UNDERWATER BREAKTHROUGH

ELECTROMAGNETIC TECHNOLOGY DEVELOPED FOR SHALLOW AND DEEPWATER OIL EXPLORATION

A DASI CSEM transmitter on a board a survey vessel. This electromagnetic transmitter uses a horizontal electrical dipole to generate an electromagnetic signal about 30 metres from the seafloor. Much of the development in refining CSEM for application to oil and gas exploration has focused on increasing both output strength and phase stability of the source waveform, which are critical for successful detection of resistive layers in a strongly conductive medium © Offshore Hydrocarbon Mapping

In the continued search for recoverable offshore oil and gas reserves to supply the world's increasing energy demands, the exploration industry is turning to a new technique to detect hydrocarbons. The industry, traditionally a slow adopter of new technologies, is seeking new ways to cut the risks of drilling non-commercial wells and to reduce spending on costly appraisal drilling. Vivienne Macey outlines the workings of a new technology, developed by an Academy MacRobert Award finalist, that is able to seek out oil and gas under the sea floor.

Controlled Source Electromagnetic Imaging (CSEM) is a sounding technique, increasingly used by oil exploration companies to extend their knowledge of an exploration prospect before incurring drilling costs. CSEM has been recognised as a useful exploration tool; it is used not only by the largest oil producers but also by the newest minimally-funded exploration start-ups.

Until recently the technique could only be usefully applied in deep water, at depths of more than 1,000 metres. However, scientists at an oil industry survey services company, Offshore Hydrocarbon Mapping plc (OHM) have come up with solutions that now make it possible to utilise the method in water as shallow as 50 metres.

MAKING WAVES

Traditionally oil and gas exploration companies have used seismic mapping to explore the geology of the sea floor. The technique uses acoustic pulses sent into the ocean bed with receivers detecting the reflected waves. The waves are used to create images of the sub-seafloor structure. Seismic mapping works well in many contexts but cannot easily distinguish between water-bearing and hydrocarbon-bearing geological formations.

CSEM's clear identification of hydrocarbons significantly reduces the risk of drilling dry exploration wells. As many as two thirds of exploration wells generally fail to result in commercial recoveries. By helping oil exploration companies understand as much as possible about prospects, the technique can help avoid the cost of drilling test wells. The technique also has the ability to accurately detect the edge of reservoirs, which can reduce the number of costly appraisal wells that exploration and production companies need to drill. With the savings made, oil company budgets can be applied to test many more prospects.

In the most recent development for the technology, its value as a pre-drill exploration tool has been recognised by Norway's Ministry of Petroleum and Energy. The ministry has placed conditions on a number of new exploration licences which require the use of electromagnetic survey data, enabling companies to make better decisions regarding whether to drill or drop prospects.

CONTROLLED SOURCE ELECTROMAGNETIC IMAGING

The survey process is a non-invasive technique that maps variations in the resistivity of the geological formations below the seabed. By transmitting close to the ocean floor and recording the returning electromagnetic signals, changes in the electromagnetic field are measured and the resulting data is processed to provide information on the resistive structure of the subsurface. The resistivity in hydrocarbon-bearing layers is typically between 10 and 100 times greater than the surrounding strata. This contrast is used to detect the presence or absence of hydrocarbon reservoirs and their distribution.

The technique uses a 125 kVA horizontal electric dipole source, which is towed 30 metres above the seafloor in up to 3km of water. The source transmits a low frequency signal to an array of receivers positioned on or just above the sea bed. To produce an electromagnetic signal that will penetrate deep into the seafloor, very high currents and low frequency signals, typically in the range of 0.01 to 10 Hz, are used. Signals at these frequencies can penetrate several kilometres below the seabed.

Despite the high currents used at the transmitter, the signal at the receiver is tiny: typically nanovolts per metre or less. Each receiver detects and records these electromagnetic fields at the ocean floor.

The signal being detected is so small that even the slight motion or vibration of a sensor can generate a response of a similar magnitude to that from the source.

Electrochemical noise can also mask the signal. To prevent interference with results, the receivers have had to be developed using ultra low-noise electrolytic electrodes and are weighted to prevent motion. Ensuring accurate timing between the source waveform and each of the seabed sensors is also vital. Each sensor is synchronised to GPS, as is the clock on the source waveform. Throughout the survey process the clocks must be regularly checked to GPS to keep them precisely co-ordinated.

The variation of the received signal as the source is towed allows the team of scientists to determine the resistivity of the underlying formations. The team then use complex algorithms, including forward modelling and inversion techniques, to turn the electromagnetic data into 2-dimensional and 3-dimensional images of the geo-electric structure of the subsurface.

INTERPRETING DATA

The images not only identify resistivity anomalies but can also map out their location, indicating the presence and distribution of hydrocarbons within an oil company's prospect before drilling.

The success of the application of CSEM relies on careful planning of the survey and skilful interpretation of the electromagnetic data. Some subsurface formations can display the same high resistivity as hydrocarbons. In these cases, a high level of interpretation is necessary. The CSEM team will look at the extent of the resistive anomaly and the surrounding geology to identify whether the data relates to hydrocarbon saturated sands or another highly-resistive formation, such as carbonates.

In the case of multi-layer reservoirs, the technique can distinguish between the hydrocarbon formations if the layers are far enough apart. However, in areas where hydrocarbons are finely interbedded with sand and shales, the technique is sensitive to the overall interval in which hydrocarbons occur, rather than to the pockets of oil and gas.

Deployment of an OHM long dipole receiver
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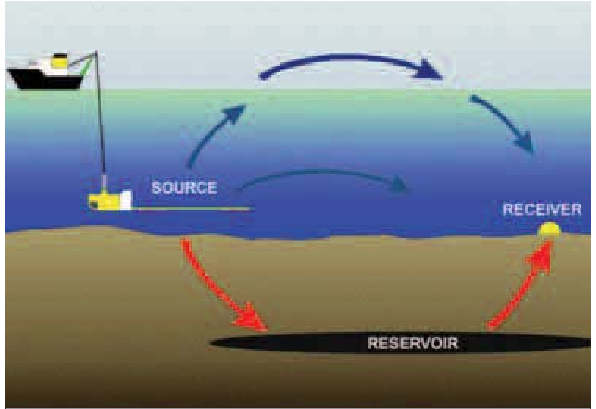
Electromagnetic receivers, pictured here onboard a vessel before deployment, are positioned on the ocean floor to record the response of the electromagnetic field. The units have ultra sensitive and ultra low-noise electronics and precise instrument response calibration. They also offer variable receiver dipole lengths for different environmental noise conditions © Offshore Hydrocarbon Mapping



A controlled electromagnetic signal is generated by a horizontal electrical dipole source towed close to the seafloor. Stationary receivers on the ocean bed record the response of the electromagnetic field to detect electrically resistive bodies in the subsurface. The signal detected by a seafloor receiver consists of three main components: (1) the direct signal from source to receiver, which is highly attenuated due to the conductivity of sea water, (2) the subsurface signal, shown in red, which travels through the earth layers beneath the source and receiver, and (3) the 'airwave' signal, which interacts with the earth's atmosphere © Offshore Hydrocarbon Mapping

25 YEARS OF ACADEMIC RESEARCH

CSEM has been developed over the last 25 years in the academic sector. It has been used extensively by the geophysical community as a tool for investigating the fluid properties in marine hydrothermal vents, mid-ocean ridge volcanic systems, and to map gas hydrate deposits.

More recently, advances in power transmission and signal stability were initiated into the towed source so that it could be applied to exploration for oil and gas. The company commercialised the technology following years of academic research at Cambridge University, and at the National Oceanography Centre in Southampton. The technique underwent proof of concept trials in 2000, showing that the result of the CSEM survey agreed with the known extent of the field. The integrated resistance through the reservoir interval was very similar to the resistivity measured in well logs from the field. The system then carried out its first fully commercial survey in 2002 with a major US oil company.

In most cases, oil companies will already have seismic data over the prospect to be surveyed by CSEM. The seismic data can identify structures which may trap oil and gas but give very little information on the nature of fluids. However, the seismic data can be co-rendered with CSEM survey data to give oil and gas explorers more detailed information about their prospects.

Initially, the developers faced a lack of understanding and some scepticism towards the technique from academics and the industry. Oil and gas exploration professionals were accustomed to using seismology as the key exploration tool, and to examining seismic sections with sharp acoustic boundaries. Many found it difficult to appreciate that the technique was so different to seismology, in that it was examining a different physical parameter which was complementary to seismic data. Gaining acceptance and understanding of the technique took years of educating the industry and academics. The developers began a slow process of explaining the technique in the early 1990s, presenting at conferences, publishing papers and discussing the technology with industry figures and academics.

SHALLOW WATER CHALLENGES

Until recently CSEM could only be used in explorations for offshore oil and gas reserves in tracts of deep water. Technical challenges posed by 'airwave' interference swamping the response from below the seabed in shallower water had, until now, limited its application to areas of ocean 1,000 metres deep or more. Seawater is very conductive and the direct signal between the source and the electromagnetic receiver on the seafloor is highly attenuated. The primary signal spreads downwards, interacting with the more resistive earth, and can be used to determine the structure below the sea floor. But there is also a part of the received signal that interacts with the air – this is referred to as the 'airwave'.

In deep water, the thick blanket of conductive seawater dramatically reduces the amplitude of this signal path so it has a minimal effect on results. However, in shallower water, this signal can be large, and can swamp the signals relating to the subsurface structures being surveyed. With electromagnetic signals being extremely dispersive, it is very difficult to separate the 'airwave' energy from the response from below the seabed using simple methods based on wavefield approximations. But now, the CSEM team has developed ways of mitigating the 'airwave' effect, enabling the technique to be used in water depths as shallow as 50 metres in some areas.

PREP WORK

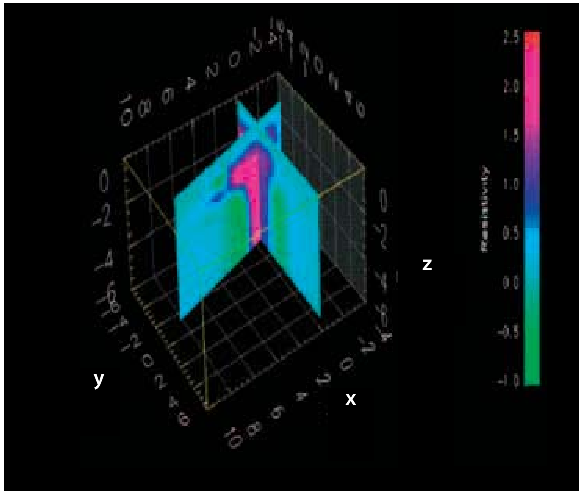
A simple approach to reducing or removing the airwave proved unworkable, with each survey and environment posing its own unique challenges. Instead a range of different techniques that can be applied in isolation, or as a combination as necessary, were developed. Firstly, careful planning before a survey is designed helps prevent the 'airwave' swamping the response from the seafloor. The parameters of each survey can be precisely tailored to limit airwave intrusion. By modelling the geo-electric responses anticipated from the area to be surveyed before applying the technique, the CSEM team can make the best choices about key factors such as the most effective dipole orientation and source waveform to collect survey data with minimum interference. In some cases, this alone is enough to enable the technique to detect hydrocarbon reservoirs in shallower water depths.

Elsewhere, more advanced techniques need to be applied to further suppress or isolate the 'airwave'. These include new methods of acquisition to minimise the generation of airwave energy during the survey, advanced methods for processing signals that reduce or eliminate the 'airwave' during data processing and imaging, and interpretation methods that use the information in the 'airwave' to better determine the geo-electric subsurface structure.

STATE OF PLAY TODAY

As a direct result of the shallow water breakthrough and the use of innovative survey design, data collection and processing, CSEM is being increasingly adopted by oil companies around the world, for a range of applications including searching for reserves in previously unexplored areas and detailed appraisal of known reservoirs. In the last couple of years the technology has been used commercially in West Africa, Brazil, the Falkland Islands, Malaysia, Norway and offshore Aberdeen, Scotland.

CSEM's shallow water uses range from simple surveys to confirm the presence or absence of commercially viable oil and gas reserves, to more complicated survey work to plot how hydrocarbons are distributed. OHM say "If we use drilling activity as an indicator of how much this grows the market for the technology, we see 30 to 40 times more drilling in these shallower waters than in the deep water market".



CSEM data can be used to give a cross section of resistivity distribution in the sub-surface. The presence of potentially hydrocarbon-bearing layers can then be assessed by studying vertical and horizontal resistivity variations © Offshore Hydrocarbon Mapping

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