PRECISION MEASUREMENT OF Hz IN MARINE MT

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Abstract

Since 1998 major hydrocarbon companies have increasingly used marine controlled source electromagnetics (MCSEM) to determine the resistivity of deepwater offshore geological structures already discovered with the marine seismic technique. Although MCSEM is very costly, it is far less so than drilling a dry hole. This paper proposes a new MMT technique that provides information equivalent to MCSEM at significantly reduced cost.

Marine CSEM

Since 1998 major hydrocarbon companies have increasingly used MCSEM[1] (Figure 1) to determine the resistivity of deepwater (~1000 m) offshore seismic structures (possible hydrocarbon traps). Hydrocarbon companies wish to avoid the high cost (~US$50 M) of offshore "dry holes". The ships used for MCSEM cost approx. US$70,000/day, and a single marine MT ± CSEM measurement point costs approx. US$10,000. However, this is far less than the cost of a dry hole.

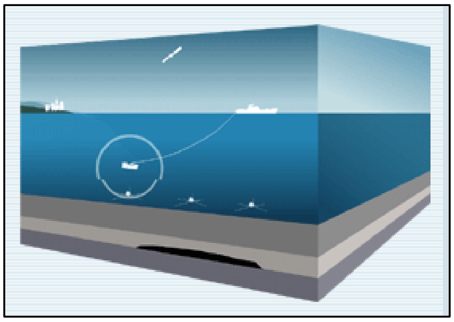

Figure 1: "Sea Bed Logging" technique of Electromagnetic Geoservices ASA (emgs).[1]

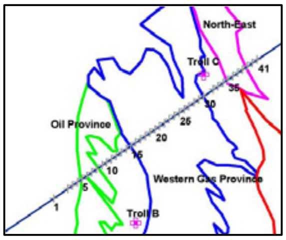

Figure 2: Layout of Troll SBL survey.[1]

Hydrocarbon-charged marine sediments have an electrical resistivity significantly higher (~100-~250 ohm-m) than a typical geologic section of "fresh" marine sediments (1-3 ohm-m). Figure 2 shows an MCSEM line over the North Sea Troll field. Figure 3 shows the normalized MCSEM Magnitude vs. Offset (MVO) on this profile for a given offset. The anomaly ranges from 0.05 (5%) to 4.0 (300%).

MCSEM vs. 4-component MMT

It is widely held that only the MCSEM technique can reliably determine the resistivity of offshore seismic structures because the horizontal components of MMT are known to be much less sensitive than MCSEM to relatively thin, nearly horizontal resistive bodies (such as the typical offshore hydrocarbon deposit), and anomalies arising from the natural field are too small to be detected reliably in any case.

The MMT TE/TM resistivity/phase (not shown) computed from the Figure 4 model have anomalous resistivity ~15% and anomalous phase ~4 degrees, or approx. 10%. So the largest MMT anomalies (using 4 component marine MT) are comparable to the smallest acceptable MCSEM anomalies.

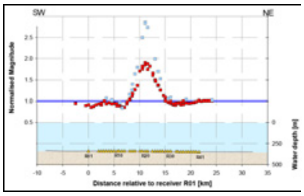

Figure 3: Average normalized magnitudes at an offset of 5 km ± 0.25 km. Red squares represent electric measurements; light blue squares, magnetic measurements; triangles, receiver positions.[1]

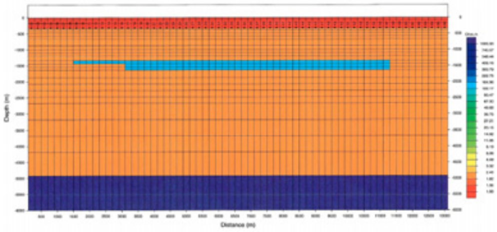

Figure 4: 2-D cross-section of the Troll Field used for 2-D MMT forward modelling. MMT stations are the small black circles (no. 2-66) on the seafloor ~340 m deep. The hydrocarbon-charged layer (200 ohm-m) is 100 m thick (left), 300 m thick elsewhere, forming a 9.8 km wide horizontal rectangular prism in cross-section. The background rocks have resistivity of 2 ohm-m. The sea water has a resisitivity of 0.25 ohm-m.

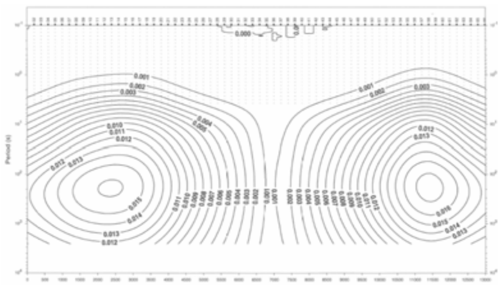

Figure 5: Tipper magnitude (max. 1.7%) computed from the model of Figure 4, displaying the usual maxima directly above extreme boundaries, central minimum, and zero background.

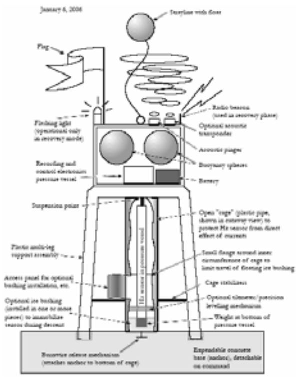

Figure 6: Cartoon of an apparatus[10] for the concept.

Precision measurement of MMT Hz

Can the ~1.7% anomaly of Figure 5 be detected against the theoretical zero background? The actual background is a non-zero error floor caused by misalignment of vertical sensor, calibration error, uncompensated temperature variation, topographic effect, geological noise, etc.

Bottom topography is known and can be corrected. MCSEM suffers from geological noise at least as much as does MT. Instrumentation can be made with precision components, and suitably precise calibrations can be performed. Seafloor temperature is stable.

Alignment error is probably the most serious because a small error (< 1°) causes a relatively large "false" tipper reading which resembles the anomalous signature. This bias error is always positive and cannot be removed by stacking.

If we require an error floor of 0.004, then the maximum permissible alignment error of the vertical sensor is ~0.25°. This accuracy in alignment is easily achievable with careful design and precision levelling. A less costly passive levelling approach can be used in which the Hz sensor is suspended precisely vertically, and acts as a damped pendulum[10].

The approach therefore appears feasible both in theory and practice. Advantages of using the natural field and a multiplicity of vertical sensors, compared to MCSEM, include: cost saving by use of much smaller vessels (~$3000/day compared to ~$70,000/day for specalized MCSEM vessel); no need for a controlled source or the ~$500,000 tow cable; lighter weight and smaller footprint, thus easier deployment; less costly apparatus, which minimizes cost of lost equipment, enables measurement redundancy and reduces spatial aliasing; better lateral resolution; wider frequency band for improved inversions; greater depth of investigation; and no air-wave problem.

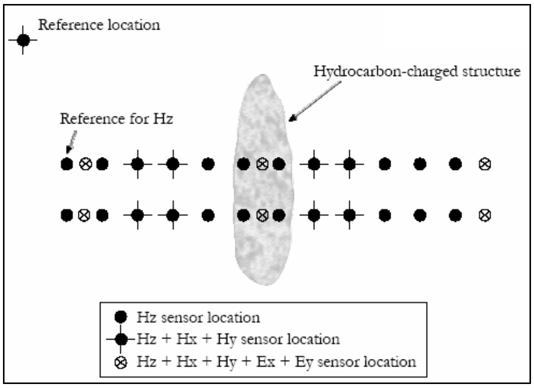

Figure 7: MMT Hz is measured simultaneously at many seafloor points. The measurements are taken along suitably positioned profile(s) which cross the structure to be studied. The "production" measurements are normalized to measurements of Hz made at an off-structure reference location; among other things this removes the effect of temporal variations of the source field. Several sequential deployments of the measuring equipment can be made, all normalized to the same reference location.

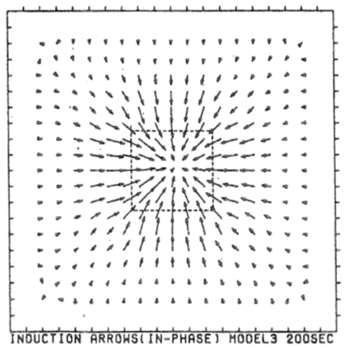

Figure 8: In this plotting convention, the real portion of the IV points towards the negative resistivity anomaly. The arrows would point away from a positive resistivity anomaly such as a hydrocarbon-charged structure.

Determination of "sign" (+/-) of anomaly

Magnitude of Hz alone may be used to infer the presence of a meaningful resistivity contrast. However, combination of Hz with Hx and Hy of the magnetic field arising from the natural source permits unambiguous determination of the "sign" of the resistivity anomaly. For example, we may utilize another standard MT parameter called the "Induction Vector" (IV) which is well known to the art. The

IV (Figure 8) is a complex quantity with real and imaginary parts. The IV requires measurement of all three components of the magnetic field, that is, Hz and Hx and Hy at the same or nearby locations. The actual azimuths of Hx and Hy are usually not critical as long as both horizontal sensors are orthogonal, which in practice may be achieved such as by fixing them in a rigid frame. The attitude of the horizontal sensors is usually known to ±1°, and this is usually sufficient. Accuracy of orientation of the vertical sensor is more critical, as discussed elsewhere.

Conclusion

The MMT Hz concept described here appears to be theoretically and practically feasible. It represents a lower cost alternative to MCSEM. Applications can be expanded to reservoir monitoring with permanent seafloor sensor arrays.

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