THE AMERICAN OIL & GAS REPORTER®
OCTOBER 2005
The "Better Business" Publication Serving the Exploration / Drilling / Production Industry

Gravity, Magnetics Still Play Key Roles

By Corine Prieto

HOUSTON–Nowhere is the dizzying growth of innovative, computer-driven technology better represented than in the oil and gas exploration industry. Yet, despite the plethora of quantitative programs, some experts argue that even the best of today's technological applications cannot replace yesterday's humble sciences.

Gravity and magnetics still have a place at the exploration table.

Coincidently, this year marks the 75th anniversary of both the advent of gravity and magnetics exploration and the creation of the Society of Exploration Geophysicists. One can argue that the first exploration application emerged in 1640, but it was really Gulf Oil's 1930 plunge into gravity and magnetics surveying for oil exploration that launched the sciences as unique and valid contributors to worldwide energy exploration. And since that time, acquisition technology has continued to advance at a mind-boggling pace–from La Coste's Zero Length Spring to Sandwell and Regan's satellite measurements. Data processing itself has evolved from Hammer's 1939 gravity terrain corrections to Akins real-time techniques. Today's interpretational methodology is produced online and in real time using PC-based workstations.

But has the utility of this first evolution science expired as a favored value-added, cost-effective exploration tool? Has the value-added aspect of potential fields been replaced by the explosion of multidimensional imaging technology? Where does gravity and magnetics fit in amidst the dazzling array of seismic technological breakthroughs that continue to reinvent themselves by the nanosecond?

More to the point, what is being done in terms of gravity and magnetic applications today, how is the technology developing and adapting to meet the demands of the new exploration environments (including deep water, deep geology and unconventional resources), and what truly justifies the existence of these sciences in an operator's exploration and production strategy, given the backdrop of advanced exploration technology?

The fact is that gravity and magnetics technology continues to play an important role in exploration and production applications, with a blend of standard techniques being interwoven with new cleverness.

Visualization, Interconnectivity

Surprisingly, yesterdays' standby gravity and magnetic applications are still playing an integral part of interpretation today, albeit with more sophisticated visualization and interconnectivity to the other exploration sciences. As Chuck Guderjahn, BP's manager of exploration excellence, says, "We keep global practitioners internally connected using a technical network that provides support for problems and disseminates the latest thinking rapidly."

Specifically, new visualization tools maximize the presentation of results. In addition, multifaceted software facilitates fast, accurate and real-time integrated work sessions with 2-D and 3-D gravity/magnetic-based structural models, integrating not only seismic horizons, but also seismic refraction and velocity volumes and wells.

Likewise, today's interpretations of salt and sediment interfaces are producing highly sophisticated, integrated multiscience models. Contrary to a single, "one-science" perspective, they are based on the results of multidisciplined efforts. Prestack depth migration (PreSDM) workflows are a case in point, suggests Harold Yarger, one of Chevron Texaco Gulf Coast's senior geophysicists.

"Prestack depth migration, without support from gravity models, can result in poor imaging below salt. In deepwater regions of the Gulf of Mexico, gravity data provide a unique supplement to subsalt seismic imaging by ensuring consistency with observed gravity," he says. "Using gravity-based modeling makes the PreSDM workflow more efficient, while greatly decreasing the probability of well bottoming in salt at the target depth."

The prestack depth migration interface scheme with gravity data is straightforward, with the gravity-based model results imported to the migration process, ultimately returned to the interpreter for refinement, and then again often returned to the modeling scheme for a second-round iteration at migration.

High-resolution aeromagnetic (HRAM) data have also demonstrated their use in PreSDM due to their uniquely sensitive reaction to top-of-salt relief. This sensitivity has proven to provide a valuable perspective and a very useful tool for guiding top-of-salt picking during the sediment flood phase of a PreSDM workflow.

Finding The Foundation

Most geophysical interpretations are driven by the premise that basement is the foundation of a basin. In essence, basement is the bedrock on which much of the dynamics for hydrocarbon accumulation and/or migration rest. When Integrated Geophysics first delivered a basement interpretation in 1986, the view was that the basement structure map for the Gulf of Mexico was not necessary for successful exploration. Canyons mapped at depths of 50,000 feet with 15,000 feet of throw were not acceptable and basically misunderstood.

Today, however, new tectonic models and basin restorations indicate that perhaps the basement is not deep enough. Closely spaced HRAM data have been instrumental in interpreting the geologic genesis of the Gulf. No longer are basement structure and lithology hypothesized or extrapolated from 50-mile loop data sets. This fundamental geological information is discernable with the availability of high-resolution aeromagnetic data.

One critical application of HRAM technology in the Gulf is delineating the mid-Jurassic sequence boundary. It is essential to recognize the variability in the location of the mid-Jurassic sequence boundary, which may, in fact, lie as close to the crystalline basement as to be identical in some places, but thousands of feet shallower than igneous basement in others. The key is to maximize the utility of HRAM data to significantly refine the correlation between the magnetic signature associated not only with the basement structure, but also to Cretaceous volcanics with deep-focused seismic sections.

Another use of HRAM-based Gulf of Mexico basement structure is described by ChevronTexaco's Harold Yarger, who points out, "In the absence of good (adequate) depth to (seismic) basement reflectors, HRAM provides good depth estimates useful for resolving autochthonous salt structure via gravity modeling."

Using closely spaced data grids of a half mile or less, HRAM continues to be a multifaceted contributor to Gulf exploration. From assisting in the development of the Gulf's tectonic framework, to detailing the top of salt for migration, and to bottoming an autochthonous salt interpretation, aeromagnetic interpretation is being kept quite busy.

The new kid on the block is a measurement-while-drilling tool developed jointly by the British Geological Survey and Halliburton Sperry Drilling Services. First applied in the North Sea in 2000 where it has gained quick acceptance, the technology was introduced to Gulf of Mexico operations in 2004.

"Data from magnetic surveys have also been found useful at the production stage," according to Dr. Susan Macmillan of the British Geological Survey. "Directional drilling operations require continuous monitoring of the azimuth and inclination of the well path, both to ensure the target is reached, and for safety reasons, to avoid collisions with existing wells."

Confidence levels associated with these estimates have to be good. This is accomplished by monitoring all aspects of the earth's magnetic field (that is, the main field, external fields and the crustal field). MWD magnetometer data is called interpolation in-field referencing, or IIFR. Gyroscopic tools are an accurate and standard method of achieving directional control, but gyros can add higher costs in respect to both drilling time and money. This may explain why MWD continues to gain favor in the Gulf of Mexico, Alaska and other areas around the world.

Sea-Sat Data

In 1986, the David T. Sandwell team at the Scripps Institution of Oceanogra-

FIGURE 1A

Free-Air Map (West Florida Shelf)

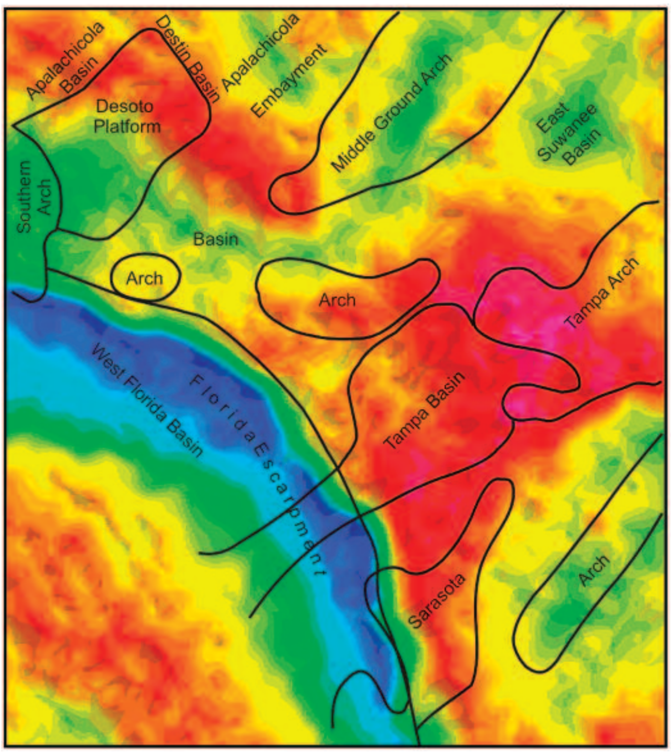
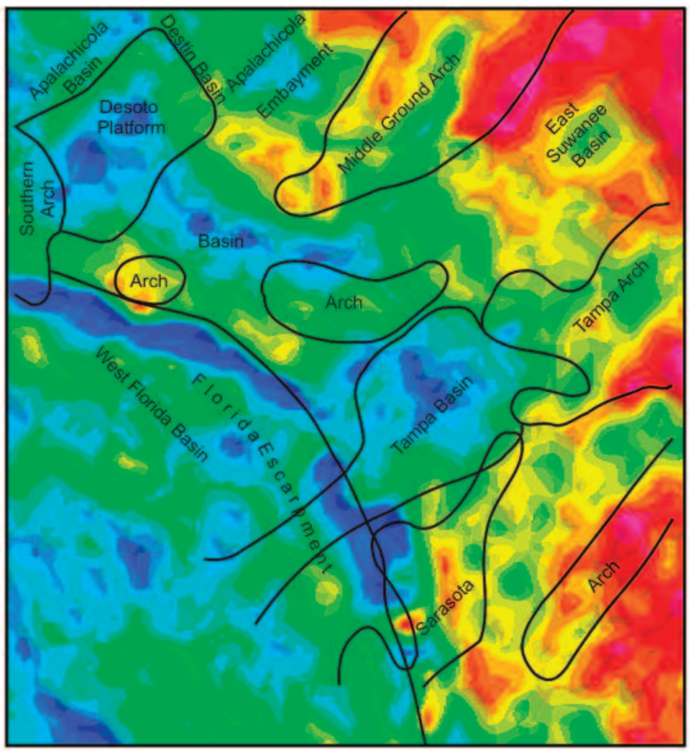


FIGURE 1B

Isostatic Residual Map (West Florida Shelf)



Shown at left is a Sandwell free-air gravity field with a regional geologic features overlay. At right is a properly processed isostatic residual gravity field with a regional geologic features overlay.

phy released the first phase of satellite (altimeter)-derived free-air gravity data. Coined "Sea-Sat," these data opened the door to offshore preseismic evaluation with gravity data. Once the satellite data are reduced to the Bouguer and residual gravity fields, the data can clearly delineate structural elements on offshore continental margins worldwide, including basins, transform faults, horsts, etc.

The current Sandwell Version 11.1 data grids are based on eight-kilometer spaced satellite traverses of viable taxpaid data. The data have been reprocessed commercially with enhancement results worth the cost. As described by new ventures geologist Craig Davis at Newfield Exploration Co., "The hottest (development in) gravity and magnetics is the new and improved Sea-Sat data, which have much better resolution and are very helpful in deciding on the prospectivity of a new venture block internationally."

In the Gulf of Mexico, Sea-Sat data have become a utility data set for the regional picture on which many tectonic models have been developed. It is important to use the correct map; regional gravity maps such as free-air, Bouguer, or isostatic residual gravity are often used to interpret regional trends and structures of the subsurface geology. To someone not reasonably familiar with gravity data, it may seem immaterial what each map represents. But in the final analysis, the most important consideration should be using the gravity data that provide the soundest geologic interpretation.

The West Florida Shelf examples shown in Figures 1A and 1B compare free-air and isostatic residual maps–developed from the same basic data–with published regional geology of the West Florida Shelf. The comparison illustrates how only one map, the isostatic residual, can be readily interpreted to agree with the identified geologic features. Calculating an isostatic residual involves certain assumptions, among which are the choice of crust/mantle density contrast and compensation depth. Tests have shown that when the data are processed correctly, robust and high-confidence regional interpretations are produced.

Today's exploration geophysicists are only too aware of the cost-saving aspects

FIGURE 2A

Measured Marine Gravity

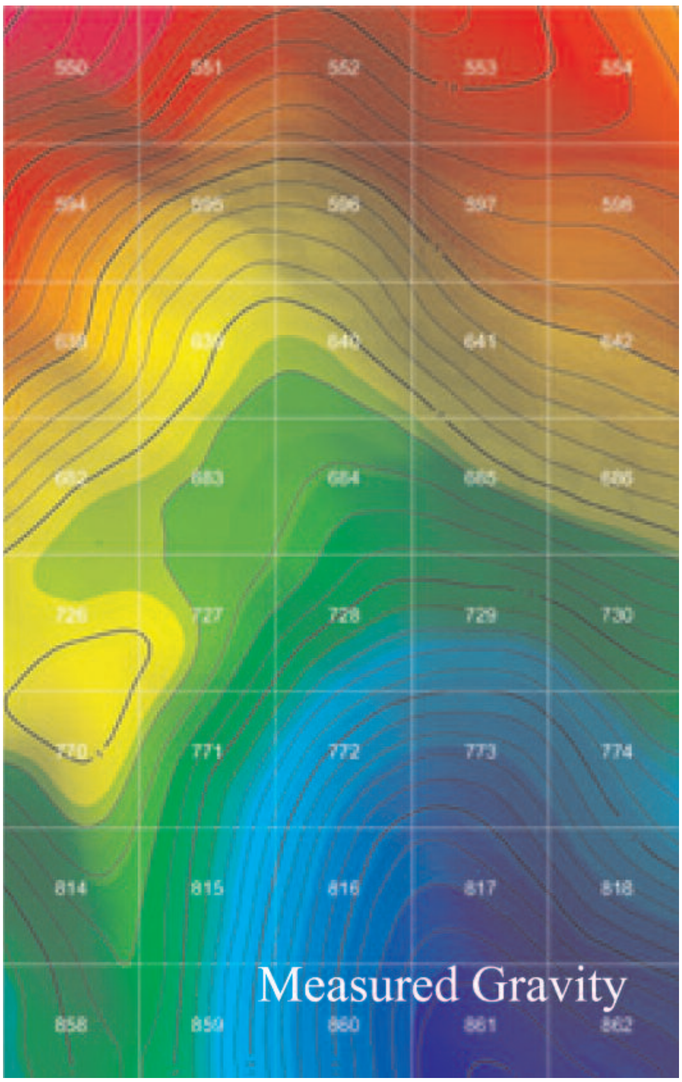
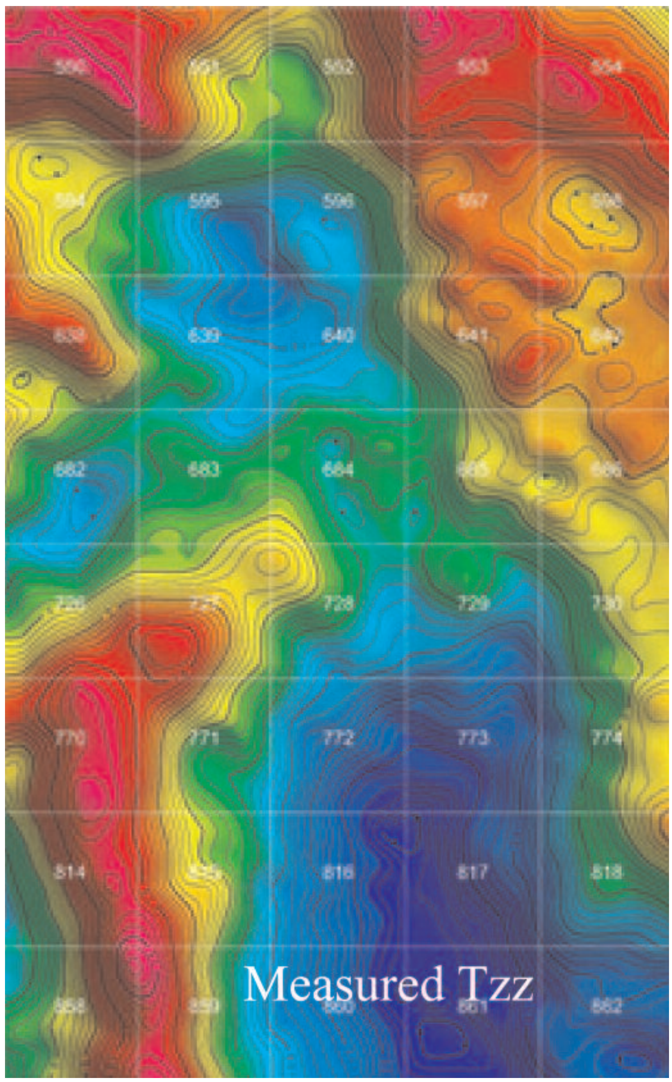


FIGURE 2B

Measured Marine Full-Tensor Gravity



Shown here is a comparison of measured marine gravity and measured Marine-FTG™ vertical tensor component from the Gulf of Mexico. The tensor data provide a higher frequency content, which is utilized in salt interpretations. Data courtesy of Bell Geospace.

of the Sea-Sat free-air data, and are using the data to its full potential.

Full-Tensor Gravity

The ability to discern with confidence the geometry of the low-density (salt) section is a common salt/sediment interface problem that continues to frustrate exploration efforts in deepwater regions of the Gulf of Mexico. It is best solved by integrating multiple datasets, including full-tensor gravity (FTG) gradiometry.

Applying FTG data to exploration was hampered by the timing of the technology's entry into the workflow. When gravity gradiometry data entered the market in the late 1990s, industry conditions led operators to reduce exploration budgets, and the research and development funds required to evaluate any new data sets were extremely limited, if not nonexistent. Therefore, tensor data was left at the door untested and was a slow starter for reasons not of its own fault.

Full-tensor gravity gradiometry uses matched pairs of accelerometers to measure subtle changes in the earth's gravity, and measured FTG data shows greater detail than measured gravity data alone (Figures 2A and 2B). Airborne gravity gradiometry has been adapted for onshore applications. For example, the mineral industry uses FTG extensively in exploring for base and precious metals, and diamond exploration projects (both kimberlite and alluvial) have kept data gathering busy.

A common Gulf interpretation project that involves incorporating tensor data is one in which a prospect lies along the edge of a prospective minibasin with a trapped-amplitude poorly imaged by seismic data. Three-dimensional earth models are built based on detailed full-tensor and regional marine gravity data constrained by bathymetry, density volumes derived from calibrated velocities, a seismically interpreted top-of-salt horizon, the magnetic basement structure surface, and the Mohorovicic discontinuity surface. An interpretation process that integrates these data sets with forward calculations and 3-D inversion techniques can put a valid constrained solution for the base-of-salt surface on the table for explorationists.

Marine tensor data continues to be an exceptional tool for defining accurate salt structure. The salt detailing obtained through interpreting these data is providing new and valuable insights into salt rugosity. The possibility that the base-of-salt is rugose and causes seismic rays to disperse is not a preferred view, but it does draw concern for trap integrity.

A 'Second Science'

Gravity and magnetics is often thought of as an alternative to seismology, but truthfully, it should be considered as a complementary "second science." Does it still contribute to exploration efforts as a value-added, cost-effective tool?

Glenn Morton, general manager of Kerr-McGee China's office, responds by referencing an example from the company's operations in China. "We have a (seismic) structure–a four-way closure–that has a gravity high and a magnetic high. The conundrum is whether this is a buried volcano. I need to know how thick the volcanics are, and there are basalt flows in this area, therefore, there must also have been a source for these flows. So what I need is a way to determine gross lithology from potential fields. In some sense this is not any different than what is being done in trying to distinguish salt lithology from clastic lithology in the Gulf of Mexico."

Today's challenges articulate a demand for regional work that is as strong now as it ever was, according to BP's Guderjahn. "BP continues to use potential field data using traditional methods from basin- to prospect-scale," he says. "For the future, in addition to pursuing technological advancements, there is much to be gained by routinely integrating all of our investigation tools to unlock the enigmatic puzzles we often encounter."

That, in a nutshell, is the new workflow: integrating different data sets–including gravity and magnetics–to seek targets in increasingly complex geological environments. In China, one of the causes happens to be basalt. In the Gulf of Mexico, the problem is typically related to salt.

Today, 75 years after gravity and magnetics first entered the exploration scene, potential fields input continues to be embraced worldwide, especially where seismic sections are problematic. Gravity and magnetic applications in seismic processing have gained significant respectability. From the United States to Yemen, determining depths to magnetic basement establish a basin's structural framework, while at the same time in many areas, delineate "fault" targets for drilling. And who would have thought that a new technology option would emerge using magnetics in downhole MWD applications to provide cost-saving measurements at the drill site?

As gravity and magnetic applications have evolved in tandem with the complexity of modern exploration technology, an emphasis on the validity of input data must be made. For the explorationist, gravity and magnetics can play a key role in geological and geophysical interpretations, but improperly processing these data can undermine the validity of the results and have severe economic consequences. The cost responsibility imposed on an interpretation demands a conscience concern to the quality of the data being utilized. It is important that data processing and/or data merging techniques applied to potential fields data retain the full fidelity of the measured data. ❐

Editor's Note: The author acknowledges the individuals quoted in the preceding article for their time and willingness to share their insights, Marianne Antoniak for her assistance, and the British Geological Survey and Bell Geospace for contributing data and graphics.

CORINE PRIETO

Corine Prieto is founder and president of Integrated Geophysics Corp. in Houston. Her 34 years of diverse experience in oil, gas and mineral exploration and exploitation includes working in the most prolific onshore and offshore petroleum provinces in the lower-48, as well as the North Sea, Africa, the Middle East, the Far East and the West Indies. Prieto's former corporate affiliations include Superior Oil Co. and Mobil Oil Corp. She holds a bachelor's in physics and mathematics from the University of Texas-El Paso, and a master's in applied physics (geophysics) from the University of Toronto.