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Marine Time Domain CSEM - The First Two Years of Experience

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SUMMARY

The CSEM method can measure and understand the fluid content and its changes in a pore space. The method is based on detecting the resistivity contrast of the resistive reservoir fluid to its conductive surrounding media. Recent advances in electronics now make it possible to reliably collect marine time domain electromagnetic data, or tCSEM . As the tCSEM method records only the Earth s response and is collected in a style similar to seismic, it can be robustly integrated with seismic data. By recording in the absence of the active source, the airwave phenomena also can potentially be isolated from the subsurface response in shallow water. Commercially available nodal systems have successfully collected marine tCSEM data and examples are discussed. New cable based systems are under development which contain densely spaced sensors for recording both the electric and magnetic fields. Combining cable and nodal systems will provide for more robust integration with seismic and borehole measurements.

Introduction. For greater than 40 years, the seismic method has been the geophysical workhorse of the oil industry. While it offers the best description of the reservoir shape and stratigraphy, it falls short on describing the fluid properties of the pore space as elastic waves predominantly travel through the rock matrix. In particular, many of the changes that take place during the production life of a reservoir do not exhibit a detectable acoustic property change. Recently, marine controlled-source electromagnetic (CSEM) methods have found hydrocarbons after their response to thin resistors was understood (Eidesmo et al. 2002). The use of marine CSEM has gained momentum, and now just may become the most significant technology development in oil exploration since the advent of 3D seismic.

Most service providers of CSEM technology transmit a frequency-targeted source into the earth, often this is referred to as frequency domain CSEM or fCSEM. This source is almost always a continuous square-wave and both the active source and the subsurface response are recorded at nodes distributed along the seafloor. As a consequence, the much larger primary field often swamps the weaker Earth response (secondary field), particularly at short source receiver offsets and in water depths of less than 200 m. This shallow water affect is commonly called the airwave phenomena. Time domain methods, however, offer a solution to this shallow water limitation (Weiss 2007, Avdeeva et. al. 2007).

Time variant magnetic fields of either natural or artificial origin cause eddy currents within the conductive sediment layers. (Strack 1992, 1999) These eddy currents are time variant as well and they cause a secondary EM-field that can be sensed with magnetic or electric sensors placed on the sea floor or in the wellbore. With time-domain, or transient CSEM (tCSEM™), one transmits a current into the Earth and charges the subsurface. The current is then switched off and the charge drains from the Earth. Transient responses to this artificial electric field are then measured by sensors that record both the electric and magnetic components. The duration of the "on" and "off" time of the source is optimized to each particular problem. Additionally, every current switch represents the initiation time, or time zero, for a given transient. Figure 1 shows a typical time domain source waveform and the resulting electric and magnetic fields.

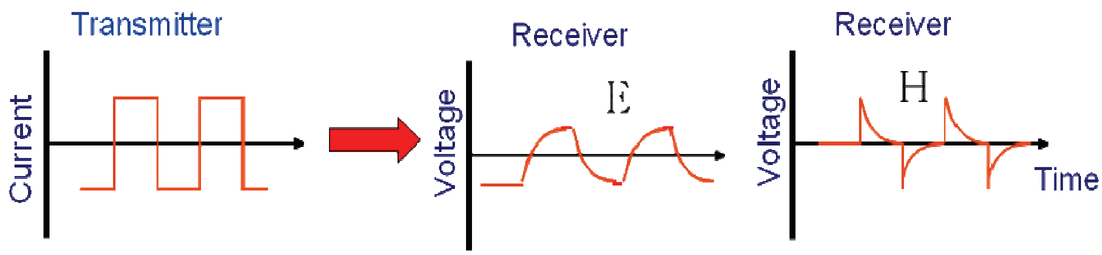

Fig. 1: Time domain source waveform and the rsulting electric and magnetic fields recorded at the receivers.

Like seismic, which synchronizes the recorded response with its impulsive source, tCSEM™ transients have a start and finish that correlate to current changes in the source. For each source receiver offset, we obtain a unique transient and we can leverage this time-offset relationship in our processing and interpretation of the data. As time-domain CSEM is collected in a style similar to the seismic it can be robustly integrated with seismic data and utilize the processing strengths of seismic where one can apply noise suppression, signal enhancement (stacking and filtering) and imaging algorithms. The integration with seismic method is particularly important, as the EM method is based on the physics of diffusion and is of much lower natural resolution than that of seismic which is based on acoustic/elastic wave propagation.

As the tCSEM™ method records only the Earth's response and is broadband, it has the potential to detect weak reservoir responses due to low resistivity contrast or complex shape. As mentioned earlier, by recording in the absence of the active source, the airwave phenomena can potentially be isolated from the subsurface response in shallow water. As can be seen in Figure 2, at far offsets the airwave has come and gone due to its fast diffusion velocity and the subsurface response occurs later in the transient.

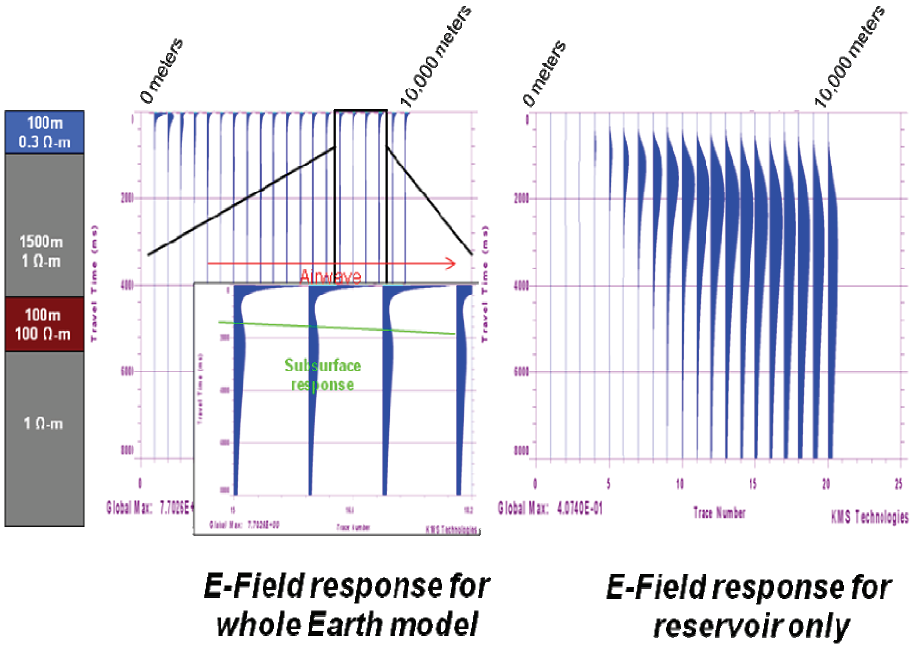

Fig. 2: Time domain 1D forward model for a typical reservoir in shallow water. Transients are treated like seismic traces and create a common receiver gather. The airwave phenomena can be shown to separate from the subsurface response as a function of time and offset in shallow water.

Understanding the movement of water-floods and steam-floods has historically been recognized as the largest prize in reservoir dynamics monitoring. With proper surface and down hole measurements, one can potentially determine sweep patterns, sense pressure depletion, or identify residual or by-passed pay and also optimize production performance on a predictive basis. The goal is now to integrate nodal and cable based acquisition systems with down hole measurements and seismic to provide the optimal set of EM measurements.

Nodal acquisition. In the shallow (70 m to 1110 m) waters of the Mediterranean Sea off the coast of Egypt, BP collected the first commercial tCSEM™ survey and announced that "time domain CSEM reveals known reservoirs where conventional CSEM is not successful" (Thomsen et.al. 2007). The survey for BP was carried out by Electromagnetic Geoservices (EMGS) under the scientific advice of KMS Technologies. The latest generation of commercial CSEM hardware was utilized to generate the highest quality time domain CSEM data with the same operational efficiency and overhead as that of a fCSEM survey. This was made possible through careful system response evaluation and cross calibration of the hardware. To date, multiple time domain CSEM have been collected by industry and have shown that time domain will likely have the same range of applications as conventional CSEM, from reconnaissance to prospect specific.

Through the IPP program (The Initiative for Proliferation Prevention Program) of the US Department of Energy, KMS Technologies became the exclusive commercialization partner in the West for marine time domain electromagnetic technology developed in Russia. In 2007, KMS Technologies and its IPP partners successfully collected tCSEM™ data in the Caspian Sea in water depths ranging from 15-20 m with a specialized prototype time domain system. Figure 3 shows the containerized source on the back deck of the survey vessel. Figure 4 represents the inversion results for a transient from the Caspian data, recorded at an offset of 1199 m. The resultant inversion produces a robust fit to the anticipated subsurface resistivity

Fig. 3: CSEM transmitter winch on the back deck during the Caspian survey.

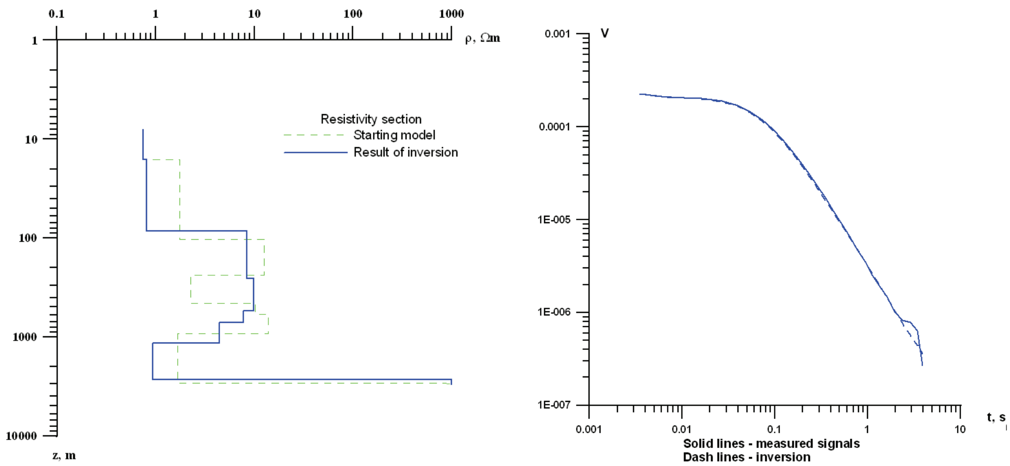

Fig. 4: Inversion results for transient recorded at 1199 m offset.

Cable acquisition. For tighter acquisition and appraisal and production applications the nodal system is augmented by a cabled system, presently under development. The tCSEM™ ocean bottom cable system will record both electric and magnetic field measurements and will provide denser sensor spacing than is typically afforded by nodal systems alone. Figure 5 portrays one scenario for an integrated node and cable based acquisition system. Dense sensor spacing is particularly important since lateral resolution of the tCSEM™ method is scalable to it. In other words, the denser the receiver spacing, the better your lateral resolution and the integration with single well and borehole-to-surface measurements. As the cable system has a very high degree of precision for positioning repeated deployments will advance the use of EM technology for reservoir monitoring through the acquisition of time lapse surveys. Additionally, the tCSEM™ system will feature buoy based recording and real time quality control of data, and is deployable with VSO seismic cable system to provide a direct integration with the seismic method.

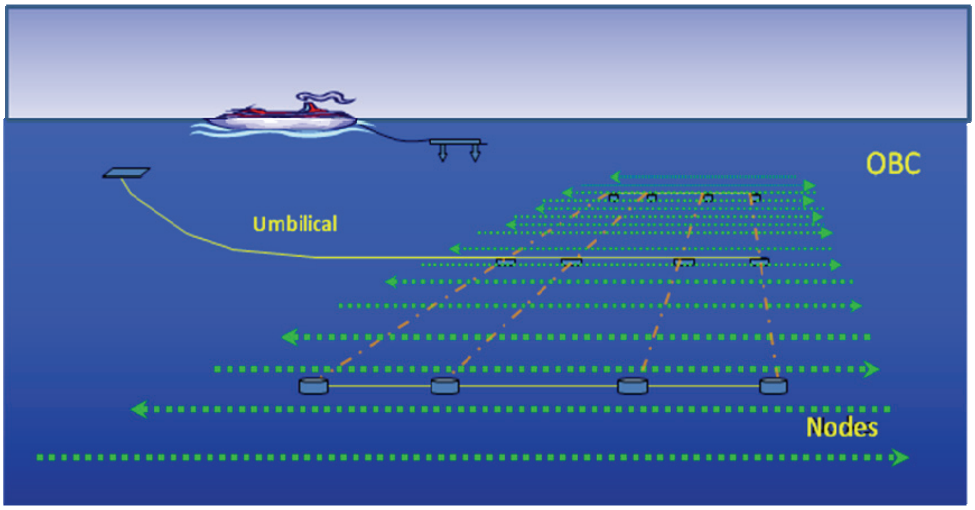

Fig. 5: Integrated node and cable acquisition for EM reservoir illumination.

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