Gravity/Magnetic Data Use Surges

(Editor's note: The Geophysical Corner is a regular column in the EXPLORER and is produced by the AAPG Geophysical Committee. This month's column is part one of a series on "The Renaissance of Gravity," titled "Recent Advances.")

By BRIAN S. ANDERSON
and MARK E. WEBER

Fifty percent of the world's seismic fleet is now recording gravity and/or magnetic data – representing a 100 percent increase over just two years ago.

The question is: What happened?

The ongoing surge in use of gravity to the present historic high levels can be attributed to several recent key developments, including:

❒ The industry is involved in more challenging exploration plays than ever before.

❒ Increased costs of exploration and drilling.

❒ Major advances in data resolution.

❒ Three-D modeling software applications are now integrating seismic, gravity and magnetics on the same workstation.

❒ Three-D seismic has not answered all our questions.

❒ Cost-effectiveness of the gravity and magnetic techniques.

A Brief Look Back

Historically, gravity and magnetic data were primarily used as a basin reconnaissance tool for determining gross features of an area. Key elements are depth to high-density basement (often coincident with economic basement), sediment thickness, fault delineation, mapping of volcanics and salt modeling.

A common approach was to have a gravity and magnetic "guru" on staff, or as a consultant, who would disappear with all the data and return some time later with an "answer."

If the results of the gravity and/or magnetic work did not agree with the seismic interpretation, the "guru's answer" would generally be disregarded.

Although much good work was achieved, results had been limited by the resolution of the recorded gravity and magnetic data, and the lack of cohesive integration.

Advances in Resolving Power

At a recent technical meeting in Houston, Ed Biegert, non-seismic methods specialist for Shell Development, asked the question: "Why do we re-acquire gravity?"

His own answer to the question was: "For the same reasons we re-acquire seismic data."

Although the gravity fields mapped in prior years have not changed, our ability to accurately measure and process gravity on a ship has improved dramatically – just as we have improved our ability to shoot, record and process seismic data (figure 1).

Recent advances in gravity measurement at sea include:

❒ Upgrading from analog to digital control and acquisition systems.

❒ Higher data sampling and recording rates (200 Hz sampling, 1 Hz recording).

❒ Precise DGPS positioning for removal of ship accelerations.

❒ More accurate measurements of water depth.

❒ New data processing developments (signal to noise enhancement, micro-leveling, etc.).

With these advances, industry has seen stunning improvements over data recorded as recently as 10 years ago. In many cases, there is an increase of up to 10 times the data per unit area in new surveys over older data, with a correspondingly higher level of confidence in interpreted geological results.

Many operators are routinely incorporating new high resolution gravity into their interpretation projects, particularly in the deep water Gulf of Mexico. This integration is facilitated by new workstation software applications (figure 2).

Gravity Data Accuracy

One very experienced oil company gravity and magnetic interpreter quotes the following approximate interpretable accuracies of data in the Gulf of Mexico:

1. Sidney Schafer Water Bottom Gravity (shelf to 600-foot water depths), over 2,000- to 4,000-foot horizontal distances; primary limitation is sampling – station spacing: 0.1 to 0.3 milliGal (mGal).

2. Legacy Deep Water Marine Data (over 10 years old) over 10,000-foot horizontal distances: 0.5 to 1.0 mGal.

3. New High-Resolution Deep Water Marine Data (1991 or newer), over 1,500- to 3,000-foot horizontal distances: 0.1 to 0.5 mGal.

The above examples are general estimates based on several criteria, including positioning, instrumentation, sampling, processing techniques and associated bathymetry accuracy. Recent work has shown that errors of 0.3 to 1.0 mGal or greater can be introduced into data due to use of incorrect water depth or positioning information.

The importance of data resolution makes a thorough investigation of the gravity data prior to interpretation a sound practice. As with any geophysical technique, ambiguities still exist, and the limitations of the technique should be thoroughly understood.

Just What is a MilliGal?

Not many of us have a good grasp of what this measurement unit of gravity means, or in more general terms, the impact of gravity data accuracy on geologic interpretations.

"We already have a gravity map" is often heard at oil companies.

The following is an exercise in converting gravity (milliGals) into a meaningful geologic quantity (thickness of salt – in this case, thickness of a salt lens).

Modeled Salt Thickness vs. Gravity Data Accuracy – Sensitivity Models

Using a generalized density vs. depth curve for the deep water Gulf of Mexico,

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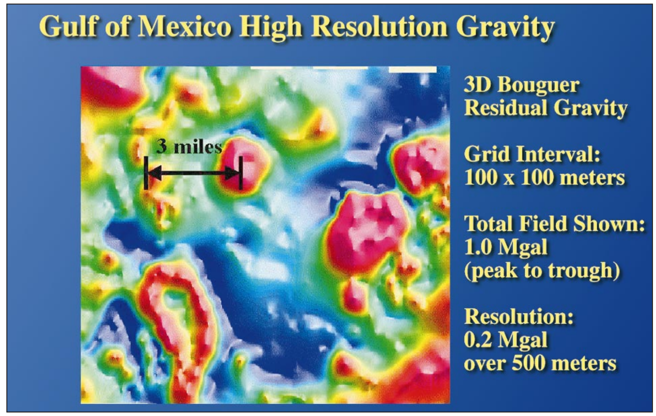

Figure 1 – A sample of new high-resolution gravity in the deep water Gulf of Mexico.

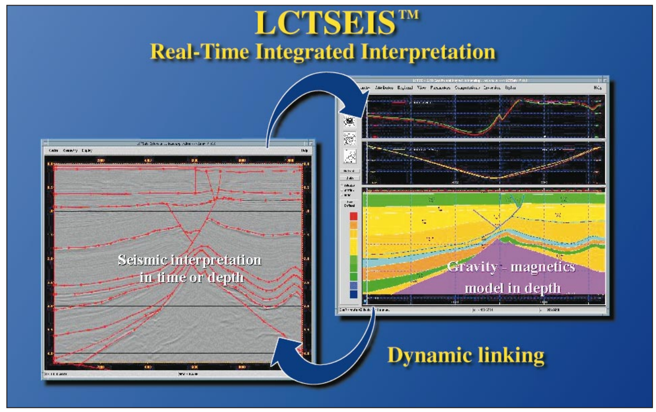

Figure 2 – Today's workstations handle integration of seismic, gravity and magnetics.

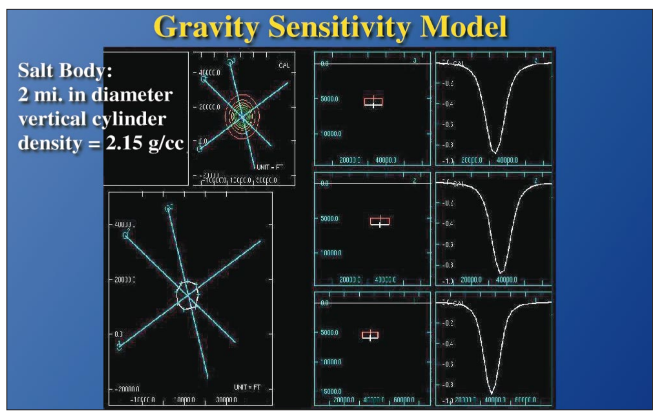

Figure 3 – Salt body model for determination of required gravity data accuracy.

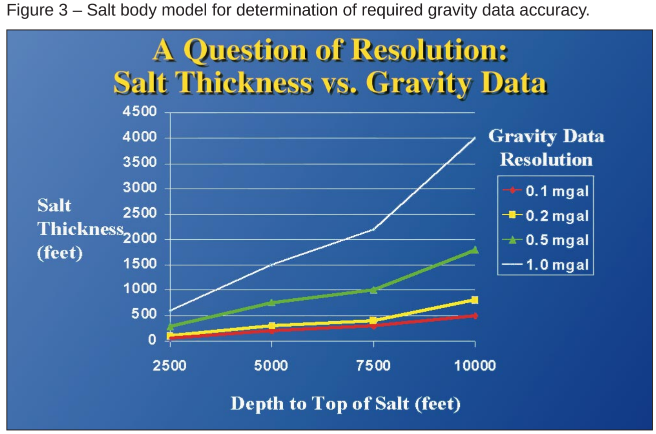

Figure 4 – Salt thicknesses accuracy chart, using differing accuracies of gravity data.

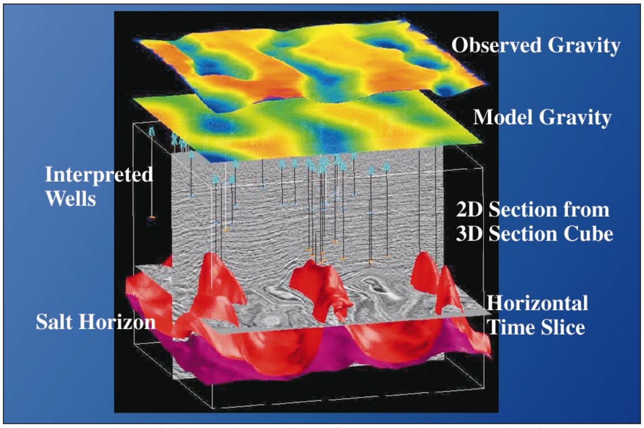

Figure 5 – High resolution gravity used to refine 2-D and 3-D seismic velocity

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we have constructed a series of sensitivity models for a salt lense, two miles in diameter (figure 3).

The salt was inserted into the density model at several depths. At each depth the thickness was varied to establish data points for a salt burial depth and thickness vs. gravity response chart (figure 4). The results of these models quantitatively demonstrate the need for accurate gravity data in deep water salt modeling.

Admittedly, this is an over-simplified example, but it is effective in demonstrating the need for good quality gravity data to obtain meaningful geological results.

To read the diagram, go to the x-axis (depth) and find the 7,500-foot depth point. Moving upwards on the chart to the 0.1 mGal data curve, we see on the y-axis that 0.1 mGal data, when modeled for salt at this depth, will provide approximately plus or minus 300 feet accuracy in modeled salt thickness.

For 0.2 mGal data this range grows up to 400 feet; for 0.5 mGal data results are plus or minus 1000 feet; and for 1.0 mGal gravity data (most older gravity data sets in the deep water) the results are plus or minus half a mile of salt!

The Present Economics Of Gravity and Magnetics

New high resolution gravity data costs approximately $1,200 per Gulf of Mexico OCS lease block, or $12 per line mile for new 2-D high resolution data (e.g. gravity from TGS-Calibre Phase 45 Program).

Costs for 2-D models are in the $2,500 to $5,000 range, and full 3-D gravity and magnetic modeling studies can cost from $25,000 to $50,000 or more depending on the complexity of the model.

In terms of new data acquisition, crew and equipment costs are in the range of $1,500 per day or less. In areas like the deep water Gulf, many companies are finding this a worthwhile investment. When rig rates are pushing well over $100,000 per day, it is easy to understand why.

Next month: A review of gravity/seismic interpretation applications and methodologies that have been proven successful in the Gulf of Mexico and around the world.

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Integration: A Practical View

(Editor's note: The Geophysical Corner is a regular column in the EXPLORER and is produced by the AAPG Geophysical Integration Committee. This month's column is part two of a series on "The Renaissance of Gravity," titled "A Practical View of Integration Methods.")

By BRIAN S. ANDERSON, MARK E. WEBER and JOHN E. BAIN

Even with the best quality 3-D seismic data, an interpreter can have a troublesome task in defining the salt/sediment boundary at the flanks of a salt dome, salt sheet or other complex structure.

For decades, gravity has been used in the Gulf of Mexico to address this problem. The major differences in how it was done then and how it is now done are twofold. It's better today because of:

❒ Better acquisition technology and processed data.

❒ Truly integrated workstation software tools.

By incorporating a co-recorded data set with each data set (e.g. seismic & gravity) independently measuring a related property of the subsurface, the interpreter can place a much higher degree of confidence in the final geologic interpretation.

To quantify this observation, case studies show that incorporating 3-D seismic with high resolution gravity and magnetics can alter the base of salt interpretation by several thousand feet from the 3-D seismic interpretation alone.

Team-Oriented Exploration Tools

With the trend toward highly focused exploration teams, the smooth interaction and coupling of multiple geophysical disciplines is essential. Explorationists are expected to employ and be familiar with more disciplines on a continuing basis.

The development of workstation applications, which enable the interpreter to simultaneously refine the subsurface model using seismic, gravity and magnetic data, has been a giant step forward.

A flow diagram for such an application is shown in Figure 1.

In using a new software tool kit, high resolution gravity now can be applied to an increasing number of seismic velocity modeling projects. This technique is employed using the procedure outlined below.

1. High resolution gravity is recorded and processed along with the 2-D or 3-D seismic survey. Present techniques allow for delivery of processed gravity data in advance of, or in parallel with, processed seismic data delivery.

2. The seismic velocity data are used to create a corresponding density section (or volume, in the 3-D case) by means of a flexible velocity-density conversion tool kit, incorporating:

❒ Gardner's Equation.

❒ Nafe/Drake, Hilterman and other density-velocity relationships.

❒ Use of available empirical data (e.g. velocity logs, check shot surveys, gamma-gamma density logs, etc.).

❒ User defined conversion algorithms or formulae.

❒ Other approaches.

3. The density model can be as simple or as elaborate as the corresponding velocity model – up to and including a discrete value of density for each x-y-z node within the profile or volume of data.

4. Input of digital horizon data (again, 2-D or 3-D) as interpreted on the seismic workstation. The system incorporates a "universal translator" for the conversion of one type of horizon to another to accommodate company partner teams, etc.

5. Computation of the gravity field of the model, input of gravity data as recorded on the survey, and a direct comparison between the two fields.

6. Manipulation of the model using both forward modeling and inversion processes based on minimizing the misfits between model and measured gravity fields.

7. On completion of the modeling and/or inversion process, the revised earth model is converted into the velocity domain, providing an improved starting point velocity model for depth migration.

8. This iterative process and feedback loop continues throughout the seismic migration and interpretation process.

How it Works: Gulf of Mexico Example

Figure 2 is a cross section through a full three dimensional model of a salt feature in the Gulf of Mexico. The density cube is derived from available well control. The top of salt is typically obtained from a simple initial stretch to depth from the time interpretation. Later – in the interpretive processing sequence – this is updated with the post-stack or pre-stack depth migration results.

The base of salt is input from an initial time interpretation. In many cases the initial base of salt interpretation is provided with confidence factors, e.g. a 10 might be assigned to high seismic confidence areas, a 0 being assigned to seismic blind zones, and grades in between. The gravity modeling can then be constrained by the high seismic confidence areas, and the low (seismic) confidence areas are then of most interest in the search for a better interpretation using gravity modeling results.

The density and velocity data are analyzed, typically using cross plots, and a function is derived to convert between the density and the velocity volumes. The gravity effect of the density volume is computed and compared with the observed gravity data, and the differences are resolved through a series of automated structural and density inversion techniques.

The final model should contain as much seismic-gravity constraint as possible for optimal results, often involving close interaction between the gravity interpreter and seismic interpreter at the same workstation.

Once the final density model is constructed, the density-velocity function is used to translate the alterations into an apparent velocity cube. Figure 3 is the final result of this process. Note the original outline of the salt body (prior to

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Figure 1 – Flow diagram for integrated seismic-gravity-velocity interpretation.

Figure 2 – Initial density model, deep water Gulf of Mexico.

Figure 3 – Revised velocity model after application of gravity, with initial salt outline shown.

Figure 4 – Full integration: Incorporated into this Gulf of Mexico interpretation are a 3-D seismic volume; 3-D velocity volume; 3-D density volume; calculated and observed gravity fields; interpreted well data; and interpreted seismic horizons.

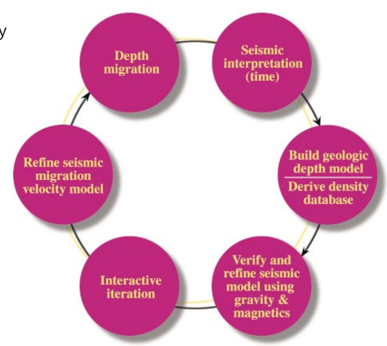

Figure 1

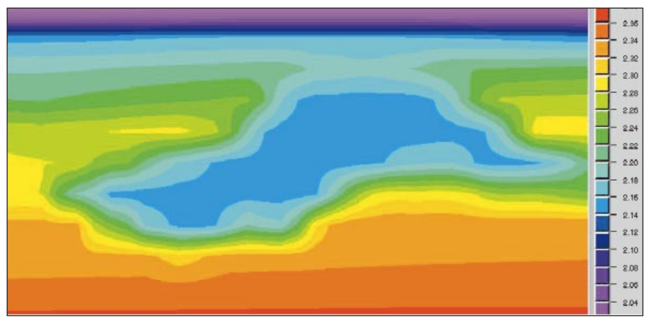

Figure 2

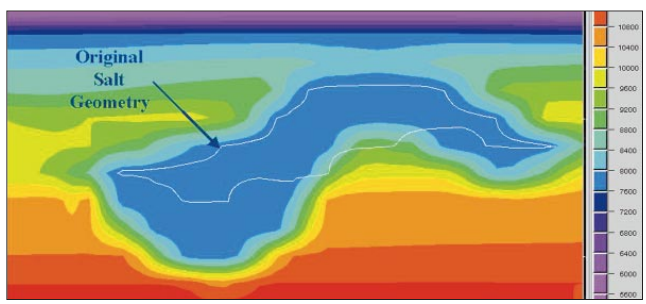

Figure 3

Graphics above courtesy of LCT Inc.

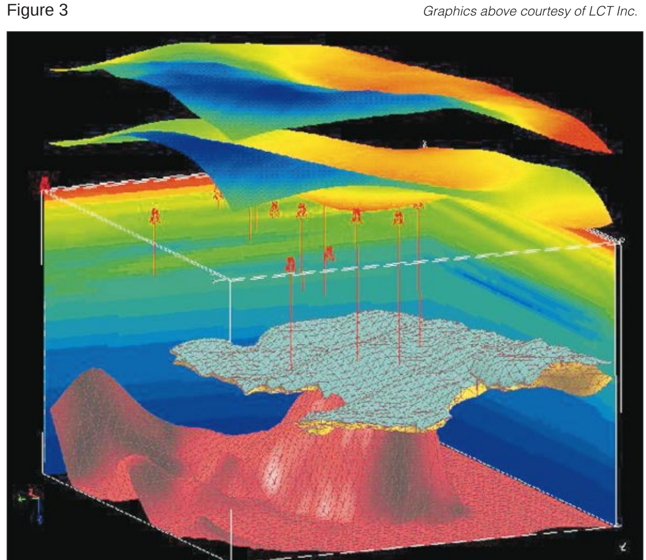

Figure 4

Petrocaem display courtesy of CGG-Petrosystems

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integration of the gravity and seismic results), shown as a white outline. In this case, several thousand feet of change in the base of salt are indicated through the multi-disciplinary approach, as compared with the seismic-only approach.

A full 3-D view of an integrated seismic-gravity model with well control is shown in Figure 4 (page 12).

This process, in addition to providing important and independent corroboration and improvement to the seismic interpretation of the base of salt, also provides an important source of long wavelength velocity information beneath the salt masses.

This information, when injected back into the velocity model used for producing the final base salt and sub-salt images, can have a dramatic impact on the enhanced quality of the seismic processing results.

Economic Impact

In today's team-oriented exploration environment, the availability and use of real-time interpretation software tools allow for the integration of gravity and magnetic data at the same workstation. This approach is now embraced by a growing number of oil companies for:

❒ Increasing confidence in their geologic interpretations.

❒ Decreasing risk.

To be most effective, the integration of gravity and magnetics must take place at the earliest stage of prospect development, and can continue throughout the exploration process.

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