Managing uncertainty
Derisking oil exploration in complex environments

Featured Explorers
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Offshore oil prowess
Eni’s expertise in deep offshore oil exploration

As the planet’s easy-to-find petroleum resources mature, deep offshore exploration and production lead the trend to the more difficult and challenging regions. Eni is one of a handful of leaders.

By Graham Chandler

Peak Oil theories aside, it’s no secret that the world’s easily-found petroleum reserves have mostly been discovered already. And as the planet continues to consume at the rate of nearly 1,000 barrels a second they are depleting. Exploration companies are pushing further into frontiers where environments are harsher, or were hitherto limited by technologies of the day.

The International Energy Agency predicts that oil will continue its dominance of the world energy scene well through 2035. By then, the organization projects, daily global consumption will have increased 18 percent to 99 million barrels per day. There will probably be enough to go around, but it’s ever-increasingly located in more expensive and complex frontier locations. So that’s where the exploration is trending.

New technology such as horizontal drilling and multistage fracturing is already unlocking vast new production levels from fields long abandoned as uneconomic—North America’s Bakken formation for example, which is expected to soon be producing a million barrels a day. These tight and shale plays are skyrocketing in countries around the world and will help advance world production numbers. But it’s the frontiers where the big new elephant fields are being discovered.

Leading the new frontier exploration trend is the deep and ultra-deep offshore: the east coast of South America, the east and west coasts of Africa, and the Gulf of Mexico for example. Brazil is reported to have nearly 48 billion barrels of oil in water deeper than 600 meters. One field alone—the Lula—holds probably 6.5 billion barrels. Africa’s offshore west coast is where the world’s most active deepwater fields are found—primarily Angola and Nigeria.

The Gulf of Mexico, with more than 3,400 offshore production facilities, has been producing for decades. But further out, 300 or so kilometers from shore, the water is deeper and the geological formations are older. Esteemed energy research firm IHS CERA has suggested there’s nearly 13 billion barrels of recoverable deepwater oil out there yet. And already Shell’s Perdido production platform is on location producing from deposits 2,400 meters below the surface.

Knowledge of these deposits’ existence has been around for some time. Geological theory suggested the reservoirs were out there in sedimentary units past the offshore delta fans and into the turbidites. But the technology to explore and produce them wasn’t.

Holding back seismic exploration was largely the presence of massive salt layers which can be over two kilometers thick, laid down millions of years ago as ancient oceans evaporated. These high velocity media, with strong lateral velocity contrasts, induce such intense bending in the seismic waves that lots of the reflected energy can’t be recorded. This creates problems especially in the imaging of the salt flanks and in the formations below salt.

Leading the technological frontiers that have been unlocking the ‘salt barriers’ and making the discoveries possible is a handful of world companies. One who has developed the expertise is global player Eni. Luca Mapelli, Potential Data Team Leader at Eni, explains how progress was made in seismic modeling that led to the breakthroughs. “First you search for easy targets, then when you need to increase the reserves you start looking for difficult targets,” he says. As these targets became the deep offshore, improved seismic processing capabilities were coming to the fore over the past decade, which opened up ways of looking beneath salt layers. “Explorers were able to better look beneath salt,” he says, “which still poses imaging difficulties, but less than before.”

Those advances included better processing through PSDM, RTM and better data gathering using WAZ, MAZ, and coil shooting says Mapelli. PSDM, or Prestack Depth Migration, is a model-based seismic imaging methodology. Compared to conventional time migration image processing, which assumes that seismic waves are propagated in straight rays, PSDM is quicker and slower but the payoff is more precise determination of reservoir...
structures. RTM, or Reverse Time Migration, can boast simplicity and superior imaging quality by using a full solution 2-way wave equation—it makes no approximations limiting the direction in which seismic energy can travel. WAZ (wide-azimuth), MAZ (multi-azimuth) and Coil shooting are advanced acquisition techniques aimed at addressing the illumination problems inherent in traditional narrow-azimuth marine seismic.

Coil shooting, used in exploration for deep offshore fields, consists of streamers towed behind a ship on spiral routes rather than on the traditional regular geometric grids. It provides full azimuth coverage of the targets allowing more detailed imaging than conventional techniques, and the data acquisition rate is faster compared to other multi azimuth techniques such as MAZ or WAZ.

While these advanced techniques are now indispensible in the deep offshore arena, there’s much more to it. For consistent success, integration of techniques and methodologies has become paramount. “A new approach to exploration has to be developed with a higher integration, at all stages, of different disciplines,” says Mapelli, “such as seismic reflection and gravity modeling, both inverse and forward. Only such synthesis improves our ability to constrain non-unique results predicted by theory, allowing for solutions that are distinct and robust in practice.”

“I could never stress too much the necessity of close integration between seismic and gravity data interpretation,” he says. “It should not be intended as a simple sharing of results, but as a new working approach where each discipline drives the other.” This is possible because seismic velocity (the basic property measured

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-Luca Mapelli, Potential Field Team Leader at Eni
Earth Explorer

**Offshore oil prowess: Eni’s expertise in deep offshore oil exploration.**

by seismic methods) and gravity share a common factor: density.

He explains that, as seismic velocities depend on elastic parameters and density, gravity inverse modeling could help in the definition of a density volume that could drive the definition of the seismic velocity volume, which is an essential part of the migration process in PSDM. The link between velocity and density is based on empirical relations that are more reliable if statistically controlled by well logs, i.e. sonic and density logs.

“During the interpretation phase, both gravity/magnetic data and seismic data could be used together to derive a unique geological model,” continues Mapelli. “The contribution of gravity data is more important wherever seismic data encounter imaging problems such as the presence of thick salt, gas hydrates, basalts etc. The higher the initial uncertainty is, the greater the value of a gravity/magnetic and seismic integrated approach will be.”

Mapelli uses Geosoft software for data integration, as it allows processing of potential data in a unique environment, and the ability to load other data such as seismic and wells to better constrain the interpretation process, he says. “The drill plotting capabilities help with the integration of gravity data and well data. When available, well data can give a strong constraint on the interpretation.” Modeling capabilities, 2D as well as 3D, provide an easy way to check the consistency of a seismic interpretation, he adds.

These integrated techniques played an important role in the greatest discovery of Eni’s exploration history: the massive gas field in the Rovuma basin offshore Mozambique, which the company reported was “beyond expectation.” Exploration wells in the Mamba South showed up to 22.5 tcf, Mamba North 7.5 tcf, and Mamba North East 10 tcf; for a total of up to 40 tcf of gas in place. These are in waters 1,800 metres deep with overall well depths of 4,500 metres; “Exploration success was boosted by the application of proprietary technologies in the area of seismic mapping,” states the company’s 2011 Annual Report.

Gravity data acquired together with seismic data played a key role in the processing and interpretation says Mapelli. “The gravity dataset helped in the definition of the main depocenters, especially the isostatic map which clearly shows the thickest part of the sedimentary section,” he explains. “Other elaborations helped in the enhancement of the anomalies thus providing a better view of the structures affecting the area. A 2D modeling along selected profiles allowed us to fine tune the geological model with a sequential adjustment of the initial model until the misfit error fell below a predefined threshold.”

It has been an exciting proof of Eni’s expertise and technology. The company plans eight more wells over the next two years to monetize Mamba’s reservoir potential. For other companies, there are still thousands more square kilometres of offshore to explore. “Even the big salt provinces of west Africa, Gulf of Mexico and Brazil should be investigated in even greater detail and depth,” says Mapelli.

Development and enhancement continue, but so do new challenges. “While great improvements have been achieved in seismic imaging as well in potential data methodologies, the way forward is to improve the inversion methodologies for seismic data as well as gravity/magnetic data,” says Mapelli. “A real 3D joint inversion between gravity and seismic is the Holy Grail. Passing from a cooperative inversion to a joint inversion is the real step forward to get a unique geological model that satisfies the available data.”

The advances are paying off handsomely for many companies; one winner has been explorers’ reduced per barrel finding costs. Although exploration costs dwarf typical onshore per well figures, the sheer size of the deep offshore discoveries reduce the per barrel numbers. Brazil’s deep offshore Santos Basin for example yielded 30 billion barrels discovered with just 32 exploration wells.

It has been an exciting proof of Eni’s expertise and technology. The company
Superior detective work
The promise of airborne gravity gradiometry

By Dan Zlotnikov

A relative newcomer to the resource exploration world, gravity gradiometry is already having a major impact. Its potential for producing high-quality data has caused many explorers to take notice and wonder how they might best make use of the technology.

Just like the commonplace airborne gravity survey, an airborne gravity gradiometry survey responds to the gravitational pull of large masses on an accelerometer. Here’s how it works: Fly over a particularly dense object, such as a rich underground ore deposit, and you register a spike. Traditional gravimeters measure the force exerted on them from one direction only, usually straight down. If a survey does not fly directly over an anomaly but slightly to one side, the odds it will detect that anomaly decrease sharply. Gravity gradiometers, on the other hand, measure forces from the sides as well, greatly improving the ability to detect objects.

Dan DiFrancesco, Business Development Manager for Gravity at Lockheed Martin, U.S.A., explains that the technology originated with a US military project in the 1970s: a navigation tool for Trident nuclear submarines. When the Cold War ended, the project was declassified and gradiometers became available for commercial use.

There are two gradiometer designs in use today, says DiFrancesco. One is the Full-Tensor Gradiometer (FTG), which is the original instrument, developed by Bell Aerospace and now being made by Lockheed Martin following its acquisition of that company in 1996. The other is the FALCON®, a partial-tensor instrument jointly developed by Lockheed Martin and BHP Billiton which was designed to aid in the latter’s search for diamond-bearing kimberlite pipes – small targets not easily found with a traditional airborne scalar gravity survey.

DiFrancesco notes that FALCON® measures two tensors with high fidelity whereas FTG measures all six with a lower fidelity. Though the two instruments arrive at the solution by different means, they produce very similar results.

Two of the world’s three leading gravity gradiometry providers, Bell Geospace and ARKeX, use the FTG, while Fugro Airborne Surveys holds exclusive rights to fly FALCON® surveys.

In addition to the three commercial providers, a number of new airborne gravity gradiometry solutions are under development, but are not yet commercially available.

PRACTICAL TRADE-OFFS

Chris van Galder, AGG technical advisor for Fugro Airborne Surveys, says BHP was so pleased with the results produced by the FALCON® that it fast-tracked completion of a second instrument. Fugro, which took control of BHP’s gradiometers in 2008, has gone a step further: in 2012 it began offering commercial HeliFALCON® surveys, the helicopter platform allowing it to fly slower, take more measurements per kilometre, and produce higher-resolution data.

Airborne gradiometry data isn’t cheap. Alan Reid, a potential field geophysics expert who has served as client consultant, puts the price of a large airborne gravity gradiometry survey at roughly
$200 per line-kilometre (though current market conditions have seen this figure decrease slightly). The high price reflects the high cost of the instrument itself.

“You spend several million dollars to buy one, work out how much you can charge per kilometre, and soon you decide you want to eat up a lot of kilometres,” Reid says. Flying slower means booking more time on a rare machine (only 11 gradiometers exist, notes DiFrancesco), and that in turn means higher costs per kilometre.

Still, when the budget permits, gravity gradiometry delivers. Bell Geospace CEO and President Scott Hammond recalls a survey De Beers commissioned because it needed extremely high-resolution data to find small kimberlite pipes. Bell used a Zeppelin airship and the resulting data allowed De Beers to find anomalies less than 100 metres across. However, practical constraints intervened: The Zeppelin was caught in a dust devil and both it and the gradiometer suffered significant damage. Therefore, Hammond doesn’t expect to see widespread use of Zeppelins for surveys any time soon.

DiFrancesco believes more robust and resilient designs could prevent such problems. “There are hybrid airships coming on-stream that I think will make a difference.”

ANYTHING AND EVERYTHING

A versatile tool, gravity gradiometry can locate anything with a density gradient.

“In oil and gas exploration, gravity gradiometry has proved valuable for sub-basalt and sub-salt definitions, pinnacle reefs, and dykes,” says DiFrancesco. “It has also been used in mining applications, to find iron oxide-copper-gold type deposits, banded iron, and kimberlites, as well as porphyry copper and placer gold-type activity. There have been a lot of case studies showing the value of this technology.”
But the gradiometer’s sensitivity can be a curse as well as a boon. As van Galder notes, “the good thing about a gradiometer is that it can detect anything; the bad thing is it detects everything.” This means geologic “noise” (van Galder points out that real-world rocks don’t have perfect, uniform densities), not to mention the noise produced by the plane’s acceleration.

Reid says the “astonishingly crisp” results produced by airborne gravity gradiometry are all the more impressive given that “the accelerometers are being run at their absolute limit. “You’re putting these accelerometers into something that’s being buffeted around. What the pilots are doing is just a shade short of impossible. Flying sensitive accelerometers in a light aircraft is an incredibly difficult thing to do.”

Hammond puts the sensitivity into context:
“We’re looking at one part in 10^11th in the force of gravity. It’s such a small signal that it’s hard to see. When you’re trying to do that on an airplane that’s flying through all kinds of turbulence, the noise is many orders of magnitude higher than the signal you’re looking for. Getting rid of that noise is critical.”

Data processing algorithms are just one part of the puzzle. Bell has been using turbine-retrofitted Second World War DC-3 planes, which Hammond says are large, slow, and able to handle much more turbulence.

Marco Antonio Braga is exploration manager for iron at Vale, which has flown some 100,000 line-km of airborne gravity gradiometry over the past 10 years. He says it’s important to know how factors on the ground affect the quality of data. “We fly surveys at 5 a.m., stop at 8 a.m., then come back at 4 to 5 p.m. and fly again,” he says, adding that if the conditions aren’t right (e.g., strong winds or heat), they won’t fly since they know the data won’t be good enough.

**EDUCATION AND EXPERIENCE**

Neil Dyer, chief technology officer for ARKeX, says experience and specialization are equally important. ARKeX specializes in hydrocarbons, which enables it to focus on its customers’ end-goals,

“We pay a lot of attention to the design of our ratio between the spacing of the survey lines, the tie lines, and the processes we use to level the data and minimize the filtering that needs to be applied in the post-processing sequences,” says Dyer.

DiFrancesco points to customer education as a crucial component of successful gravity gradiometry use: “I strongly believe that the end-users – the oil and gas and mining companies – need a deep understanding of what the capability provides.”

Dyer agrees. He notes that just a few years ago, ARKeX was rejecting more than half of all inquiries they received after feasibility modelling indicated gravity gradiometry was not suitable in certain cases. ARKeX and its peers have been trying to educate potential customers about what gravity gradiometry can and cannot do, and these efforts are beginning to bear fruit. “There are now repeat customers for these services,” notes DiFrancesco, “and more and more people are using this technology in conjunction with, or in advance of, seismic surveys. In short, there’s more acceptance now.”

**RIGHT TOOL FOR THE JOB**

Still, despite the promise it holds, gravity gradiometry should not be seen as a cure-all. As Dyer points out, “there is perhaps a feeling that gravity gradient will solve all problems. Rather, the technology should be seen as expanding the proportion of situations in which a gravitational measurement is applicable.”

“We’re still looking for density contrasts; if there isn’t a structure with a density contrast, we’re not going to help,” says Dyer. “That’s where we like to get involved, in identifying that situation before a lot of money is spent.”

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-Dan DiFrancesco
Suppose you’re an energy company in search of new discoveries: Where do you look if you want to make the best use of your limited cash reserves?

The question has as many answers as there are energy companies. Some look near areas known for previous discoveries; others turn to regions where they have the strongest expertise; some may look in areas with existing high-quality survey data; while still others focus on less-rich reserves made economical by good infrastructure links.

Yet regardless of the preferred course of action, one thing virtually all explorers must face is diminishing returns on investment. It’s the harsh reality that forces them into more and more inaccessible and challenging territory.

“A lot of the low-hanging fruit is now gone,” says Dr. Mark Davies, who until 2009 was chief scientist at airborne gravity gradiometry provider ARKeX Inc. “We’ve been driven into areas where exploration is difficult, often because of extreme weather, be it cold or hot. Imaging is difficult in such conditions.”
In 2011, Davies founded the specialist geosciences company Bridgeporth Ltd., which focuses on regions that have seen little exploration due to security and logistical concerns. The company also works in extreme climates such as Africa and Northern Canada.

“Our niche is gravity, magnetics and remote sensing. We’ve done work in minus-forty conditions and in plus thirty-five,” says Davies. “Electronics aren’t built to sustain temperatures like that, so we’ve had to modify equipment, as well as the way we acquire data, to take account of those extreme conditions.”

Bridgeporth’s technical director, Dr. Nick Harrop adds that complex projects requiring technological, instrumentation and geophysical problem-solving are par for the course for many explorers.

The bigger challenges, says Harrop, are security and logistics, and this is where Bridgeporth’s unique experience comes to play. “Other companies are perhaps less willing to specialize in this area, whereas Bridgeporth has a lot of in-house expertise for managing political, operational and security risks in complex environments.”

**CONDENSING TIMELINES**

Long delays are inherent in exploration work, and these delays can carry greater risk when exploring in challenging regions.

“Prior to bidding on acreage, you’re probably doing twelve months of work as part of a new venture,” explains Davies “Then, once you bid on a project and are successful, you have to do a follow-up study, including gravity, magnetics and seismic.”

In total, it may be three to five years before a block of claims begins generating revenue — a time frame that comes with a separate set of concerns if the project is in an area that’s geopolitically uncertain. The question, says Davies, then becomes: Is the region going to be politically stable long enough for the client to start producing? In short, will there be payback?

The goal is to condense what are normally three years of work into 12 months, an achievement made possible by integrating...
security and logistics as part of the project. Having security consultants on staff means fast results, says Davies, noting that "managing security and logistics concerns is half the headache when working in these areas." Bridgeporth's extensive network of security personnel means the company is able to stay abreast of any potential problems.

Another element that can shorten timelines is rapid data processing. Coarse-resolution gravity and magnetic data is available globally, allowing energy explorers to quickly and cost-effectively identify areas of interest. Once a target region has been selected, explorers can use higher-resolution airborne surveys to get more information.

Davies explains: "Everything we do is focused on acquiring data rapidly, then processing and interpreting it in real time and making decisions on-the-fly for the client. We acquire the data within a large footprint, and we process and interpret the data in real time. As we in-fill, we get a better and better picture and can continually update the client." Obtaining data while surveys are ongoing can help clients plan seismic programs prior to the completion of remote sensing. This is important because in most cases, clients cannot afford to shoot seismic across an entire survey area. To illustrate this point, Davies cites a recent project in East Africa: "In an area that comprised about 60,000 square kilometres, the client had a little more than 2,500 line kilometres of seismic to shoot." Working closely with the seismic contractors, Bridgeporth was able to further expedite the process, saving time and money.

BUILDING RELATIONSHIPS

Building relationships on the ground is another critical requirement when working in politically sensitive environments. Mineral surveys tend to be "postage-stamp sized" in comparison with hydrocarbon surveys, says Davies. No matter how fast the work is performed, a survey team working on a hydrocarbon project will likely remain in the area for months at a time.

"The security and logistics experts will always tell you not to be repetitive or predictable. However, when it comes to a minerals project, we're generally visible from the same point on the ground throughout the entire survey, so if there's one thing we are, it's repetitive and predictable. We have to be. As a result, we come up with more creative
solutions to mitigate against that easily tracked repetitive behavior."

Hydrocarbon surveys cover a larger area, which allows the survey aircraft to vary its routine somewhat. But there is a trade-off: the large area might overlap the territory of not just one but six or seven local indigenous tribes.

In both scenarios, it’s essential to talk with local residents.

We pride ourselves on our rapport and liaison work with local communities," says Davies. "It’s all about getting the boots on the ground, talking to the communities, and getting them to understand that we’ll be bringing revenue into the area in the long term."

Getting the proper rapport with the local communities makes the job easier not only for Bridgeporth, but for any seismic and mining or oil companies that follow the survey teams — a foundation of goodwill the latecomers benefit from.

HAVING THE RIGHT TOOLS

When it comes to acquisition technology, Bridgeporth strives to use the best instruments available for a given project, says Davies. "If we think a gradiometry system will work, we’ll use that; if we think a high-resolution gravity system is best, we’ll use that.” The key, he stresses, is integration. "You can acquire the best data in the world, and lots of it, but unless you integrate everything, no one piece of technology will give you a complete picture."

A tool that has contributed to getting the complete picture, for Bridgeporth, is Geosoft’s Oasis montaj platform. The company uses Oasis montaj and GM-SYS 3D for gravity and magnetic data processing and interpretation. Bridgeporth field crews perform quality control on the collected data before passing it on to the processing team. After the data has been cleaned and processed, it can be integrated with third-party data for the area such as 2D or 3D seismic, geological information and well information. All of these datasets are combined with the new survey data to produce as complete a picture as possible. "It truly becomes a multidisciplinary interpretation project,” says Davies.

One of the reasons Bridgeporth chose Geosoft is the ability to easily integrate proprietary algorithms and workflows developed by their Research and Development team. Davies points to Geosoft’s extensibility as a crucial benefit. "We favour a number of processing routines and a lot of the functionality of Geosoft’s processing is excellent, so why re-invent the wheel? We also write our own Geosoft Executables and then fold that into the software. That gives us the flexibility we need to tailor workflows."

Flexibility and integration, in their skill sets as well as their technology, mean Bridgeporth can handle projects under almost any conditions. Says Harrop: "My tick boxes start with the security experts saying they can provide us with a secure camp area, and from there we have the capability to build anything. If there’s no landing strip, we can build one; if there are no accommodations, we can bring our own; if there’s no power, we can bring that too. We can handle all those things."

The company currently operates ground and marine teams, in addition to three aircraft: a Cessna Grand Caravan C208B, a Pilatus Porter PC-6 and a twin engine Basler. It expects to add a fourth plane and a helicopter to the fleet, in addition to having access to a range of aerial platforms via a portfolio sister company.

"The Basler in particular is a powerful tool in any arsenal. With a robust airframe, a range of special mission capabilities, low operation costs, and excellent long range capacity, it is the ideal aircraft for the kind of surveys required by the hydrocarbon and mineral industries. With marine, land, and airborne capabilities, there is no terrain or environment that is inaccessible for Bridgeporth," says Davies.

Looking forward, Harrop predicts more and more exploration work will be done in politically sensitive areas. "There are many such regions and countries tend to experience geopolitical sensitivity in cycles," he says. "Some countries you wouldn’t have gone to before, you would perhaps consider visiting now, and vice-versa."
Petrobras is a perfect fit for exploration and production geophysicist Julio Lyrio, who joined the Brazilian company in 1987. “What makes Petrobras different from many other companies in the industry is the fact that it was born as an exploration enterprise,” says Lyrio. “Fortunately this focus on exploration has not changed.” To this day the company’s main objective has been to discover where the oil is in Brazil. “The recent pre-salt discoveries are a validation of this dedication,” he says.

Petrobras has a strong world presence in the oil and gas industry: it can boast the largest market value in Latin America, with nearly 70,000 employees operating in 27 countries; and two and half million barrels equivalent per day of production.

Significantly, it’s a technological leader, recognized especially in the highly challenging deepwater exploration and production
environments. “Challenge is our energy,” quotes the company’s website.

The pre-salt discoveries Lyrio refers to are recently-announced findings from those cutting-edge research techniques: in the Santos Basin 300 kilometres off the southeastern coast of the country and 7,000 metres below the South Atlantic Ocean surface. Potential is up to 33 billion barrels or more – some of the world’s largest ever – of light sweet crude oil. Just finding them was a challenge. Beneath two kilometres of ocean water lies a post-salt layer (so-called because it was laid down later than the salt layer) half a kilometre thick, then another two kilometres of salt before reaching the pre-salt layer which contains the oil deposit.

That it was a challenge to find is an understatement. That post-salt layer is made up of high velocity rocks that can make it almost impossible to seismically image formations below them, because seismic waves in the salt have such a different velocity than the rocks above. And this is where integration of gravity and magnetics with seismic data were used to advantage.

Lyrio has learned the value of extensive integration of exploratory tools to reduce risk and enhance successes. “Gravity and magnetics have contributed effectively as tools to support interpretation that can produce quick results with low cost and reduced environmental impact,” he says.

With the world of oil and gas exploration needing increasing sophistication as the easier deposits have been largely found and exploited, the importance of new and complex methods becomes paramount. “The exploitation of hydrocarbons presents a growing demand in terms of technological innovations, particularly the software,” says Lyrio. “In the field of geophysics, technological solutions that integrate different geophysical methods in exploration have become increasingly important.” More and more today, gravity and magnetics are often shot well before bringing in the seismic equipment.

And the techniques are no longer restricted primarily to exploration of virgin territory either. Today, gravity and magnetic methods are being used in Brazil for re-evaluation of mature fields to extend production. Lyrio says Petrobras is using new and advanced gravimetric and magnetic interpretation in regions where environmental issues hamper the use of other geophysical methods such as seismic.

“In earlier times it was believed that the role of potential methods was limited to the
initial stages of exploration,” he says, such as delineation of basins and major geological structures. “With with the development of interpretation techniques, the availability of specialized software, new techniques for data acquisition, and development of measuring instruments, potential methods have expanded the exploratory process.” He says Petrobras uses these potential methods where other methods present difficulties. Potential methods help the interpreters in mapping intra-sedimentary structures such as salt and volcanic spills, for example.

Lyrio describes a case where gravity data became a decisive factor in validating seismic. “During the interpretation of seismic data in a determined area, an important geological structure was defined,” he explains. “But with the conversion of [seismic] data in time for depth, the mapped structure suffered significant modifications in terms of direction, and the interpreters were uncertain whether the new direction of the structure was real or only an artifact.” He says once the gravity data were incorporated, the new structure was readily validated.

Choosing the right software for situations like this is critical in smoothing and speeding the interpretation process. “Petrobras uses the most advanced software in the market for potential fields,” says Lyrio. “About 80 percent of the company’s gravity and magnetic projects use the Geosoft platform for interpretation, preparation of maps and grids, and assembly of the database.

“The great advantage of using the Geosoft platform is the fact that it provides the ability for tight integration, from the database through to the preparation of the maps,” says Lyrio. “This has eliminated the need for multiple software and the constant migration of information from one program to another.” The variety of software platforms with which Geosoft interacts makes it easy to exchange information between other exploration systems used by the company.

Another advantage that Lyrio likes: the software runs on a PC. “That’s a benefit over other programs that require specific hardware,” he says. Finally, he says it’s very user friendly which makes the platform attractive to new users.

“The variety of tools available for processing and interpreting our gravity and magnetic data, and ease of application, allows us to achieve project completion in a short period of time,” he says.

Petrobras’ solution also includes company-developed software. “We have developed our own technology,” he says, “mainly where the specialized functionality we require isn’t commercially available.”

Lyrio sees continued growth in the use of potential methods in geophysics well into the future, with a continuing resurgence in their application to hydrocarbon exploration. The reason he says lies in the increasingly complex geological problems being faced and the improved equipment available for dealing with them. He sees one of the largest changes on the horizon to be a change in scale – potential methods will no longer be mainly confined to the broader picture of major features, but will become a viable option for acquiring detail in more specific situations. “A consequence of this will be a bigger demand for technology to deal with integration of exploration methods,” he says, “since the goals will be ever smaller and more difficult to interpret.”
Since graduating from Purdue University in 1981, Geophysical consultant Mark Longacre has been dedicated to the field of Oil and Gas exploration, specializing in gravity and magnetics. He’s had direct involvement in over 1,000,000 line kilometers of high-resolution aeromagnetic (HRAM) data acquisition, processing and interpretation.

For the past 20 years, Longacre and his geophysical consulting company MBL Inc. have been providing clients with maximum insight through fully-integrated geological and geophysical solutions to Oil and Gas exploration. The main objective: risk-reduction and prospect enhancement through a better understanding of the subsurface geology.

Longacre credits his success to the fact that he has managed to stay small, focused and closely connected to all aspects of his client’s projects. “I do most of my projects on site in my client’s offices. Working side by side with the seismologists, basin petroleum systems people and the structural geologists, I become a member of the team. That’s one of the reasons I am as successful as I am.”

In recent years, Longacre has seen an increased interest in the use of gravity and magnetic methods with an emphasis on an integrative approach to projects. It’s an approach that fits well with his team philosophy. “From an exploration sense, I’m no longer a geophysicist working remotely on one specific piece – I’m part of a team contributing to a whole understanding of the project.”

Integration was core to uncovering critical new knowledge on the Earth’s crustal structure in his recent research of the Eastern Mediterranean Basin (EMB). “The Eastern Mediterranean project is a classic example of integration,” says Longacre. “We were able to collect all the data we needed – not just...
Longacre and his associates, together with researchers from BP Egypt Exploration and the National Oceanography Centre in Southampton, UK, shared their EMB research findings in a presentation at the EGM 2007 International Workshop held last year in Capri, Italy. It was well received, says Longacre. “Structural geologists and petroleum technologists were able to come up with a new interpretation of how and when the Eastern Mediterranean Basin actually opened, and we discovered that the EMB opened in a completely different way than we previously thought.”

This discovery provided new insight on the direction and age of the initial rifting, crustal structure and sediment thickness.

And it led to new understanding of the basin heat flow, maturation of source rocks and hydrocarbon migration pathways.

All this information has enabled exploration decisions to be more defined. And, since the project was completed, Longacre notes there has been substantial drilling activity and exploration success with significant discoveries on the Offshore Nile Delta in Egypt.

“There were big faults that we couldn’t understand,” says Longacre. “But once we understood how the basin actually opened, we were able to achieve a better mapping of the tectonic elements. This has all helped to focus exploration in certain areas.”

For Oil and Gas Explorers, knowing where to focus is critical. “The cost of a frontier exploration dry hole is 100 to 120 million dollars and costs are going up,” says Longacre. “That’s a lot of money. Spending a fraction of that to really make sure there are no surprises when you’re ready to drill makes good sense.”

As explorers look at deeper, more remote and more costly targets to meet global energy demand, proven, low-cost techniques like gravity and magnetic are being brought in earlier in the project cycle to minimize the risk of conducting expensive seismic investigation in potentially less productive basins.

Moreover, several areas scanned decades ago can be re-examined utilizing higher resolution data and new techniques such as gravity gradiometry and satellite gravity. And software advances are enabling integration and interpretation of these data to levels unheard of a decade ago.

“There’s definitely more interest and use of gravity and magnetic methods today,” says Longacre. “The cost of exploration has risen dramatically and the end result is that Oil companies are making sure they look at everything.” This includes a lot of previously unexplored areas of the world’s geology.

“We’re pushing the envelope geologically. We’re going out and exploring in areas we’ve never looked at before. We’re being brought in much earlier in projects and really high grade areas even before they shoot 3-D seismic.”

It’s also driven by stronger interest in the tectonic evolution of basins, adds Longacre. “We’re more interested in the crustal aspects, like crustal structure and depth to MOHO, than ever before. These sorts of things can play a big part in how the basin formed, sedimentation rates, petroleum systems, maturation and paleo-continental margins. And gravity and magnetic methods are ideally suited to help answer these types of questions.”

Being able to better integrate potential field data with the other kinds of geophysical and geological data has been key. “We’re much more integrated than we’ve ever been,” says Longacre. “With today’s software and technology, integration from the gravity and magnetic world to the seismic world is a seamless one. Data and maps can be easily shared and used in GIS, petroleum systems software and seismic workstations.”

Advances in technology have also provided the ability to turn things around much quicker, in hours instead of days. “Technology has enabled results on demand. You’re much more flexible, and able to turn in different directions based on what the data tells you,” he says.

For his integrated consulting needs, Longacre is a dedicated user of Geosoft’s Oasis montaj and GYM-SYS software for processing, data integration, modeling, interpretation, and exploration analysis.

“Geosoft is still by far the best software for generating gravity and magnetic interpretations, and products that can be easily integrated into the seismic world,” he says. “You can add your own tools and your own software with the powerful Geosoft GX toolkit. This means you can still differentiate yourself with software that other people don’t have, and customize it to suit your needs.”

And given that his clients use a variety of different technological platforms, Longacre notes that the main advantage is the seamless integration of the software. “I can process data, work on maps, and build the model in the same platform,” he says. “I can generate something and send it knowing that in a few minutes, they can have it at their work station and on their screen.”

Going forward, Longacre sees huge potential for gravity and magnetic methods to add more value as the Oil and Gas industry moves to more integrated exploration approaches.

“In general, the gravity and magnetic consulting community is full of talented people that are pushing the envelope,” says Longacre. “Gravity and magnetic methods have huge value, and as the integration continues, more and more value can be added. We’re generating knowledge that others can run with and build on.”

With today’s software and technology, integration from the gravity and magnetic world to the seismic world is a seamless one.

-Mark Longacre
A Marathon record
Innovative integration of gravity and magnetic methods help Marathon Oil Corporation maintain world leadership in oil and gas exploration

By Graham Chandler
W hen Pat Millegan came to Marathon Oil Corporation in 1983, he brought with him a keen interest, and experience in gravity and magnetic methods for oil and gas exploration. Now with 32 years of industry experience under his belt, there’s little the company’s Geoscience Consultant, Subsurface Imaging doesn’t know about the techniques – the whole gamut from planning and specifying surveys, quality control of the data and its processing through to integrated interpretation; all using the latest innovations.

It’s made him a valuable team asset for a company like Marathon, which has a strong record of success in exploring for oil and gas around the globe. One of the oldest oil companies in the industry, Marathon was established in 1887. Headquartered in Houston, Texas, Marathon is the fourth largest integrated oil and gas company in the US, with revenues over US $56 billion in 2007.

Marathon’s exploration activities focus on adding profitable production to existing core areas – the U.S., Equatorial Guinea, Libya and the North Sea (UK and Norway) – and developing potential new core areas in Angola and Indonesia. The company has long been active in Libya’s Sirte Basin, one of the most prolific oil and gas producing areas of the country, which still contains sizable undeveloped reserves. Marathon’s concessions there currently produce about 345 thousand barrels of oil equivalent per day on a gross basis and encompass almost 13 million acres. Marathon holds a 16.33 percent working interest in the Waha concessions in Libya.

Behind Marathon’s record of success is a focus on realizing the full potential of their upstream assets through knowledge integration and technological innovation. In the oil and gas business the key to optimizing production and resource development is quick and accurate description of reservoirs. Marathon’s expertise in reservoir characterization often begins with seismic imaging, but it emphasizes integration of all geoscience, petrophysical and engineering data into fully integrated interpretations.

An important part of their integrated approach is effective use of potential fields methods. The benefits of such an approach are higher success rates in discovery, drilling and production activities and Marathon’s record illustrates that.

Gravity and magnetic methods have proven to be effective in many regions of the world, particularly in sub-salt areas. Without the use of these data, prolific sub-salt traps would be much more difficult to locate and image. Using seismic alone, the high velocity salt layer absorbs and scatters the energy, distorting any picture of prospective reservoirs lying beneath the salt layer itself. Used in a tightly integrated fashion, potential fields methods can supply a better estimate of the salt shape and size, which is then used to improve the seismic imaging.

Offshore West Africa, the Gulf of Suez, the Red Sea, and of course the Gulf of Mexico are all regions where gravity and magnetics have enhanced exploration in this way. Though generally considered to be complementary to seismic, in some cases drilling decisions have been made on the basis of gravity and/or magnetics alone particularly when seismic imaging is challenging. In one case, aeromagnetics has been credited with the discovery and delineation drilling of Ras El Ush Field in the southern Gulf of Suez in the 1990’s. Today, the integrated workflow used in the Gulf of Mexico salt interpretations is an integral part of decision making for leasing and drilling.

Sub-salt imaging is a prime example of where these methods excel, but not the only one, says Millegan. “Gravity and magnetics are doing well with the current resurgence of exploration in general,” he says. “Exploration is becoming more difficult, entering remote areas and areas of poor seismic imaging.”

Working with the techniques for better than three decades, Millegan has seen their value and potential over the years. “Gravity and Magnetic techniques have never ceased being valuable to the exploration effort,” he says. “As exploration in general increases at increasingly higher costs, gravity and magnetics’ proven track record for risk reduction and integrated G&G [geological and geophysical] analysis has kept it in demand.”

Integrating them with other data streams these techniques have played, and continue to play, an important part in Marathon’s longstanding expertise and successes in accurate reservoir definitions and delineations. “Integrating gravity and magnetics with seismic, each measuring different, but related rock properties, offers more robust geologic interpretations,” explains Millegan. “This provides management with the best information available to make leasing or drilling decisions.”

Management and integration of gravity and magnetics is just part of the team effort, but it’s a critical part. “My success is measured by the success of the team with which I am working,” says Millegan. “Often there is a direct cause and effect, where gravity and magnetics offer something direct, such as the calculation of salt mass, or the depth and extent of a structural block, or the presence/absence of volcanics in the section.” Or, sometimes the contribution is less concrete, he says, like perhaps a regional geologic/tectonic analysis that helps the team integrate various disciplines, thus helping to focus their decision making. “It’s all kept Marathon at the leading edge of oil and gas exploration.”

Use of gravity and magnetics with Marathon is increasingly impacting its technology needs. “We are busier than ever,” says Millegan. Marathon added Dr. Neda Bundalo to their Subsurface Imaging team in 2007. “Neda has allowed us to continue to offer high quality work in a timely fashion,” he says. “Our workload for gravity, magnetics and EM has doubled this year. More now than ever we need our software tools to be responsive, integrated, and technically state-of-the-art. This is a huge challenge.”

Millegan sees the use of potential fields methods in geophysics continuing unabated. “As the search for oil and gas gets more and more challenging and expensive in increasingly more difficult water depths and terrains, all geophysical tools must be applied to reduce the financial risk to the oil company,” he says. “Many of us can argue that potential fields geophysics has been under-utilized in our industry. Many have predicted the demise of potential fields geophysics in every decade. But we are still here and we are doing more energetically and financially impacting work. We must continue to improve our skills and our tools to meet new challenges.”
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