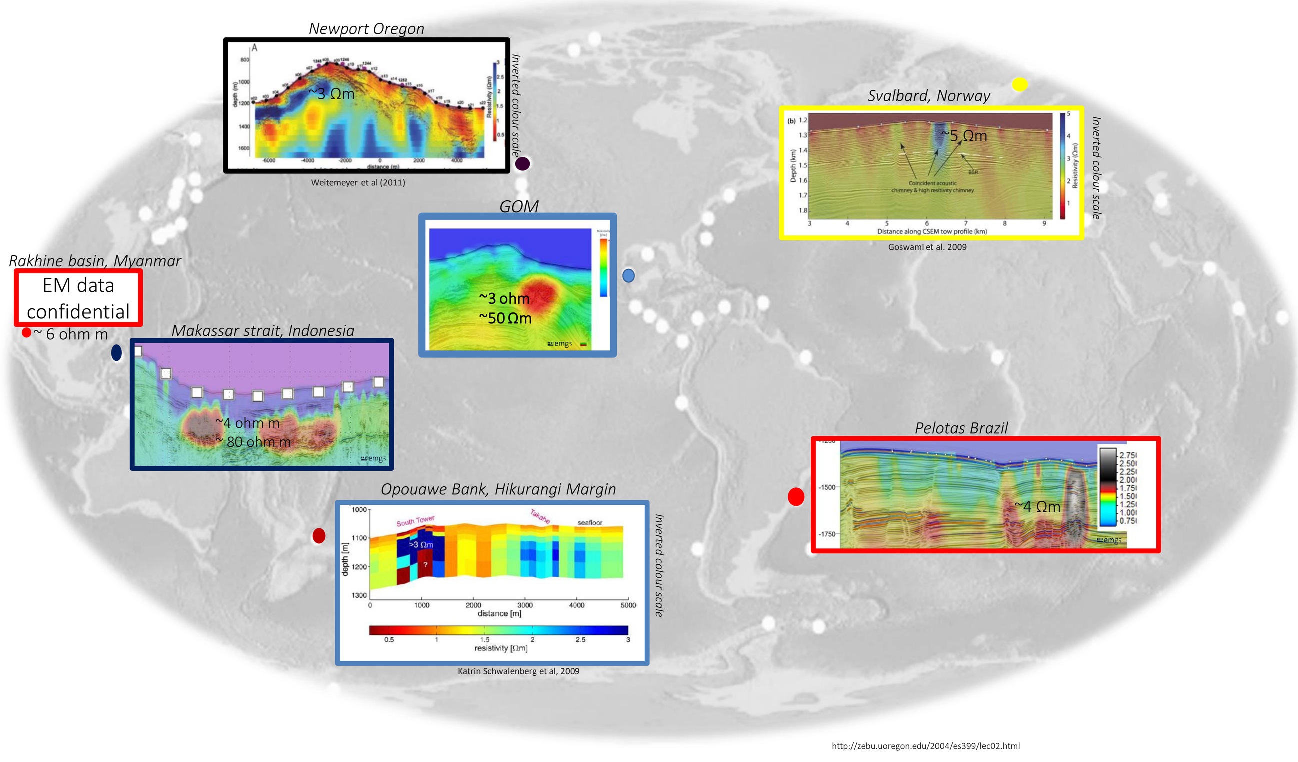
A 3D receiver grid provides a 3D data set

3D Inversion is run on the acquired data to produce a 3D resistivity volume

The 3D Resistivity Volume generated from inversion could be directly loaded into the workstations for further integration and interpretation.

Global hydrate identification using CSEM

Panel 4



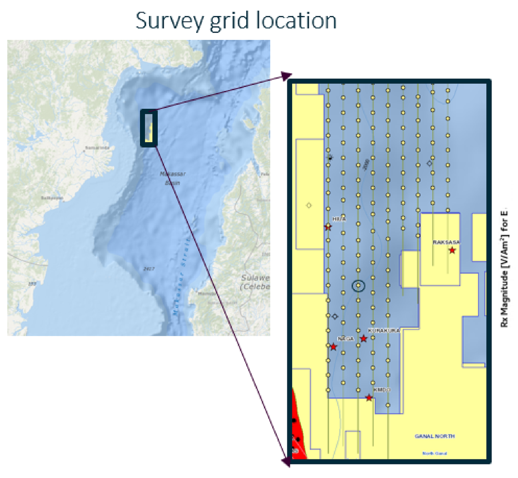
- CSEM is very sensitive to hydrates and the associated free gas accumulations.
- Resistivity of hydrates, in most cases, ranges between 3 Ω m to 10 Ω m
- In some areas the resistivity is as high as 80 Ω m which could be attributed to free gas or very highly saturated hydrates in high quality reservoir.

Study Area – Makassar Strait, Indonesia

Panel 5

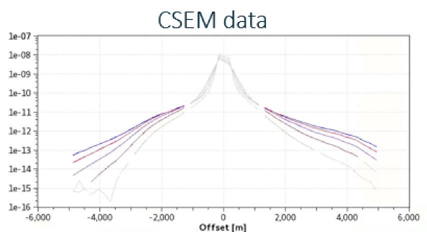
- 3D grid with a 2km receiver spacing and 2Km towline spacing
- Frequencies used: 0.875 Hz,1.375 Hz,2.375 Hz,4.375 Hz,8.625 Hz
- Data offsets up to 5000 m included in the inversion
- Start model containing single resistivity value in the entire subsurface (Half space) was used for this inversion.

Survey grid location



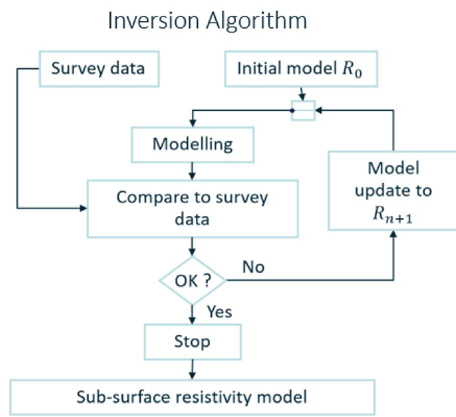
3D CSEM survey area in Makassar Strait

CSEM data



EM magnitude shown for the "circled" receiver shown in the grid map to the left

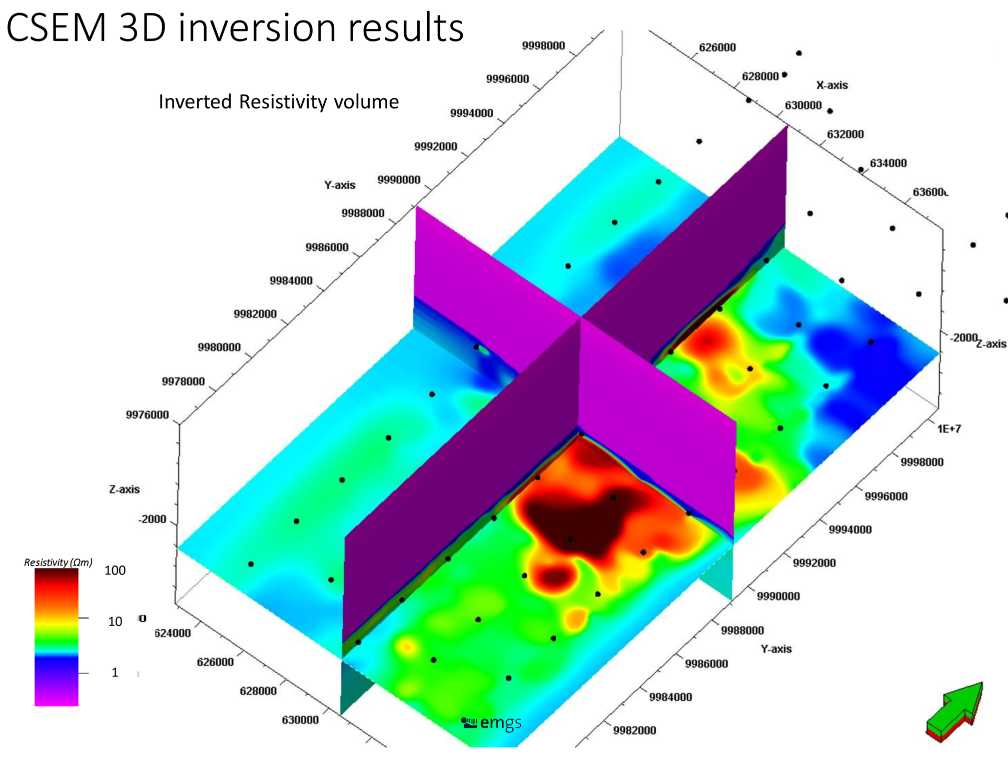
Inversion Algorithm



CSEM 3D inversion results

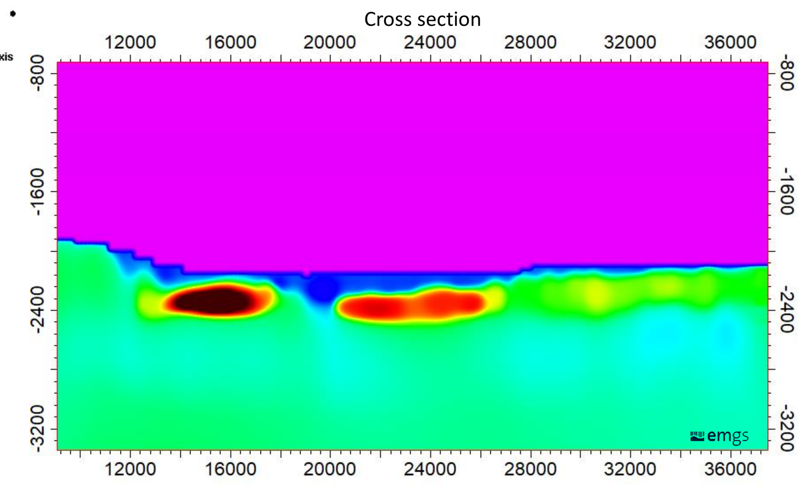
Panel 6

Inverted Resistivity volume



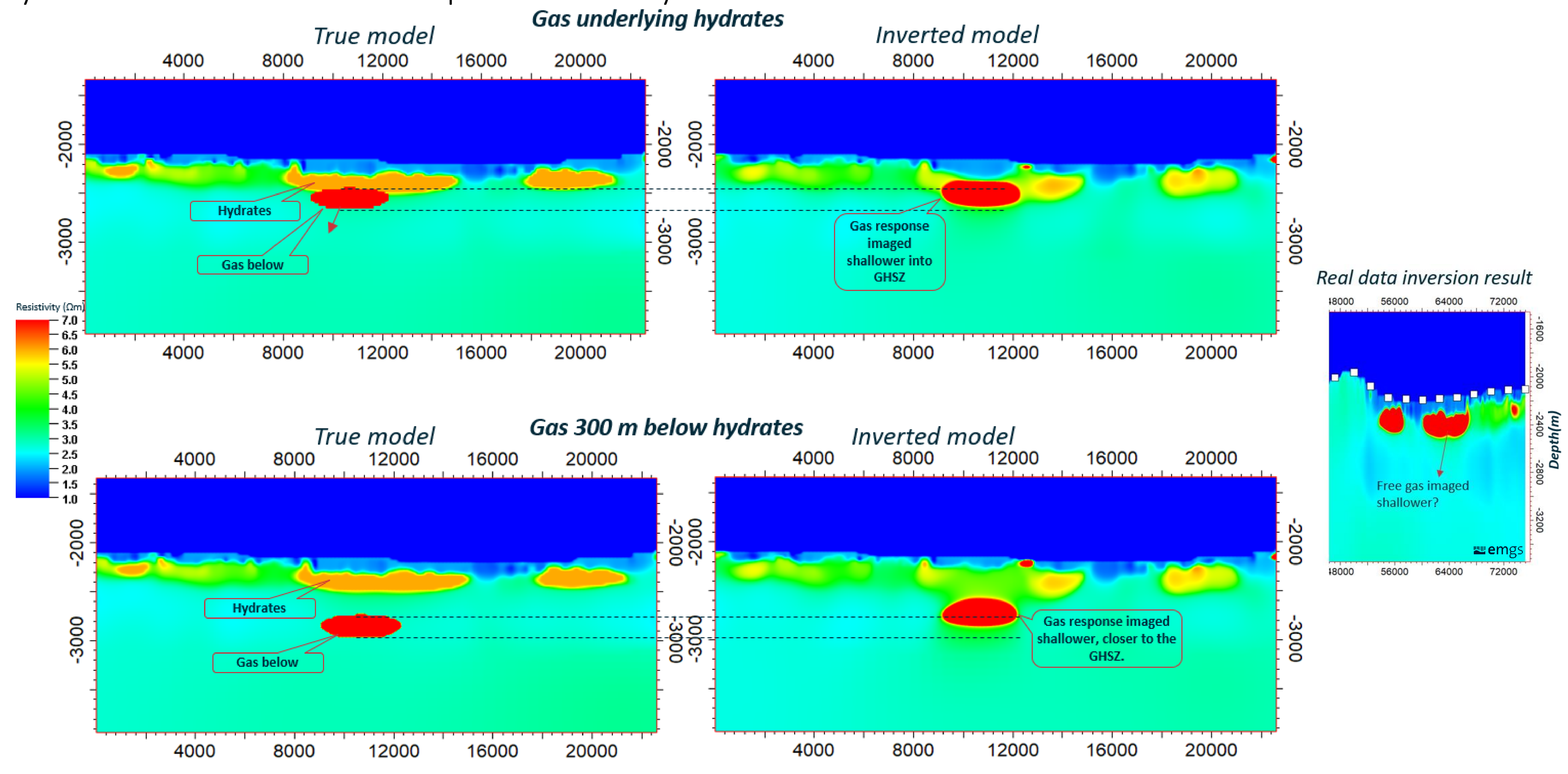
- Result of a 3D CSEM inversion is a resistivity volume in depth domain.
- Results are quality controlled based on data fit, consistency of the result to different start models and geological conformance of the resultant model.
- In the current case final QC'ed resultant model showed several resistive anomalies with resistivity ranging between 2 – 150 Ω m. Depth of these anomalies ranged between 100 – 800 m below mud line

Cross section



Synthetic tests to evaluate depth of anomaly

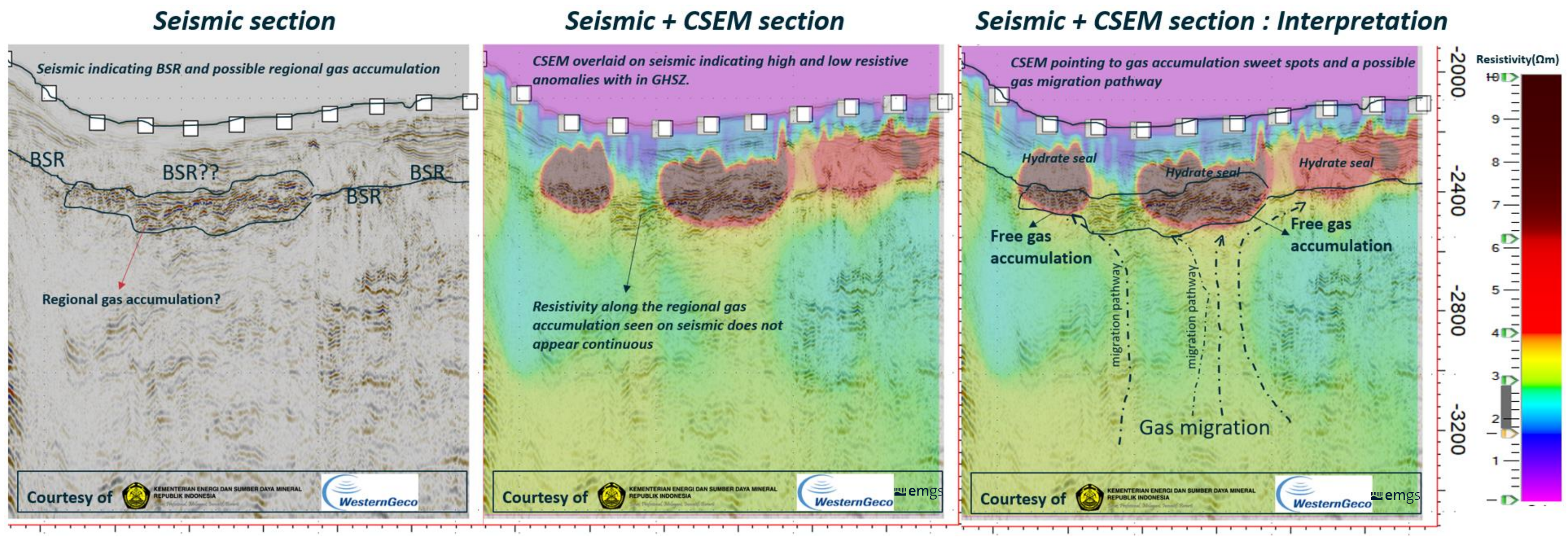
Panel 7



With hydrates in the overburden, inversion can image the gas below the hydrates. However it tends to move it shallower, merging with overlying gas hydrate response.

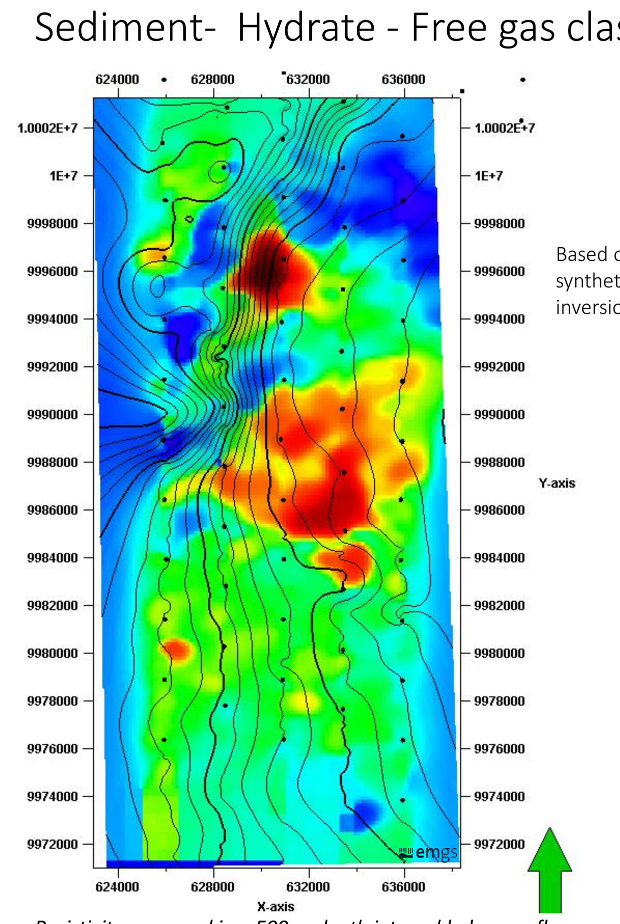
Co-Visualization of seismic and CSEM data set

Panel 8



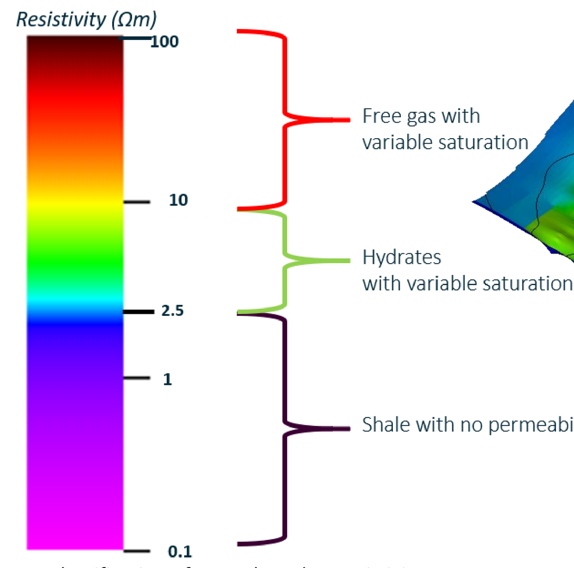
Sediment- Hydrate - Free gas classification based on resistivity

Panel 9



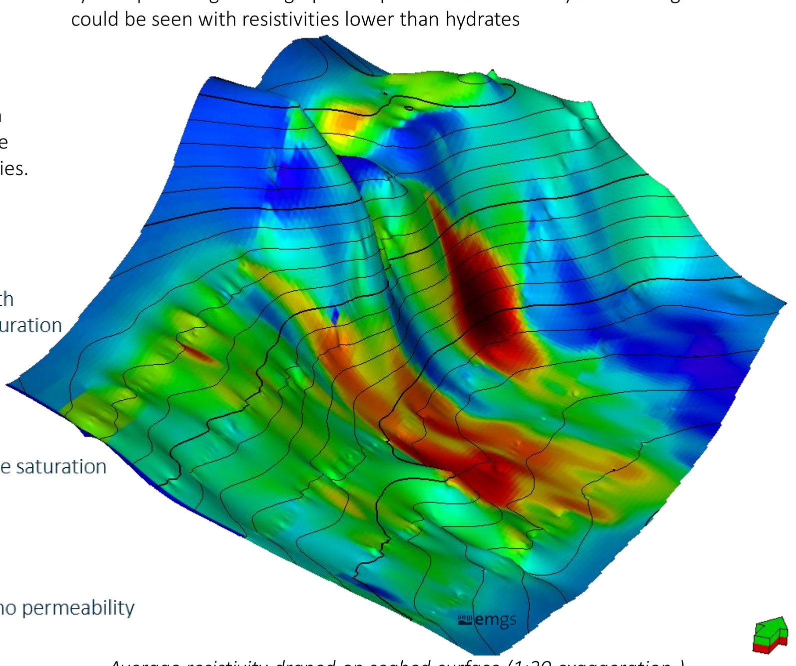
Resistivity averaged in a 500 m depth interval below seafloor

Based on the global hydrate analogs (Panel 4) and based on synthetic inversion studies (panel 7), resistivities seen in the inversion resultant model has been classified into 3 categories.



Classification of strata based on resistivity

Free gas accumulation with hydrates acting as seal and the turbidite sand system providing a stratigraphic trap mechanism. Non-hydrate baring shale could be seen with resistivities lower than hydrates



Average resistivity draped on seabed surface (1:20 exaggeration)

Conclusions

Panel 10

- CSEM derived resistivity is a valuable measurement that could differentiate between low and high saturated hydrocarbon accumulations.
- Result from a 3D CSEM acquisition can provide information about areal extant of saturated hydrate / free gas accumulations, which could help in making accurate estimation of their volumes in place.

Acknowledgements

Panel 11

We would like to thank Western-Geco, Center for Data and Information Technology on Energy and Mineral Resources(PUSDATIN), Ministry of Energy and Mineral Resources of the Republic of INDONESIA for allowing EMGS the use of their seismic data.

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