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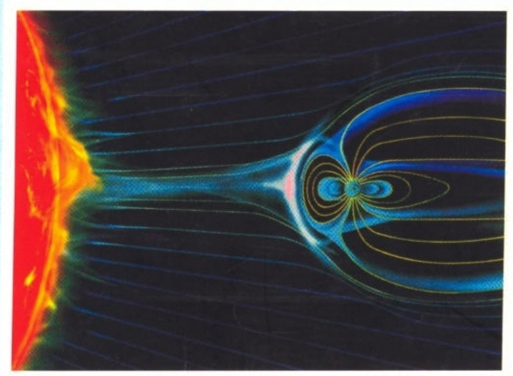

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论 文 集

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Marine Time domain controlled source electromagnetics (tCSEM™), another way to illuminate marine reservoirs

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Abstract

A decade ago, marine electromagnetics was reserved for academic applications only. Today the marine electromagnetic industry is one of the fastest growing industry with already close to 200 Million US $ revenues and numerous commercial service companies

Many marine electromagnetic surveys (> 250) have been carried out by various oil companies around the world. Most of the surveys were said to be successful, but much of the application work has been proprietary, so details are scarce. Publicity in the popular press, and in the investment community, has made this a currently fashionable topic in the industry. However, because many oil companies have little in-house EM expertise, a lot of effort is still needed to make the marine electromagnetics a routine service.

In the Western marine oilfield context, both *natural source* magnetotellurics (MMT) and *controlled source* electromagnetics (CSEM) have been used, usually in the continuous-wave mode, or frequency-domain context. For both techniques, acquisition contractors exist and several commercial instrument manufacturers are emerging. In Russia, additional electromagnetic methods such as marine time domain electromagnetics ("MTEM") and the "electrokinetic marine method" ("EMM") have been used. This *time-domain* class of techniques offers possible advantages over the frequency-domain techniques.

The essential advantage of time-domain electromagnetic techniques is that the source is a transient, *i.e.* is not active during the time interval when the (very weak) signal arrives from the subsurface. This enables detection of the subsurface signal without interference from the source; in this respect it is the same logic as used in seismic techniques. It also allows separation between the response from the ocean and the prospective subsurface formation.

We carried out several demonstration surveys: one in Western waters using a commercial CSEM system and crew and one in the Caspian using our Russian team that developed a prototype time domain nodal system. Selective examples underscore our predictive modeling results.

Introduction

Partly because of the recent mergers and acquisition in the oil industry, numerous emerging technologies for exploration, appraisal, development and production have disappeared from the market. Several of them have unique capabilities and could deliver significant values to oil companies if applied correctly. Electromagnetic methods are one of these techniques. Unfortunately they have not been routinely applied to reservoir characterization and drilling problems, despite the wide success of borehole electromagnetic methods in the oil industry. This is now changing.

Over the past decade, the academic geophysical application of marine EM has come a long way from the pioneering work of Charles Cox in the 1970's (e.g. Cox et al., 1971) to the advances of Constable and Cox (1996), Heinson et al. (2000), Yuan and Edwards (2000), and MacGregor et al. (2001). These advances, coupled with recent breakthroughs in instrumentation technology, data processing algorithms, and interpretation tools, have all made marine (and land) EM more reliable and have fueled the industry with great interest. This interest has materialized over the last eight years through the establishment of industry sponsored consortia, in house research programs and numerous proprietary surveys carried out in major offshore oil field environments worldwide.

One consortium was established in 1995 at Scripps Institution of Oceanography and University of California at Berkeley funded by the National Science Foundation, oil companies, and service companies that over time has included: Anadarko, AOA Geophysics, British Gas, BP, BHP, ChevronTexaco, EMI Instruments, ENI, ExxonMobil, GERD, Shell, and Statoil. The consortium has reached numerous milestones in instrumentation (e.g. Constable et al., 1998), interpretation technology (e.g. Hoversten et al., 1998) and applications (e.g. Hoversten et al., 2000).

Significant oil company in-house research programs have been conducted by ENI-Agip, ExxonMobil, and Statoil. The research project conducted by ENI-Agip has lead to the development of next generation technology for the commercial application of marine (natural source) MT (e.g. Zerilli, 2000, Zerilli & Botta, 2000), and the realization of pilot exploration projects in noisy seismic areas of the Mediterranean, Gulf of Mexico and the North Atlantic (e.g. Zerilli, 1999). The March 2007 issue of The Leading Edge was dedicated to CSEM.

A spin-off company (Electromagnetic Geoservices A/S (EMGS) located in Norway) that is leading the techno-transfer of the CSEM technology to full commercial service with presently over 90% market share worldwide (e.g. Eidesmo et al., 2002, Ellingsrud et al., 2002). In addition, a spin-off from the University of Southhampton, Offshore Hydrocarbon Mapping (OHM) has appeared on the market. Schlumberger acquired AOA's marine operations (AGO) and Geosystem. Another university spin-off was formed from the University of Edinburgh in the UK, MTEM, and was acquired by PGS recently. MorganStanley is predicting the marine EM market to grow to $600 million per annum by 2009.

As currently practiced, frequency based controlled source marine electromagnetics (f-CSEM) has a limiting features, which is related to the strong signal of the sea water layer. Presently, f-CSEM only works in water depths greater than ~ 2 times the target depth beneath the seafloor. Time domain electromagnetics (tCSEM™) allows us to overcome that limitation, as it works in principle at any water depth (and even dry land), as the signal generation and reception are separated in time. Based on this understanding and many years of experience and leadership in land TEM, KMS Technologies works with a Russian team, through the US Department of Energy and developed a complete marine t-CSEM™ system and field tested it in the Caspian recently. In addition, we carried out a full commercial survey with great success for a major oil company using EMGS with custom modified equipment.

A time domain system consists of a moving transmitter and remote receivers located on the ocean floor. Newer versions using in addition cabled receiver system are under development. Figure 1 shows an example of such a system. A marine transmitter is towed behind a ship along a tow line. Stationary receivers record the

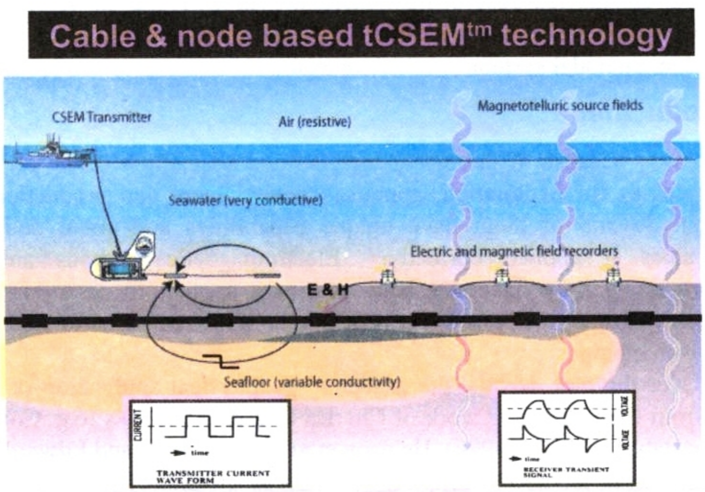

Figure 1: Sketch of marine controlled source EM survey setup.

electromagnetic field components at the ocean floor. While most receivers are nodal receivers, cabled systems are currently under development.

The same receivers can also record the response of the natural electromagnetics fields (Marine MaegnetoTellurics – MMT). The response data is then processed and interpreted in various ways. Figure 2 shows the modeled response from a transmitter at the sea floor with the sea being the upper half space and the Earth being the lower half space. Here, you can clearly see that with increasing resistivity the separation between ocean response and Earth response (Sea bottom response in the figure) becomes larger.

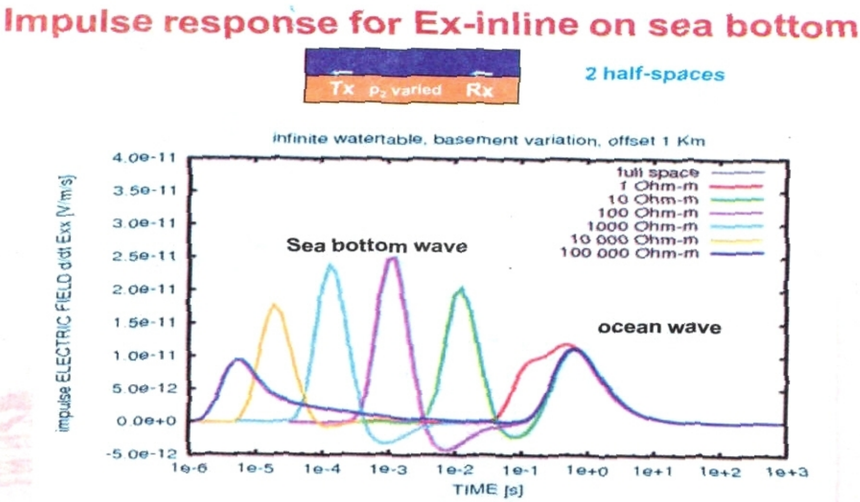

Figure 2: **Electric field response (impulse response) for 2 half spaces with the top being the sea water. The source and receiver are at the bottom of the sea water. Varied is the resistivity of the lower half space. Note that increasing resistivity of the bottom half space will increase the separation between water response and earth response.**

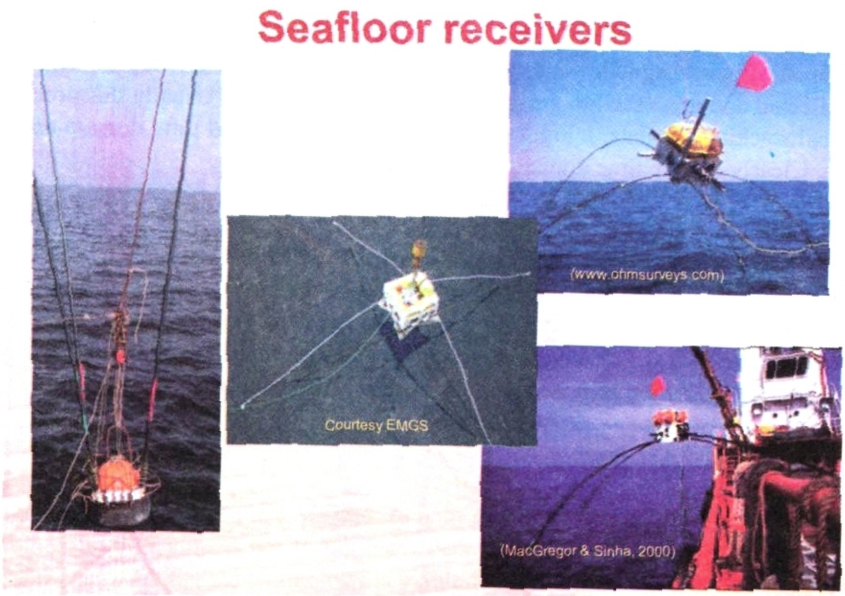

Figure 3: **Examples of marine seafloor receivers.**

Figure 3 shows an example of sea floor receivers. We used the EMGS receivers in the center and the receivers on the left for time domain acquisition.

Figure 4: Examples of marine transmitter.

Figure 4 shows an example for marine transmitters. Again we used the EMGS transmitter on the top right and our time domain transmitter at the bottom for time domain surveys.

Work Flow

As with all electromagnetic data, the signal-to-noise ratio is an issue. The data must be carefully collected and processed to get a good signal-to-noise ratio. Usually this processing is done before vertical stacking the data. Figure 5 shows examples for land time domain and marine time domain data. Clearly marine time domain EM data looks a lot better.

Field test results

Over the past years we carried out several marine tCSEM ™ surveys. Unfortunately, due to the proprietary nature of the data we can only show some results from the field trial with the Russian system. Figure 6 shows the inversion results for two source position on either side of the towline above the receiver. The inversion results are comparable indicating that the data quality is sufficient. In addition they match the geologic section that is known.

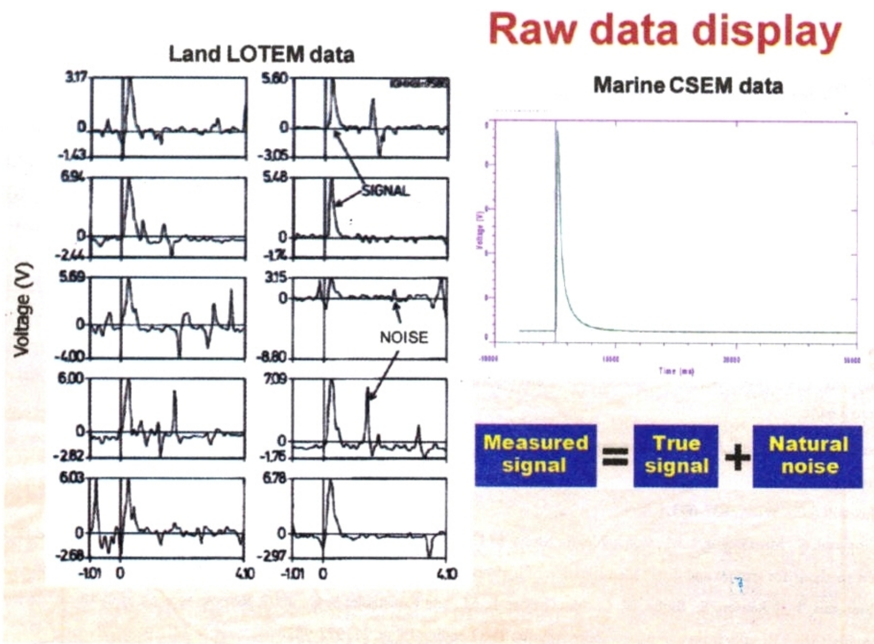

Figure 5: Raw field data examples for land (left) and marine transients.

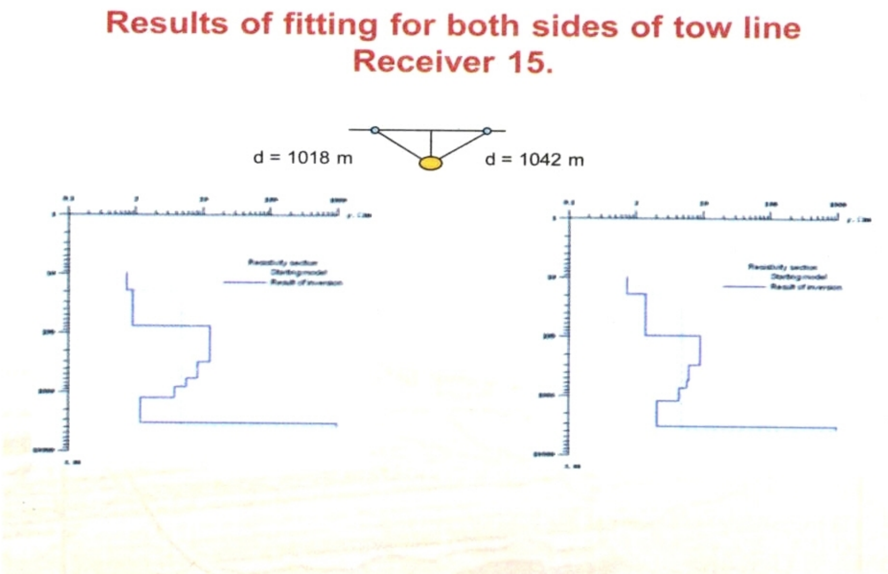

Figure 6: Two inversion results for both sides of the tow line for marine tCSEM™ data.

Conclusion

A few years ago, it was not clear if time domain electromagnetic could be used for marine applications. Since, we developed the technology, data processing algorithms, and interpretation methods, and demonstrated that the technology is viable for shallow and deep water applications.

Time domain CSEM (tCSEM™) allows a clear separation between the ocean wave and the Earth response, thus it is not hindered as fCSEM to operate in shallow waters.

Field results have shown that the data is stable and all components can be interpreted effectively.

Acknowledgments

A project of this scale is always a team effort. We thank our colleagues in KMS Technologies (N. Allegar, T. Hanstein, S.L. Helwig, Y. Martinez, C.H. Stoyer, and G. Yu) and an unnamed major oil company. Support for the Russian development came from the US Department of Energy. M. Caplan was the project leader and kept the project moving forward. The project in Russia was lead by A. Tulupov with the following team members (V. Kyaspar, E. Lisitsyn and others)

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