The vision thing

Where are the potential-fields geophysics methods going? My crystal ball is as cloudy as anyone's, but the profession is seeing an upsurge of innovation and I'm seeing some of my young man's visions turning into reality instead of old man's dreams (Joel 2:28).

The changes in data resolution and sensitivity are making completely new applications possible, so that potential-fields methods are expanding from regional tools into prospect scale and to some extent to reservoir scale.

In the next 10 years, I believe that we will see more than 75% of the following objectives achieved.

Gravity surveying

1) Satellite gravity data will take over completely in the offshore regional environment and will be used routinely in planning all offshore seismic surveys.
2) Marine and land gravity acquisition will go to higher resolutions and sensitivities and will remain bread-and-butter work.
3) Conventional airborne gravity will become available at higher sensitivities, better resolution, and lower prices.
4) Vector gravity data will be collected from moving platforms (land, sea, and air).
5) Gravity tensor gradient measurement will become widely used, notably for reservoir problems, and will be available from multiple contractors using more than one instrument type. Their increased sensitivity will permit them to penetrate the minerals sector.
6) Borehole gravity data will (finally) find widespread use in the reservoir environment.
7) Absolute gravity and gravity gradient surveying will become routine both on the ground and on moving platforms. It will impact the whole subject very strongly, from oil and water production monitoring and measurement (via excess mass calculations) to control of routine ground and marine surveys.

Magnetic surveying

1) The sedimentary basins of the world will be more than 25% reflown for aeromag at line spacing of 500 m or less, to delineate sedimentary structure and to assist with direct hydrocarbon detection.
2) Vector magnetic surveys will be routinely offered, at least in the minerals environment.
3) Two- or three-component vector magnetic gradiometer flying (using wingtip and stinger mounted or helicopter bird mounted total-field sensors) will become routine, at least in the minerals environment, but will make some inroads into the petroleum sector.
4) Magnetic tensor gradient surveys will be on offer.
5) Much of the flying will use pilotless aircraft.
6) Aircraft compensation using neural networks will become routine.

Processing and interpretation

1) Wavelet transform methods will assume a role at least as important as Fourier methods now play.
2) Equivalent source methods will do the same, penetrating interpolation, derivative calculation, and interpretation itself.
3) Neural networks will achieve major penetration of the potential-fields data processing and interpretation business.
4) It will come to be generally recognized that isostatic corrections are as important as Bouguer corrections if the geology of an area is to be well understood from the gravity measurements.
5) There will be close integration of geologic information and potential-fields and seismic data on the workstation. This will involve earth models described by boundary surfaces separating volumes with different physical properties (as some systems do now) rather than storing the physical properties of the model in a 3-D matrix.
6) There will be virtual-reality-type interaction with the geologic model using a data glove or similar device. Constraints to help keep the model geologically sensible will be simply put in place.
7) Short of that, on-screen interpretation of mapped images with the creation of virtual transparent interpretation overlays will be routine even on PCs, especially as large flat-screen monitors become big enough to use as virtual light tables. (It's possible with cheap commercial software in a limited way right now).

Other methods

1) We will see magnetotelluric and other EM methods back in action in petroleum prospecting (they never left mineral prospecting) to a significant extent, especially in difficult areas
2) The value of gamma-ray surveys as a basic mapping tool will come to be more widely recognized, and gamma rays will be more widely used for the purpose in both mineral and petroleum search.
3) The enormous value stored in existing data will be more widely recognized, leading to greatly improved archiving and databasing, and shared access to centrally stored databases with sophisticated rights-based access control (it's happening already).

Why do I say all this?

- I first became aware of the promise of gravity gradients when I was a graduate student (a while back now). I've been watching for their emergence ever since and even had a go at getting an instrumental project off the ground at one stage.
- Then SEG's special conference volume on superconducting devices woke me up to magnetic tensor gradients and their possibilities. Unfortunately, those are still in the laboratory, although I hear Bradley Nelson has done some preliminary flying tests.
- The number of contractors experimenting with gravity or magnetic gradient devices is now getting pretty high. The innovative work by Peter Hood at the Geological Survey of Canada, Doug Hardwick at the Canadian National Aeronautical Establishment, and Geometrics is finally being taken up. I remember being all charged up by Peter Hood's presentation on vertical magnetic gradient measurements at the Exploration 77 Conference.
- It must be nearly 10 years since I first experimented with Euler deconvolution using real magnetic gradient data

Editor's note: This collection of thoughts about the future of gravity and magnetics arose from an email discussion between Pat Millegan and Alan Reid. Reid, an active member of the SEG G&M Committee, has been instrumental in helping the community agree on data transfer standards after 30 years of "discussion."

Their email chat prompted Millegan to solicit comments from others about the future of the G&M disciplines. All thoughts and comments were written for inclusion in this article.

supplied by Geometrics.
- As a reviewer, I'm seeing more papers from very bright people applying little-known mathematical techniques to real problems.

We live in exciting times.

—Alan Reid
Reid Geophysics

There aren't many grav/mag in-house specialists left in oil companies. Marathon, Unocal, Conoco, Phillips, ExxonMobil, Chevron, Texaco, Shell, and TotalFinaElf come to mind. And many of us are staring retirement and/or downsizing in the face. In the future, the business of gravity and magnetics will change. All the in-house specialists that I know believe that our companies will not replace us when we retire or leave. And without in-house advocates, these historically underutilized tools may disappear. The contractor's job will change to a more hands-on, in-house role.

Someone from the seismic community commented to me in the mid-1990s that gravity and magnetics were dead. I replied that the very active G&M community would be surprised to hear that. Soon after, Tom LaFehr won the Maurice Ewing Medal, SEG's most prestigious honor, and we (AAPG and SEG jointly) published a volume of G&M case studies (which has sold more than 1200 copies and has won the Award of Excellence from the Houston Chapter of the Society for Technical Communication).

Costs and visibility are a problem today. Seismic costs are huge! And even though G&M are still an excellent value, companies often opt to save those small expenditures. For example, if you don't do marine gravity while you are doing the seismic, you won't go back out there just for the gravity. Don't be shortsighted.

Gravity and magnetics are being overshadowed by very flashy seismic visualization technology. We need to find a way to interact in that arena.

Marine magnetotellurics shows a lot of promise in subsalt imaging in the Gulf of Mexico. It adds another rock property that is not encumbered by density nil zones and overpressure.

—Pat Millegan
Marathon Oil Company
Houston, Texas, U.S.

1) The future of airborne and borehole gravity gradiometry is excellent ... if only there were a working, commercially viable gradiometer!
2) The buildup in airborne survey capacity over the last decade and the current malaise in both hydrocarbon and mineral exploration have turned standard aeromagnetic surveys into a commodity business. This is forcing the survey contractors to develop niche markets by utilizing technologies that reduce costs in certain environments (e.g., crop-duster planes, HeliGrav) or demand a premium in return for competitive advantage (e.g., magnetic and gravity gradiometers, a number of specialized electromagnetic systems).
3) The evidence is building from mineralogy, alteration, geochemical, radiometric, electrical, and magnetic studies that certain hydrocarbon fields display a measurable surface expression. This will lead to a more multidisciplinary approach to prospect exploration before the seismic crews move in.

—Stephen Reford
Paterson, Grant & Watson
Toronto, Ontario, Canada

I have worked 17 years for a major U.S. oil company, nine years as a G&M interpreter in both U.S. and international venues, and eight years in computer support developing in-house applications and supporting vendor products including overseeing Oracle databases. My remarks apply to what will happen in larger U.S. oil companies.

- Over the next few years more Unix applications will migrate to cheaper, easier to use, and increasingly powerful networked PCs. G&M applications will use PC or Unix server technologies to link to databases and other interpretation tools to allow much better integration of interpretations. This will allow G&M interpreters to be true members of an interpretation team. In fact, they may become leaders of the push to bring data together early in the process.
- I think that interpreters will find uses for gravity and magnetic gradients, whether they calculate them or measure them. However, costs of collecting gradient data will continue to make measured gradients hard to argue for in our current lean money environment. New technologies in borehole gravimetry and more widespread use of electrical methods will also have an impact.
- Aging of the oil company explorationists will have an effect in the G&M community. The lack of new hires in the G&M area over the past decades will result in a decline in the numbers of G&M specialists in larger oil companies. This will be good for the consultant community. Contractors have tended to hire younger work-

ers. As experienced G&M specialists retire from the majors, they will inevitably move to consulting and contract work. Larger companies will not replace specialists as they retire, and will use outside consultants more. Some companies will move to an "only-when-needed" use of gravity and magnetics data rather than maintaining staff specialists. To make sure these contract interpretations are useful, companies will need to fully share information with contractors, possibly making them part of internal company teams. Issues of trust and ethics will need to be resolved to make these teams work. Smaller companies, which already make extensive use of consultants, have a better understanding of these issues than the majors.

- The current low budget environment will not last forever, although this does not mean that high prices are inevitable over the next decade. Continuing declines in existing fields and increasing demand for oil in developing countries will tend to drive up prices, but this demand will fluctuate and threats of oversupply will not go away. Prices will continue to be uncertain during most of our careers.

I forecast that we will continue to live in interesting times.

—*Jerry Hensel*
Staff research scientist
Chevron

Downsizing of core (technical) staff, such as gravity and magnetics professionals, is an organizational concept that should be scrutinized with careful thought and planning by an energy company. The subsequent loss of individual talent will break the very link between an outside consultant and its in-house counterpart that a corporation is attempting to maximize, and will immediately shut down effective communication. The result is limiting technological applications and severing the collaborative synergy produced by a fluid and often spontaneous exchange of ideas, insight, and instinctive thinking. It is the internal specialist that is crucial to the process of identifying corporate needs, exchanging knowledge with the outside consultants, and ensuring that quality-control mechanisms are initiated and monitored. Nowhere is the impact of reorganization greater than on the ability of the corporation to maximize its outsourced human capital.

—*Corine Prieto*
President
Integrated Geophysics Corporation

Historically, G&M has filled a conventional need within Chevron, that is, providing assistance with local and regional exploration projects and modeling.

More recently, the acquisition of HRAM (high-resolution airborne magnetics) surveys has become well established. Accompanying this, visualization has allowed close integration of disparate data sets using GIS technology. In this environment, satellite and HRAM images, seismic horizons, geology, culture, and topography can all be seamlessly superimposed, merged, and readily shared between users.

I foresee this trend to continue, with more and more projects being initiated from the outset as an integral part of a project's GIS database.

On a different note, reservoir depletion studies have been carried out in the past using borehole gravimetry. However, the results were often limited by the inability to model and visualize effectively in 3-D. Given that these problems have been overcome to some degree, gravity may yet provide a useful tool to monitor reservoir levels.

Regional gravity modeling tied in to basin maturation studies can also give valuable information to explorationists while recent developments in sea-bottom MT (magnetotellurics), also a potential field technique, may give answers to the subsalt imaging problem.

—*Nick Gant*
Coordinator, G&M
Chevron Overseas Pet. Inc.

I was just talking with Bill Cathey, and he made an excellent point, that part of the problem (our challenge) is that there really are no standards (or guidelines) that nonspecialists can use to judge interpretation products. In other words, some sort of yardstick is needed for nonspecialists to use for understanding interpretation products, or the kind of products they need for their particular exploration play. The recent suite of papers in *TLE* on modeling is a great step in the right direction regarding this, but more is needed, I think—like inversion, depth to source, 2-D versus 3-D, airborne versus land versus shipborne, and on and on.

I think that our community has sort of dropped the ball regarding some of the new high-resolution data sets, particularly aeromagnetics. Some of the data is incredible, but what do they mean? What minerals/rocks are responsible for the observed anomalies? We know they are shallow, but we do not know a lot about depositional (or emplacement) scenarios for these intrasedimentary sources. We know that they can correlate with faults/structures seen in seismic sections, but we also know that we see them where faults are not observed in seismic sections. Furthermore, we know that often anomalies are not observed over mapped faults from seismic sections. It seems that the best we can do so far is to draw lines through them and say that they are intrasedimentary and that they may be produced by mineralization within a fault plane, or by offsets of magnetized sedimentary layers.

—*Dale Bird*
President
Bird Geophysical

I see that the future of G&M technology greatly depends on a successful development/improvement of airborne systems and the borehole gravity meter. An improved airborne magnetic gradiometer and particularly an accurate airborne gravity gradiometer have been a dream of the exploration industry for decades. Hopefully, we can have a practically successful airborne gravity gradiometer within a few years. Relatively speaking, a gradiometer is more important for the mining industry than for the petroleum industry. In general and even in the future, the best available gravity gradiometer cannot be better than the best available gravimeter in detecting a geologic target deeper than 2-3 km. Petroleum exploration will find a combined use of gravimetry and gradiometry much more powerful. If the size (diameter) of the borehole gravity meter system can be significantly reduced, e.g., from the current 4.125 inches down to 3-3.5 inches, many aspects in petroleum, from exploration to time-lapse reservoir monitoring, will benefit. Frankly speaking, extremely accurate, repeated

ground gravity measurements are not good enough to apply to the real world. We cannot afford to wait a few years to conduct the next survey and detect reliable and meaningful gravity changes of interest.

Better and more practical interpretation tools are required. There are many theoretical studies on 3-D gravity and magnetic inversion. Everyone seems to have a favorite approach. For a very simple model, most of these different methods will give quite good and similar results. For a complex field case, most are impractical. Of course, the nonuniqueness can be reduced mainly by more constraints. But we should be able to provide better reliability analysis of the solution. During the past two decades, many rapid, gradient-based interpretation techniques such as Euler deconvolution, analytical signal, and source parameter imaging have been developed. One trend is to obtain a geometry-independent depth estimate. This can be furnished by a use of higher-order derivatives. In order to get a quality solution, we need to develop more efficient algorithms to remove noise. Moreover, a combined use of the regional computer time and memory consuming 3-D inversion and a local, gradient-based, rapid interpretation is more useful and interpretable.

(Editor's note: Xiong Li wrote this while with BHP. He was part of a team that succeeded in bringing one of his predictions to fruition, an airborne gravity gradiometry system that is in operation today.)

—Xiong Li
Fugro-LCT

No matter how far we progress, there is always room for incremental improvement. We are continually surprised with instrument improvements and new ideas for using old instruments and data. I see no end to innovation.

I see many changes coming in interpretation methodology. With compute-speed increases, there is no reason not to do the job correctly anymore, meaning increased application of 3-D tools, especially as we get better and faster modeling tools to work with.

We are continually looking for new applications of our present knowledge. Pushing our technology into the realm of seismic processing and interpretation will continue to lead to new insights, better interpretations, and more geologically correct answers to our exploration questions.

Our techniques have been oversold in the (distant) past, and it has taken more than a generation to recover. In the wake of new instruments and techniques, it pays to remember the past, do our job meticulously, and let the results sell the methods.

—Chuck Campbell
President and senior geoscientist
ACCEL Services, Inc.
Current chairman, SEG Gravity and Magnetics Committee

It has been interesting to read from earlier times in geophysical exploration and also during our careers about the demise or very short future that gravity and magnetics have just had or are about to have. Even in one of the early SEG presidential addresses, not much hope was expressed for the future of our discipline. Very early in the life of LaCoste and Romberg, the two former professors predicted that they could make all the gravity meters ever to be needed in commercial exploration in about one year. It is true, I believe, that oil and gas exploration is experiencing major adjustments owing to the more profound changes occurring in the large international companies, and at some point we will see a marked decrease in the need for our services. Of course, it is difficult to predict without a crystal ball, and our predictions generally have not been very good in any case, but here goes: I think we have until the middle of (this) century before I will look for another kind of work. In the meantime, it is imperative to stay current in the broader spectrum of geophysical technology and to never stop asking, "How can we help improve the results from seismic exploration?"

—Tom LaFehr
LaCoste & Romberg

Corresponding author: alan@reid-geophys.co.uk