EM in the 21st Century – Looking for Oil, Gas and Water

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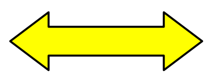
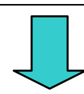
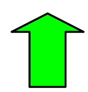
Although the topic of this paper is supposed to be "EM Applications in Industry", I will try and focus on specific applications over an explicit time with the exception of mining (left to my capable colleague, Nick Sheard). I have attempted to make the paper as comprehensive as possible but am aware that I have undoubtedly overlooked numerous great projects and contributions. So with this in mind…….

Looking for resources

How much exploration is being done for geothermal, groundwater and petroleum resources using Electromagnetic methods? And what is the forecast for the near-future? We have all held our breath for years assuming that political and economic situations would improve in our favor. And we are not alone. The seismic industry seems aptly mystified as resource needs should grow. However, exploration having had its brief spurts seems to be seeing a decline instead of growth. Industry statistics show that in March, 2002, there were 31% less seismic crews working worldwide than one year previous (Hart's E&P, May 2002).

Hence, a brief summary of predictions for Electromagnetic applications to Petroleum, Geothermal, and Groundwater exploration in the short term, given graphically, is shown in below.

Petroleum	
Geothermal	
Groundwater	

The basic conclusions are:

1. Petroleum exploration using various EM geophysical methods seems reasonably steady and should continue as such.
2. Geothermal exploration has declined and will probably stay depressed until economic factors improve
3. Groundwater exploration seems to have increased. Not only is the need for water becoming increasingly apparent in many places around the world, but the application of geophysics is becoming more useful.

Currently, most petroleum exploration is done with MT. Shallow TEM (such as the Geonics or Zonge systems) is performed on a fair percentage of the MT sites to provide statics corrections. LOTEM systems (such as Stratasearch and Montason) are designed to look for targets, either directly or indirectly, lying within 10,000 feet of the surface. The new Barringer DICON system hopes to map petroleum indirectly.

Geothermal exploration has routinely used MT for mapping since the 1970's. Shallow TEM is used at perhaps 50% of the stations for statics corrections.

The search for groundwater, which is becoming an increasingly more valuable resource around the world, employs shallower techniques such as Geometric's Stratagem™ system, AMT, or shallow FEM and TEM techniques.

Current Technology-

Acquisition Equipment

Routinely, EM systems are broad-band, 24-bit A-to-D (or close) using GPS for synchronization or timing. The systems are smaller and lighter-weight than a decade ago. Most are multi- to unlimited channels. Development by companies such as Electromagnetic Instruments, Geometrics, Geonics, Metronix, Phoenix and Zonge has all been competitive-driven.

Most of this development has occurred in the latter part of the 1990's and has greatly improved the capabilities for faster, better surveys.

New Acquisition Systems

Several new systems are under development or are just coming into commercial use. They include:

1. Statoil Marine CSEM – Statoil has just recently publicized the development of a marine EM system which they call "seabed logging". In their 2001 annual report they state, "Statoil has now developed a new exploration method called seabed logging, based on electromagnetic waves which supplement the acoustic waves used in conventional seismic surveying. This solution makes it easier to identify hydrocarbons, and has already been under testing for some time.

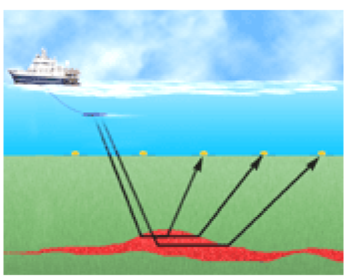


Figure 1: Marine CSEM system with towed transmitter. EM signals are recorded at receivers placed on the seabed.

A separate company, Electromagnetic GeoServices, has been established with Statoil as the majority shareholder to sell services relating to seabed logging. The basis for the new technology was laid at the group's research centre in Trondheim." Statoil has performed tests off of West Africa and in the Norwegian Sea. The system is designed to determine if beds contain hydrocarbons by mapping resistivity. Statoil has also developed a 3D modeling code (Kong et al, 2002).

2. Barringer Airborne MT system, DICON This system has been privately funded and under development for several years. Some test surveys have been flown and the first commercial survey should be done in 2002. The system measures orthogonal components of the E and H fields. Application for petroleum will probably be intended more for mapping alteration effects due to hydrocarbon migration rather than mapping of structure or stratigraphy associated with oil/gas traps. The system can also be applied to exploration for other resources.

3. Montason Technology TEM/LOTEM. This system is also privately funded and has been in development for about five years. It uses a somewhat conventional loop source (large amp, fast turn-off). The uniqueness of the technique is in the processing and interpretation. It is founded on measuring fields associated with boundary wave splitting and theories developed in Russia more than a decade ago (Shvartsburg and Zuev, 1991; Ekzhanov, Zuev et al, 1992). By measuring the H field with high accuracy, and using their total solution to Maxwell's equations, they determine subsurface boundaries and properties. The system is designed to determine stratigraphy associated with hydrocarbon emplacement and uniquely identify rock/fluid properties. Test surveys have been completed and commercial usage should begin in 2002. Development is underway for a LOTEM (line-source) to increase the depth of investigation.

Improvements have also been made to large TEM transmitters, such as

1. Phoenix Geophysics Transmitter, the T-200: Output current = 160 amps, 1600 volts
2. Stratasearch Transmitter: Output current = 300 amps, 600 volts dc

Both are gps–synchronized with receivers and can be used for a variety of controlled-source geophysics such as LOTEM, IP, and CSAMT.

Processing

The major advancements in processing were made in the late 1990's. Robust processing schemes (such as those described by Larsen et al, 1996: Zerilli et al, 1997) have greatly improved the abilities of MT acquisition in noisy environments. These various processing schemes are now routinely applied to data after acquisition.

Some of the new TEM systems are developing proprietary signal processing in order to improve the S/N ratio and to realize more information from the data. These processes are borrowing concepts from other industries such as seismic and EE.

Interpretation

In the past two years, I feel that the greatest advances have been made in interpretation. Studies by numerous groups, both private and academic, are yielding 3D codes which are just becoming commercially available and useable by interpreters. These codes greatly enhance our ability to provide accurate interpretations of subsurface structures and stratigraphy. Previously, or still, we often attempt to interpret data with 2D forward and inverse codes, frequently forcing the data into a 2D regime when 3D effects are obvious. We explain the problems to clients and provide the best interpretation we can, even if it means applying corrections to the data (such by decomposition or disregard of certain portions of the data spectrum).

Work in 3D solutions has been forwarded by several groups and individuals including Randy Mackie and Bill Rodi, Michael Zhdanov and Univ. of Utah colleagues/students, Greg Newman and David Alumbaugh, Eldad Haber and Doug Oldenburg (and other Univ. of British Columbia researchers), Sasaki (Japan), John Booker, and Adam Schultz and Mark Everett.

As an interpreter, I can attest to how 3D inversion will make my work better and faster. After numerous iterations and days of work, 2D forward and inverse modeling resulted in the cross-section shown in Figure 2. The section is shown with depth in z direction to 10 kilometers and distance along the section (x direction). The section is plotted at a scale of 1:1.The primary focus of the interpretation was to map the dip on the thrust front (shown by arrow). My interpretation used 20 frequencies over 4 decades. There was extreme 3D distortion at about 40% of the stations. I applied different decompositions techniques (e.g. LaTorraca) in an attempt to minimize the distortion.

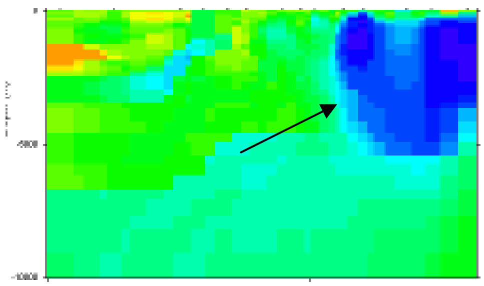


Figure 2: MT cross-section produced by 2D modeling

A 3D inversion was performed by Randy Mackie. He used 10 frequencies over about 4 decades. After 20 iterations, he produced the section shown in Figure 3. The 3D inversion images the dip of the thrust plane extremely well, and probably more accurately than the 2D model. The 3D inverse did not model the subsurface well at depth, but this is most likely a factor of number of frequencies and iterations used.

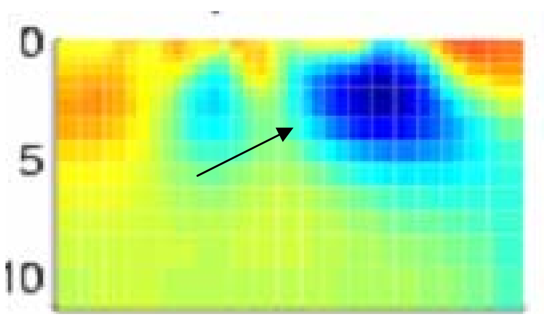


Figure 3: MT Cross-section produced by 3D inversion (Mackie, 2001)

Work in this Century

In the past few years, MT and EM technologies have been applied for geothermal, petroleum, and groundwater exploration throughout the world.

Although geothermal exploration has been on the decline (primarily from economic factors, especially in the Pacific region), surveys have been conducted in Chile, Costa Rica, U.S, Greece, Canada, Nicaragua, El Salvador, Japan, New Zealand and the Azores. Thought to be the world's highest MT recording, a station was acquired in the Chilean foothills at an elevation of 17,723 feet and without extra provided oxygen!

MT is the method of choice for geothermal exploration, with shallow TEM becoming more routine to provide statics correction (Cumming et al, 2000). And even though new surveys are not necessarily being acquired, review of existing data is being done in anticipation of future projects and development (G. Nordquist, personal communication).

Figure 4: MT acquisition for geothermal exploration in Chile (courtesy Geosystem srl)

The hunt for Groundwater has seen an increase as this resource becomes increasingly more important for irrigation, public supply, and processes. Surveys have been conducted in Puerto Rico, Chile, Brazil, China, U.S. and other countries using Stratagem™ (hybrid AMT/CSAMT), AMT, FEM and TEM. Although most of these surveys are proprietary, examples of applications have been published on: Airborne EM for groundwater at the Arizona/Mexico border (Wynn, 2002), AMT for groundwater in Texas (Pierce, 2002) and ground FEM in Brazil (Steensma and Kellett, 2000). This latter survey was followed up by Airborne FEM.

MT now seems to be reasonably accepted by oil companies in the search for oil and gas. Although the incidence of surveys has not increased significantly, the method is used for exploration primarily in seismically-difficult areas such as overthrust and high-velocity (carbonate, volcanic) cover. In certain areas, MT is also applied for reconnaissance usually as a forerunner to more-expensive seismic surveys.

Recent MT surveys for petroleum have been conducted in Albania, Greece, Italy, Iran, Japan, Bolivia, Holland, Libya, China, Romania, Poland and Germany.

China continues to be a major consumer of MT for petroleum. Different agencies within the country have purchased more than 200 Phoenix MT systems and numerous systems from EMI. They reported a discovery based on MT, gravity and magnetics in 2001 (Dou et al, 2001)

Very few MT surveys have been acquired in the U.S. in recent years. However, more than 1000 MT stations of 1980's vintage have been re-interpreted for use in petroleum exploration in Washington, Wyoming, Oregon, California and other states. This study is designed as a pre-cursor to new exploration as the clients realize the usefulness of MT for exploration in the increasingly important oil and gas plays of the western U.S.

Marine MT has been commercially acquired in the North Sea and Gulf of Mexico, applied for sub-salt and sub-basalt exploration (Hoversten et al, 2000; A. Orange, personal communication).

LOTEM surveys are not widely used but have been acquired in the U.S. for shallower oil plays. Stratasearch feels they have gained a better understanding of processes above oil and gas fields such as resistivity changes caused by migration. Ziolkowski et al (2002) describe using a LOTEM system to do reservoir monitoring.

The new Montason LOTEM system had its first field survey in 2001. This system is designed to indirectly and directly detect hydrocarbon reservoirs but can also be applied to other resources like minerals and ground water.

The Future:

Electromagnetic methods seem to have their place in exploration. I sense that more applications will be made for groundwater with exploration for hydrocarbons and geothermal hopefully increasing. It would seem, that as the world's need for resources grow, the various EM methods should continue to provide useful tools for exploration.

There may also be applications of EM in aiding seismic statics corrections. Some attempts have been made over the past two decades (den Boer et all, 2000; author's experience) but the stumbling block appears to be the difficulty of integration of the seismic and EM data. Sorely needed is a workstation, or platform cross-over, so that EM information can readily be utilized in seismic processing and interpretation.

Some tests have also been done on mapping water and CO_2 floods or hydrocarbon reservoir monitoring with TEM. Work has proceeded on this for several years and some results were recently published (Ziolkowski et al, 2002; Wright et al, 2001). Encouragement by universities and companies should fuel more efforts in this application.

The largest advances will most likely come from the implementation of 3D inversion codes on PCs so that interpreters and researchers can better understand and interpret the data. This should also lead to more acceptance in the industries as we will be providing a better, more accurate product.

Lastly, the future will likely have a shortage of EM geophysicists. Our industry's average age continues to get older. Encouragement needs to be given to young geoscientists to enter the field of electromagnetic geophysics. The AGI reports (AGI, 2001) that the number of university students enrolled in geosciences has dropped 66.8% between 1983 and 2000. And, the median age of geoscientists (which is basically the same for geophysicists) is 48 years old. With early retirements, or even normal retirement at age 60, our industry will face a void of scientists unless more students are attracted into our field.

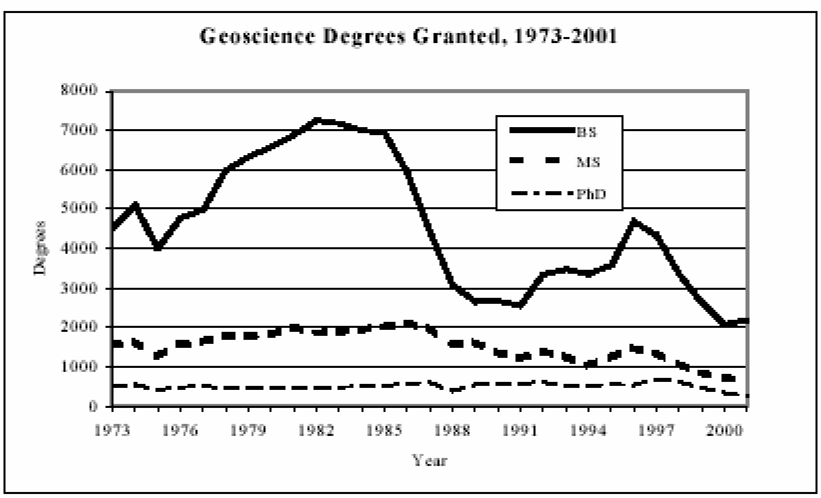


Figure 5: Geoscience degrees awarded from 1973 to 2001 (Source AGI, 2001)

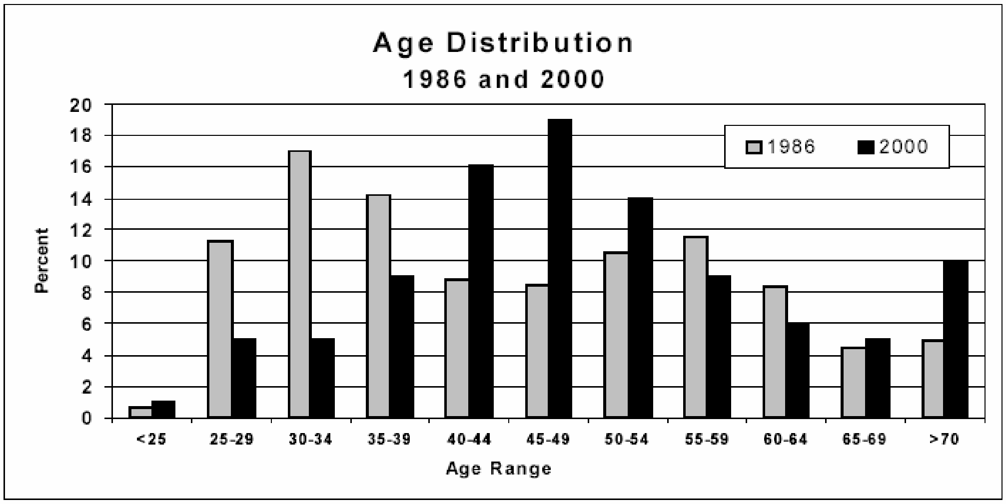


Figure 6: Age distribution of working geoscientists (Source AGI, 2001)

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