The Gulf of Mexico - From Various Vantage Points

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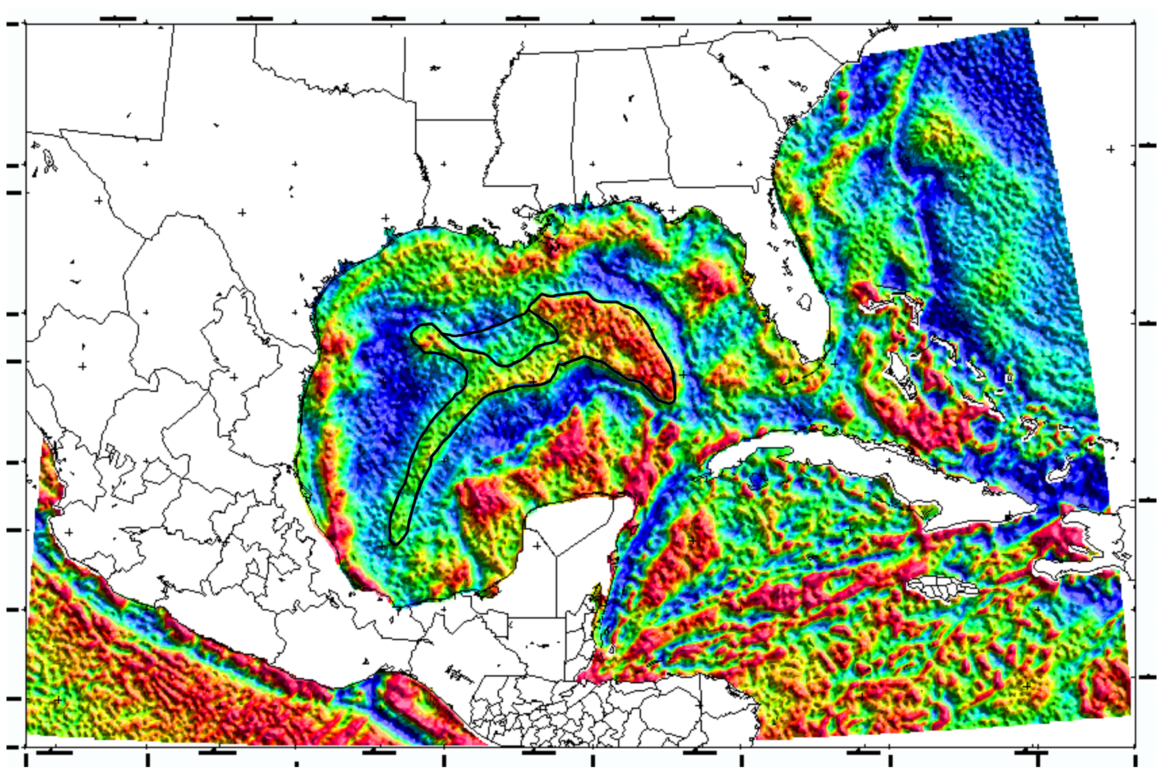
Oftentimes in exploration geophysics we tend to focus on specific near-term exploration prospects, as dictated by the current economics of our business. However, it is becoming clearer that in "mature" basins, such as the Gulf of Mexico, new play concepts are often derived by challenging old paradigms.

Examples include the Subsalt Trend, the Perdido and Mississippi Fan Fold Belts and the Viosca Knoll carbonate play. One way to initiate new paradigms is to take another look at the basin from different vantage points, often using different data types to provide insights to the geology.

Birds-Eye View

One option is to step back and look at the region from a birds-eye view. Through this process, integrated exploration teams take what they've learned from their microscopic view of detailed prospects and plug it into the macroscopic view of a region as a whole. Regional gravity data can often provide a framework to tie together these different scales.

The crustal geometry and tectonic framework have had a profound influence on the subsequent geologic history of the Gulf of Mexico. Knowledge of the present-day position of oceanic crust and its boundaries with transitional crust can provide important insights for understanding the development of regional petroleum systems of the Gulf of Mexico. A new interpretation of these crustal boundaries is underway, based on satellite-derived isostatic gravity anomaly maps.

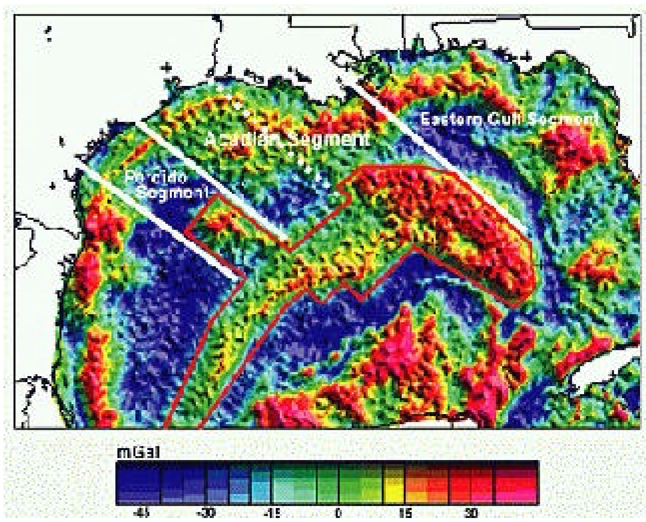


Satellite-derived isostatic gravity anomaly in the Gulf of Mexico. The central positive anomaly correlates with true oceanic crust. Shoreward lies transitional crust, an area of highly attenuated often intruded, and relatively thin crust.

Satellite-derived gravity data sets are generally regarded as capable of resolving structures with gravity responses longer than about 25 km. Maps at scales of 1:500,000+ are typically used. It is not uncommon to identify failed rifts, perhaps floored with volcanics, within transitional crust.

Looking from the birds-eye view also helps us divide the US Gulf of Mexico into different geologic provinces using the isostatic gravity anomaly, regional seismic control, regional topography, and magnetic data sets. Integration of these multiple data sets confirms that the subsequent geologic history of the Gulf was highly influenced by the underlying rift/drift geometry and crustal segmentation.

By observing the Gulf of Mexico from the birds-eye view, one can identify lineaments related to rift transfer zones, outline the primary depositional systems, and segregate the salt prone regions into areas exhibiting different styles of salt deformation.



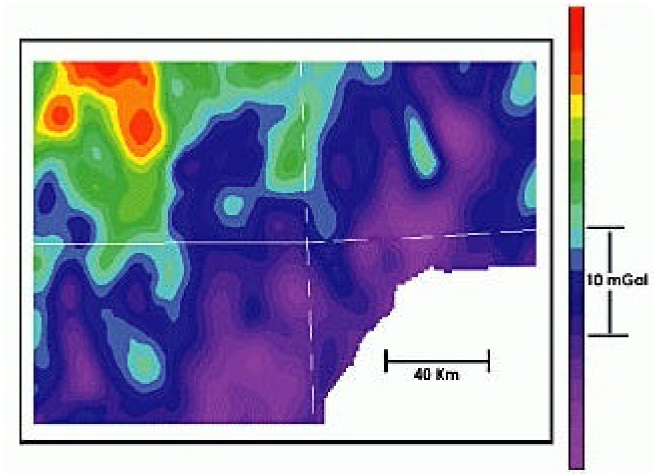
Generalized interpretation of crustal boundaries, northern Gulf of Mexico from satellite-derived isostatic gravity anomaly. Modified after Watkins et al, 1995 and Peel et al, 1994.

Macroscopic View

Zooming in to the next level in the use of gravity data sets is the utility at the "macroscopic" level. This level is defined here to include structures such as basement tectonics, sediment depocenters, and primary salt feeder systems.

This level of study is typically done for projects on the order of a US Gulf of Mexico protraction area (e.g. Green Canyon). While some of the geologic structures of interest at this scale (typically 1:100,000 to 1:500,000) can be seen using satellite-derived data sets, we typically run into the limitations of satellite-derived gravity data very quickly for problems of specific exploration focus.

To illustrate this point, examine the difference in gravity between a modern high-resolution shipborne gravity survey and satellite-derived gravity data (both reduced with identical parameters). The differences between shipborne and satellite-derived data are shown here to be in excess of 40 mGal over this deepwater Gulf of Mexico region. Short wavelength features differ by as much as 20 mGal over 20 km (half width).



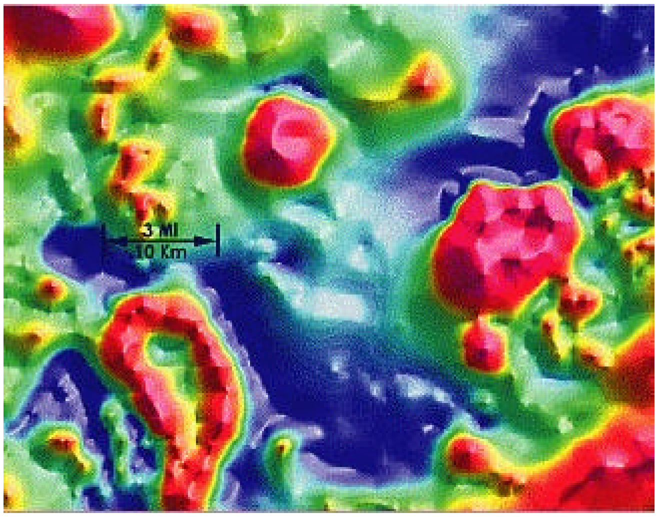
High- resolution ship-borne gravity minus satellite-derived gravity from the deepwater Gulf of Mexico.

Many of the features related to basement architecture, primary salt feeder systems and sediment depocenters are on the order of 2-10 mGal over 1-20 km. Therefore it is critical to use high quality shipborne gravity data sets at the macroscopic scale.

<u>Sub-Macroscopic View</u>

Zooming in to the next level in the utility of gravity data sets is at the "sub-macroscopic" level. This level is defined to include structures such as tabular salt masses, sediment fairways adjacent to and beneath salt and stratigraphic traps. This level of study is typically done for projects on the order of a few OCS (3 miles by 3 mile) blocks and up. Projects at this scale are typically performed using 2D-acquired gravity data sets with perhaps 1 mile line spacing (1.6 km), infilled over the prospect with detailed data from 3D-acquired gravity or full tensor gradient (FTG) data sets. The along-line resolution and accuracy of 2D-acquired versus 3D-acquired gravity data is identical. The increased resolution of 3D-acquired gravity data sets comes from the closer line spacing (often 250-500 meters).

The next example is a high-pass residual Bouguer gravity enhancement, which removes the long wavelength information. This enhances short wavelength gravity features that are more closely related to salt bodies and sediment traps. The total amplitude range on this map is 1 mGal, showing the strong coherency of short wavelength features (as small as 200 meters) with amplitudes of only a few tenths of a milliGal (mGal).



High-resolution shipborne gravity data. Total field is 1mGal, peak to trough.

Displays such as this can be used qualitatively to infer the position of salt flows (e.g. the gravity low shown in blue trending to the northeast) and salt pillows (e.g. the larger gravity low shown in deeper blue in the south central location). Sediment fairways and mini-basins (shown in the yellow to red anomaly bands) rimmed by the salt features can also be inferred. Interesting correlations can be made with these maps by overlaying the existing oil and gas fields and searching along trend for analogs.

<u>Full Earth Models</u>

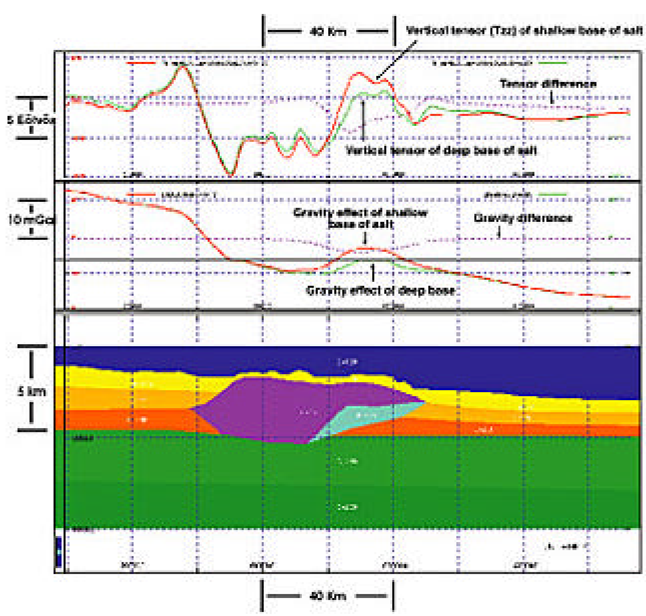
One primary utility of gravity and magnetics at this scale is its quantitative use via modeling. The intent of modeling is to derive a single earth model, comprised of structural information and rock property data including density, velocity, resistivity, and magnetic susceptibility, that agrees with the observed geophysical data (e.g. seismic, gravity, magnetics, magnetotellurics/MT). This can be done in both a forward and inverse modeling mode.

Forward modeling occurs when we construct an earth model, compute its theoretical geophysical effect (e.g. seismic, gravity, magnetic response), and compare the computed effect with observed geophysical measurements. For example, alternative yet-equally-viable seismic models can be discriminated by comparing the calculated gravity and magnetic effect of each possible seismic model with the observed gravity and magnetic fields.

The earth model can then be modified to obtain a best fit to all input control data. In this manner, gravity and magnetics data are used to enhance confidence and reduce ambiguities in seismic interpretation. Often, an interpreter or team of geoscientists performs integrated forward modeling jointly using the seismic, gravity, and magnetics data all on the same workstation. In this manner, physical constraints and knowledge of the local geology are easily incorporated into the model view.

Below is an earth model, where a tabular salt mass is shown in pink. An alternative interpretation of the base of salt for this example is depicted by adding a 1,000-meter thick wedge of salt shown in light blue at a depth of approximately 4,500 meters. The difference in vertical gravity between these alternative salt models reaches a peak of 4 mGal and extends over approximately 20 km.

This anomaly is easily observed with high quality, 2-D-acquired shipborne gravity data. The peak amplitude of the difference gravity field between the alternative models is on the order of 10 to 20 times the measurement accuracy of vertical gravity (Tz) from modern shipborne gravity data sets.



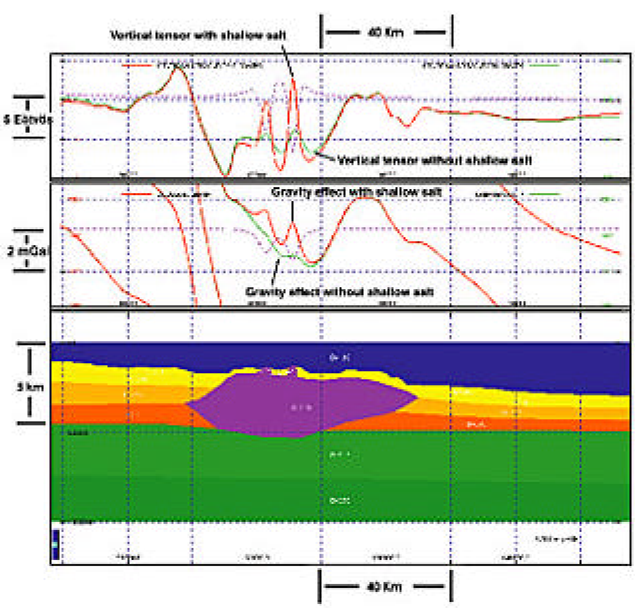
A comparison of vertical gravity (Tz) and vertical tensor (Tzz) on a salt model with shallow vs. deep base of salt.

In the upper panel, we have computed the vertical gradient of gravity for the model, namely, the Tzz component. The units are measured in "Eötvös," equal to 1/10th of a mGal per km. The difference in vertical gravity between these alternative salt models reaches a peak of 4 Eötvös, over approximately 20 km, and with quite gentle slopes. With published accuracy on the order of 1-2 Eötvös for measured full tensor gradients, this relates to approximately 2-4 times the measurement accuracy for the tensor component. Thus, one would expect this feature to also be identifiable in the tensor field. However, given that it is easily seen in the conventional marine (vertical) gravity data (Tz), the increased cost of tensor gradient data over high resolution marine gravity is generally not warranted for a geologic question of this sort (namely, base of salt geometry at these depths).

Much discussion is taking place in our industry over the use of full tensor gradient components for assistance in mapping salt features. We strongly support the use of tensor components when available. In our own modeling work, we have yet to see sufficient cost versus technical benefit to suggest the use of measured tensor components for all but the most critical and shallowest of geologic questions. The reason for this is that the falloff (attenuation) with depth of a gravity tensor component is ($1/depth^3$), while that of vertical component gravity is ($1/depth^2$). Accordingly, the resolution of vertical gravity (Tz) versus that of tensor gradients (such as Tzz) for mapping base of salt below about 8,000 –10,000 ft, is nearly equivalent.

However, when the geologic anomalies are shallow, gravity tensor components provide their maximum benefit. Examples of the ideal application of tensor gradients include detecting complex geometries on top of salt bodies, identification of shallow density/velocity anomalies related to gas charged zones, or other similar shallow geologic problems.

In the next figure, we have modeled shallow salt that comes up vertically essentially to the seafloor in two spots. Oftentimes, seismic data has a very difficult time imaging the top of salt when the salt is shallow and steeply dipping, as in this model. It is not uncommon for seismic interpreters to allow the gravity modeling a fair amount of latitude for proposing alternative interpretations on the top of salt for situations such as this.



A comparison of vertical gravity (Tz and vertical tensor (Tzz) on a salt model with shallow salt.

In this model, the salt has pierced above the so-called “Salt Nil Zone” and the sediments are lower in density than the salt (Bain et al, 1993). Therefore, the shallow salt causes a positive gravity anomaly. In the middle panel, the vertical gravity (Tz) display has been exaggerated and is now showing 2 mGal for each division.

The gravity anomaly due to the shallow salt (shown by the difference gravity) is sharp and has peak amplitude of about 1.5 mGal (on the order of five times the measurement accuracy). Notice in the upper panel that the computed tensor gravity anomaly (Tzz) is more than 10 Eötvös (also five times the measurement accuracy of full tensor gradient systems), but of very short diagnostic wavelength.

We believe that this is an excellent example where full tensor gradient gravity data would improve the geologic interpretation. Where shallow features (or similarly, shallow gas chimneys) exist, it is essential to derive a detailed model of the shallow structures (and perhaps strip away their gravity effects) in order to properly separate out these shallow effects from the deeper structures of interest.

Microscopic View

In addition to conventional basement mapping and delineation of salt and sedimentary structures, much work is being done using high resolution gravity and magnetics data to assist in the construction and improvement of velocity models for use in depth imaging of seismic data. In the Gulf of Mexico, this typically involves incorporation of the birds-eye view to put the regional tectonics, and associated gravity gradients into perspective.

This is followed by the macroscopic view, which produces a depth to basement model, and a better understanding of the primary sediment depocenters and salt movements. Next, a localized and detailed earth model is derived using all available geological and geophysical inputs to produce an initial model in three-dimensions. This model is iterated upon using the seismic, gravity and magnetics (and recently, marine MT) to derive an improved earth model that best fits all of the available geological and geophysical control. This density model is then translated to an apparent velocity model and used for the next round of seismic depth imaging. Companies have reported that this integrated model-based process saves cost and cycle time in critical depth imaging projects.

Seismic, gravity, and magnetics data integration and modeling should form an integral part of exploration programs in the Gulf of Mexico. Through careful and close integration of these multiple data sets, we can attain our goal of reduced exploration risk through a more thorough understanding of the earth.

Acknowledgement

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References

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