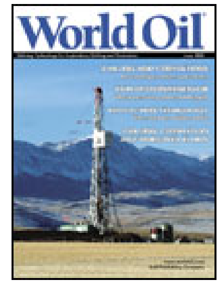
WorldOil
The oilfield information source

Exploration/ Reservoir Vol. 226 No. 6 June 2005



New EM technology offerings are growing quickly

After decades of languishing in scientific use, a variety of geo-electromagnetic techniques are coming into the commercial arena.

Perry A. Fischer, Editor

Electromagnetic-field methods, broadly called geo-electromagnetic, can be divided into two categories: passive magnetotellurics (MT) and active electromagnetic (EM) logging. While MT of various types is making headway, it's EM logging that has seen an explosion in the past five years. The reasons for this seem to be a technology whose time has come: a group of scientists, all thinking independently, but along the same lines, combined with some competition, when Statoil and ExxonMobil inadvertently discovered they were in a race.

Part of the answer is that the cost, weight, and sensitivity of various electronic components have gradually improved over the years. Another reason is that this technology has had problems in shallow water, but can work quite well in deep water, where well costs add an extra incentive to use new methods. In addition, the precise geometry, signal timing, mathematics and computer algorithms that process that data have greatly improved as well. An overview of what these technologies are, their status, and some field examples are discussed.

INTRODUCTION

There have been comings and goings in many exploration methods. The reasons for why these cycles occur vary and can change rather abruptly. Sometimes, it's because a newer technology takes all the attention, such as 3D seismic, along with the budget dollars. Sometimes, it's due to good or bad marketing, or because a champion was able to convince one company to take the risk and fund the research. And of course, luck always plays a role in exploration success.

Determining the success of various exploration methods is always statistical in nature. When that is compounded by the fact that they may be highly useful in one type of geology and virtually useless in another, many years, wells, and much money and faith need to be invested to determine in which geologies, and with what statistical efficacy, these novel techniques are useful. Often, management reaches its limit well before statistical certainty is achieved. Thus, the luck of how the first few field trials turn out can be paramount.

Finally, that strange positive pessimism of a new exploration technology turning out to be an excellent "don't drill" indicator, but a lousy "do drill" indicator, makes determining long-term utility an extremely complex task for management.

So where do we stand with the new EM methods? Well, the jury is still out, mostly because publicly released data have been sparse. But investment is surging, the learning curve is rapid, early results look promising, and there is no shortage of proponents or new service providers.

HISTORY

Geo-electromagnetic methods have been around for several decades, beginning in the 1950s and ?60s, particularly in the mining industry and in academia. Various terms, including *geo-electric, geo-electromagnetic,* or *geophysical electromagnetics* are used interchangeably in this article, although some folks would find differences for each of these terms. A bewildering maze of methods for oil and gas prospecting include Magnetotelluric (MT), Transient ElectroMagnetics (TEM), Frequency Sounding (FS), Induced Polarization (IP), Induced Polarization Profiling (IPP), and Controlled Source ElectroMagnetics (CSEM). There are many others. For oilfield marine use, CSEM is easily the dominant technology, with MT pulling a distant second. On land, various DC and transient EM schemes are the direction the technology has taken.

Russia has been especially active in furthering geo-electromagnetics, including uses for oil and gas exploration. In Russia, millions of square kilometers have been surveyed by field crews using geo-electric methods. Surveys varied between 100 and 150 in the 1960 -'70 period, dwindling to 20↕ 30 in the 1980s, and falling even further in the 1990s. [1] But that situation has now reversed.

These methods played a "significant role" in discovering several oil and gas fields in Western Siberia, most notably, structural uplift in Paleozoic basement that eventually resulted in Urengoy field - one of the largest gas fields in the world. [1]

In the West, Steven Constable of Scripps Institute is probably the one most responsible for bringing geo-electromagnetic methods into oilfield use, although many others played key roles as well, most notably Lucy MacGregor and Martin Sinha from Southampton (now with OHM). Constable sought an association with AOA Geophysics, to license Scripps' CSEM technology to the company, train its staff, and offer the emerging technology to oil companies for commercial use.

The first test of the AOA partnership was a test of electromagnetics used for MT, offshore Scripps' home at San Diego. Surveys for Agip and BP followed. Constable believes that the present diminished interest in MT will change, and that both MT and CSEM will eventually be the choice of oil companies. [2]

In 1999, Statoil and the Norwegian Geotechnical Institute were working on their own CSEM system, called SeaBed Logging (SBL). When Constable was asked for a peer review of SBL, he gave it his blessing as a possible direct hydrocarbon indicator tool. In November 2000, collaboration between Scripps, Southampton Oceanography Centre, the Norwegian Geotechnical Institute and Statoil resulted in the first CSEM survey to see if the method could directly detect hydrocarbons in deep water, offshore West Africa. This is where the present array of CSEM, SBL and similar systems begins to take off. A year later, the technology was used to for Shell, Enterprise and Statoil in a true pre-lease fashion for an upcoming Norwegian round.

RAPID COMMERCIALIZATION

One of the reasons for so much collaboration was a shortage of people with the needed expertise, as well as a shortage of equipment. The availability of equipment increased quickly, while many of the academics who had any experience are now working for private firms. Within a two-year period, several companies were formed. Statoil established a company called emgs in February 2002 (which won a *World Oil* award in 2003), and it sold to Warburg Pincus in 2004. AOA created AOA Geomarine Operations (AGO), which was subsequently acquired by Schlumberger in 2004. The University of Southampton helped found OHM (Offshore Hydrocarbon Mapping). Meanwhile, on a parallel track, operating somewhat in stealth mode, ExxonMobil had been developing its own CSEM logging technology, called Reservoir Resistivity Mapping (R3M), with help from OHM, AOA, Constable and others. About a hundred of these surveys have now been conducted worldwide.

Land and shallow water were not to be left behind. In the East, Russia's Phoenix Geophysics was formed, while China's BGP has its own land-based EM crews. In the UK, a new startup, MTEM (MultiTransient EM), is hoping to close the land and shallow water gap, saying it has solved the problem of unwanted signal that travels along the surface and through the air. The method evolved from the Long Offset Transient Method pioneered by Kurt Strack. In 1991, Anton Ziolkowski received a $3 million grant from the European Union, to perform field tests of MTEM. An experiment over a gas storage field in France showed good correlation, but seven years later, the method was still not working well, and the money ran out. Then in 2000, working at the University of Edinburgh, Ziolkowski and Bruce Hobbs took on David Wright as a research student. Wright solved the problem within a year, and the three scientists applied for a patent.

A $350,000 grant from Scottish Enterprise enabled Hobbs and colleagues at the University of Edinburgh to build the equipment and acquire more data. Over the next two years, the company was formed and raised $13 million in venture capital. MTEM officially opened in January of this year.

Perhaps the most unusual of all is from a company called Seismic Sciences in California. The firm uses the Induced Electro-Kinetic (IEK) effect for its technology. It is based on "the well-established theory of electro-osmosis phenomena." This might be related to the new method of generating electricity by pumping fluids through tiny microchannels, discovered in 2003 by Daniel Kwok and others at the University of Alberta. It uses a sparker as a sound source, to generate the right frequencies, and works on land and offshore. The sound waves shake the oil/ water interface within the pore spaces. This movement, in turn, generates an electrical pulse, which is detected and recorded. The electrical pulse only occurs along an oil/ water interface, so it's being called a direct hydrocarbon indicator. The company says that it has been used successfully in the Black

Sea, and trials are underway in the Gulf of Mexico. Claimed success rates are unbelievably high.

Resolution remains a challenge with many of these EM field methods, although much progress has been made. To some extent, this is less important when these methods are used for broad, pre-seismic or pre-lease reconnaissance. Some emerging new uses include time-lapse geo-electromagnetic studies for crosswell imaging of CO_2 flooding for enhanced oil recovery. [3] Another use is locating and appraising heavy oil/ oilsands. One study concluded that combining TEM and DC resistivity data may prove to be an accurate, reliable way to appraise these deposits. [4]

Precisely how the EM technologies differ is sometimes difficult to say, partly because the service providers, many of whom were collaborators, are now competitors. In some cases, patents have yet to be filed, or are still in the pending stage. There could even be overlapping patents, with the possibility of legal wrangling as well.

Generally speaking, these technologies can differ in several ways. One way is exactly how they inject electrical current into the earth. The type of electricity can be varied, from alternating, to direct, to square wave (alternating direct). The frequency can be varied, as well as the signal strength. Besides source differences, various acquisition spacing geometries, together with receiver design, present even greater opportunities for variations among service providers.

The subsurface exhibits certain characteristics that can be either exploited to benefit or be a nuisance. These include capacitance and induced polarization. Another is the natural voltage difference that adjacent formations can create. Yet another is the earth's natural EM field. Add to that list the fact that electricity does not follow just the desired path through the subsurface, across the zone(s) of interest and out to the receivers, but also takes other, unwanted paths, including through the air.

Finally, the timing and portion of the signal that is actually measured varies within the different methods. Just as important is the processing algorithm employed, as well as the manner in which the data are viewed.

The myriad ways that EM methods can vary underscore the reasons why so many service providers can each claim to provide a superior technology, why so many have sprung up in the past five years and why, in all likelihood, there will be more to come. It will be up to the marketplace to determine which of these offers the best technology or, at least, which of these survives.

FIELD EXAMPLES

The basic idea behind CSEM is a type of resistivity logging. A horizontal electric dipole source is towed several meters above the seafloor behind an instrumented tow fish on a neutral buoyant streamer (Fig. 1), where low-frequency electric current is coupled through the seawater into the subsea floor.

Fig. 1. Tow fish being deployed. It will power and monitor the electric dipole source streamer. [5]

The electricity follows conductive (water-bearing) formations or low-conductive formations (oil or gas), but not shale. Several kilometers distant, seafloor receivers record the variations in conductivity. Receivers are dropped over the side of the survey vessel and sink freely down to the seabed, Fig. 2. The receivers contain a buoyancy system (yellow spheres), a data acquisition unit, an anchor and removable horizontal sensors.

Fig. 2. Receivers being dropped to the seabed. [5]

The receivers may include one or two pairs of orthogonal electric sensors (yellow, up to 15 ft, each) and one or two pairs of magnetic sensors (short, grey cylinders). Acoustic ultra-short baseline navigation (USBL) is used to establish the exact receiver positions. The receivers are held in position at the seabed by a concrete anchor. After the recording period, an acoustic signal from the vessel triggers a release mechanism, causing the receivers to float back to the surface.

An optimum source-to-receiver offset must be determined: too close and the received signal is dominated by energy transmitted through the sediment-water interface; too far and the signal is dominated by the air-water interface. Between these two lies the desired signal that is transmitted through the subsurface, Fig. 3.

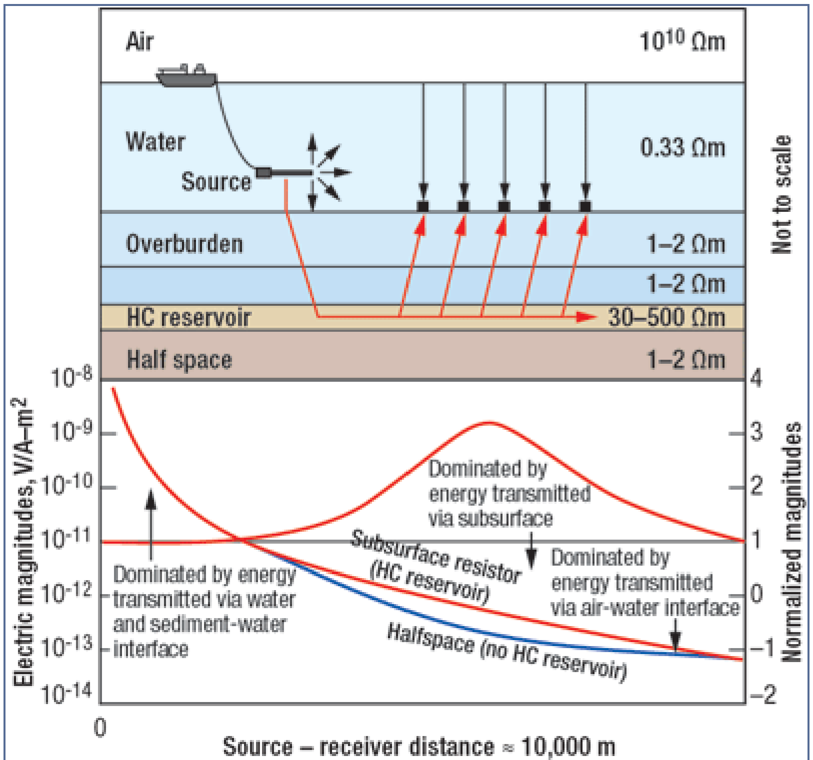


Fig. 3. Schematic of how CSEM works. Current propagates through the subsurface and to the receivers. Unwanted signal is minimized when optimum offset is used. [5]

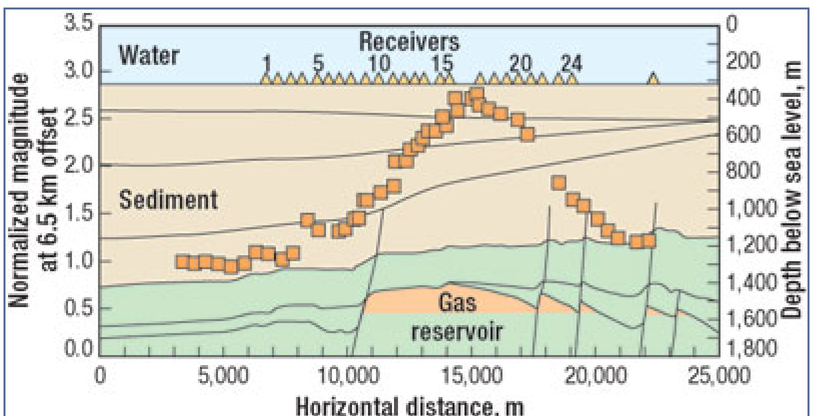


Fig. 4. Normalized MVO magnitudes, at 6 to 7 km, after median-filtering, across Troll West Gas Province, with receiver positions. Median normalized magnitudes (3.25 km from receivers at common midpoint) are plotted on a simple geological model, showing excellent correlation between SBL data and the reservoir. [6]

SBL survey over Troll field. Troll field is located in the northeastern North Sea. It is the largest gas discovery on the Norwegian shelf. The field may be separated roughly into three parts: the Oil Province, the Western Gas Province and the Eastern Gas Province. The reservoir interval comprises Jurassic sandstones, and is about 100-m thick and 1.6-km long, along the SBL survey line for the Oil Province. The reservoir interval of the Western Gas Province has a triangular shape with a maximum thickness of about 300 m, and is 8.4-km long along the SBL survey line. Hydrocarbon-filled sands show very high average resistivities up to 250 W -m and occur at a burial depth of 1,000 m. Water-bearing sandstones and overburden sediments show resistivities in the 1 - 2.5 W -m range. [5]

A continuously periodic signal with any curve shape and a frequency ranging from 0.05 to 10 Hz was emitted from the source. The peak-to-peak current was kept constant during the survey, up to a maximum current of 1,000 A. The distance from the source to the seabed was continuously monitored by an echo sounder on the tow fish and held between 25 and 35 m.

Forty-one receivers were deployed along a line crossing the Oil Province, the Western Gas Province and the Eastern Gas Province of Troll field. The receivers recorded the electric and magnetic fields as a time series before being processed into the frequency domain and combined with navigation data. The receiver registrations are then presented as Magnitude Versus Offset (source receiver distance) - also called MVO plots. The data quality of the Troll survey was excellent, with reliable information up to 10 km in the best cases.

MT over Gemini prospect. Marine MT measures variations in the Earth's passive EM fields. The ultimate source for this EM energy is the solar wind interacting with the Earth's magnetosphere. Frequencies are in the range of 0.0001 to 10 Hz. The magnetic field diffuses into Earth, attenuating at a rate that is proportional to the electrical conductivity of the subsurface. The magnetic field attenuation, in turn, induces an electric field, the strength of which also depends on the subsurface conductivity. In general, lower frequencies penetrate deeper while higher frequencies only diffuse to shallow depths, giving marine MT a depth sensitivity of 10's of meters to several 10's to 100's of kilometers, depending on the conductivity of the subsurface structure.

The technique was introduced by French geophysicist Louis Cagniard in the 1950s and has been used in oil exploration for low-cost reconnaissance of sedimentary basins, and for exploration in areas where seismic surveys are difficult because of severe topography or the presence of high-impedance volcanic rocks near the surface. The resolution of MT surveys is limited by the diffusive nature of EM propagation in the Earth; it is usually on the order of hundreds of meters to kilometers.

Marine MT uses an array of seafloor EM sensors/ recorders that are deployed over a geologic target, and record various components of the electric and magnetic field time variations. By these measurements, subsurface conductivity can be calculated.

A marine MT survey was conducted over the Gemini prospect in the Gulf of Mexico. The electrical resistivity model for the e-field inline component, TM, calculated from the data (inverted using OCCAM2DMT) is shown in Fig. 5. The color-coded resistivity is laid over a seismic section of a salt intrusion. The resistive blue structure at 2 - 4 km depths matches the salt intrusion. At depths greater than about 4.5 km, the salt is too thin to be seen in the electrical data.

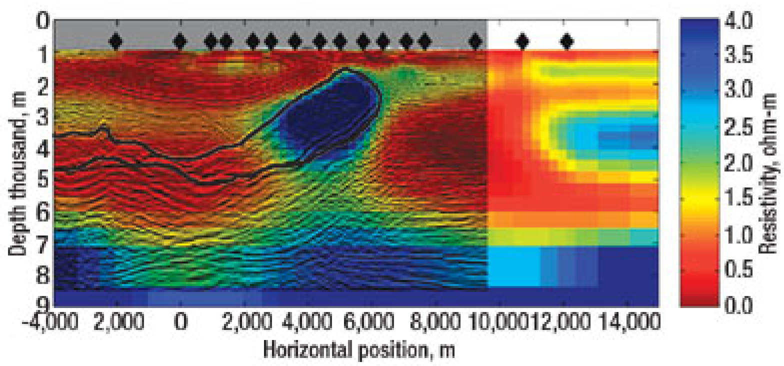


Fig. 5. The electrical resistivity model from a MT survey over Gemini prospect in the Gulf of Mexico, laid over a seismic section of a salt intrusion. [7]

CONTINUING RESEARCH

There is much active research ongoing to discover commonality, identify misconceptions, and to establish a framework that can be understood in terms of basic physics, i.e., Maxwell's equations.

There are three major consortiums continuing to further geo-electromagnetic methods. The Consortium for Electromagnetic Modeling and Inversion (CEMI) is headquartered at the University of Utah. Its sponsors include Schlumberger, Zonge Engineering and Research, Baker Atlas, BGP, emgs, Statoil, Shell, Petrobras, Norsk Hydro, ENI, BHP Billiton, and others.

The Seafloor Electromagnetic Methods Consortium (SEMC) is at the Scripps Institution of Oceanography, UCSD. Sponsors of the SEMC include AOA Geomarine Operations, BP, ConocoPhillips, ExxonMobil, GERD, Kerr McGee, Norsk Hydro, OHM, Petrobras, Statoil, Veritas and Woodside.

The Southampton Electromagnetic Advanced Research Consortium for the Hydrocarbon industry (SEARCH) is located at Southampton University in the UK.

No one - at least not yet - is suggesting that any of these methods are a substitute for contemporary methods such as seismic. While a lot of work remains to be done, if the rapid uptake and enthusiasm associated with these new methods are any indication, exploration will never be the same. WO

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