EM is becoming a major attraction

Norman Allegar of KMS Technologies explains how this Houston-based company is emerging as one of the players in the market for electromagnetic survey technology.

The company was founded in 1999 with a vision to take electromagnetic (EM) sensors to the permanent monitoring market and to establish it as a routine tool in hydrocarbon exploration and appraisal. It was recognized early on that reservoir monitoring systems could offer high value to operators, but at the time, existing seismic-based methods could not convincingly deliver the solutions needed which required knowledge of the reservoir fluid. While there was serious push and support from major oil companies, technology was the motivator for the company.

Advances in electronics had made it possible to combine surface and borehole electromagnetic measurements with 3D seismic and link fluid and porosity monitoring with an exact location in the three-dimensional space. KMS was able to accomplish this through EM technologies that offer full field reservoir identification, delineation, and monitoring through the use of sensors and methodologies. Company staff had used these technologies since the early eighties but dropped the borehole components - the key elements linking the reservoir to surface measurements - several times due to sensor realization limitations.

Now the focus is on three core areas: permanent sensors to monitor production efficiency, marine electromagnetic technology as a direct hydrocarbon indicator, and borehole electromagnetics for geosteering of the drill bit to provide deep reading resistivity measurements. Together with various alliance partners the company has been developing permanent or semi-permanent EM, gravity (density), and seismic sensors that can be integrated into a monitoring system. The sensors can be placed both in the borehole and at the surface to optimize resolution and spatial coverage.

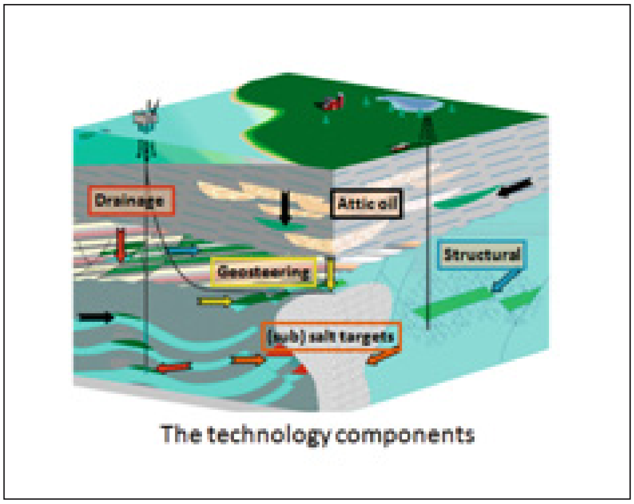

Figure 1 *Earth model illustrating high value problems targeted by KMS Technologies.*

A priority today is marine time domain CSEM (tCSEM) technology and robust integration with the seismic method. To include borehole measurements a deep reading TEM (transient electromagnetics) system has been developed for geosteering. The tool is intended to provide high resolution resistivity measurements of the surrounding formation up to several tens of metres away. It is designed to link directly to single well seismic. The power of this approach is in the ability to integrate varied measurements into a common Earth model, as shown in Figure 1, to solve a set of high value problems in the industry. These include: sub-salt imaging, production monitoring, geosteering, finding by-passed oil, and structural hydrocarbon recognition away from the wellbore.

Sensor Capability	Resolving Power				
	Distance	Fluid	Surface-to-surface	Borehole-to-surface	Borehole
Seismic	Excellent	Poor	Excellent	Excellent	Ok (more noise)
EM	Ok (5% of depth)	Excellent (water to HC)	Ok	Excellent	Excellent (less noise & distance)
Gravity	Poor	Ok (oil to gas)	Poor	Poor (no source)	Poor (no source)
Strongest Synergy	Seismic	EM/seismic	Seismic/EM/ gravity	Seismic/EM	Seismic/EM/ gravity

Table 1 *Comparison of sensor capability to resolving power. Seismic and EM methods complement each other and these two techniques used in unison offer the highest value.*

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Why electromagnetics?

The value of EM methods lies in the ability to measure and understand the fluid content in a pore space. Physically, the detection of a reservoir is based on the resistivity contrast of the resistive reservoir to its conductive surrounding. Time variant magnetic fields of either natural or artificial origin cause eddy currents within the conductive sediment layers. As these eddy currents are time variant as well, they cause a secondary EM field that can be sensed with magnetic or electric sensors placed on the sea floor or in the wellbore.

Seismic has enjoyed a long history as 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 life of a reservoir do not exhibit a detectable acoustic change. There is significant value to be realized by combining the strengths of both seismic and EM into one unified approach and focusing on delivering to the market an integrated EM and seismic solution for both borehole and surface measurements. The goal is to now integrate electromagnetics into the exploration life cycle and leverage its strengths in reservoir characterization, production monitoring, and ultimately optimized abandonment.

Permanent sensor technology for reservoir monitoring

Understanding the movement of water-floods and steam-floods has historically been recognized as the largest prize in reservoir monitoring. The economic worth of any monitoring technology resides in its ability to uniquely detect the reservoir property that both changes over time and can be attributable to reservoir performance. With such proper measurements, one can potentially determine sweep patterns, sense pressure depletion, or identify residual or by-passed pay and also optimized production performance on a predictive basis. Based on strong positive results from a study of the single-well deep reading technology value, a combination of seismic and time domain EM offers the optimal combination of permanent (in the well bore or at the surface) sensors to monitor reservoir production. See Table 1 for analysis of sensor capabilities. While EM measurements can detect changes in fluid properties where acoustic methods can not, integration of EM with seismic is key to the overall direction of linking fluid and porosity monitoring in the three-dimensional space. Placing sensors in the wellbore not only at the surface is critical to providing the resolution needed for an effective monitoring programme.

Modelling studies routinely indicate a five-fold increase in sensitivity (to changes in fluid saturation/resistivity) over

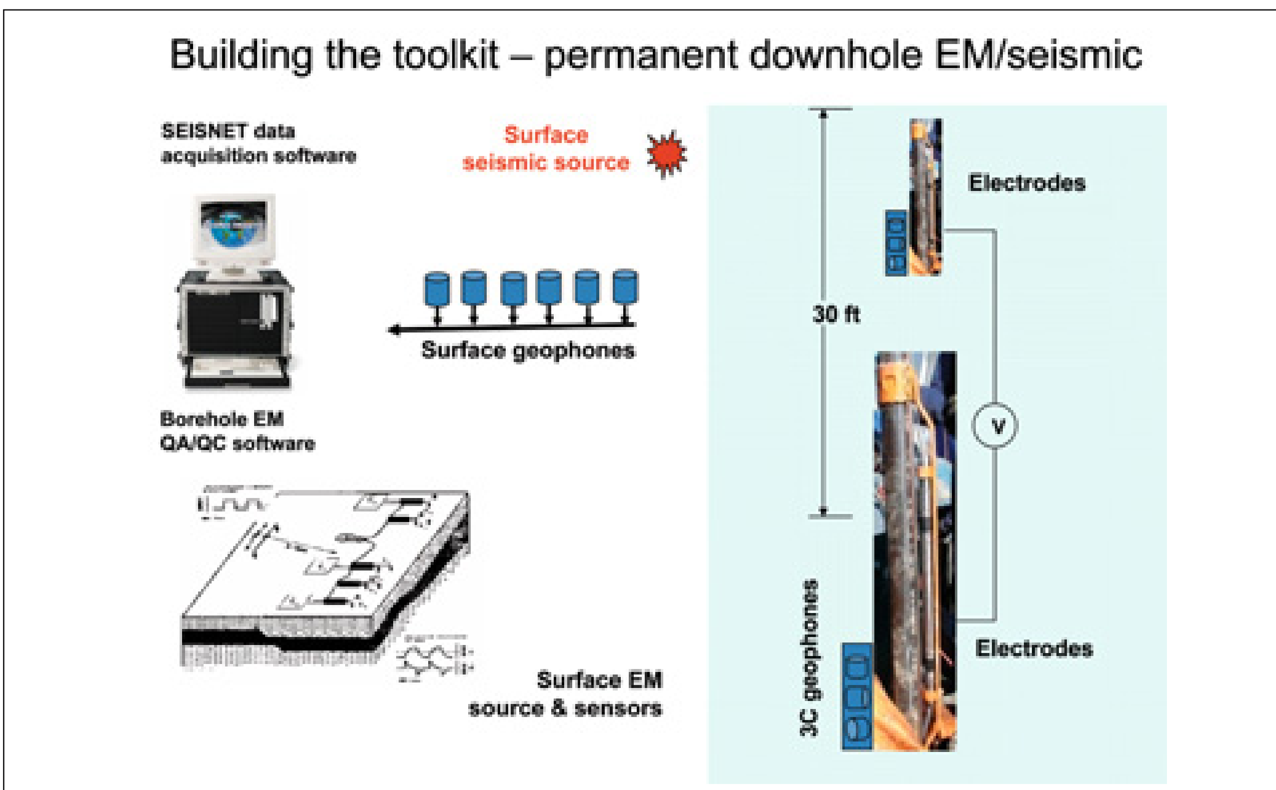

Figure 2 *Generalized schematic showing the linkages of borehole and surface measurements of EM and seismic. Recording in the borehole provides optimal resolution while recording at the surface provides areal coverage. System integration is the key.*

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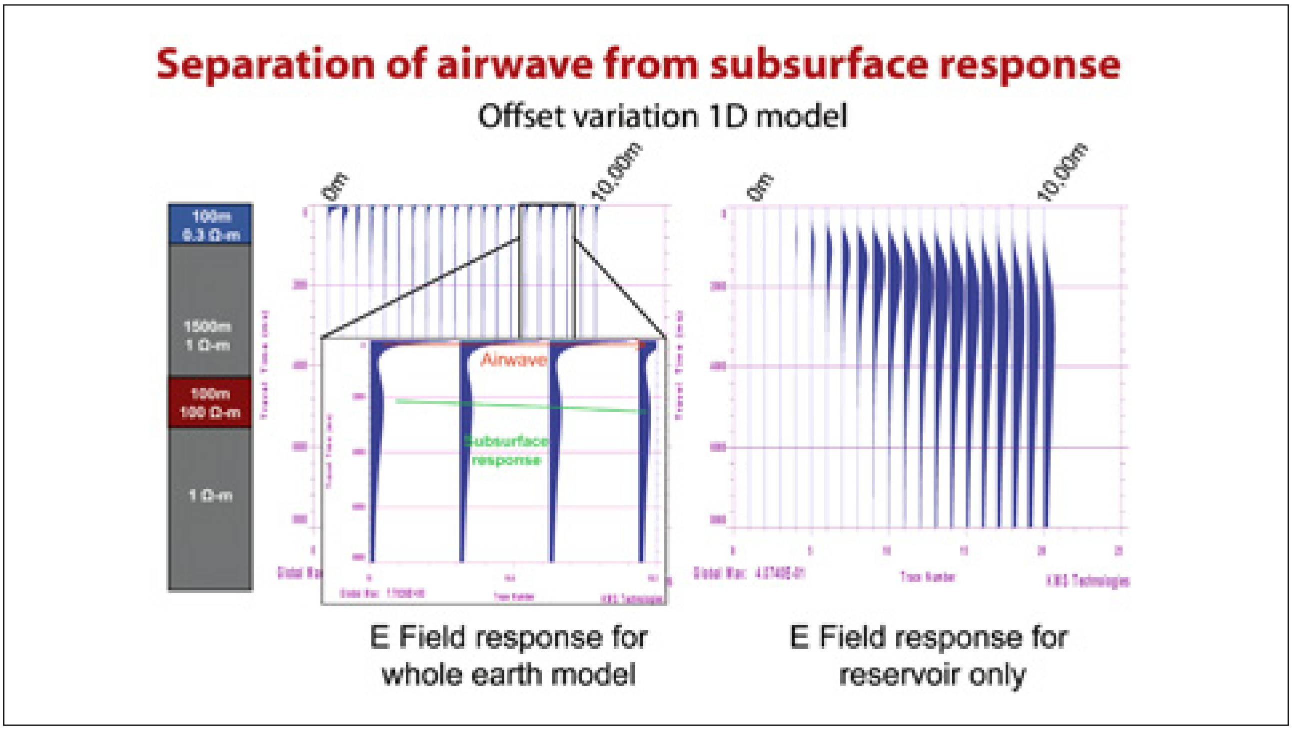

Figure 3 *Time domain 1D forward model for a typical reservoir in shallow water. Transients are treated like seismic traces and create a common receiver gather. The airwave phenomena can be shown to separate from the subsurface response as a function of time and offset in shallow water.*

surface EM when receivers are placed in the borehole. Engineering studies to understand the technical challenges and to assess the operational feasibility and design have been completed and KMS is currently looking together with its commercialization partner WellDynamics for a field trial. Figure 2 provides an overview of how such a system will work. Ultimately, integrating the borehole and surface EM measurements with seismic will give the reservoir engineer a monitoring tool that utilizes the imaging strengths of seismic and the fluid detection capabilities of EM.

Marine CSEM

Five years ago, the marketplace began its first tentative forays into the application of marine controlled-source electromagnetic (CSEM) methods to finding hydrocarbons. Since then, the use of marine CSEM has gained momentum, and just may become the most significant technology development in oil exploration since the advent of 3D seismic.

The beauty of marine CSEM lies in its ability to measure and understand the fluid content in a pore space without having to first drill a well. As resistors warp an electric field, in marine CSEM applications we use a horizontal electric dipole - an active ‘controlled-source’- to impart an artificial electric field into the Earth. High resistivity lithologies and pore fluids are the resistors that then alter this artificial electric field and seafloor receivers are used to record those changes.

Most 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, particularly at short source receiver offsets and in water depths of less than 200 m.

KMS Technologies began its involvement in marine CSEM in 2001, at a time when few in the industry would believe that time domain methods could be taken offshore. Through the

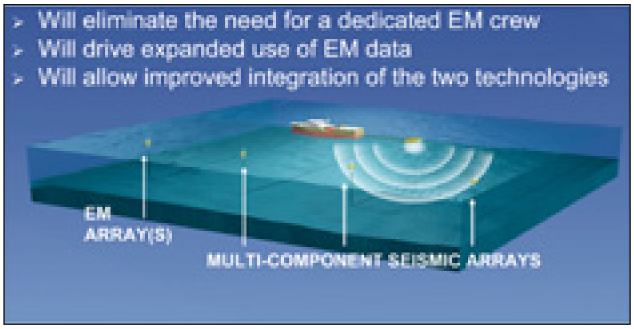

Figure 4 *OBC style EM acquisition, deployed like seismic OBC. This scheme offers strong synergies in acquisition and data collection between seismic and EM.*

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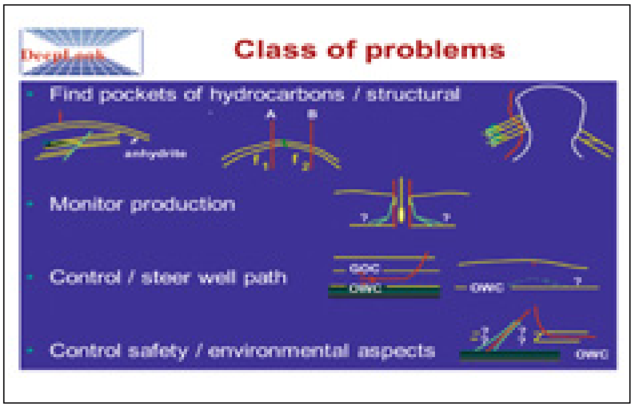

Figure 5 *Deep reading resistivity tools offer significant impact to the industry, ranging from better hydrocarbon evaluation to geosteering and LWD applications.*

IPP program (Initiative for Proliferation Prevention Program) of the US Department of Energy, KMS became the exclusive commercialization partner for recording marine time domain electromagnetic technology developed in Russia, patented as time-domain marine CSEM (tCSEM). In 2007, KMS 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.

With time-domain, or transient, CSEM, we transmit a current into the Earth and charge the subsurface. The current is then switched off and the charge drains from the earth. The duration of these 'on' and 'off' times is optimized to each particular problem. Transient responses to this artificial electric field are then measured by sensors that record both the electric and magnetic components. Every current switch represents the initiation time, or time zero, for a given transient. 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 processing and interpretation of the data.

As time-domain CSEM is collected in a style similar to seismic it can be robustly integrated with seismic and utilize the processing strengths of seismic where one can apply noise suppression, signal enhancement, and imaging algorithms. The integration with seismic 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 wave propagation.

As the 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. Another benefit of recording in the absence of the active source is that the airwave phenomena can potentially be separated from the subsurface response in shallow water. At far offsets the airwave has come and gone due to its fast diffusion velocity and the subsurface response occurs later in the transient. In the modelling example in Figure 3, one can see how the subsurface response separates from the airwave phenomena as a function of time and offset

In the shallow (70 m to 1110 m) waters of the Mediterranean Sea off the coast of Egypt. BP announced in its 2007 SEG Recent Advances and Road Ahead talk that 'time domain CSEM reveals known reservoirs where conventional CSEM is not successful'. One can imagine taking the tCSEM method into the shallow waters of the world's known petroleum provinces or into new frontiers areas such as the Arctic Shelf. The survey for BP was carried out with a customized commercial CSEM system. Electromagnetic Geoservices (EMGS) acquired the data and this led to collaboration with the company. It allowed KMS Technologies to bring tCSEM to the market place. The latest generation of EMGS's CSEM hardware was optimized to generate the highest quality time domain data with the same operational efficiency.

Cable-based acquisition system

In April of 2007, the company signed an exclusive agreement with Reservoir Exploration Technology (RXT) involving use of electromagnetic technology for cable based seafloor applications. The EM cable system under development is expected to be ready for commercial utilization in early 2009 and will be deployable with RXT's VectorSeis Ocean (VSO) cable and four component sensors. The system will feature buoy based recording and real time quality control of data, providing the client with improved operational and cost

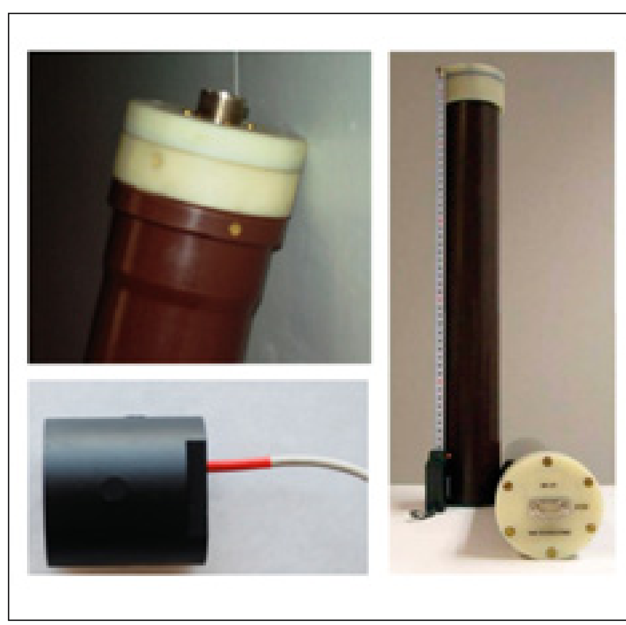

Figure 6 *Marine induction coil magnetometer, MIC-121 (upper left), Land induction coil, LIC-120 (right), and flux-gate sensor (lower left).*

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efficiencies. Innovative in-sea handling will result in efficient deployment and retrieval with minimal man-handling, thus reducing HSSE risks. The dipole source capable for horizontal and vertical operation is presently being optimized for broadcasting a transient signal and for operations in water depths ranging from 10-500 m.

The tCSEM cable system will record both electric and magnetic field measurements and will provide denser sensor spacing than is typically provided by CSEM. Completely integrated and synchronized sensors, along with special noise isolation and elimination, will ensure the highest data quality. 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 the lateral resolution and the integration with single well and borehole-to-surface measurements.

The use of cable-based tCSEM brings EM technology to reservoir monitoring through the acquisition of time-lapse surveys. The cable system has a very high degree of precision for positioning repeat deployments, similar to what has been realized by 4D seismic. Of course, by acquiring EM data in a fashion similar to seismic and in conjunction with seismic, one can obtain the best possible integration of the two technologies. Figure 4 shows a potential EM and seismic OBC deployment.

Borehole system development

With regard to time domain EM for geosteering and deep reading resistivity measurements, the tool being developed generates a magnetic field in the surrounding rock and records the induced voltages generated when the current is switched off. Perturbations in the recorded voltages are indicative of changes in resistivity. The physics are similar to the land Lotem (long offset transient EM) system or the tCSEM system.

The development started with a pilot project funded by the DeepLook consortium (a collaboration effort of the oil industry to spawn new technologies) in 2000. Since then, several feasibility phases have been successfully completed as well as a field trial with a major E&P company where resistivity changes were reliably detected tens of metres away from the tool. Figure 5 identifies many of the high value applications that can be addressed by a deep reading resistivity tool.

In order to optimize the recording of transient signals, KMS Technologies has developed proprietary induction coils which offer superior bandwidth and sensitivity. Induction coils have been specifically developed for use in collecting EM measurements. As a by product KMS also developed frequency domain marine coils. Our marine coils offer compact size and moderate weight, reducing the space required for deployment on an ocean bottom receiver and the size of necessary buoyancy units. Optimizing the frequency response of the coil for its intended purpose forced KMS to work with several expert sensor groups yielding superior sensitivity and bandwidth. In addition to marine coils, we also offer land induction coils which have been developed to measure variations of the Earth's natural magnetic field and are particularly well suited for MT. As required by MT, they cover a wide frequency range from .0001 Hz up to 1,000 Hz. As with all of our coils they show industry leading low-noise characteristics and a very stable transfer function over temperature and time. See Figure 6 for a sampling of our magnetic sensors.

Figure 7 *Field crew collecting MT stations.*

Land EM acquisition

Various EM methods describe the Earth's conductivity from shallow to much greater depth. They include CSEM and for passive measurement of the Earth's natural EM field, magnetotellurics or MT. Through our alliance with BGP, one of the world's leading geophysical service contractors, we are globally acquiring EM data (mostly MT and Lotem) for oil and geothermal exploration. KMS Technologies offers land MT and Lotem data acquisition, processing and interpretation services as well as marine MT data processing and interpretation, including 3-D MT data inversion. Integrating MT with seismic will have significant benefits in basins where seismic imaging is challenged by salt or basalt.

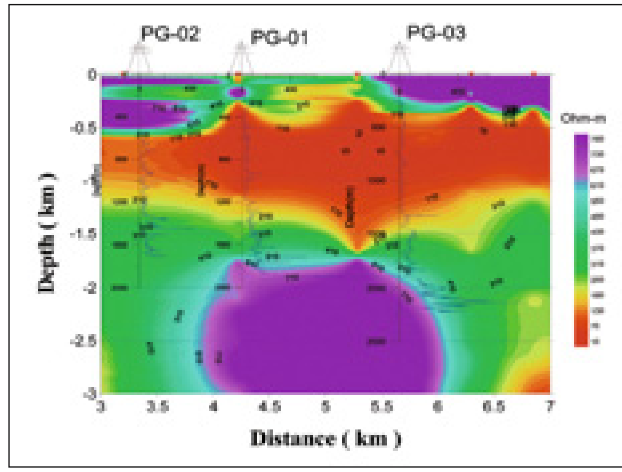

Figure 8 *Unconstrained 2D inversion of collected MT data shows strong correlation to well control. High values of apparent resistivity are colored from green to purple. Zones of high resistivity seen in the MT data are also seen in the well data.*

Conclusion

The application of electromagnetic methods has increased in the past two decades because of an improved understanding of the technology, improved availability of the services, and higher quality of the EM measurements. Historically, deep transient electromagnetic methods comprised a completely different discipline in geophysics, in spite of the fact that many of the principles are similar to the seismic one. As the hardware has evolved, however, modern day acquisition systems now can offer the ability to reliably collect time domain EM data. Robust integration with seismic, well log data, and other geophysical measurements (gravity, magnetic, etc.) will further increase the reliability and precision of the EM method. Electromagnetics can be expected to become a routine part of the exploration life cycle and will play a significant role in reservoir characterization, production monitoring, and ultimately optimized abandonment.

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