Chopra, S., Strack, K. – M., Esmersoy, C. &
Allegar, N.

2007

Introduction to this special section: CSEM

The Leading Edge 26, 3, 323 – 325

Introduction to this special section: CSEM

The marine controlled-source electromagnetic (CSEM) method for finding hydrocarbons was introduced in the 1980s but only found commercial acceptance about five years ago. However, this brief time has been long enough for this method to earn the label of being possibly the most significant technology in oil exploration since 3D seismic. Indeed, the field has grown so rapidly that it will be the subject of simultaneously published special sections in both SEG journals—perhaps an unprecedented occurrence. The March-April issue of GEOPHYSICS will have 10 peer-reviewed papers on CSEM. TLE's special section presents several case studies that show the value of the technology in reducing risk for exploration and development projects. Most CSEM surveys are marine but CSEM is also done on land, mainly in Russia and China. Marine CSEM is mostly done in the frequency domain; land activities are split between frequency domain and time domain.

Several research groups (Scripps Institute of Oceanography, The University of Toronto, Cambridge University, and Southampton University) have been experimenting with CSEM measurements since the early 1980s as have companies like ExxonMobil (which has developed its own brand of CSEM technology, Remote Reservoir Resistivity Mapping), Statoil, and ENI. Today, the major providers of CSEM data acquisition and processing are Electromagnetic Geoservices (EMGS), Offshore Hydrocarbon Mapping (OHM), and AGO, a Schlumberger company. It is estimated that in excess of 250 surveys have been carried out worldwide (including the North Sea, northwest Europe, West Africa, North and South America, India, the Far East, the Mediterranean, and the Gulf of Mexico). These surveys have been collected in different geologic settings and a wide variety of water depths (Figure 1).

CSEM surveys have been historically designed as one or more 2D lines across a targeted resistor. The positions of these receiver lines are predetermined and based on forward modeling. In recent years, more complex survey designs have been used to expand the CSEM's imaging capabilities and extend its use to more difficult targets.

The basic idea behind CSEM surveying for hydrocarbons is simple. The difference in conductivity between water-saturated shale and sandstone is usually small (resistivity 1–2 Ω–m). However, if the sandstone were saturated with oil or gas, its resistivity increases significantly (10 to several hundred Ω–m). Thus, there is often a high-resistivity contrast between hydrocarbon-charged reservoirs and the surrounding water-saturated sediments.

For CSEM surveying, a controlled electromagnetic source in the form of a horizontal electric dipole is towed on a neutrally buoyant streamer above an array of receivers deployed on the seafloor. The best electromagnetic component to "see this" are the inline (i.e., parallel with the source dipole direction) electric fields. The source continuously emits a periodic low-frequency electromagnetic signal which propagates in all directions. Some radiated energy travels through the water column to the water/air interface and is referred to as airwave. Some of these airwaves travel along the water/air interface essentially at the speed of light and then back through the water to the receivers. The receivers therefore record both the direct waves traveling from source-to-receiver, and refracted energy from the water/air interface and the subsurface formations. These receivers on the seafloor measure both amplitude and phase of a signal that results from the resistivity structure of the subsurface. The electromagnetic energy is rapidly attenuated in the conductive seafloor sediments as their pore spaces are water-filled in shallow water, so the airwave can overwhelm the signal from subsurface formations. As a result, CSEM surveying has historically been confined to deepwater. But recent advances in data processing and modeling technologies are allowing extension into shallower waters.

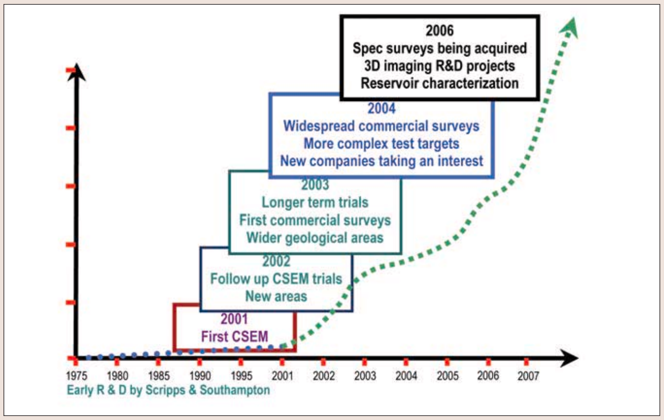

Figure 1. *Evolution of commercial CSEM. Vertical axis is number of surveys (in intervals of 50).*

The emitted electromagnetic radiation decays exponentially in a conductive medium, the decay rate increasing with frequency. As a result, the resolution length increases with the depth to the target. This is in contrast to seismic waves whose amplitudes decay geometrically as they propagate, and their resolution always remains proportional to their wavelengths which are essentially unaffected by the propagation. Consequently, CSEM is considered a low-resolution technique and must be integrated with higher-resolution methods.

An electromagnetic field requires both magnetic and electric fields, so the recorded signals have electric and magnetic components. The data are recorded as a time series and often processed in the frequency domain. Similar to the historic development of magnetotellurics noise reduction, it is anticipated that more time-domain processing will be seen in the future. As the receivers fall freely on the seafloor, their orientations are typically not known and are derived from the recorded vector electric and/or magnetic data. Suppression of the airwave and noise reduction is another aspect of CSEM data processing that is challenging but where the quality of the data and its interpretation could be improved. In fact, excellent examples of how to overcome this problem already exist.

One interpretation product, a magnitude versus offset display (MVO), consists of the normalized amplitudes at individual frequencies of the electric field signals (magnitude) as a function of the offset (i.e., the distance between transmitter and receiver). The normalization is with respect to a reference receiver from an area that represents the background resistivity profile without the targeted resistor (i.e., the hydrocarbon reservoir). A similar approach can be taken in analyzing the phase versus offset data (PVO). This approach may be applied to both the electric and magnetic components. So, by studying variations in the received signal, as the electromagnetic source is moved along the array of receivers, resistivity contrasts in the subsurface can be evaluated.

Marine magnetotelluric (MT) data are often acquired with CSEM data and, because these data are sensitive to conductivity, they can be an effective complement to CSEM.

The time domain (transient) method distinguishes itself from the others in that it acquires wider-band data in the time domain and analyzes the transient signal. The method works by injecting a square wave (sometime coded as pseudo random binary sequence) into the ground and measuring the response at electromagnetic receivers along a line. This section shows only some land examples from India and China but we anticipate some marine examples in the future.

For land data, since there is no water to diffuse the airwave effect, the direct airwave arrives almost instantaneously at the receivers. The Earth's response coming from the diffused electromagnetic energy appears later in time and, therefore, the airwave and Earth responses are separable in time. This method is proving useful for tar sand projects in Alberta, where thick oil sands, resistive and close to the surface, cause a large anomaly. By using all electromagnetic field components, it can effectively reveal conductive and resistive targets and be used in combination with hydrocarbon "charge" effects (e.g., induced polarization).

As CSEM is fundamentally a detector of resistivity contrasts, it can be used not only to identify hydrocarbons, but also hydrates and a range of high-resistivity lithologies. For example, salt, basalt, limestones, tight (cemented) sediments, gas hydrates, etc. all exhibit high resistivities and so could produce CSEM anomalies if there is sufficient resistivity contrast with the surrounding rock. Thus, interpretation of CSEM anomalies could be ambiguous without use of proper geologic constraints. Additionally, the dimensionality of the body can have a large impact on the recorded signal. In view of this, a modeling exercise is usually done prior to each survey to understand the imaging problem, and to optimize the survey parameters. These parameters can include source frequency or time window, source azimuth, and receiver positions. All CSEM methods used commercially employ offsets often significantly larger than exploration depth and thus 3D modeling is important for EM data interpretation and survey design.

Seismic data, based on the acoustic impedance contrasts in the subsurface, can offer high-resolution images of the geologic structures that could possibly contain hydrocarbons. However, the presence of hydrocarbons is difficult to confirm before drilling, because as oil replaces brine in a reservoir (resulting in a change of electrical conductivity of as much as three orders of magnitude), this change may have little effect on acoustic impedance and may not be detected convincingly on seismic. Seismic AVO responses (and other attributes) may be caused by fluid or lithologic variations and it is difficult to distinguish between them. As stated above, CSEM data on the other hand are primarily sensitive to fluid properties and their distribution within a reservoir, but since this methodology is based on the physics of diffusion of electromagnetic fields in the Earth rather than wave propagation, it is of a much lower resolution than seismic. It thus seems logical to leverage the strengths of each method, such that their combination helps reduce ambiguity and risk. Consequently, CSEM data are usually overlain in color on depth-migrated seismic sections, often after having gone through either a depth migration or inversion scheme. Such sections indicate the presence of hydrocarbons in relation to the potential traps. This combined procedure finds a useful application for prospects involving stratigraphic plays which often have feeble or no seismic expression. Another interesting application is in thrust areas, where one may encounter trap leakage due to faulting or seal failure, and be associated with low hydrocarbon saturation. CSEM data would indicate anomalies only where there is high hydrocarbon saturation. For this very reason, CSEM can be a very cost-effective way of high grading different exploration projects and leads.

Although most CSEM applications reported today are in exploration, we hope that in the future, CSEM methods will focus on development and production as well. Efforts are under way to integrate seismic, CSEM, well-log data, and other relevant data (gravity, magnetic, etc.) These efforts will ultimately increase the reliability and precision of the method and take the technology to the next level.

The seven papers in this special section cover a range of topics addressing different aspects of applying CSEM.

Colombo and De Stefano integrate various data types using joint inversion. In addition to showing a thorough forward modeling example, they indicate several potential data results. They have already applied this method successfully at various places around the globe. They are targeting their results for the improvement of PSDM.

Dell'Aversana discusses the use of electromagnetic attributes for improving the comprehension of any given data set before taking up any multidimensional inversion. These attributes include the gradient of inline electric fields, the integral of the MVO curves, the semblance with respect to a reference MVO trend measured at well locations, and the instantaneous frequency of the data (phase derivative with offset). This approach is demonstrated by application to real data sets and by obtaining confirmation from drilling results.

He et al. illustrate in several case histories how a time domain source excitation can be used to simultaneously carry out frequency domain, time domain, and induced polarization measurements. Thus, they are optimizing the use of the different sensitivities of the different methods. Their results correlate well with seismic which is used also in the interpretations. They have a high success rate using this technique to find additional hydrocarbon reservoirs.

Hokstad and Rosten describe the relationships between depth migration of seismic data and frequency-domain CSEM data, highlighting the similarities and dissimilarities between the two processes. Though their discussion and example is restricted to the marine case, the authors claim that the theory and methodology are applicable to land CSEM methods as well as transient EM sources.

Johansen et al. discuss how marine CSEM data (in this case, seabed logging, a proprietary technique of Statoil) can be interpreted on a standalone basis and integrated with seismic data. They introduce a depth-conversion technique that can be used in the initial phase of interpretation, and explain the use of depth migration for estimating the lateral extent and depth of prospects. They finally suggest a classification of system for CSEM anomalies.

MacGregor et al. demonstrate that the analysis of the CSEM survey combined with the existing seismic data allowed a more robust and in-depth understanding of the Ernest prospect in North Falkland Basin. This will help the license holder make confident decisions in its exploration process.

Strack and Pandey describe the use of transient electromagnetics for land exploration. They use electric and magnetic fields combined to delineate prospective sediments under basalt cover. The interpretation includes independent and joint inversions and 3D modeling to understand anomalous structures. A well drilled several years after the survey confirmed the survey results.

We thank all the authors for their valuable contributions and hope that the *TLE* readers find the developments of this increasingly important technology both informative and interesting. TLE

—*Satinder Chopra*
Calgary, Canada

—*Kurt Strack, Cengiz Esmersoy, and Norman Allegar*
Houston, USA

KMS Technologies – KJT Enterprises Inc.
6420 Richmond Ave., Suite 610
Houston, Texas, 77057, USA
Tel: 713.532.8144

info@kmstechnologies.com

Please visit us
http://www.kmstechnologies.com//