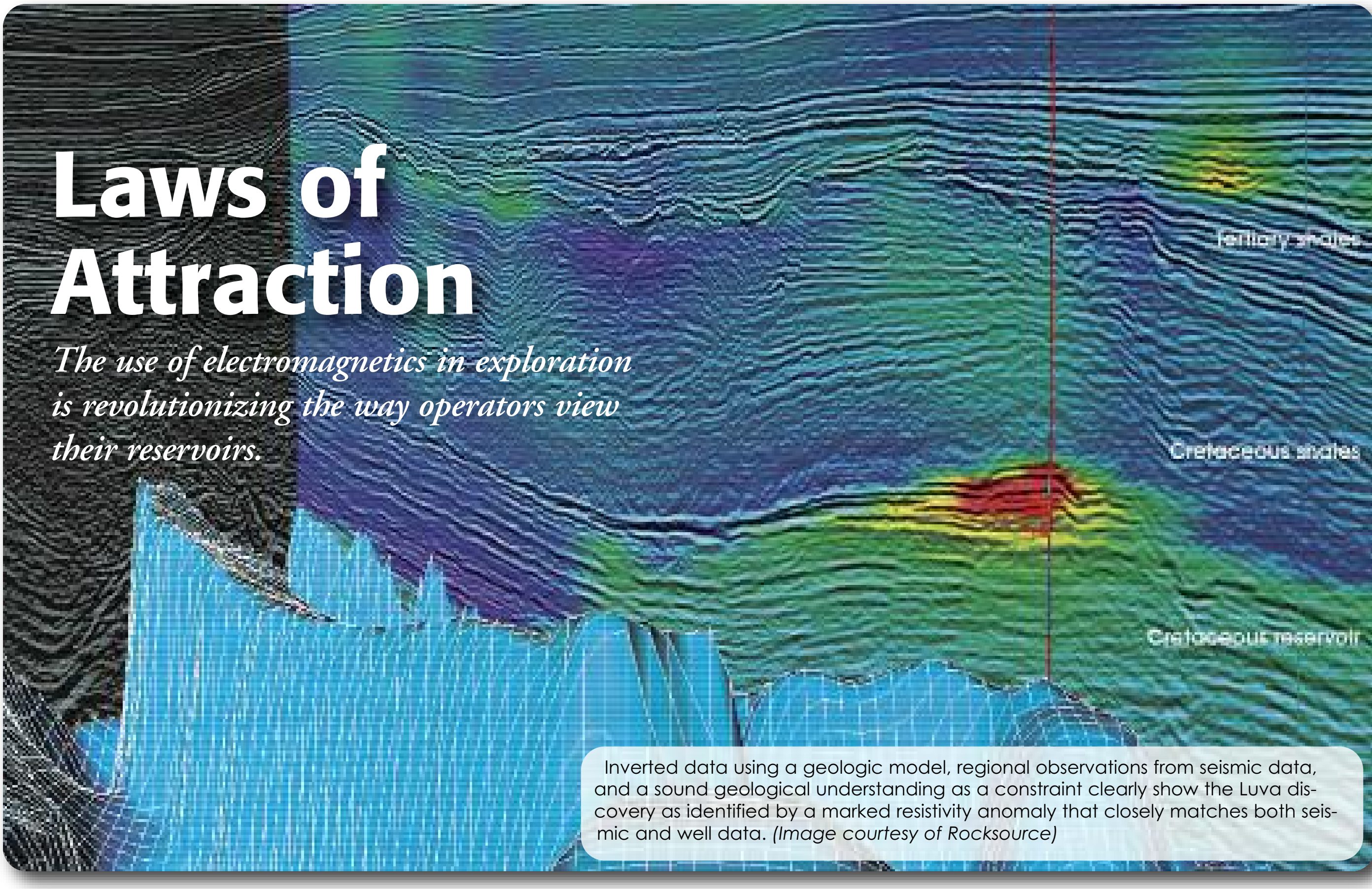
Laws of Attraction

The use of electromagnetics in exploration is revolutionizing the way operators view their reservoirs.



Inverted data using a geologic model, regional observations from seismic data, and a sound geological understanding as a constraint clearly show the Luva discovery as identified by a marked resistivity anomaly that closely matches both seismic and well data. *(Image courtesy of Rocksource)*

Subsurface resistivity information obtained from electromagnetic (EM) surveys can help detect and estimate the total hydrocarbon volume more accurately than by using only conventional seismic data. Where seismic surveying maps structures, electromagnetic surveys map resistivity distribution. Combining the two can lead to a significantly greater understanding of subsurface properties. –

E&P asked several of the top experts in electromagnetics – four from EM service providers and one expert from an exploration company – to more fully explain the use of EM data and why companies should not overlook this important exploration tool.

The panelists include Dr. Jonny Hesthammer, chief technology officer, Rocksource ASA (an exploration company); Jorn Christiansen, vice president of business development, TGS-NOPEC Geophysical; Ken Feather, vice president of marketing, Electromagnetic Geoservices (EMGS); Andy Overton, marketing manager, OHM Surveys; Leon Walker, president, PGS EM; and Marcus Ganz, electronics marketing manager, WesternGeco.

_E&P_ What can controlled source electromagnetic (CSEM) surveys tell you that seismic cannot?

Feather: A quick summary is that EM measurements are more sensitive to fluids; seismic measurements are more sensitive to rock. EM surveys provide information that is more directly related to the presence of hydrocarbons. But the greatest success rate can be achieved by using both forms of measurement.

In more detail, traditional offshore exploration, with no use of EM, achieves a typical discovery rate of around 25%, so roughly one in four exploration wells are discoveries. Combining EM information with seismic and other geological information gives a clearer, more complete picture of the subsurface. The explorationist can literally "see more." Not surprisingly, this two-pronged approach enables better exploration decisions and accelerates the decision process, resulting in a significant improvement in exploration efficiency and performance.

As an example of the benefits EM can bring, the Director General of Hydrocarbons for India recently presented a case study showing a material improvement in offshore India discovery rates, from the 20% level to more than 50%. He attributed this increase to an improvement in the geological understanding of the subsurface and the continued use of [EM] survey technology. In conclusion, operators who include EM in their work flow and decision-making process will enjoy a competitive advantage over those who don't.

Hesthammer: Seismic data are sensitive to contrasts in density and velocity, giving rise to reflections that can be used to map subsurface structures. Since oil and gas are lighter than water, sometimes it will be possible to get a seismic response related to a hydrocarbon-filled reservoir.

However, it often turns out that there is no measurable response. And, to make the matter worse, sometimes you can get a significant response with as little as 5% to 10% (i.e., non-commercial) gas saturation. As such, the seismic data are great for mapping subsurface structures but often (although not always) unreliable or unable to say something about the fluid content (oil/gas versus water).

EM data are sensitive to contrasts in resistivity. The contrasts cause energy to propagate back to the seabed, where it can be recorded by receivers. Low hydrocarbon saturation does not give rise to significant resistivity contrasts and will therefore not be recorded by the receivers. However, high hydrocarbon saturation (i.e., commercial) gives rise to significant resistivity contrasts that can be recorded by receivers. As such, EM data can, under the right circumstances, say something about the fluids within a reservoir (hydrocarbons versus saltwater) provided that the resistivity contrast is big enough.

Christiansen: Seismic is the most powerful exploration tool in the search for oil and gas. With seismic, high-resolution structural images of the subsurface are obtained, and rock and fluid properties can be derived. With CSEM, the resistivity of the subsurface can be modeled.

However, due to the nature of electromagnetic fields, the resolution is normally low. To improve the resolution, the model can be constrained by using information known from the seismic and from nearby wells. As oil and gas have high resistivity compared to water, the CSEM method can recognize petroleum accumulations and then be used to reduce the exploration risk when applied together with the seismic.

Walker: I would just add a couple of points. First, I would say that, probably because of the development of surface seismic techniques, we tend to think first about the application of a new geophysical technique to the exploration work flows. However, because of the great sensitivity of resistivity to changes in saturation, in addition to its use in a broad range of exploration and appraisal scenarios, we will see the development of 4-D EM relatively quickly compared with that of 4-D seismic.

Second, the industry has come to regard the expression "CSEM" as synonymous with the node-based method using a continuous source. As my co-panelists are aware, the PGS method is somewhat different in that we use a transient source function, and we stack the data, hence MTEM – multi-transient EM. The transient method has a key advantage in that it can be used both onshore and in all depths of water. We see a large market in shallow water, where there is a huge drive to find satellite fields and to maximize recovery from current reservoirs from existing infrastructure, and from onshore where more than 80% of the world's reserves lie.

Ganz: The marine geophysical market consists of CSEM to map thin resistive bodies and marine magnetotellurics (MMT) to outline large basin features. Magnetotellurics will provide an additional measurement of important features that create huge uncertainties in seismic data such as the base of salt and basalt bodies. The impact of this has already being seen in the Gulf of Mexico as we integrate magnetotelluric data with wide-azimuth data in order to greatly improve the complex subsalt images. Electromagnetic measurements are non-distinctive, while seismic measurements are unique. Hence CSEM and MMT are extremely complementary with seismic, and the key to extracting the value is the integration of these complementary measurements. The markets for these integrated measurements will grow together.

E&P **What scenarios make EM data acquisition interesting/feasible?**

Overton: CSEM has been proven to work in a wide range of water depths and geological conditions; two of the most interesting scenarios to note are shallow water and steep bathymetry.

Originally thought to be a deepwater-only technique, by addressing the so-called "airwave" problem, CSEM can feasibly now be acquired in water as shallow as 23 to 33 ft (7 to 10 m).

Acquiring data in conditions where the water depth moves from shallow to very deep can be challenging, particularly in exploration situations such as you find on continental shelves. For example, OHM conducted a survey for CNR in 2006 across the **Baobab** field in Cote d'Ivoire. The water depth varied from 1.3 miles (2.2 km) at one end of the line to 656 ft (200 m) at the other end. The resulting dataset could therefore be termed a hybrid: conventional deep water at one end and shallow water at the other. In order to interpret a dataset of this sort, in which the water depth varies so dramatically along a line, the variation in signal interaction with the air must be carefully accounted for in the inversion process; this is done by using an unstructured finite element mesh to accurately model the fields as the water depth changes, thereby taking the variation in signal interaction with the air into account in the inversion process. Despite the dramatic variation in water depth, the reservoir was accurately imaged as a high-resistivity body.

Christiansen: We use CSEM on prospects we have identified from interpretation of our 2-D data. Our mission is to provide the oil and gas companies with multiclient data they can use in their search and to help them reduce risk, for example, in application work for new acreage. CSEM is one such tool.

Both TGS and the oil and gas companies can use the CSEM data to rank prospects and areas. TGS also acquires multiclient 3-D data. Normally the highest-ranked prospect from 2-D and CSEM is then selected.

Feather: On a geological level, EM data acquisition is always interesting because resistivity information is an independent measurement that enables a more complete geological understanding of the subsurface. One of the key benefits of integrating resistivity with other forms of geophysical and geological information is that the end result is a clearer and more complete picture of the subsurface. This enables better exploration decisions more quickly, which in turn improves exploration efficiency and performance.

On a technical level, our current operating envelope is offshore environments ranging in depth from approximately 164 ft to 11,483 ft (about 50 m to 3,500 m), and we're developing technology to extend this to even shallower water. [We have overcome the air wave and towing challenges] using up/down separation processing, time-domain EM techniques, and precision-source positioning and towing technology.

Hesthammer: EM data acquisition and analysis are interesting because the technology has the potential to significantly reduce exploration risk. When doing classic prospect evaluation, an oil company needs to estimate the likely chance of a source rock being present and buried deep enough to generate hydrocarbons. Next, the hydrocarbons must have migrated into a reservoir that can contain them. And finally, the hydrocarbons must be trapped in the reservoir so that they do not leak to the surface. One or more of these factors will be associated with uncertainties, and when multiplying them, you get a typical (worldwide statistics) chance of making a discovery of about 25%.

If you collect EM data over the same prospect and you see an anomaly that you think is related to hydrocarbons, you have a direct hydrocarbon indicator (DHI). Depending on how good the DHI is, you will de-risk your prospect, and the chance of success will increase. But there will always be a chance of a false negative (EM data does not give a response although there are hydrocarbons present) or a false positive (EM data shows a response that is not related to hydrocarbons but something else). This complicates the analysis and challenges the exploration geoscientists.

Rocksource has over the past several years developed tools to handle these uncertainties in all parts of the work flow and has developed its own proprietary software to take care of the analyses, including advanced 3-D modeling and inversion. Rocksource also has a large EM team (15 people) with experience in how to deal with algorithm and software development as well as advanced analyses. Because analysis of EM data is complex, such expertise is needed in order to sufficiently de-risk prospects.

Walker: As my friends have said, the feasibility of an EM survey depends on many factors.

The most important is the resistivity profile on and off the reservoir. This is very analogous to seismic, where having some idea of what you are looking for is a great help. This presents new challenges – ideally we would like the resitivity log to go to the surface, which is seldom the case, and now we need to think very carefully about which kind of resistivity tool was used to log the well – there is a lot of anisotropy down there!

Maximum efficiency is achieved by getting maximum current into the ground. Offshore, the local resistance of the seabed is low – the same as the seawater – so the trick is to use as big a source as possible whilst paying due attention to safety.

Onshore, things are not quite so easy. The local resistance of the ground determines how much current can be pushed in – Ohm's law applies. We can't use voltages of more than 1,000 v because the cables and connectors quickly become operationally difficult. So before each survey starts, we visit the site to determine how we can minimize this local ground resistance, and our crews are experienced on how to adapt to any changes in the terrain.

We are often asked if we can image reservoirs below shallow resistors, or if we can detect stacked resistors. The answer, as usual in geophysics, is "it depends." MTEM data is acquired very much like 2-D seismic data. We have a source and a line of receivers. We have regular, accurately known geometry with a range of offsets. So if the conditions are right, we can undershoot the upper reservoir to illuminate the one beneath.

The final important issue is the so-called airwave. We know that this arrival is not purely through the air but is influenced by the subsurface resistivity profile and so contains some information about that subsurface, but it is huge compared with the energy diffusing back from the subsurface, which contains only information about the subsurface. Therefore, separating these two energy packets gives the inversion algorithms much more chance. When you shoot MTEM data onshore, the airwave arrives at about the speed of light well before the subsurface energy comes in, and we can see just how large it is. We just mute it out in processing. When the survey is in shallow water, you still have an airwave which you want to separate -- hence the focus on this in the industry. We believe that the MTEM method gives the best way of doing this, and if your survey is in shallow water (which for EM is about 980 ft or 300 m), then MTEM will give the best chance of imaging a deep or small reservoir.

Ganz: EM technologies may be applied to a wide variety of exploration targets; near surface to as deep as 13,123 ft (4,000 m) below the sea floor. The ability to predict reservoir fluid properties ahead of the drill bit means a considerable risk reduction for exploration programs and also a significant advantage while considering offshore license bidding. EM techniques are interesting as they allow us to take geophysics even further by reducing risk and helping us better understand a reservoir.

_E&P_ How hard is it to get good, true data using CSEM?

Overton: Getting good, true data during CSEM surveys is possible providing sufficient care is taken throughout the survey process during the pre-survey planning, data acquisition, and post-survey interpretation.

If you have a well-designed survey with appropriate plan and transmission frequencies along with reliable equipment (source, receivers, boat), you should get good data every time. OHM has heavily invested in improving our survey equipment, and clients are now seeing the benefits of this in terms of improved acquisition capabilities (approaching 100% receiver reliability) and therefore improved survey results.

Hesthammer: Service providers currently provide very good data quality, and this is not the main current issue – although we see large room for improvement still. The challenge lies in the ability to sufficiently understand the EM data and how it reflects changes in resistivity in the subsurface.

Currently the industry lacks good enough knowledge – or the industry does not have available the tools needed – to carry out advanced processing and analysis. As such, there will be statements like "there are case examples where the EM technology fails." The EM technology does not fail, but the people analyzing the EM data must understand the complexities associated with the analysis. Such an understanding is important both prior to and after acquisition. Prior to acquisition, such knowledge can help avoid collection of EM data in settings where the technology cannot be expected to provide results needed for decision-making.

Christiansen: With proper pre-survey planning using other available geophysical and geological information, we normally get conclusive results processed from the CSEM data. However, the interpretation of the resistivity model derived from the CSEM is not straightforward since high resistivity also can be caused by rocks such as limestone and salt.

The electromagnetic method has been in use for decades; however, the offshore application in the search for oil and gas has only been available for a few years. Development of new source and receiver arrays and more effective ways of deploying equipment and acquiring data continues with all the contractors to make CSEM a more cost-efficient and reliable method.

Feather: Acquiring good-quality EM data reliably, consistently, and efficiently in a wide range of marine operating conditions is a non-trivial task. But for the last six years, since the first trials of seabed logging, it's been a prime focus of EMGS. Over that time, we've developed the right tools, technology, people, and processes to do it successfully.

Ensuring the quality of data requires the tight integration of a number of resources: survey vessels with bespoke handling gear; experienced crew; a high power, fully controllable source; ultra-sensitive receivers; absolute knowledge of positioning (for both source and receivers); and accurate synchronization of transmitted and received signals. The continued investment of time and effort involved in developing and integrating this system, along with our careful choice of technical partners (including Siemens, Kongsberg, Sonardyne, Concept Systems, and Bennex), has paid rich dividends.

Dedicated EMGS engineers onboard are responsible for monitoring the quality and completeness of the data collected. Onboard processing helps accelerate generation of the final answer product for our clients and helps provide our "Fast Track" –- a means of ensuring any survey extensions or adjustments can be agreed upon while the vessel is still on station. In addition, this onboard capability guarantees no vessel ever leaves the survey area without a complete dataset.

Walker: I have already mentioned the necessity to get maximum current into the ground for each shot. Then it comes to down to quality of the crew and the equipment. Most of the personnel on our crews, both onshore and in marine, have long experience in the seismic industry. An MTEM survey is conducted much like a seismic survey – 2-D seismic onshore and ocean-bottom-cable in marine. We have adapted seismic health, safety, and environment management systems, and all our crews operate to the highest industry guidelines.

With our use of cable-based systems both onshore and in marine, we are able to provide real-time quality control during our data acquisition. Thus, we can see if our cables are in the right place (acoustics in marine and GPS onshore), and we can check the data as it is acquired. Our trained field geophysicists monitor signal-to-noise carefully and adjust the source functions and vertical stacking appropriately in real time. Furthermore, we can press on with delivering quick-look products simultaneously with the acquisition.

Our equipment is proprietary – good EM data is all about good signal-to-noise. We are looking for some very small signals, and there is often a lot of noise. The packaging of the receiver systems looks a lot like seismic, but the source systems are very different. Until now we have been using a commercially available source onshore, but we will shortly be launching our new source, which offers greater flexibility and hence better data.

Ganz: It is known that CSEM will detect resistors often associated with hydrocarbon deposits in marine environments; therefore, it represents a significant advance in deepwater oilfield exploration. CSEM has been called the most significant new technology in oilfield exploration since the development of 3-D seismic acquisition 20 years ago.

WesternGeco has a program called multimeasurement constrained imaging (MMCI) that combines seismic technology, full-tensor gravimetry and MMT to reduce exploration risk in subsalt exploration programs. Considerable success has been experienced using 3-D seismic with prestack depth migration techniques to improve understanding of potential reservoir structures lying beneath the salt. These techniques can be made more efficient and economical if MMCI techniques are applied first.

E&P How do you integrate the data with other modeling data?

Overton: OHM works closely with our clients to ensure that both their existing knowledge and expertise of their prospects, combined with our in-depth understanding of applying and integrating CSEM with other geophysical data, allows the best possible insights and end results.

OHM and Rock Solid Images are launching a consortium called WISE (Well Integration with Seismic & EM), along with six oil company partners and the UK government, to further develop methods. Investigations will include establishing the optimum algorithm for remapping CSEM results into higher-resolution seismic data, developing joint inversion for seismic and CSEM data, and analysis of the risk reduction impact of the integrated interpretation of data. Ultimately, we would propose real value comes from integrating various data types into a whole earth model.

Hesthammer: You typically carry out modeling prior to acquiring EM data. This is done to test how well you can expect the technology to work in a specific setting, and this part is very important as the technology is not always suited for de-risking prospects. The modeling part should use all information and knowledge available to the geoscientist, including seismic data, well data, and a sound geological understanding.

After acquisition, you process the real data and compare the real data to synthetic data. This will give you an indication of whether or not your model is representative (i.e., you have developed a likely correct model). The processed data will subsequently be compared to seismic data, well data, and the geoscientists' general geological understanding of the subsurface to see if there is a fit.

The more data you have available, the better analysis you can typically do. This integration is crucial, and it leads to an iterative process that involves further modeling, further processing/inversion/migration, and further integration with seismic analysis, etc. Such an approach is complex and time-consuming, and Rocksource has spent much time and resources to develop tools and procedures that will make this process as efficient as possible and to ensure that good decisions are made.

Feather: EMGS has just launched Clearplay, the world's first fully integrated EM system. With Clearplay, there are four parallel paths to integration. The first happens internally – ensuring all the ingredients EMGS has developed are integrated seamlessly with each other.

The second happens externally, the result of using a decade of real-world experience to create the best fit between Clearplay and our customers' work flow at each of its stages – from feasibility studies through survey planning, data acquisition, and data processing and imaging, to interpretation and data storage. The closeness of this fit enables customers either to use all the components of the Clearplay system or select elements they need to support their internal capabilities.

The third is achieving integration of EM with seismic and other data. All Clearplay data is output in an industry-standard format for easy import by customers' own systems. The Petrel plug-in, Bridge, developed with technical partner Blueback Reservoir, facilitates seamless integration with other geophysical and geological information within the Petrel platform. And, in an advanced stage of development, is software to enable joint inversion of multiple data types.

Finally, Clearplay integrates three complementary EM measurements and methods: frequency-domain EM, time-domain EM, and MT (magnetotelluric).

Walker: As Jonny says, we need to take all the geophysical knowledge of the target into account when modeling to determine feasibility. An interesting example of this is a feasibility study we have done using MTEM to monitor the steam front in steam-assisted gravity drainage in the tar sands in Canada. Here we have used seismic to determine the geometry of the target, well logs to give information about rock and fluid properties, and rock physics modeling to see how the steam chamber may be functioning in the complex three-phase flow. We reckon MTEM can be used, but to be sure we really need to interface a reservoir simulator to our EM modelers.

Ganz: From the early stages of feasibility to the final interpretation, it is critical to make use of all the available data. Working closely with our customers, our overall goal is to produce an interpretation that is consistent with all the known geology and data types. With the addition of Geosystem to WesternGeco we now have more than 25 years experience in EM data modeling, processing inversion, and interpretation. In the past year or so we have acquired more than 2,000 sites of marine magnetotelluric data in the Gulf of Mexico and have incorporated this with full-tensor gravity into a joint inversion, which has been combined with the latest wide-azimuth 3-D seismic data to form the largest MMCI to date. We have considerable experience now with 3-D joint MMT and CSEM inversions and 2-D joint CSEM and seismic inversions.

***E&P* What is on your "brag list" – what you do bigger/stronger/faster? How about your "wish list" – what you wish you could do now, and how far off is the development of that technology?**

Christiansen: The resistivity anomalies we want to image normally emit a very weak signature; hence, the deployment of equipment is time-consuming and an expensive exercise, making resistivity data an exclusive product with only a selected number of prospects measured.

The offshore application of CSEM in the search for oil and gas has proved its value. We hope technology will improve and one day we will be able to acquire CSEM along with the profiling of the 2-D or 3-D seismic surveys.

Overton: Our strength is data acquisition; with two custom vessels, OHM offers our clients lower costs and improved results. Quick, efficient, and effective survey operations are something else we are especially proud of, as well as data integration – bringing well log, seismic, and EM data into one usable package.

OHM is also known for its customer service – high levels of communication with our customers to ensure we are offering the right thing at the right time and the right price. By placing staff in our customers' offices we help them truly understand and integrate our data into their E&P workflows.

CSEM also has applications in reservoir appraisal and management; OHM and Rock Solid Images have an ongoing R&D project, funded by the UK government and working in collaboration with BP, to develop these applications. One of the key components of moving from an exploration to production environment is the intelligent integration of CSEM data with complementary data from seismic and well logs. By doing this we can use the strengths of each to move beyond simple images of resistive and conductive structure and provide maps of lithology and fluid properties across a field.

Integrating geophysical data types can provide information on a reservoir that is either not available or is unreliable using any one data type alone; by doing this we hope to improve the quality of reservoir information available to engineers and geoscientists making decisions on field development and management in the future.

Hesthammer: Rocksource has established a work flow and software that allows for detailed and efficient analyses of EM data with focus on the decision-making process that is at the core of an E&P company. As such, we have the capability to carry out numerous analyses within a short time-span using highly advanced algorithms.

Rocksource does both modeling and processing/inversion in full 3-D and has a dedicated team of highly qualified and competent EM experts and geoscientists to ensure the best possible quality of the analyses. This gives us a significant advantage over those that do not have such expertise and tools and makes us an attractive partner for other oil companies interested in de-risking prospects with CSEM technology.

The technology is still in an early development stage (compared to, for instance, seismic technology). As such, there is large room for improvement related to both hardware/acquisition and processing/integrated analyses. As the industry increases its knowledge of the technology, we expect to see an increasing use of CSEM data and hopefully associated successful results.

Feather: In 1997, the founders of EMGS conceived the possibility of adapting CSEM technology to detect hydrocarbon reservoirs under the sea. Their technique, "seabed logging," proved remarkably successful, and they became the founding fathers of a completely new industry.

With hydrocarbon reserves now being depleted faster than they can be replaced and finding costs increasing exponentially, an improvement in exploration efficiency and productivity is essential. Introducing EM in to the traditional exploration workflow enables better decisions, and this will help improve the performance of the industry.

Walker: I am most pleased that we have conducted successful MTEM surveys in a wide range of terrains onshore and in shallow water offshore. Onshore, we have conducted surveys on the tar sands of Canada, the pancake geology of Wyoming, and thrust belts of India and Trinidad, and through shallow gas in India.

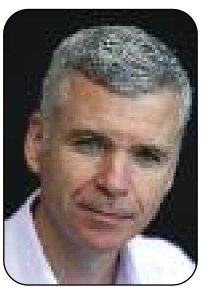
As I have said, the key to good data is getting the current into the ground, and we have been successful on farmland, dry prairie, desert, frozen tundra, and in the jungle. Offshore we have successfully imaged reservoirs in water depths down to 197 ft (60 m) and with a depth of burial as much as 1.4 miles (2.3 km).

With regard to the future, PGS is developing a towed EM system that will provide huge efficiency gains in marine. Our investments are directed at giving value to our customers.

In summary, I am proud to be working in EM – both the present and future are very exciting!

Ganz: Within Schlumberger and WesternGeco, we have a huge geoscience community with great expertise in electromagnetics. The expanded use of this technology gives our people an outlet to apply and enhance our knowledge in this field. EM is the most significant technology to be added to the seismic portfolio in recent years. We are committed to its continued development through our ongoing R&D and training programs. The uptake by the industry is encouraging, and we envision continued growth as this technology is further proven. We will continue to develop our portfolio of products and services that integrate different and complementary measurements to produce the best results possible. ♦

Jorn Christiansen
TGS-NOPEC Geophysical



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