Shortcut to commercial discovery

God is in the details, it is said. That holds true in everything, including geological exploration. 3D controlled-source Electro Magnetic (CSEM) has entered the market almost 15 years ago and is considered a cutting edge technology used by O&G companies for marine subsoil exploration. This special report examines what CSEM is, how it works, and what is its biggest added value. We talk with industry players (technology owners and users alike) and ask them how this new tool is being used in E&P processes and decision making. The overarching conclusion that seems to emerge is that, when combined with traditional seismic, 3D Electro-magnetic surveying (3D EM) leads to higher precision reservoir modelling, reduces geological uncertainty and results in a superior interpretation of reservoir characteristics and, as such, in increased probability of success and significant cost savings. That means an accelerated schedule for finding and scooping the resource, getting it faster out of the ground and to the market, and saving time and money in the process.

Historical background:
CSEM, once seen as a deepwater hydrocarbon exploration method, has established itself over the past 15 years as a powerful geophysical tool. According to Steven Constable, “theory significantly predated practice”: the very first paper introducing marine magnetotelluric (MT) method (which is “intimately linked to marine CSEM”) was written in 1953 (by L. Cagniard), the first publications proposing marine CSEM date from the 1960s (P.R. Bannister, L. Brock-Nannestad, Charles Cox and Jean Filloux). Early equipment and experiments belong to Cox and Filloux, who “deployed both electric and magnetic fields recorders in 1000- to 2000-m water offshore California” in 1961. Although academic research has occurred since 1970s (with academic built instruments and mainly to study oceanic lithosphere), only when industry started exploring at depths greater than 1000 m (in late 1990s) and developed adequate deepwater technologies, that marine CSEM gained commercial significance. Thus, the first modern research CSEM survey took place only in 2000 (offshore Angola), with global commercial activity picking up around 2004. Today, it is considered a mainstream technology.

What is CSEM?
It is a high precision hydrocarbon detection method used in offshore exploration. CSEM measures subsurface resistivity from the seabed, and allows to identify sweet spots and good reservoirs vs. not so sweet and poor ones with a higher degree of confidence. It does not replace the technology currently used (seismic remains the cornerstone of exploration), but can be used together with the classic instruments in the toolkit to double check, course correct and refine the targets chosen, rank the prospects and provide solid arguments for drill-drop decisions. The technology “maps out resistivity anomalies or thin resistors that could identify hydrocarbon-filled traps”, but is reported to have potential application in monitoring carbon sequestration and mapping gas hydrates. Historically, seismic data has been used as a main tool for decision-making on drilling wells (“predrill reservoir appraisal”). So, what does CSEM bring new? CSEM is sensitive to hydrocarbon saturation and volume and uses electric resistivity as a hydrocarbon indicator: “electrical resistivity of the subsurface is a physical property that is strongly correlated with the fluid content and saturation of hydrocarbon reservoirs. The resistivity contrast between background geology and hydrocarbon reservoirs is often one or more orders of magnitude, making resistivity very suitable as a hydrocarbon indicator when measured from the seafloor”.

1 Steven Constable, “Ten years of marine CSEM for hydrocarbon exploration”, Geophysics, Vol. 75, No. 5 (September-October 2010), p. 75-78.
How it works:
Data acquisition is conducted by means of grids of receivers, which are placed on the seafloor (1-3 km apart from each other) by a 3D EM surveying vessel. “As a general rule, in frontier exploration over large areas where acquisition has to be cost effective and is aimed at large hydrocarbon accumulations, a coarse acquisition grid with, e.g., 3 km spacing between receivers and source towlines is used; an appraisal survey which aims to accurately delineate a discovery and identify possible smaller near-field accumulations uses a dense acquisition grid with, e.g., 1 km spacing”

4” tells us the VP for Imaging and Integration, Friedrich Roth, of EMGS - a specialized geophysical service company. The receivers have electric and magnetic sensors. Depending on the company, these receivers can look differently. Each receiver has a concrete anchor made of patented soluble cement. These anchors ensure rapid sink rates. After CSEM is completed and receivers are detached, the anchors remain on the seabed where the cement dissolves in a period of 6 - 9 months.

Example of a receiver
A: device  B: cement anchor  C: receiver placed on anchor

A horizontal electric dipole (HED) source5 is towed close to the seafloor and some 30 m above the receivers that are deployed on the seafloor. The HED transmits a low-frequency electromagnetic (EM) signal that goes in all directions, passes through the water column, into the seabed and subsurface and is reflected back to the surface. The receivers record the strength of these returned signals. The “frequency content (...) is based on information from regional geology. A typical base frequency is between 0.2 and 1 Hz.”6 Generally, frequencies used in CSEM range from 0.1 to 10-12 Hz, and in MT from 0.0001 to 1 Hz). But, how is the exact frequency for a given play determined? According to Roth, “In contrast to seismic, EM signals experience strong attenuation as they propagate through the earth. The level of attenuation depends on frequency and formation resistivity. During survey design the source frequencies have to be chosen such as to make a good trade-off between resolution and depth of investigation. This is achieved through the pre-survey 3D modeling studies.”7

The entire process involves deployment of receivers (which free fall to seabed) and of the high power source, towing the antenna. After the EM process is finalized, the source and receivers are retrieved, the data is downloaded and pre-processed on the vessel. This data is then inverted into 3D earth resistivity models. The resulting model provides a horizontal and vertical image of resistivity, which is expressed by means of a color scale in which red represents high resistivity and blue/purple - low resistivity. See one such map below.

---

4 ROEC interview with Friedrich Roth, EMGS VP for Imaging and Integration, August 13, 2015.
5 An HED consists of two electrodes approximately 250 m apart. The HED is towed behind an instrumented tow fish on a buoyant streamer.
6 Reference 3, p. 57.
7 Idem 4.
A high correlation between seismic and CSEM results has been observed with various study cases showing that CSEM can accurately predict the presence or absence of hydrocarbons (see p. 7), thus minimizing and even eliminating surprises in drilling. But, not all anomalies represent hydrocarbon accumulations. Other structures (non-hydrocarbon ones) such as “volcanic provinces, salt basins and salt diapirs, basement highs, and carbonate platforms”\(^8\) can cause resistive anomalies as well, which is why CSEM has to be used together with seismic data.

**Market uptake: who used CSEM, where, with what results**

![Market uptake diagram](image)


Note: white boxes indicate academic experiments; red circles indicate the first three independent companies that started offering marine CSEM services (AGO, OHM, and EMGS).

---

\(^8\) See reference 3, p. 57.
Competitive landscape: CSEM has essentially created a new branch of service industry. In comparison to its early days (when there were only 3 independent companies offering the service – AGO, OHM, and EMGS), the market has evolved significantly. Now, aside from the independent CSEM companies, other geophysical services companies have added CSEM to their portfolio (Petroleum Geo-Services (PGS), Rocksolidimagex (RSI), PetroMarker, Oceanfloorgeophysics (OFG)), the big service industry players have created dedicated departments (Schlumberger has an Integrated Electromagnetic Center of Excellence in Milan, Italy). The oil majors too, have adopted the technology and even built internal CSEM expertise. Key industry players describe a positive experience with CSEM technology.

In a 2009 interview to GEOExpro magazine, Leonard Snrka, Chief Research Geoscientist with ExxonMobil Upstream Research Company (author of the Snrka Patent filed by Exxon in 1983), was asked the following question: “ExxonMobil [one of the early users of this technology] has done many surveys in several basins. Are you pleased with the results you have achieved?” This is what he had to say: “We have now acquired 53 surveys over a range of discovered reservoirs, for calibration purposes, in field development areas, and over exploration prospects. We are very pleased with the results from these surveys, all of which increased our learning such as the necessity to acquire wide-azimuth CSEM data. Our pre-drill prediction technical success rate for CSEM surveys is very high. One measure of success is our plan to continue using this technology in a number of basins, in both previously visited and in new areas.”

More recently, Dr. Gerwin Karman, Commercial Lead Geophysics at Shell, offered this view: “Shell started using CSEM technology in the early 2000’s (about 2002), initially to trial and learn from this nascent technology. First surveys were done over known fields to assist understanding the nature of CSEM data. At the moment, CSEM is mainly used for exploration purposes, although the potential for delineation is recognized as well.” Shell uses CSEM “at or after the moment of 3D seismic analysis” to assess, prioritize and de-risk prospects.

In August 2015, Petrobras had this insight to share on its experience with 3D EM: “Petrobras started using 3D CSEM data in 2004, but it was only in 2012 that 3D CSEM data inversion gained momentum. Already, in the early 2004 survey as well as another survey performed in 2007, as a proof of concept of this technology, the results so obtained encouraged the company to invest in CSEM technology” told us Mr. Marco Polo Pereira Buonora, Director for New Seismic Methods, Petrobras E&P Division. According to him, Petrobras “had a 100% success rate to show that all dry wells in a given area had no CSEM anomalies. In addition to that, we had 77% success in wells with hydrocarbons and their connected CSEM anomalies, i.e.: 7 wells with hydrocarbons against a total of 9 (7/9)”. But he also said that “The real adoption of such novel technology, as viewed by the seismic community of hydrocarbon explorers, is a slow process. It is a continuing and persistent teaching and learning process. The seismic interpreters are gradually seeing the value of CSEM technology.”

To gauge the lesser known uses of CSEM such as mapping gas hydrates or reservoir monitoring during production phase, ROEC has reached out to EMGS Founder and Technical Director, Svein Ellingsrud: “Gas hydrates, and gas trapped below hydrates are more resistive than the surroundings. We have mapped gas hydrates. They are shallow but you can use higher frequencies which gives better resolution. Scripps also have several papers on mapping gas hydrates. CSEM can be used for monitoring. However, due to frequency dependent attenuation more shallow targets are better off. A 3D CSEM survey was conducted over the Troll West Oil Province in 2008. CSEM was calibrated to resistivity well logs and inverted for saturation. Seismic was calibrated to the porosity logs and inverted for porosity. The 2 inversions gave the volume that differed with less than 10% of the official operators numbers, based on production logging. Gas that was injected could also be seen. So yes, CSEM has the potential for monitoring. Gas is difficult to monitor by seismic as residual gas gives a similar response as a full saturated sandstone.”

---

9 http://www.slb.com/services/seismic/geophysical_processing_characterization/seismic_reservoir_characterization/ele
12 ROEC interview with Marco Polo Pereira Buonora, Gerente de Mètodos Não Sísmicos, Petrobras/E&P/EXP/GEOF/MNS, August 28, 2015.
13 ROEC interview with Svein Ellingsrud, EMGS Founder and Technical director, August 5, 2015.
Impact on the environment:
Any new idea/technology brings with it the concern about its impact on the environment. A 2011 Environmental Impact Assessment of this technique used for O&G Exploration and Production\textsuperscript{15} commissioned by the International Association of Geophysical Contractors (IAGC) which reviewed over 400 reports and publications, concluded that “EM technologies use extremely low frequencies (ELF). ELF fields are defined as those less than 300 Hz and include common household electrical systems that operate on 60 and 50 Hz standards” (Executive Summary, p iii). To put things in context, the report offers a useful comparison between low frequencies [such as radio waves used in AM (750-1,000 kilohertz) and FM (80-100 megahertz)] and high frequencies [such as gamma rays form cosmic sources and from radioactive elements with frequencies in the range of $10^{18}$ to $10^{20}$ Hz] – see p. 6. The low frequency fields cannot break molecular bonds, therefore are classified as “non-ionizing radiation”. EM technology uses extremely low frequencies (<10 Hz) and long wavelengths which “carry very little energy” and “have essentially no potential for direct effects on the health of marine animals” concludes the report.

Comparative Electromagnetic Frequencies (in Hz)

Effects such as underwater noise emission, light emission or small oil spills are not unique to EM surveys. However, what is unique are: “electromagnetic emissions from a towed electrical source” or “source emissions”; and “electrolysis at the electrodes” or “chlorine emission”. I will focus on the first: The study does say that some EM equipment and activities can potentially affect some members the marine ecosystem. The most sensitive [to EM fields] group of large marine animals are likely to be the elasmobranchs (sharks, skates and rays) which “have highly developed electroreceptive organs” used for navigation or prey detection. But, these behavioral health effects are deemed negligible due to the short exposure time (minutes) and limited area (only within a 400 m radius). The general conclusions states:

“EM sources as presently used have no potential for significant effects on any of the important animal groups such as fish, seabirds, sea turtles, and marine mammals. In addition, any cumulative effects from EM surveys are negligible compared to EM anomalies, induced fields from natural water currents, and other anthropogenic EM sources such as those originating from undersea equipment especially underwater powerlines and associated electrodes.”(p. xi)

The Barents Sea - a cautionary tale

Although exploration started here 30 years ago, more than 300 surveys have been completed and 100 wells drilled by 2014, the only field put in production is Snohvit, with another one (Goliat) currently under development.\textsuperscript{16} In the Barents Sea alone, application of CSEM on a regional scale (since 2008) has increased exploration success: five recent discoveries were made – Skrugard (2011), Norvarg (2011), Havis (2012), Wisting (2013) and Hanssen (2014). CSEM has been used in combination with seismic multiclient data (acquired during 2008-2013) and proved useful in screening prospective drilling sites.

If CSEM data leads to more accuracy in de-risking prospect fields and narrowing down the area of interest, governments should be interested in it too. In fact, after the article “Three Disappointments in the Barents Sea”\textsuperscript{17} appeared in GEO ExPro magazine in September 2014, the Norwegian Petroleum Directorate requested full access to the EMGS library\textsuperscript{18} in order to see whether O&G companies indeed take into account Best Available Technologies (BAT) and data that can spare taxpayer money, when they make drilling decisions.

Norwegian Continental Shelf: correlation between strength of EM anomaly & commercial discoveries


\textsuperscript{17} http://www.geoexpro.com/articles/2015/05/three-disappointments-in-the-barents-sea

\textsuperscript{18} http://www.emgs.com/content/1078/Norwegian-Petroleum-Directorate-has-requested-access-to-all-inverted-EM-data-acquired-by-EMGS
The Black Sea

The Black Sea is regarded as an emerging hydrocarbon region, with interest heightened by several recent discoveries: the Domino-1 well in Romania (2012), the Istranca-1 discovery in Turkey (2012). In Bulgaria, the expectations of the Han Asparuh block are yet to materialize (preliminary drilling to be conducted in 2016). But how significant are the gas finds in the Black Sea? For 3 years, the only publicly available information on the scope of the resource for Domino-1, for instance, has been the large range estimate of 42-84 Bcm. For the Black Sea to become a success story, improved regional understanding of prospectivity is key. However, national legislation (different jurisdictions), country and commercial self-interest do not favor regional cooperation in hydrocarbon exploration. The fragile post-2014 Black Sea geopolitical climate too is not particularly conducive to joint initiatives, as operators stick to a “business as usual” rhetoric and seem more concerned with the low oil prices. Precisely because the Black Sea is less geologically explored, the argument for making use of CSEM to accelerate exploration and increase its chances of success should be compelling for all the Black Sea countries.

In Romania, the exploration risk is borne entirely by the private sector and there is no cap on recouping capex (100% cost recovery allowed). So, how does the use or decline of using this technology affects the government? The Romanian state shares no exploration risk (zero, in fact), but if the government has to wait until the investor recoups his capex (which is not a small amount), then it’s another story. If there are no barriers to recouping investment and no incentives in place to motivate operators/concession holders to be efficient, what is the point of being thrift, if everything you spend is allowed for cost recovery? In effect, that means that the more companies spend, the more they can recoup and the later the government could increase its share of profit because it would have to wait for investors to recoup their costs first. Consequently, it would be a great step forward to embed in the regulatory requirements a “carrots and sticks” mechanism (some form of incentive for using best available technology, such as CSEM in marine exploration) to motivate companies to reach commercial result faster and cheaper. By remaining technology neutral during tender rounds, Romanian authorities do not favor uptake of new technologies and can delay the moment when extra taxes on Profit can be levied or, even influence the amount of revenue to be collected. In the absence of such regulatory levers, the only incentive remains the self-interest of the company, which often resorts to BAT to optimize cost. A favorable factor is the pre-existing and favorable experience with this technology of OMV (the main titleholder in the Romanian Black Sea) which has used it in the Barents Sea and is well familiar with its benefits.

With 70% of estimated global offshore resources not yet explored, improved decision making on whether (and where) to drill or not to drill is becoming increasingly important. Every competitive advantage matters. With E&P budgets are under duress, O&G companies need all the available tools to reduce uncertainty in reserve estimation and increases discovery rates. To date CSEM technology has been used in the Barents Sea, Norwegian Sea, North Sea, South China Sea, the Gulf of Mexico and the Mediterranean. Potential next generation applications of CSEM technology can include mapping gas hydrates, reservoir monitoring during production phase, monitoring carbon sequestration (already attempted at Valhal field and the North Sea Sleipner Ost gas field) as well as “search and study of offshore fresh-groundwater resources” (Constable).

19 http://www.novinite.com/articles/168296/Bulgaria-to+Advertise+Black+Sea+Gas+Deposits+in+US
20 Last year, OMV Petrom spent EUR 19 Million on exploratory drilling of the shallow water Marina 1 well. By comparison, drilling expenses for deep water well Domino-2 were estimated by pundits at 100-150 Million USD. On average, during 2012-14, Petrom invested annually cca. 1 Billion EUR as capex in the E&P segment. The company has been constantly underlying over the last years the expensive operating costs of an offshore exploration vessel, such as Deepwater Champion, to the tune of 1 Million USD/day (http://www.zf.ro/burse-fonduri-mutuale/petrom-si-exxon-au-descoperit-in-marea-neagra-gaze-care-ar-putea-valora-14-miliarde-de-dolari-9330068 ).
21 The new O&G fiscal package (to be introduced in 2015) has not yet been presented to the Romanian Parliament.
Instead of a conclusion

Innovation cannot go unused, especially when it can maximize success and significantly shrink the chances of failure in geologic exploration. It has often been said in the Romanian public space that the average success rate of offshore exploratory drilling is 20-25%. Well, 3D EM [CSEM] is a technology that can significantly improve these odds and the overall chances of striking oil/gas (to as high as 90%). Any technology that increases confidence in prospects and decreases dry hole risk definitely merits attention. The Black Sea is not a self-fulfilling success, investors have to put in the capital, operators - the know-how, governments - the effort to define clear rules and regulations and, all stakeholders – to show “pragmatic openness to evidence” (as Paul Krugman would say) when faced with availability of a technology that can shorten the time and pain of bringing new resources on-stream. A technology that allows faster commercial discovery should never be a wasted opportunity.