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Earth Explorer

TECHNIQUES
Sea Floor Exploration for Massive Sulphide Deposits

PERSPECTIVE
Looking Deeper into the Subsurface to Close the Discovery Gap

FEATURED EXPLORERS
Nautilus, MBL, Petrobras, Marathon Oil and Brazil's Museum of Earth Sciences

COVER STORY

MOUNTAIN MISSION

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SPECIAL REPORT

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In this issue, Earth Explorer reports on an International Polar Year initiative that has brought together a global team of geoscientists to probe the world's last great unexplored mountain range. Our article on Sea Floor Exploration looks at how mineral explorers are turning to the ocean bed as a source of metals to meet growing demand from developing economies such as China and India.

In our special feature on Oil and Gas we explore integrated approaches (combining gravity and magnetics with seismic, geology and other earth data) that are helping to reduce risk and drive discovery success in frontier and deep water environments.

Researchers from McMaster University provide perspective on targeted geoscience initiatives that are uncovering new opportunities in old mining camps. And in our Rock Science article, we visit inside Brazil's Museum of Earth Sciences which is celebrating its 100th anniversary.

A few of these stories were inspired from reader suggestions, and we welcome your comments and ideas. Visit us at **www.earthexplorer.com** or email us at **earthexplorer@geosoft.com**.

Carmela Burns
Editor, Earth Explorer

Working in the field of mining exploration by geophysics.
El Goumi Najib, 2007 Photo Contest finalist.

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in this issue

Earth Explorer

Earth Explorer is a magazine dedicated to covering the ideas, people and companies that contribute to the success of earth exploration. It is a community publication of Geosoft Inc.

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PHANTOM MOUNTAINS
under the Antarctic Ice

An international project probes the world's last great unexplored mountain range. Catch is, it lies under three kilometres of ice.

By Graham Chandler

Fifty years ago, a team of Soviet scientists was conducting a seismic survey as they headed for what is known as the Pole of Inaccessibility, the point in the Antarctic furthest from any coast, when they made a remarkable discovery – a massive subglacial mountain range that has left earth scientists scratching their heads. According to received theory, it shouldn't be there. Hypotheses had predicted there would be nothing but a vast and somewhat featureless plain much like Canada's interior.

"We don't have a clue as to why these mountains should be there at all in the middle of a continent," says Fausto Ferraccioli, Airborne Geophysics Group Leader of the British Antarctic Survey. "It's really a mystery to have a very high mountain range in an old Precambrian region. Typically mountain ranges are created by collisional processes or by extensional processes. But these mountains are really very, very high, and the last collision that happened in East Antarctica was about 500 million years ago, so these mountains should have been basically eroded."

Left largely unexplored for the past five decades except for confirmation by US aerial radar survey in the 1970s, the Gamburtsev Mountains are now front and centre of the international AGAP (Antarctica's Gamburtsev

Province) Project, and the British Antarctic Survey is one of the participants. "This is a major flagship project of the International Polar Year," says Ferraccioli, "and it will involve six different countries – the US, Germany, China, the UK, Australia and Japan."

The initiative is led by the Lamont-Doherty Earth Observatory of Columbia University and is not only multinational but also multidisciplinary, "including aerogeophysics, traverse programs, and passive seismic instrumentation complimented by future ice core and bedrock drilling," says Michael Studinger, Doherty Research Scientist at the Observatory and co-chief scientist. The crews expect to be in the field early November 2008 to mid-January 2009.

Spurred by the mysterious mountains, four basic questions have arisen that underpin this international team's work. How does topography influence initiation and development of continental ice sheets? How do major mountain massifs form within intraplate settings with no straightforward plate tectonic mechanism? How do tectonic processes control the formation, distribution, and stability of subglacial lakes? (There are lakes under this ice too) Where is the oldest climate record in the Antarctic ice sheet?

To acquire data for some answers, over the past two years the team has been preparing the complex logistics and developing an airborne geophysical system for the project: ice-penetrating radar, LiDAR (Light Detection and Ranging), gravity and magnetics.

It's more than scientific curiosity about the earth's formation processes. Answering these questions will help our understanding of climate change. "One of the fundamental questions in Antarctic science is when, where and how the Antarctic ice sheet formed," says Studinger. "Preliminary ice-sheet modeling suggests the Gamburtsev Subglacial Mountains are the likely location for initiation of the East Antarctic ice sheet, and therefore could be a key factor in understanding the onset of glaciation in the Paleogene 35 million years ago."

He explains that in order to understand the evolution of the Antarctic ice sheet over such long time scales we need to understand the relationship among Antarctic geodynamic processes, ice-sheet dynamics, and global environmental change. "For example mountain uplift can influence climate and thus ice-sheet dynamics," he explains. "In turn, climate change can lead to increased erosion rates and accelerated mountain uplift." It has been suggested that during warmer periods, this terrain was drained first by ice streams and then, nearer the coast, by rivers from which thick sediments accumulated. "We have a conceptual understanding of these processes but it is essential to move towards quantitative models." He adds that a lack of first-order data sets for most of the continent has so far precluded formation of such a model.

It's expected that data gathered during

"In this particular region, we believe that there may be ice that is over 1.2 million years old and so this would provide us with an unprecedented record of climate change in the past.

-Fausto Ferraccioli

LEFT PAGE: The surface of the Greenland ice sheet. Photo courtesy of Michael Studinger, Lamont-Doherty Earth Observatory of Columbia University. TOP RIGHT: Fausto Ferraccioli, Airborne Geophysics Group Leader of the British Antarctic Survey. BOTTOM RIGHT: Remote field camp and Twin Otter aircraft, similar to what will be set up at the AGAP north site. Copyright British Antarctic Survey.

the AGAP project will go a long way towards this end. "We want to find out what these gigantic mountains are and where they come from; because no-one really knows how they formed," says Studinger. "There is really no straightforward explanation as to how you get such high mountains in the interior of a continent." He says the new data will enable us to "uncover" this phantom mountain range, which is larger than the Alps.

Ferraccioli says there are several scenarios, e.g. "that these mountains are actually quite recent, for example they could be related to a hot spot, which is in essence a hot mantle similar to what we've seen in Iceland. This would basically radically change our view of East Antarctica as a sort of stable, Precambrian continent."

Searching for the oldest ice on the planet also provides critical input to knowledge of past climate change, helping our understanding of today's global warming. Ice cores contain valuable preserved records of past atmospheric composition, volcanic eruptions and other environmental information. "In Antarctica, we have drilled at a series of locations and retrieved ice as old as about 900,000 years," says Ferraccioli, which provides a record that far back. "In this particular region, we believe that there may be ice that is over 1.2 million years old and so this would provide us with an unprecedented record of climate change in the past."

Although the airborne magnetic and gravimetric survey will be able to hint at mineral composition, none of the AGAP research is aimed at mineral exploitation. Copper, lead, zinc, gold and silver have been found on the Antarctic peninsula and oil and gas is most likely present in its sedimentary basins, but by international agreement exploitation has been banned. The 1959 Antarctic Treaty dedicated the continent to peaceful use, established international exchange of scientific data and outlawed new territorial claims; and in 1991 the signatories agreed that "any activity relating to mineral resources other than scientific research" is prohibited. The AGAP project fits: a 1998 follow-on preserved the continent as an archive of the world's climatic past and a barometer of the planet's future.

Part of the reason exploration of this mysterious subglacial topography has been limited is simply logistics. The Antarctic is a forbidding place. Ice covers 98 percent of its land and in winter extends to an area larger than the continent itself. Thirty million cubic kilometres of ice depresses its bedrock by 600 metres and tilts the icesheets towards the centre. It constitutes 72 percent of the world's fresh water yet precipitation is about the same as the driest parts of the Sahara. The record low is –89.2 degrees C. And distances are daunting. "The survey region is about 1000 kilometers away from the South Pole and equally about 1000 kilometers away from Davis and Zhong Shan, which are respectively the Australian and Chinese bases on the other side of Antarctica," says Ferraccioli. "So it's really in the middle of nowhere. It's the highest spot on the East Antarctic Ice Sheet. It's over 4,000 meters high." He compares the challenge with going to Mars. "On the surface, all you would see is a white ice sheet," he says.

The thickness of that ice will be probed by the airborne radar, which can image ice over four kilometres thick. "We can understand the layers of ice," says Ferraccioli, "which gives you an idea of basically [how] ice ages. The layers can be correlated with future drill sites, which the Chinese are interested in." Eventually a more permanent base for drilling will permit an expensive but revealing entry into the oldest levels of ice and the rock below the ice. "If in five to ten years' time, the Chinese do attempt to drill there, it will only be to sample the rock of this mountain range," says Ferraccioli. "Not for mineral exploitation but really just to try and verify the geophysical interpretations." Even just one drilling effort would help ground-truthing in a large way but still be far from providing the entire picture of the mountain range, he adds.

The radar will reveal some details on subglacial lakes too, which may be affecting the dynamics of the ice sheet. The glacial lakes are a major objective of the project. "We will be surveying some large subglacial lakes with the aerogeophysical survey," says Robin Bell, Director, ADVANCE Program at Columbia's Earth Observatory. Exploration by remote submersible is on the horizon too. "There are plans to enter both subglacial Lake Vostok and Lake Ellesmere in the next few years but no submersible this season."

ABOVE: Flight testing in Kangerlussuag, Greenland. From left to right: Jason Preston (Kenn Borek Air Ltd.), Michael Studinger (Lamont-Doherty Earth Observatory of Columbia University), Nick Frearson (Lamont-Doherty Earth Observatory of Columbia University), Adrienne Block (Lamont-Doherty Earth Observatory of Columbia University), Travis Goetzinger (Kenn Borek Air Ltd.), Colin Anderson (Kenn Borek Air Ltd.). Photo courtesy of Michael Studinger, Lamont-Doherty Earth Observatory of Columbia University.

The aeromagnetics will provide indications of subglacial geology, by assisting with mapping of possible volcanic regions, major tectonic boundaries and potentially thermal anomalies. "Then we use gravity," says Ferraccioli, "which will give us indications of possible sedimentary basins, the thickness of the crust and will also give us indication of possible anomalies such as density in the upper mantle." A hot spot he says would indicate a low density mantle.

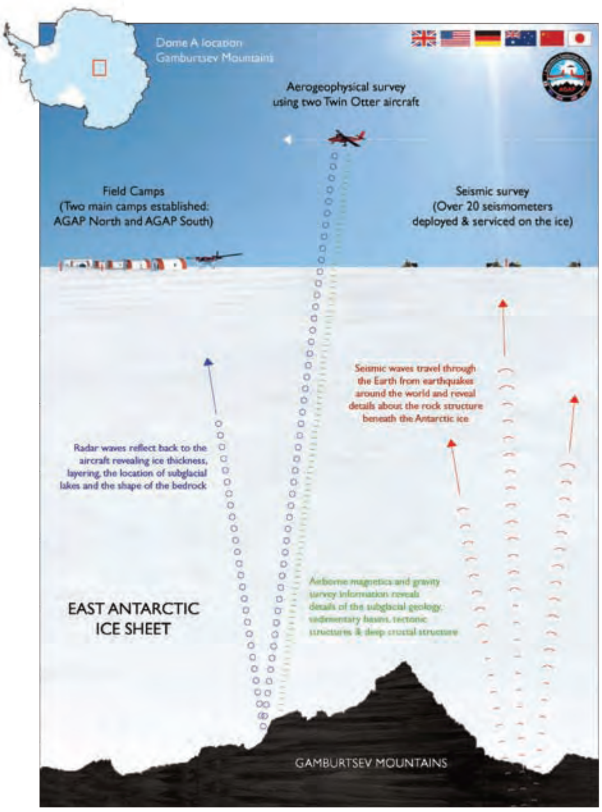
Data gathered will be varied and of a large volume so both standard and specialized software is needed to process them. For example, each four-hour flight will generate 500 gigabytes of data. "It's a large data set with a variety of data streams that differ substantially in size and structure," says Studinger. "This makes the use of multiple software packages necessary." Some of these he says are developed in house using Matlab, for organizing and structuring the data sets and for initial quality control and archiving.

The gravimeter for the survey will be provided and operated by Sander Geophysics Ltd. who designs and uses its own company software for quality control, data reduction, viewing, and map production. "After initial quality control and archiving of the airborne and ground magnetic data with our Matlab tools we use Geosoft's Oasis montaj for further processing, data analysis and map production," says Studinger. Oasis montaj allows efficient importing, viewing, processing and sharing of diverse earth science datasets and images. "We use the basic airborne geophysics package and several extensions for modeling, filtering, and source depth estimates that enable us to perform state of the art analysis of our airborne magnetic data," he says.

Ferraccioli says potential field data, such as magnetic and gravity, is obviously non-unique, "so we're also going to fit our interpretations with seismology – which in particular will give us indications of the crustal thickness and again possible anomalies in the upper mantle." The potential field data will be processed using Geosoft. "We will be doing gravity and magnetic modeling using GM-SYS." This tool enables design of 3-D models depicting subsurface structures by for example stacking montaj topography grids.

What will be the prize at the end of the process? "The product will be a new map of the sub-glacial topography of the Gamburtsev sub-glacial mountains province," says Ferraccioli. "We will have new maps of aeromagnetic anomalies over this area. New maps of Free-Air gravity, Bouguer gravity and isostatic gravity maps for the region. Then we will also be producing new crustal models to try and define the uplift of the Gamburstev sub-glacial mountains."

But these two organizations won't be taking all the credit. "Projects of this size are only possible through collaboration between many scientists and organizations from countries around the world," says Studinger. "We see the AGAP project as a model for future science projects in Antarctica." ❑



TOP RIGHT: British Antarctic Survey Twin Otter aircraft equipped with ice penetrating radar survey gear. Copyright British Antarctic Survey. ABOVE LEFT: Project overview for the exploration of the Subglacial Gamburstev Mountains. Courtesy of British Antarctic Survey. ABOVE RIGHT: US seismic team. Copyright Douglas A Wiens, Washington University.

NAUTILUS MASTERS THE SEA

Exploring the Pacific Rim of Fire for sea floor massive sulphide deposits

By Virginia Heffernan

On an autumn day in 1995, Roger Moss slipped his passport into his breast pocket, kissed his wife and baby son goodbye and embarked on a six week journey from Toronto to Lau, Papua New Guinea, where he would join other scientists aboard the RV Yokosuka, a Japanese research vessel.

The mission? To plumb the depths of the Bismarck Sea for "black smokers" that might serve as modern analogues to – and provide an exploration guide for – land-based volcanogenic massive sulphide (VMS) deposits.

Several days into the voyage, Moss found himself bent double in a tiny submersible, his calves stinging with pins and needles, as he scanned the ocean floor for vent sites. But the discomfort would be worth it. While traversing the side of a rocky ridge at depths of almost two kilometres below surface, Moss came across a tell-tale plume.

The eponymous "Rogers Ruins" now form the most northerly site of the Solwara 4 prospect, one of several high-grade massive sulphide systems being evaluated by Toronto-based Nautilus Minerals as potential mining opportunities.

"This was purely a research mission to see if we could observe VMS deposits as they were forming and apply that knowledge to land-based exploration," recalls Moss, a graduate student at the University of Toronto at the time. "I was skeptical about the possibility of them ever being mined."

But as land-based deposits become increasingly scarce, explorers are turning to the ocean bed as a source of metals to meet growing demand from developing economies such as China and India. Leading the charge is Nautilus, which has been exploring the Pacific Rim of Fire for sea floor massive sulphide (SMS) deposits since Papua New Guinea (PNG) became the first country in the world to grant commercial exploration licenses for such deposits in 1997.

Though Nautilus was a hard sell in the early days, when low metal prices were driving investors away from even the most conventional mineral exploration, the junior eventually convinced Placer Dome (now Barrick Gold) to invest in the sea floor venture through a farm-in agreement that allowed commercial exploration to begin in earnest in 2005.

Today Nautilus is preparing to start up the world's first sea floor copper gold mine in 2010, just off the coast of PNG. The company will use a sea floor mining tool to break up and suck the ore from the ocean floor and pump it though a steel pipe to a ship at surface, where the ore will be dewatered and loaded onto barges.

The first deposit slated for mining, Solwara 1, has inferred and indicated resources of 2.17 million tonnes averaging (at 4% copper cut-off grade) 7.2% copper, 0.6% zinc, 31 g/t silver and 6.2 g/t gold: small by land-based standards, but one of several high-grade deposits the company is continuously discovering.

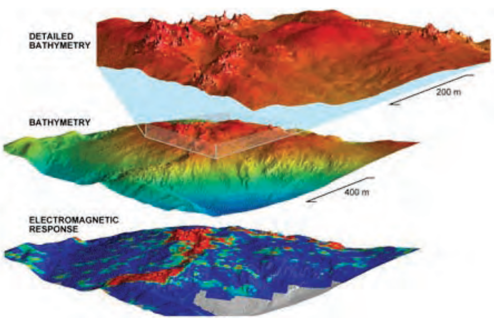
This is not the first time explorers have looked to the ocean as a source of metal. In the 1970s, a consortia of private and government companies spent about $US1 billion to mine polymetallic nodules scattered around the ocean floor in international waters. But the venture failed for a variety of reasons – low metal prices, metallurgical challenges and the lack of a title system chief among them.

Research on SMS deposits began in the 1980s when geoscientists realized that the massive sulphides forming on the ocean floor were modern analogues of the VMS deposits currently being mined on land and, as such, may hold the secret to finding more land-based ore.

To test this theory, a team led by Ray Binns from CSIRO, Australia's national research organization, in collaboration with geologist Steve Scott from the University of Toronto began to study the seafloor vents. The Yokosuka cruise that Moss participated in was one of several expeditions they helped to organize.

The focus of most of the research to date

LEFT PAGE: A Remote Operated Vehicle (ROV) and drilling equipment is used for sea floor exploration.
BELOW : Nautilus is currently conducting detailed environmental monitoring of the project site.



Bathymetry and Electromagnetics Map.

has been on hydrothermally active vent fields that produce signatures that can be detected up to 10 kilometres away. This has led to the discovery of about 150 fossil and active sites mostly lying at depths of 1500-3500 m.

The challenge for commercial explorers is to find the inactive SMS deposits that have cooled enough to be mined.

With that in mind, Nautilus has developed a deep-ocean electromagnetic (EM) technique along with its new joint venture partner, Teck Cominco Ltd., and Vancouver-based Ocean Floor Geophysics. The new technology allows the partners to better target their drilling for faster, more cost-effective exploration.

"The system is spectacularly successful in finding copper-rich systems because copper is highly conductive," says Michael Johnston, vice-president of corporate development for Nautilus.

The exploration sequence at sea mirrors that of land-based projects: outline a large area of interest, and then progressively narrow down the target. The difference is that sea floor explorers know exactly where the deposits lie in the stratigraphic sequence, an advantage that saves both time and money.

"Our systems are generally outcropping," says Johnston. "We know where that sea floor boundary is, and we drill it only when we think the system warrants drilling and want to know what the average grade of it is, not whether it is there or not."

When looking for SMS deposits, explorers first conduct a study of seafloor topography using bathymetric maps and other nautical information to find target structures. Then they run echosounder traverses to gather further detail on prospective topographic features. The next step is to go plume hunting, looking for increases in particulate material reflected by decreases in transmissivity and/or slight changes in temperature or pH.

At 1500 m below surface, ocean conditions are fairly uniform in terms of water temperature (2.5-2.6° C), acidity, turbidity and sediment concentrations. "It has the same general properties all around the planet, so what you are looking for are any slight changes in those normal conditions," says Johnston.

Geophysical surveys, both magnetic and electromagnetic, can help pinpoint the best targets. Finally, the vents are sampled by dredging, grab sampling and sediment coring. If the results are promising, core drilling follows.

"Improvements in seafloor exploration technology are continuously occurring," says Joanna Parr, project leader for the seabed minerals division of CSIRO Exploration and Mining. "This is a relatively new field of commercial endeavour so advancements are happening rapidly. Some of the techniques are unique to seafloor systems – looking for active plume signatures in the water column, for example – but others are adaptations of well-tested land-based technology."

Considering that only about 3% of the ocean floor has been explored for SMS deposits, the potential for further discovery is enormous. But there remain barriers to exploration that may prevent the activity from becoming commonplace just yet.

Though Nautilus holds tenements and exploration licences off the shores of Papua New Guinea Fiji, Tonga, the Solomon Islands and New Zealand, many maritime states do not have legislation that would allow commercial exploration in their Exclusive Economic Zones (the area in which a coastal state has sovereign rights over all the economic resources of the sea, seabed and subsoil.)

Another barrier is the environmental impact. Environmentalists worry about the potential for disturbing unique ecosystems that surround the active vent sites, which sometimes lie in close proximity to the inactive sites that will be mined. There is also concern that the particulate matter stirred up by mining could clog the gills of fish, and the noise could disturb passing fish and whales.

These impacts, and how to mitigate them, will be addressed in the Environmental Impact Statement for Solwara 1 that will be submitted to PNG's Department of Environment and Conservation by the end of the year. Nautilus is currently conducting detailed environmental monitoring of the project site.

Johnston believes that while sea floor exploration will never match what takes place on land, parts of the world that have a combination of hydrothermal activity and legislation to allow commercial exploration may become hotspots in the not-so-distant future. ❑

Our systems are generally outcropping. We know where that sea floor boundary is, and we drill it only when we think the system warrants drilling and want to know what the average grade of it is, not whether it is there or not.

Michael Johnston

The Nor Sky vessel is being used by Nautilus in their 2008 exploration program in Papua New Guinea (PNG) and Tonga.

HISTORY OF SMS EXPLORATION

Early 1960s:
SMS deposits recognised for the first time during the exploration of the deep oceans and mid ocean ridge spreading centers.

1985:
Hydrothermal sulphide systems are discovered in Papua New Guinea (PNG) by the research vessel the RV Moana Wave at a site that would later become Nautalis's Solwara 2 Prospect.

Late 1980s-1990s:
Numerous academic surveys and commercial exploration campaigns take place off the shores of PNG, Fiji and Tonga

1996:
The Solwara 1 Field is first identified by Australia's CSIRO

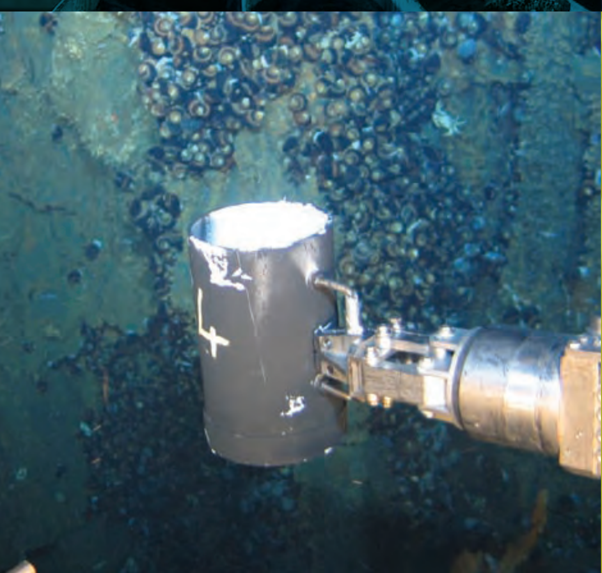
1997:
PNG becomes the first country in the world to grant commercial exploration licenses for SMS deposits when Nautilus secures its first tenement

1999:
Neptune Minerals, a UK-registered company, is founded to explore, develop and commercialise seafloor massive sulphide (SMS) deposits

2004:
In exchange for up to a 75% interest in any gold rich SMS deposits Nautilus should find, Placer Dome agrees to fund Nautilus's exploration program on its PNG tenements and takes an equity stake in the junior.

2006:
Placer Dome is taken over by Barrick Gold, while Teck Cominco and Anglo American buy a 9.2% and 10.1% stake in Nautilus respectively, further legitimizing the junior's mining plan

2007:
Nautilus announces the world's first SMS resource



SMS DEPOSITS

Size:	500,000 tonnes -10 million tonnes
Grade:	Gold 2-20g/t gold 20-1200g/t silver 5-15% copper 5-50% zinc 3-23% lead
Contained metal value:	US$400-1500 per tonne
Numbered of sites discovered so far:	~150
% of earth covered in ocean:	71
% of ocean explored for SMS:	3

Exploring for Oil with Gravity and Magnetics

Integrative approaches, combining gravity and magnetics with seismic and geology, are helping oil and gas explorers to push the envelope and focus their exploration, as they venture into new frontier and deep water environments. In this special report, we feature some of the experience and innovation that's driving new discovery success in oil exploration.

Resurgence of Gravity and Magnetics

By Mark Wolfe

Advancements in earth mapping technologies, coupled with the industry's emerging need to characterize subsurface systems, have led to a resurgence of interest in using gravity and magnetic methods in Oil and Gas exploration and development.

Gravity and magnetic (or potential field) methods have a long history of use in the oil and gas industry dating back to the 1920s, but the petroleum industry lost interest in these techniques in the early '90's due to the rapid advances in seismic techniques.

Faced with the challenge of meeting growing global demand for gas supply, the industry has been steadily expanding exploration efforts into frontier and seismicly challenging areas. Both are environments ideally suited to gravity and magnetic techniques.

"Potential fields are typically used in frontier areas to do reconnaissance exploration, to look for new basins, and to investigate large areas that might be prospective for doing more detailed and expensive seismic work," says Gerry Connard, Petroleum Industry Market Manager with Geosoft Inc., a Canada-based exploration software company.

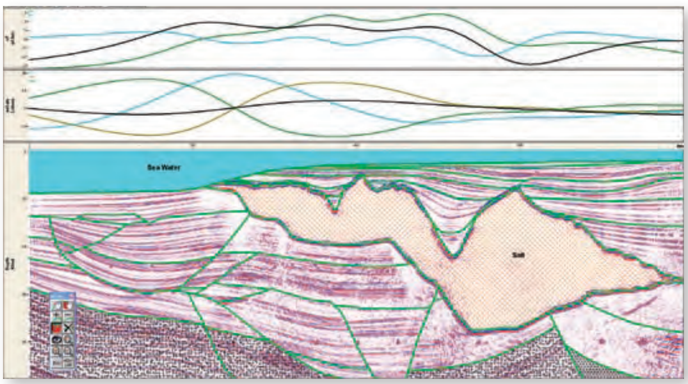
Although seismic visualization technology still remains the powerhouse of oil and gas exploration, the industry now has the tools and the knowledge to integrate the best of this technology with gravity and magnetic methods. By combining technologies, the industry has added a robust new dimension that is enabling explorers to look more quickly and efficiently into the uncharted frontier, while reducing the risks associated with technically challenging exploration.

Exploration in the new frontier areas can be an order of magnitude more costly using seismic visualization when compared to the less expensive potential field methods. Economics aside, Connard says that gravity and magnetic methods are commonly used in areas where seismic work is difficult or impossible. He notes as an example instances where you are trying to gather images beneath basalt-covered areas that have high-velocity rocks near the surface or exploring sub-salt plays. "When visualizing salt structures, seismic technology is very effective for imaging top of salt but has difficulty imaging below the salt because of the high velocity of salt," Connard says. "Gravity and magnetics have been used extensively in sub-salt exploration to integrate with the seismic data and image the base of the salt, or to assist in the processing of the seismic data."

Gravity and magnetic methods are also starting to be used by junior companies engaged in frontier exploration. "There's been an explosion of smaller oil companies starting up and getting into exploration in the last several years. These companies are really flying under the radar and are having great success," Connard says. "Many of them are starting to use gravity and magnetics in their exploration particularly in the frontier areas that have not been explored extensively in the past."

Advances in software that provide the ability to effectively display, rapidly assess, and dynamically experiment with multiple datasets have helped to reduce risk and increase prospecting capabilities in exploration. These technological innovations have helped to make the use of gravity and magnetic methods in the oil and gas industry more effective.

"From the interpretation side, there is better software available



Geosoft GM-SYS™ Profile model of salt structure integrating seismic reflection, FTG gravity, and magnetic data. Seismic image courtesy of Parallel Geoscience Corp.

to integrate the gravity and magnetics with the seismic and other geophysical and geological data," Connard says. "This kind of technological integration has been key."

Utilizing today's visualization tools, geoscientists are able to reduce risk and increase their understanding by looking at as much different data as they can, in as many different ways as they can, within compressed project time frames.

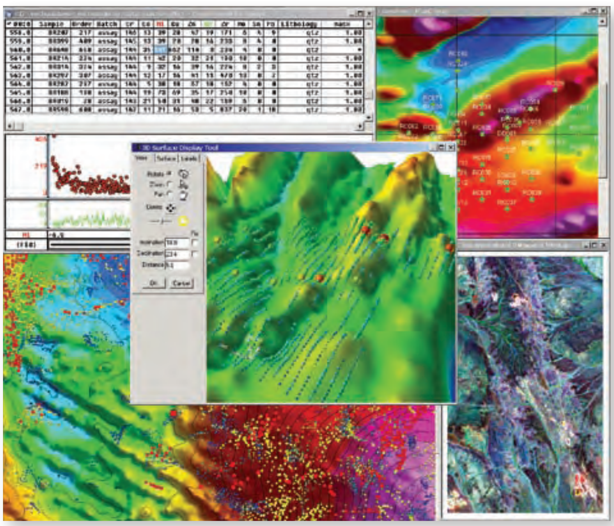
Despite the fact that exploration companies are leaner, with fewer people and shorter project time frames, Dr. Michal Ruder, Consulting Geophysicist and Principal of U.S.-based Wintermoon Geotechnologies Inc., has seen exponential improvements in productivity and data quality as a result of new software for mapping and visualization.

For Dr. Ruder, whose livelihood depends upon delivering accurate, up-to-date maps to clients in the oil and gas sector, recent advancements in integrated exploration tools mean smoother workflow and higher productivity in both two-dimensional and three-dimensional environments.

Where it used to take weeks to process and interpret geoscience datasets, today it's not uncommon for geoscientists to address the salient issues of interpretations in the course of one or two days. Increasingly, what's required for exploration is software that can handle large volumes of data and multiple data sources and data types, such as geophysical data, geochemical data, drillhole data, satellite imagery and GIS data within one single environment or transparently linked environments.

"I can remember doing batch maps, in paper copies, back in the 1980's," Dr. Ruder says. "Since then, the ability to image geoscientific datasets on a computer screen in real-time, and continual improvements in visualization software, has had an amazing impact on what we can do, as geoscientists, and how quickly we can do it."

Interpretation results are also more accurate because geoscientists have the tools to view the quality of the data in every single phase, from initial data processing and quality control through to visualization, integration, and the final interpretations.



Integrated mapping environment: Powerful exploration mapping systems such as Geosoft's Oasis montaj enable the integration and visualization of many types of data at once. From raw survey data to 3D models, you can process, interpret and analyze geology, geophysics, drillhole, GIS, and remote sensing data in a single environment.

Equipped with her laptop and mapping software, which includes ESRI's ArcGIS and Geosoft's Oasis montaj, it's not uncommon for Dr. Ruder to do on-the-spot interpretations in collaborative meetings with her major oil and gas customers.

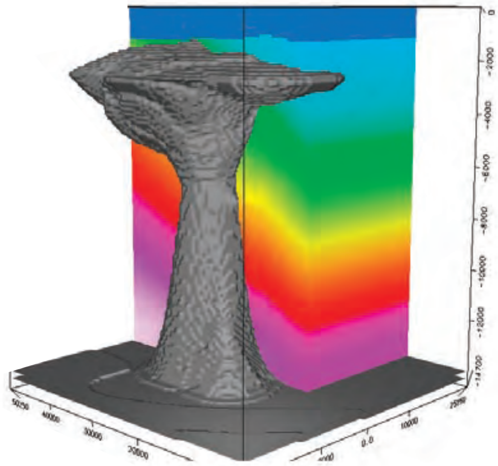
"I can do a lot of work in my clients' offices on my laptop," she says. "My mapping software offers a lot of interactivity, and testing of their hypothesis, and I can show customers results in real time."

There are efficiency and quality advantages to being able to dynamically pull customer data in, and immediately look at it as part of the interpretation whether it's well data, satellite imagery, or other types of data.

This type of rapid assessment and dynamic experimentation depends on the ability to interactively display, and enhance, different attributes in different ways, whether through contrast enhancement, shaded relief, angle illumination, or two-dimensional or three-dimensional displays.

Speed in creating and recreating visualizations, or refreshment time, is also an important consideration, especially when dealing with large datasets.

The use of specialized three-dimensional modeling software for prospect modeling of salt bodies can help to further reduce risk in areas such as potential field exploration.



Geosoft GMSYS-3D model of a salt body embedded in a 3D density volume.

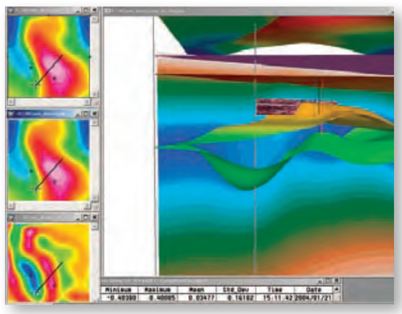
"It's very prudent to do three-dimensional modeling for prospect modeling of salt bodies when you're considering a very expensive well in deep water," Dr. Ruder says.

"We've been using 3D seismic volumes, and approximations of a 3D velocity volume in our interpretations for some time. With modeling software such as GMSYS 3D, we can convert that to depth, and ensure that it makes sense with the observed gravity and magnetic data."

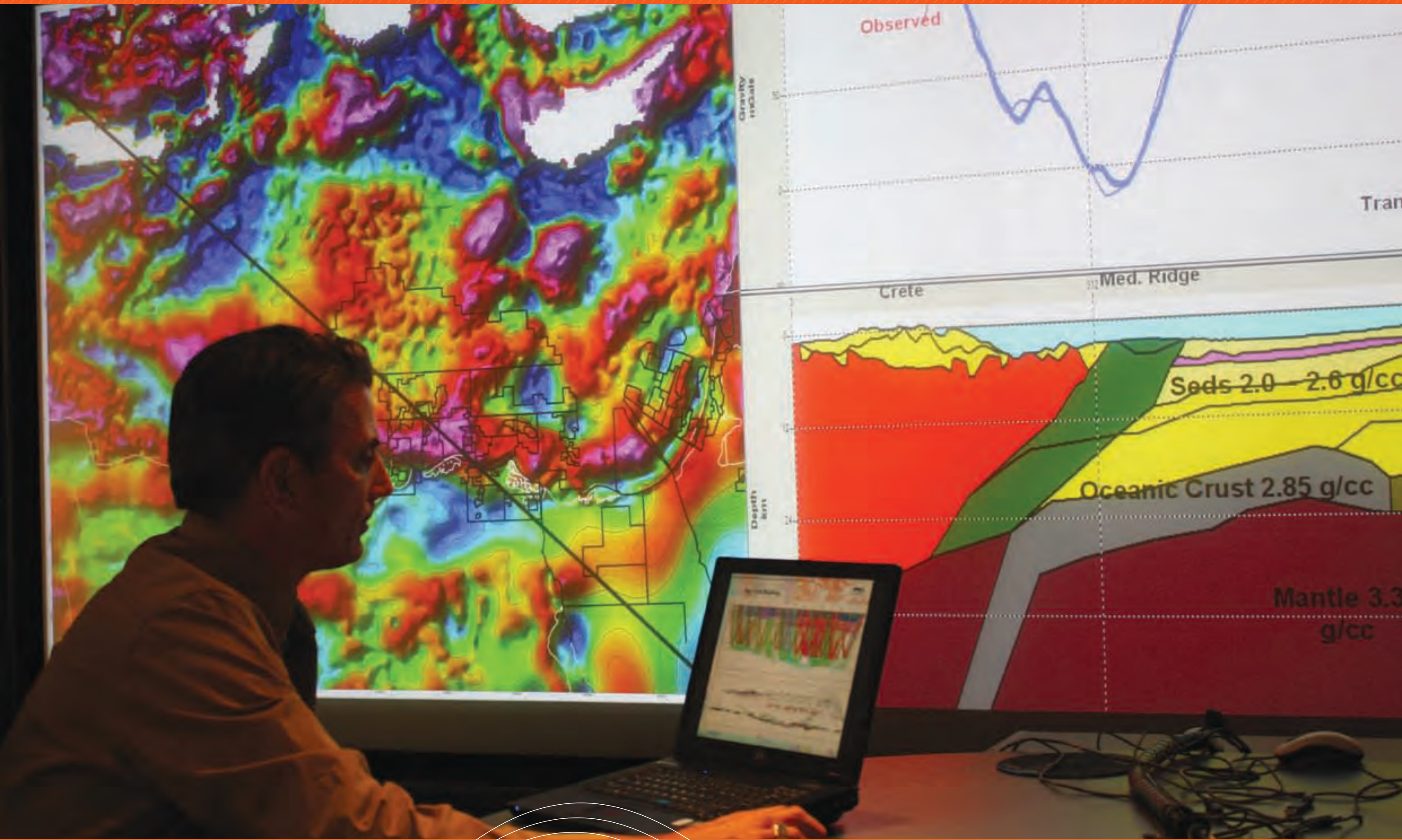
Today's visualization software also supports the easy integration of different types of datasets, including geoscientific data, satellite imagery, and other GIS data into the mapping environment. Working in multiple software environments is a reality for geoscience consultants like Dr. Ruder who need to meet their needs, as well as the needs of customers with a variety of software preferences.

While geoscientists recognize that there's a lot to gain by looking at different types of data, Dr. Ruder admits that there is still a tendency, within each discipline, to use the data that they understand the best.

"I think people don't realize how easy it is to integrate all of their datasets, whether it's seismic and non-seismic, raster and vector," she says. "GIS software and Oasis montaj provide some great tools for that." ❑



Geosoft GMSYS 3D model. The three flat maps along the left side of the workspace show Observed Gravity, Calculated Gravity, and the Difference. The black line marks the location of the seismic section shown in the 3D visualization on the right. The "+" symbol in the flat maps tracks the location of the 3D cursor in the 3D visualization (the long vertical line at the end of the seismic section). The other vertical plane in the 3D visualization is the sub-surface gravity response.



PUSHING THE ENVELOPE:

Integrated Approaches in Oil Exploration

By Carmela Burns

ABOVE: Geophysicist Mark Longacre in the High Intensity Visualization Environment (HIVE).

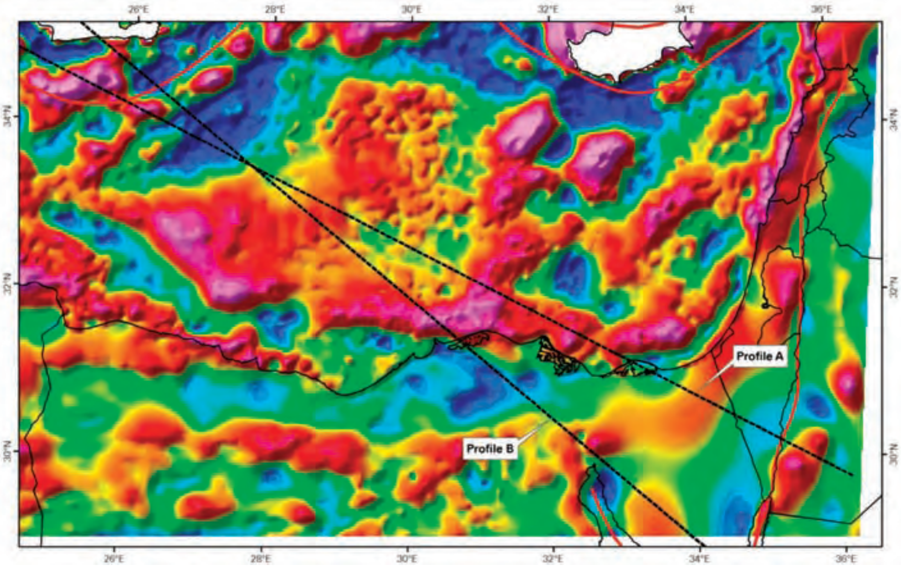
Since graduating from Purdue University in 1981, Geophysical consultant Mark Longacre has been dedicated to the field of Oil and Gas exploration, specializing in gravity and magnetics. He's had direct involvement in over 1,000,000 line kilometers of high-resolution aeromagnetic (HRAM) data acquisition, 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



Location of regional crustal profiles / models overlain on a residual gravity map (200km high pass) of the Eastern Mediterranean Basin.

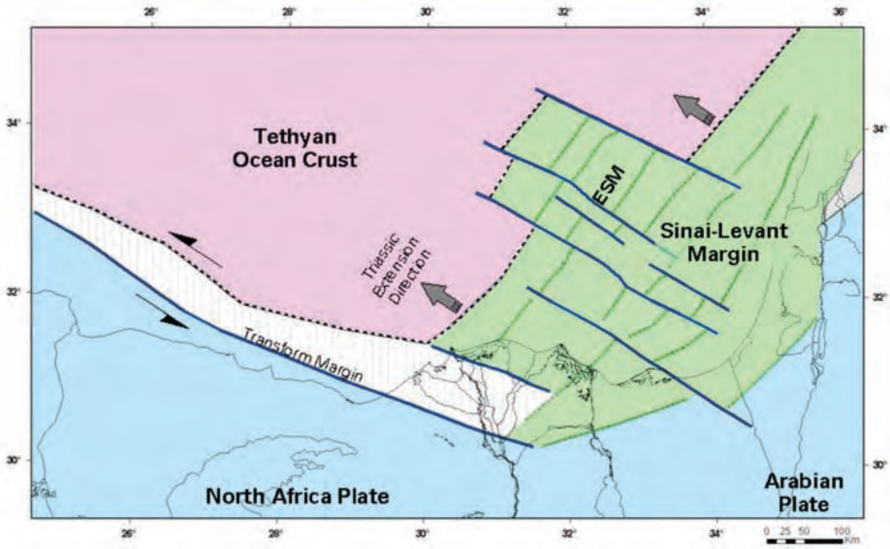
to collect all the data we needed – not just gravity and magnetic data but ocean bottom seismograph (OBS) refraction data, and very long offset reflection data."

He says the integration of all the geological and geophysical data enabled them to better define the crustal structure, which was key. Although much had been published on the hotly debated and complex EMB structure, it had remained poorly understood and suffered from diverging opinions among geologists. Obvious seafloor magnetic anomalies were lacking, making it difficult to effectively map the distribution of oceanic crust.

Comparing their final model with the initial input profile which was based largely on existing published data, they noted several major differences. For example, depth to the top of the oceanic basement and the thickness of the overlying sedimentary section is greater than that first modeled, crustal thinning across the continental margin beneath the onshore and near-shore portions of the Nile Delta is higher than initially constructed, and some previously undetected changes in geometry of the MOHO (boundary separating the Earth's crust and mantle) were found.

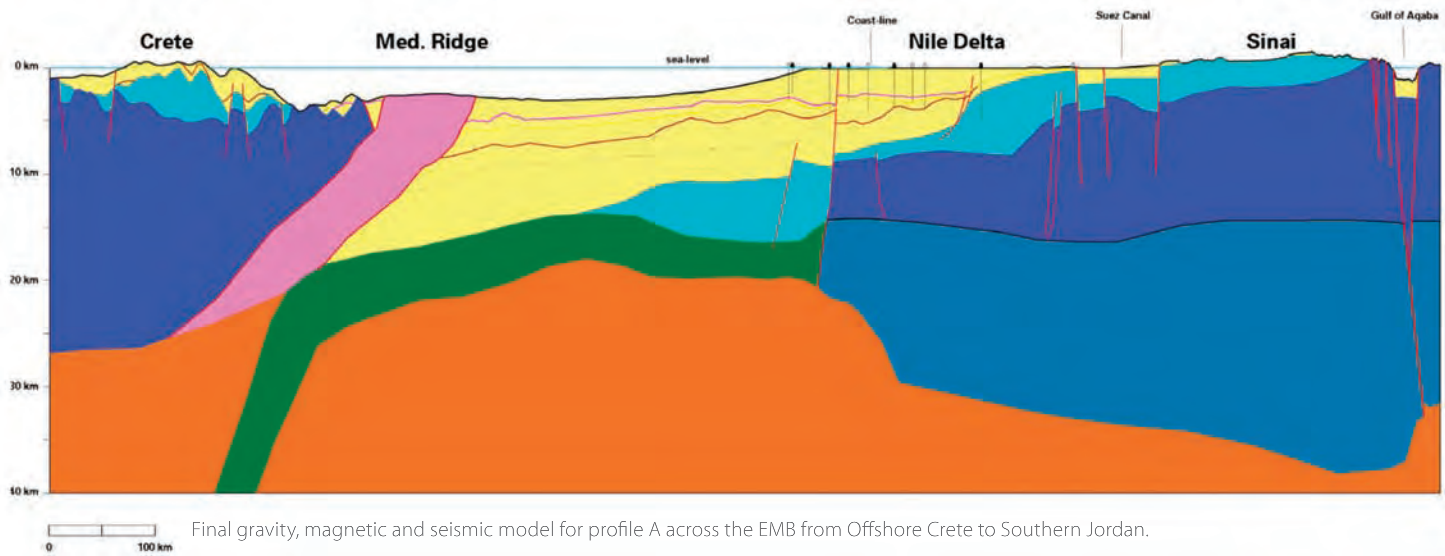
Longacre and his associates, together with researchers from BP Egypt Exploration and the National Oceanography Centre in Southampton, UK, shared their EMB research findings in a presentation at the EGM 2007 International Workshop held last year in Capri, Italy. It was well received, says Longacre. "Structural 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



Interpreted distribution of crustal type and key basement fabric within the EMB. [1]

[1] Peter Bentham, Ibrahim Hanbal, James Cotton, Mark Longacre & Rose Edwards 2007. Crustal structure and early opening of the Eastern Mediterranean Basin: key observations from offshore northern Egypt and the Levant (EAGE 2007 Abstract).



Final gravity, magnetic and seismic model for profile A across the EMB from Offshore Crete to Southern Jordan.

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."

> With today's software and technology, integration from the gravity and magnetic world to the seismic world is a seamless one.
>
> *-Mark Longacre*

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.

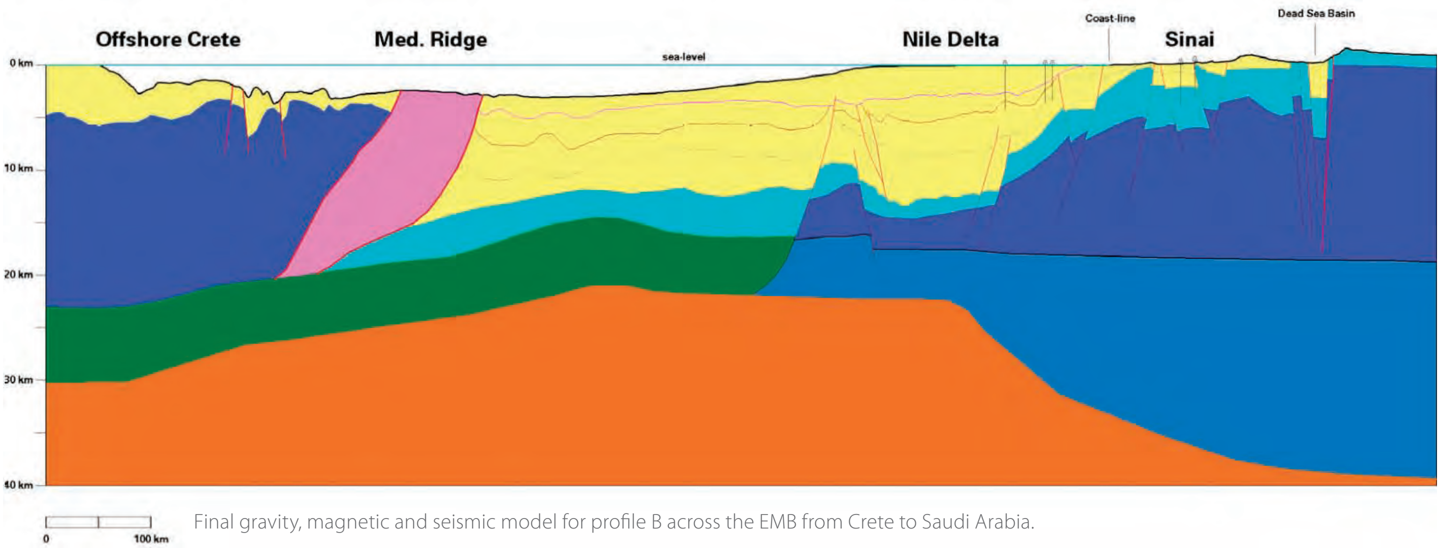
For his integrated consulting needs, Longacre is a dedicated user of Geosoft's Oasis montaj and GYM-SYS software for processing, data integration, modeling, interpretation, and exploration analysis.

"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." ❑



Final gravity, magnetic and seismic model for profile B across the EMB from Crete to Saudi Arabia.

Petrobras Deepwater Discovery Success

With its roots in exploration 55 years ago, Petrobras has matured into a world renowned integrated oil company without losing its explorer focus, leading the world in deepwater expertise.

By Graham Chandler

BELOW: New Oil Accumulation Discovered in the Santos Basin Pre-Salt Layer: May, 2008. The Petrobras discovery reinforces the notion that there is decreased exploration risk in the pre-salt layer.

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

TOP RIGHT: Petrobras' P 51 is the first semi-submersible platform built entirely in Brazil. BOTTOM RIGHT: Petrobras Director of Exploration and Production, Guilherme Estrella, collects the first oil from Platform P-52: November 2007

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.” ❑

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

When 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 $65 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.

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

> "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.
>
> *-Pat Millegan*

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 sub-salt 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."

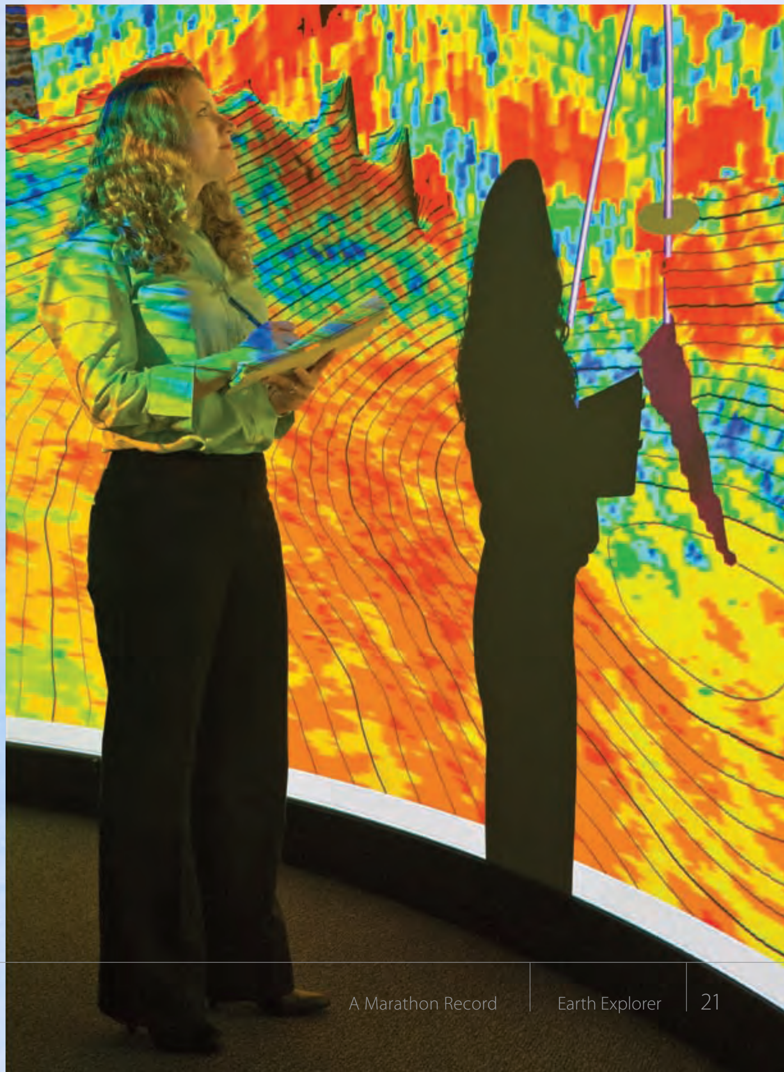
Integrating them with other data streams these techniques have played, and continue to play, an important part in Marathon's longstanding expertise and successes in accurate reservoir definitions and delineations. "Integrating gravity and magnetics with seismic, each measuring different, but related 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

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 rigorous and financially impacting work. We must continue to improve our skills and our tools to meet new challenges." ❑

Knowledge integration and technological innovation have kept Marathon at the leading edge of oil and gas exploration. Photos courtesy of Marathon Oil.



This beautiful neoclassical building is home to Brazil's Museum of Earth Sciences in Rio de Janiero. Celebrating its 100th Anniversary, the museum features a huge collection of minerals, rocks and fossils, belonging to the Department of National Mineral Production (DNPM).

ROCK SCIENCE:

Brazil's Museum of Earth Sciences Celebrates its Centenary

Brazil has one of the most vibrant mineral markets in the world, producing over 70 mineral commodities, including metals, industrial and fuel minerals. The country is known for its large mineral reserves, and also for the quality and significance of its beautiful gemstones – aquamarine, tourmaline and citrine – produced in the colonial city of Ouro Preto, Minas Gerais.

Located in Rio de Janiero, on the path to the Sugar Loaf, the Museum of Earth Sciences is home to a permanent showcase of Brazil's minerals, rocks, fossils and meteorites. The valuable collection includes over 3,000 rocks and minerals, representing over 95% of minerals local to Brazil.

Celebrating its 100thth Anniversary, the Museum's collection is based on scientific knowledge that spans several generations of geoscientists. It was originally guided by the state Geological Service when it opened in 1907, and since 1969 has been overseen by the Department of National Mineral Production (DNPM).

As it marks 100 years of service, there are plans underway to rejuvenate the Museum, says Director Diogenes de Almeida Campos. The Museum is already a vital resource for school children learning about minerals – their names and properties such as density, color, magnetism, trace and inclusions. One goal of the restructuring will be to modernize the exhibit and make it more accessible and effective as a learning environment for researchers and students, of all ages.

"In Brazil, there's movement underway to advance the teaching of geological sciences, introducing it earlier in the primary grades," says Campos. "The Museum has an important role to play in making minerals, and the earth sciences associated with mineralogy, accessible for learning."

Insight into the history of mineralogy in Brazil is key to this learning experience, and a notable exhibit recently launched by DNPM showcases the African contribution to the geosciences in Brazil. The exhibit sheds light on the important role of African slaves in the history of gold and diamond mining in Brazil. It includes a tribute to Brazilian mineralogist Jose Bonifacio de Andrada e Silva, who discovered the Afrizita (a variety of black tourmaline) and is said to have named it after his African slave Afrízio.

A naturalist and paleontologist committed to the conservation of fossiliferous sites at Crato and Santana do Cariri, State of Ceará, and at Uberaba, State of Minas Gerais, Campos has also helped to establish one of the most significant Brazilian fossil collections at the Museum. The Dinosaur Age exhibit features a collection of vertebrate fossils that lived in Brazil during the Era Mesozóica. In celebration of its centenary, the Museum recently added an exhibition on the life of Llewellyn Ivor Price, one of the greatest Brazilian paleontologists. Price collected the Staurikosaurus, the first discovered dinosaur of Brazil.

TOP RIGHT: Sugar Loaf Mountain, a granite peak overlooking Rio de Janeiro. BOTTOM RIGHT: Diogenes de Almeida Campos, Director of the Museum of Earth Sciences in Rio de Janeiro with a Quartz crystal specimen from Diamantina, Minas Gerais. Brazil is famous for the large and exceptional quartz it produces. The largest quartz crystal ever found in Brazil weighed nearly 90,000 lbs.

Minerals, and the earth sciences are integrated in all aspects of life in Brazil – contributing to the country's economy, unique landscapes and architecture. Rio's famous Sugar Loaf, with its massive gneiss dome, is perhaps one of the most spectacular granite landscapes in the world.

"Brazil has a rich history in mineralogy, and an active scientific community," says Campos. "The Museum is dedicated to capturing, preserving and showcasing Brazil's wealth of knowledge and discovery in the earth sciences." ❑

① **Aphrizite tourmaline specimen from Cantagalo, Rio de Janeiro.** A donation from the collection of Eugenio Bourdot Dutra. The Aphrizite (a variety of black tourmaline) is among the new species of minerals discovered by Brazilian statesman and mineralogist José Bonifácio de Andrada e Silva. It is believed that he named the Aphrizite in honor of his African slave Afrizio. In their natural state tourmalines are characterized by parallel ridges (or striations) which run the length of the crystal.

①

② **Imperial Topaz specimen from Ouro Preto, Minas Gerais.**
Imperial Topaz is perhaps the rarest variety of topaz, primarily found in the Ouro Preto mines of Minas Gerais, Brazil. The Imperial Topaz was named in honor of the Brazilian monarchy who prized its luxurious golden-sherry hues.

③ **Rose Quartz specimen from Corcunda, Brazil.**
Rose quartz is one of the most desirable varieties of quartz. The pink to rose red color is unique and unlike any other pink mineral species. The color is caused by iron and titanium impurities. Brazil is the only source of true well formed crystals of rose quartz. So amazing are the rose quartz crystals that the first ones discovered were dismissed as fakes by mineralogists from around the world.

②

③

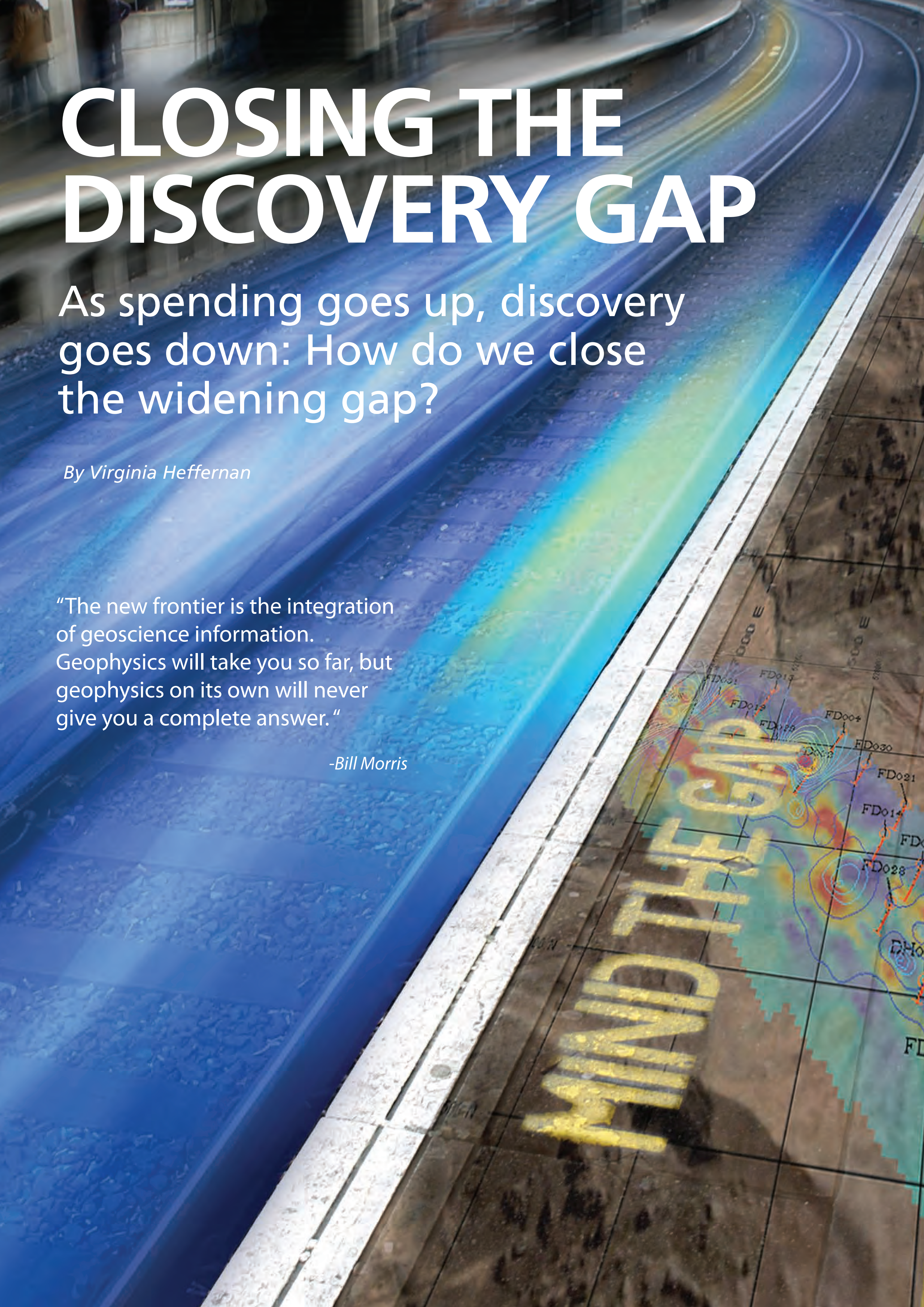
CLOSING THE DISCOVERY GAP

As spending goes up, discovery goes down: How do we close the widening gap?

By Virginia Heffernan

“The new frontier is the integration of geoscience information. Geophysics will take you so far, but geophysics on its own will never give you a complete answer.“

-Bill Morris



The cost of mineral exploration continues to rise, with global spending heading towards US$14 billion this year, yet rates of mineral discovery have been on the decline since the 1980s. Is there a way to reverse the trend?

Perhaps, says Professor Bill Morris of the School of Geography and Earth Sciences at McMaster University, but only if explorers begin to integrate geoscience information in such a way that they can see through rock and overburden to find buried deposits.

"The reality is that the old days when prospectors would go out there and find a mineral deposit on the surface are gone," he says. "We have to expand our search into deeper areas and use newer technology to enhance our search capabilities."

That shift in exploration methodology will require training, more efficient use of exploration data, and interdisciplinary cooperation: while geophysics may be the most obvious tool for exploring the subsurface, it cannot be used in isolation.

"The new frontier is the integration of geoscience information," says Morris. "Geophysics will take you so far, but geophysics on its own will never give you a complete answer."

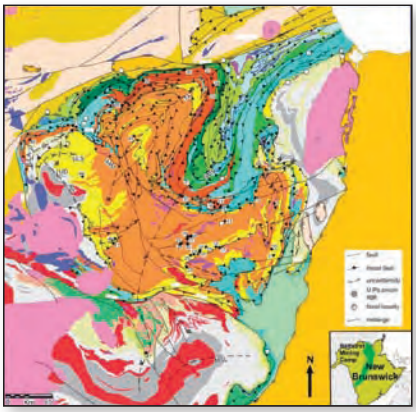
In Canada, the federal government is taking the threat of declining discovery rates seriously by committing $25 million over five years to find new base metal reserves in established mining communities. One of the main components of the Geological Survey of Canada's Targeted Geoscience Initiative (TGI), now in its third phase, is the integration of industry and government data collected over the years to conjure up new images of old camps with the hope of discovering previously undetected ore.

The TGI also aims to produce new geological, geophysical maps and geochemical maps of the target areas, create three-dimensional representations of areas with the highest base metal potential, and come up with new and improved methods to map hidden and deep-seated base metal deposits.

In the Flin Flon mining camp of northern Manitoba, for instance, the TGI completed a 2-D high-resolution seismic survey to help identify buried VMS deposits after the GSC's geological mapping in the area suggested a different structural model for the mining camp that was best tested by seismic tools. The Flin Flon deposits have high acoustic impedance relative to typical host rocks because of their mineral make-up (pyrite, pyrrhotite, sphalerite, and chalcopyrite).

"Before we turned up, the exploration techniques were pretty standard," says Simon Hammer, TGI's program manager in Ottawa, who explains that seismic has not been traditionally been used in mineral exploration, especially in relatively urban areas such as Flin Flon that have background noise. "The fact that the major stakeholder in the area then decided to follow up with 3D seismic clearly indicates that we were able to influence their exploration strategy."

Another TGI target area, and one of the focuses of Morris's research, is the Bathurst lead-zinc mining region in New Brunswick, an old camp that desperately needs new life. The area's main mine, Brunswick, is expected to close by 2010 and maybe even earlier given current metal prices, sucking about $100 million per year out of the local economy and putting 800 people out of work. Junior Blue Note Mining is also preparing to shut down the Caribou and Restigouche lead-zinc mines after less than a year of commercial production.

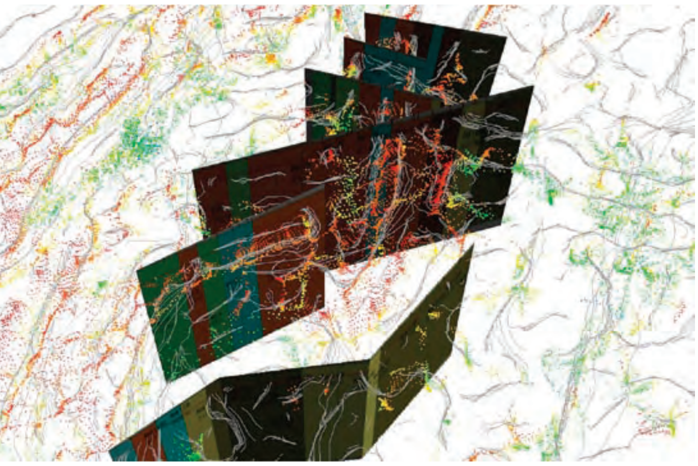


The Bathurst Camp in the lead-zinc mining region in New Brunswick.

The VMS deposits of the Bathurst camp lie in an ancient back-arc basin broken and twisted by multi-generational folding, faulting, and thrusting of several geological blocks and slivers. But the complex geology is difficult to map because most of the surface is covered by vegetation and glacial overburden, says Hernan Ugalde, a research scientist at McMaster working closely with Morris in partnership with TGI.

That's where geophysical surveys integrated with geochemical and drilling data will play a crucial role in assessing the near-surface and subsurface geology and potentially pinpointing new mineralization.

LEFT: Professor Bill Morris and Research Scientist Hernan Ugalde of the School of Geography and Earth Sciences at McMaster University. BELOW: Vegetation and glacial overburden make it difficult to map the geology of the Bathurst Camp.



Caribou Deposit: Magnetic Refinements (Worms and Euler Deconvolution).

To that end, Hernan is running detailed gravity surveys (100-200m spacing) over three VMS deposits in Bathurst – Chester, Caribou and Armstrong B – to test a theory that there is a correlation between the vertical gravity gradient and the presence of mineral deposits in the Bathurst camp.

The push from government and academia is a good first step, but the private sector must also get smarter and more efficient about how it deals with exploration data in order to make new discoveries, the McMaster researchers say. Junior companies in particular are missing the opportunity – for lack of knowledge and/or manpower – to use technology in their favour.

"Junior exploration companies, and even some senior companies, will often chase a geophysical anomaly," says Ugalde. "They may have very detailed geophysical information, but instead of going the extra mile to analyze the data and do some modeling to see, for example, what the actual plunge of the orebody is, they just drill it. But if you don't know the angle of your orebody, you can miss it."

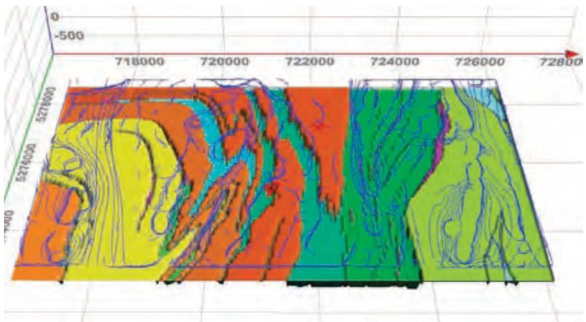
Ugalde and Morris urge companies to slow down and hire the expertise required to analyze their data properly, especially in this era of non-stop data generation.

"It's the difference between brute force and finesse in exploration," says Morris. "Should you put more money into boreholes, or should you be spending a little more money and time trying to formulate a model?"

Morris says the process of creating an exploration model has become much easier and more efficient with the advancement of exploration software, such as Geosoft, which provides a platform for integrating different datasets (e.g. magnetic, geochemical, topographic), bringing them all together as a single resource.

The ability to view these images in 3-D through GIS is also a crucial breakthrough, he says, because ore deposits are, by nature, three dimensional. The latest versions of Oasis montaj and Target, Geosoft's borehole data visualization software, allow geoscientists to work seamlessly between their Geosoft and GIS (ESRI) files without leaving the Geosoft environment.

Increased access to data and the technology to process high volumes of data in meaningful ways are two main ingredients in the new search for mineral deposits. Training is the third. As part of its mandate, TGI3 is placing significant emphasis on training university students in the broad range of skills they will require to serve the mining sector, including



Armstrong B Deposit: Structural Mapping. Geology and multiscale edge analysis (Worms).

providing them with summer jobs in the field.

Morris agrees that the industry badly needs an influx of qualified people that can make sense of data. With lots of user friendly software available, almost anyone can generate images, but only skilled personnel can separate what is meaningful in the data from what is not.

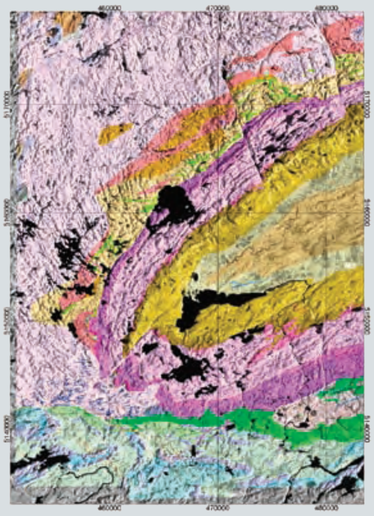
"You need direction from people with training who know how to integrate the data and understand what is behind those purple dots that you are chasing," he says. "It is in our nature to push the data set as hard as we can, to extract as much information as we can. But you're doing that at the expense of reality in some cases." ❑

DATA INTEGRATION FOR DISCOVERY:

A SUDBURY SUCCESS STORY

Wallbridge Mining, Xstrata Nickel and Vale Inco created a rare opportunity to generate new targets outside of the Sudbury Basin in northern Ontario when they decided to pool their exploration data for maximum impact on the western margin of the Sudbury Igneous Complex (SIC).

The Trill area covers several square kilometres of the Sudbury Contact footwall, the rocks that host the majority of nickel-copper-gold-PGE deposits in the Sudbury basin. The area presented an opportunity to refine the exploration model outside the boundaries of the basin when the main players shared results from 3-D seismic surveys and detailed aeromagnetic work. Bernd Milkereit of the University of Toronto guided the data integration project with the help of several experts in the fields of impact modelling, seismics and geophysical potential fields.

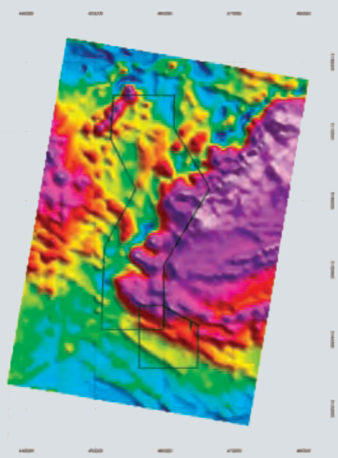


Location map. Regional geology draped over DEM of the area of study.

One component of the project integrated the geophysical potential fields data with rock property measurements from drill core and surface geology to create an improved 3-D model of the SIC and footwall contact over an area of about100 km2.

"It was a unique chance to get data from all three companies, and compile it all," Hernan Ugalde, a graduate student of Milkereit's at the time and current research scientist at McMaster University. "Companies don't normally exchange information like that, and if they do, it takes time to work with all the data to level and compile it. They normally can't afford that time."

The data integration project used new seismic methods to model the sub-crater geological environment and recognize potentially mineralized sub-crater structures, generated algorithms that distinguish between sulphide-rich and oxide-rich seismic reflectors and identified opportunities for future work. Ugalde's model based on gravity and magnetic data also identified possible new lithologies that have not yet been mapped and may have an impact on future exploration.



Regional airborne magnetic data over the area of study.

Wallbridge is currently drilling targets identified by a deep penetrating Titan-24 IP/MT survey on the Trill property. The survey covered a mineralized offset dyke, similar to the dyke that hosts the Copper Cliff mine, and the surrounding rocks, including a recently-discovered broad, arcuate belt of weakly mineralized Sudbury breccia. ❑