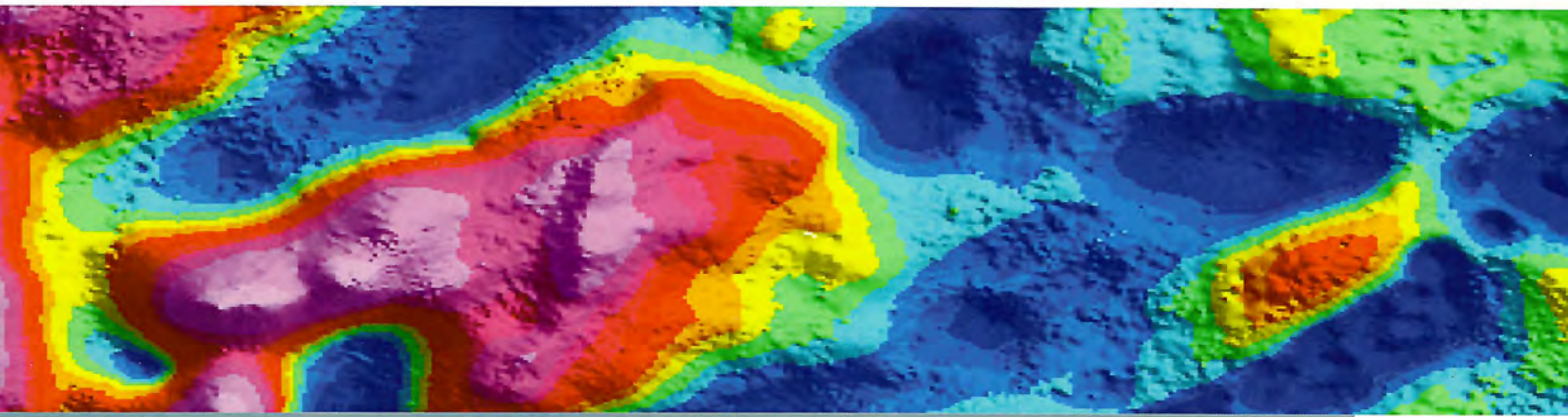
GRAVITY AND MAGNETIC METHODS

- DATA ACQUISITION
- GEOLOGIC INTERPRETATION
- INTEGRATION WITH SEISMIC DATA



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What are Gravity and Magnetic methods?

Low-cost, rapidly acquired gravity and magnetic data provide the basis for critical geologic insights sometimes undetected in the interpretation of seismic data. Small-scale variations in the earth's gravity and magnetic fields reveal lateral contrasts in the physical properties of the crust. These variations in rock density and magnetic susceptibility correlate with geologic features in the subsurface.

Gravity and magnetic anomalies indicate areas where physical properties (density and magnetic susceptibility) are different from those of the surrounding region and can commonly be associated with changes in lithology and structure. Characteristic anomalies may be associated with classic exploration targets like salt structures (gravity), reefs (gravity), and exploration hazards like thin volcanic flows within the sedimentary section (gravity and magnetics). In addition, gravity and magnetic anomalies are extremely useful in quantifying basement character, fabric, and depth. Mapping linear gradients within gravity and magnetic fields provides insights into faulting and near-surface structures.

We can quantify the nature of the geologic source of a gravity or magnetic anomaly by constructing models of property variation due to lithology and/or structure. We constrain our models with available geologic and geophysical information, including well logs, depth-converted seismic data, and other information. The computed gravity and magnetic response of the geologic model is compared with the observed data. The model is perturbed, either by forward modeling or inversion, until the computed response approximates the observed signal. The final model's density and magnetic susceptibility distribution are geophysical representations of the subsurface, providing new information on the lithology and structure of the area.

The computed density model can be converted to a p-wave velocity field and provided to the seismic velocity modeling team. This gravity-derived velocity field provides further insight into the lateral and vertical velocity structure, which is independent of the seismic information. As such, this new velocity field can be used to improve seismic data quality in zones where the seismic velocity cube's signal is compromised, for example, in regions of complex salt.

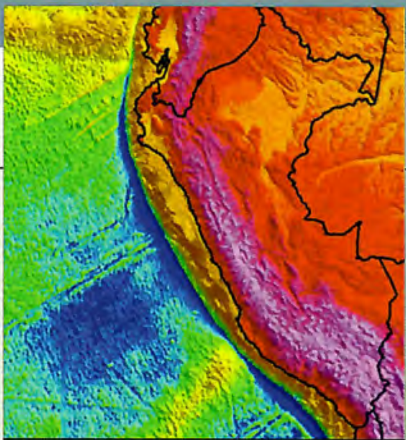
Data Acquisition

Gravity meters measure changes in the earth's gravity field as small as one part in a billion. The common unit of measurement is the mGal (0.001 cm/s^2). The resolution of static surveys on land is typically 0.01 to 0.001 mGal. Dynamic marine and airborne surveys have lower amplitude and spatial resolution, depending on survey design.

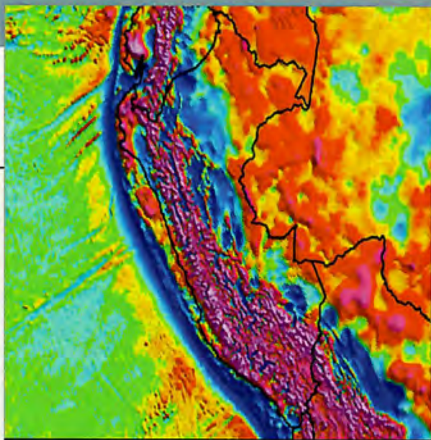
Survey magnetometers typically measure the magnetic field strength in units of nano-Tesla (nT) or gamma. Airborne surveys are typically flown in fixed-wing aircraft or helicopters. Ground surveys are useful for mapping small areas with shallow targets.

The cost of adding marine gravity and magnetic acquisition to 2D and 3D marine seismic surveys is small and well justified.

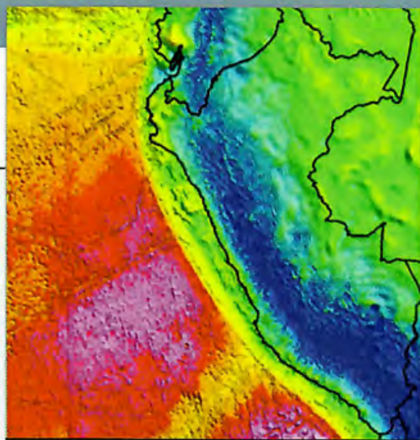
Pre-survey planning to determine the optimal acquisition parameters is critical to the success of the project. Sensitivity models are constructed to test the viability of gravity and magnetics for imaging a detectable anomaly from the expected geologic structure/lithology of the survey target. The ideal survey will resolve the shortest spatial wavelengths of anomalies present in the earth's gravity/magnetic field but will not oversample the field. This optimizes the cost of the survey (by line-km or ground stations) and reduces the risk of exceeding a reasonable acquisition budget.



Topography

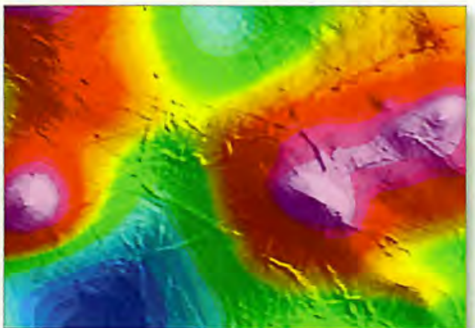


Free-Air Gravity

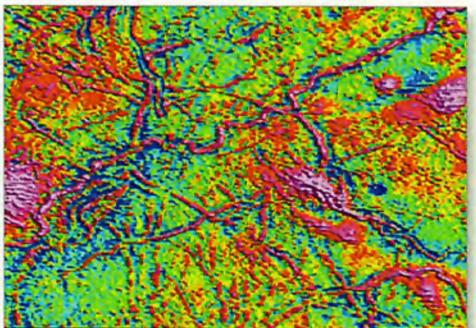


Bouguer Gravity

There are different types of gravity anomaly maps. Free-air gravity shows the lateral density contrast within the earth's crust but is very sensitive to topographic and bathymetric relief. Bouguer gravity minimizes the effect of topography and bathymetry while imaging the lateral density contrasts within the sedimentary section. Free-air gravity can be used for modeling. Bouguer gravity maps are best used for map interpretations.



Acquired Magnetics



Second Vertical Derivative Magnetics

Data enhancement techniques are used to improve the signal of interest and facilitate recognition of subtle features of significant geological importance. A gravity or magnetic lineament can be a gradient zone, linear break in the anomaly pattern, straight anomaly, or even an alignment of separate local anomalies. Long lineaments are more likely to be associated with faults than short ones, especially if they occur in swarms or are a part of a regional pattern.

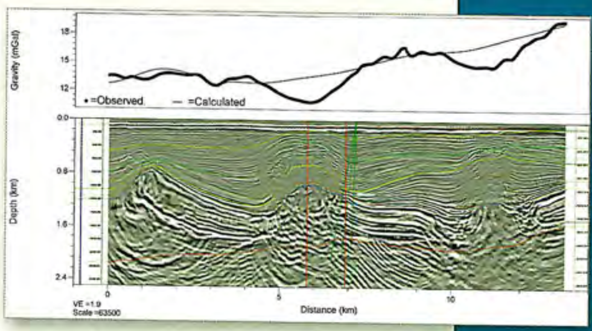
Integration with Seismic Data – Salt Volumes

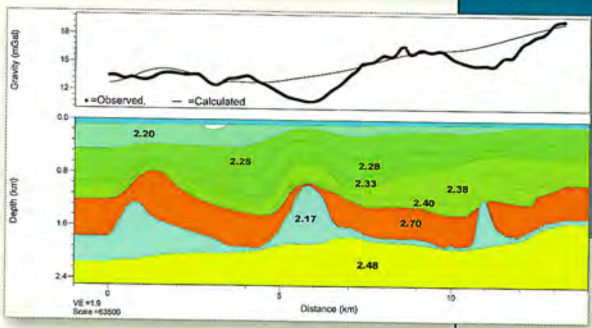
In salt provinces, the density contrast between salt and surrounding sediments can be quite large, therefore gravity can help improve imaging of sub-salt horizons.

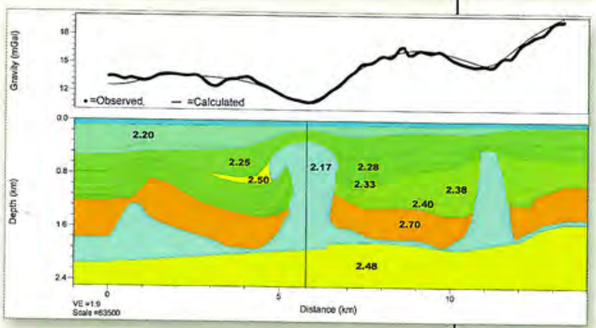
This may come in play where seismic data commonly loses resolution under the salt flanks. Mapping the base of salt is not a simple task. Using gravity response to guide base of salt imaging is very common in data integration processing and has proven to be a powerful tool.

The first image on the right is a seismic section that runs from west to east. The depth horizons are digitized from the depth-converted seismic data. On the top is a profile of computed gravity (forward model response, the thin black line) and the observed gravity (thick line). By color-coding the horizons by density, we can easily image the initial model's density structure (second image). Note that the computed gravity is a poor fit to the observed, indicating that significant changes in the total volume of salt are required.

For the calculated response to fit the observed signal, the model's salt structures are perturbed (third image). By adding more salt to the initial interpretation, the fit is improved. The negative anomalies present in the observed gravity suggest that the volume of salt is greater than that of the original seismic interpretation. Gravity modelling has provided an independent assessment of the salt structure and total volume, giving more confidence to the subsurface model for the exploration team.



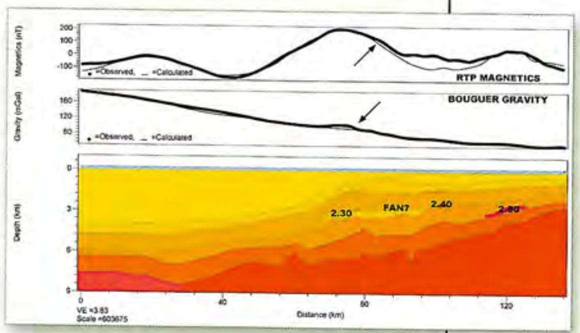


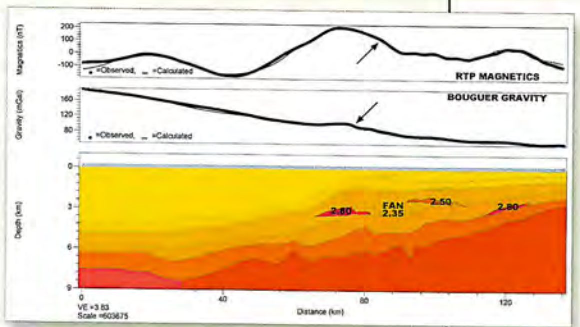


Volcanics in Sedimentary Section: Hyperdynamics Guinea Project

This is a model of marine Bouguer gravity and RTP magnetic data. It is color-coded by density. The geologic target is a proposed fan feature, identified in 2D seismic data. We generated this model to determine whether gravity and magnetic data could support the presence of the fan and corroborate its volume as interpreted from the seismic image. The upper image shows the computed RTP magnetic and Bouguer gravity responses of the model in the vicinity of the proposed fan are too low, relative to the observed signal.

The lower image shows a model iteration with modifications to the fan's geometry, density, and magnetic susceptibility. The computed response of this model, which includes volcanic material within the western portion of the fan, is a much closer match to the observed signal for both the gravity and the magnetics. This result suggests that at least a portion of the proposed fan is not sedimentary. This is an important result, as it indicates that the fan may be more limited in lateral extent than originally interpreted from seismic data.



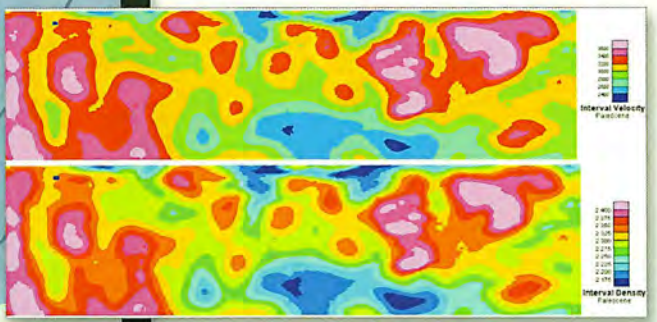


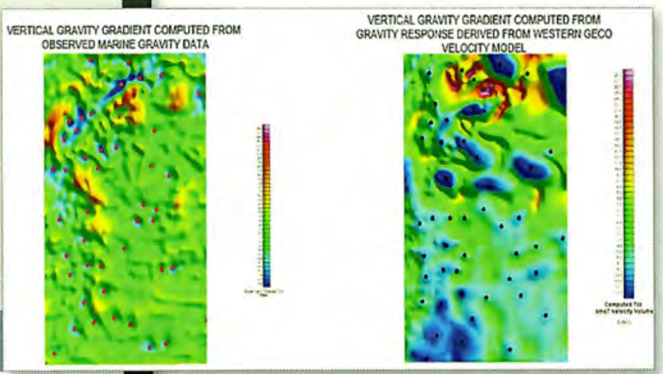
Favorable Applications – Gravity

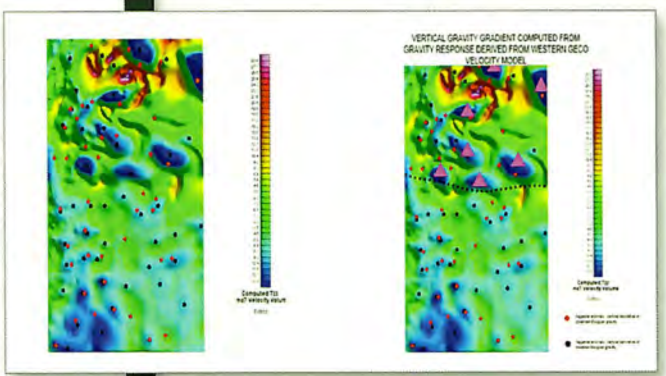
- Salt estimation
- Basin delineation
- Estimation of mineral deposits
- Detection of sub-surface cavities
- Determination of glacial thickness

Favorable Applications – Magnetics

- Fault mapping
- Depth of basement studies
- Dikes and interbedded volcanics
- UXO detection
- Mineral deposits and mine planning







Aquila and Seismic Data Quality: Pemex GOM Project

This case history shows the use of gravity interpretation to assess 3D seismic data quality in a salt province. The top figure shows the interval velocity of the Paleocene unit. We apply Gardner's Relation (Density = .23*Velocity$^{0.25}$) to the velocity interval to generate a grid of interval density for the Paleocene (lower figure).

After converting the entire 3D velocity cube to a 3D density cube, we compute the gravity response of the velocity model. Here we show the vertical gravity gradient computed from the observed marine Bouguer gravity anomaly grid (left image) and the vertical gravity gradient computed from the gravity response of the velocity model (right image). We have plotted the centroids of relative negative anomalies (assumed to be associated with salt diapirs) with red diamonds in the left image and black circles in the right image. There is good agreement between the centroids derived from the two different datasets in the southern portion of the survey, but not in the northern region. The purple triangles show significant discrepancies in character (amplitude and wavelength) from both responses.

These seven anomalies represent regions where the velocity model is inconsistent with the observed gravity signal. The velocity model predicts too much salt in these locations; its computed vertical gravity gradient is too negative relative to the vertical gravity gradient calculated from the observed marine gravity data. We can now provide this feedback to the seismic velocity modeling team, enabling them to revisit their total salt volume for these northern diapirs.

EDCON-PRJ provides industry-leading, state-of-the-art expertise in gravity and magnetic acquisition and processing, including land, marine, and airborne surveying. Our strategic partnership with Wintermoon Geotechnologies provides our clients with a complete gravity and magnetics solution, from survey design to acquisition and processing, to integrated geologic and geophysical interpretation of surveyed data. Wintermoon's services include post-processing gridded data enhancement and filtering, map-based qualitative interpretation, quantitative 2D and 3D forward/ inverse modelling, and basement-depth computation and characterization.

SUGGESTED READING

- Blakely, R. J. (1996). Potential Theory in Gravity and Magnetic Applications. Cambrige University Press.
- Grant, F.S., West, G. F. (1965). Interpretation Theory in Applied Geophysics. McGraw-Hill.
- SEG Continuing Education Course – Gravity and Magnetics for Explorationists. Michal Ruder
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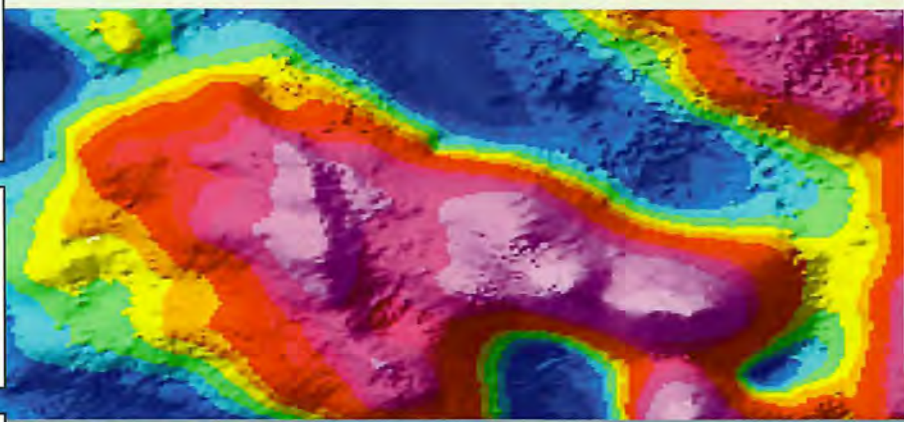

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