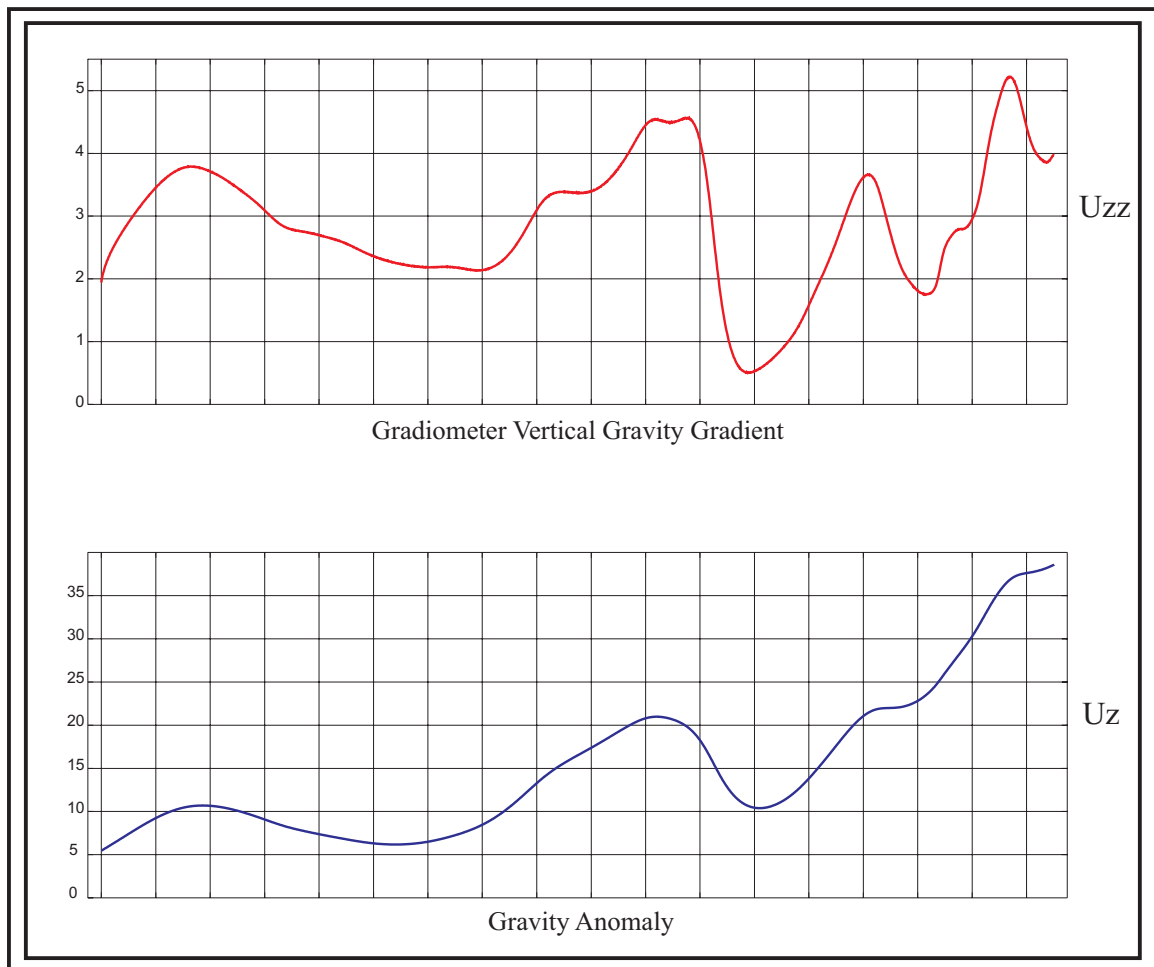




# FOOTNOTES ON INTERPRETATION

## GRAVITY GRADIOMETRY IN NATURAL RESOURCE EXPLORATION



## Introduction

Gravity gradiometry is currently a subject of intense interest and discussion within hydrocarbon and minerals exploration circles. Advocates of the technology believe it represents a technical improvement in gravity prospecting over conventional vertical component gravimeter surveys. In this footnote, we examine various aspects of this geophysical survey technique which are attracting so much attention.

### Gravity Gradiometry vs. Conventional Gravimetry

The conventional gravimeter used in exploration survey work measures a single component (the vertical component) of the anomalous gravity field vector. In contrast, a gravity gradiometer typically measures six of the nine gravity gradient terms comprising the gravity field's gradient tensor. This tensor completely describes the anomalous gravity field. Since the gravity gradient tensor is of the so-called symmetric variety, the nine-term tensor can be completely described by a select five of the nine gradient terms. Gradiometer proponents believe that the increased information content inherent to a set of gradiometer measurements can be used to enhance the geologic interpretations made with gravity data.

An appealing intrinsic advantage of the gradiometer is its greater immunity to the large linear accelerations which adversely affect conventional gravimeters placed in dynamic measurement environments, such as on ships and aircraft. If such linear accelerations are not recognized or compensated for, then they cannot be distinguished from anomalous geological-based gravitational accelerations (Einstein's Equivalence Principle), with error consequently being introduced into the geological interpretation.

From a practical point of view, conventional marine and airborne gravity surveying is currently at a high level of development, accomplished largely by tremendous advances in digital gravity sensor instrumentation and GPS-augmented navigation and positioning technologies. The gravimeter, while an exceedingly complex and intricate device, is even less so than a gravity gradiometer. Consequently it is a more economical and robust instrument package to operate and field. The existing commercial base of survey gravimeters is substantial, whereas there are only a few fielded commercial gravity gradiometer survey systems. Furthermore, the geologic interpretation of gravimeter data is well advanced, whereas that of

gradiometer data is in its infancy (and hence the purpose of this footnote). The more favorable operational economies and logistics which currently exist for the gravimeter ensure that its usage will continue for some time.

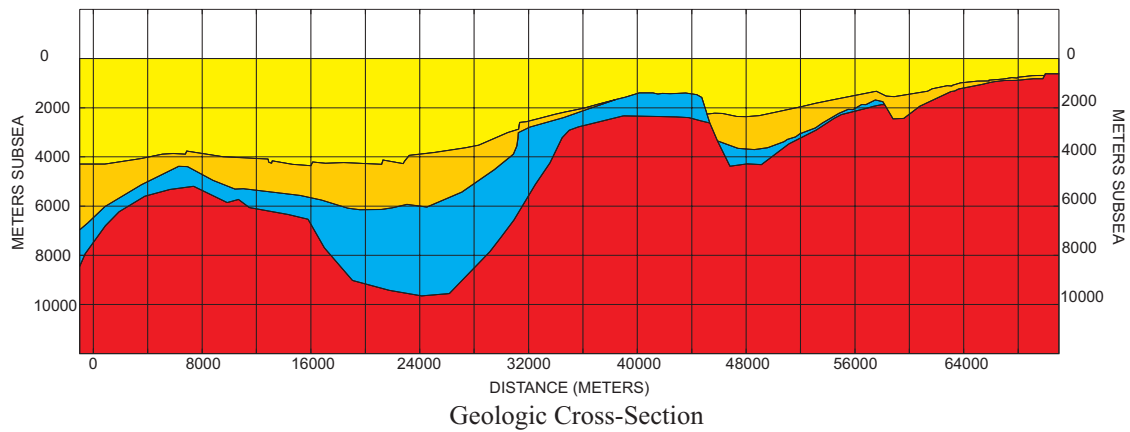
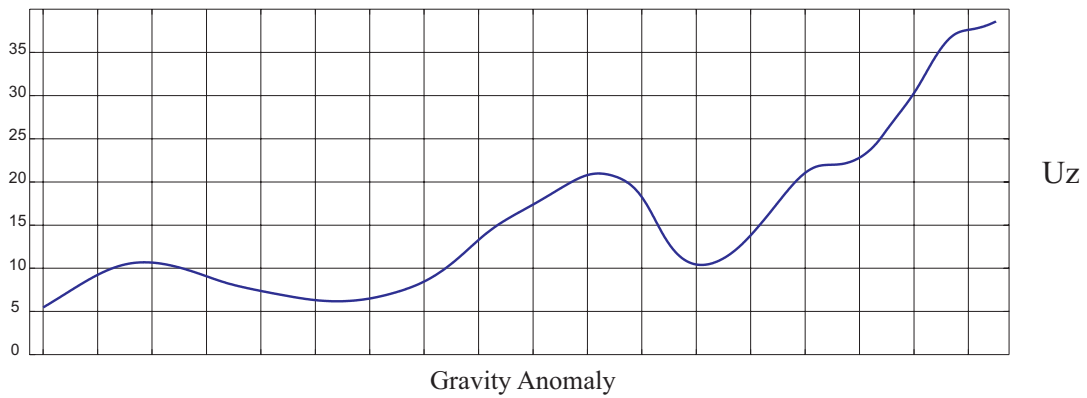
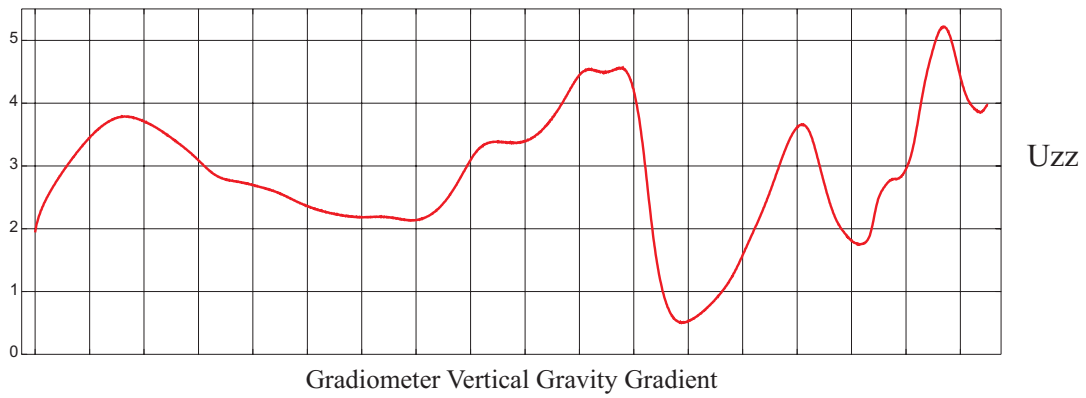
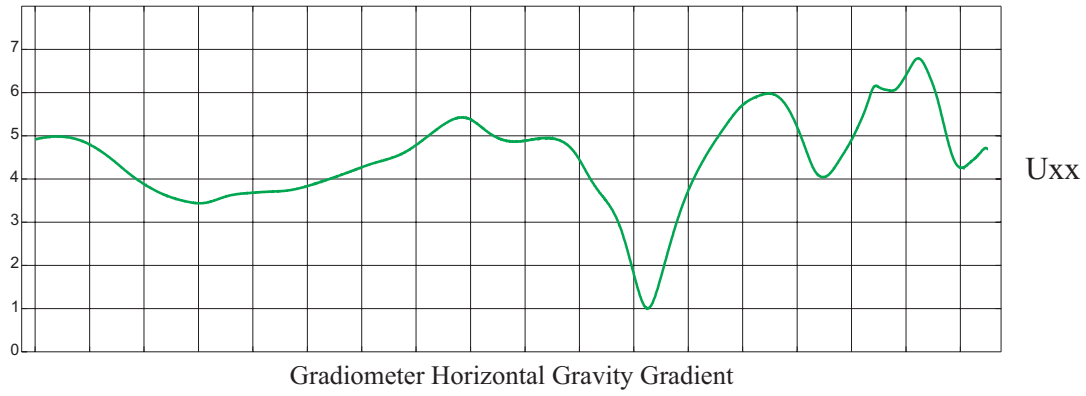
Having thus outlined some of the practical issues surrounding exploration use of gravity gradiometry, we turn now to a discussion of some of the ways gravity gradiometer data enhance the geologic evaluations of exploratory prospects.

### Geologic Interpretation Of Gravity Gradiometry Data

Various gravity anomaly enhancement maps are routinely calculated for use as geological interpretation aids at both the regional and the prospect scale. These maps are made using quantities that are calculated from conventionally measured vertical component gravity anomaly data. Interestingly, these calculated quantities are directly measured quantities in gravity gradiometer survey data. Similarly, certain quantitative interpretation methods make use of quantities which, with gradiometer data, are available as measured rather than calculated terms. Since it is generally better to measure these quantities rather than calculate them (primarily because of cross-line data aliasing effects which adversely affect the calculated quantities), gradiometer data can be used to improve certain anomaly enhancements.

The following gravity (vertical component) anomaly enhancement maps, all used for fault/edge detection and structural/tectonic analyses, can be improved using gravity gradiometer survey data: *Vertical Derivative Anomaly* - *Second Vertical Derivative Anomaly* - *Amplitude of Horizontal Gradient Anomaly* - *Amplitude of Total Gradient (a.k.a. Analytic Signal) Anomaly*. Some interesting new gravity anomaly enhancement maps are also possible with gravity gradiometry data - for instance the so-called *Tensor Invariants I1* and *I2* (Dransfield (1995); and Pederson and Rasmussen (1990)).

In addition, gravity gradiometry data promise to advance the quantitative modeling/analysis of geologic features. Bell et al. (1997) for instance illustrate improvement achieved over conventional vertical component gravity data in modeling the base of a 3-D salt volume (feature). The following quantitative interpretation techniques benefit from gradiometer measurements: *Half-Slope (a.k.a. Peters) Method* - *Werner Deconvolution* - *Euler Deconvolution* - *Structural Modeling*.



## Structural Geology Example

The greater sensitivity and resolving power of gradiometer-acquired data versus conventional gravimeter-acquired data is illustrated by the figure on the preceding page. The example shows an actual geologic cross-section from one of the marginal shelf basins in eastern Asia. The conventional gravity anomaly ( $U_z$  in the figure) is shown, as are two of the gravity gradiometer components ( $U_{zz}$  and  $U_{xx}$  in the figure). As compared to the conventional gravity anomaly, note how the two gradiometer measurements,  $U_{zz}$  and  $U_{xx}$ , better emphasize the structural highs and lows which are present, as well as the structures' bounding fault zones - all of this over a considerable span of depth ranging from approximately 1,000 to 6,000 meters subsea.

## Final Comments

Gravity gradiometry, integrated with other prospecting techniques (e.g., seismic and magnetic) appears as though it will ultimately enhance present gravity interpretation capabilities. A survey of the published literature shows that the geologic interpretation of gravity gradiometry data is presently immature in practice and application. Published results of interpretive efforts have appeared largely within only the last year or two (e.g., Bell et al., 1995, 1997; Odegard, 1995; Phair and Korn, 1995; Pratson et al., 1995; and Vasco and Taylor, 1991).

As this footnote points out, many existing gravity and magnetic interpretation algorithms are easily and naturally adapted to the interpretation of gravity gradiometer data. Klingele et al. (1991) and Marson and Klingele (1993) address this point well. Success in the area of detailed quantitative interpretation may well depend upon inverse rather than forward modeling algorithms. The interpretive power of inverse modeling for utilizing the full information content of the measured gravity gradients is rather strongly suggested by the work of Bell et al. (1997). Ultimately, the most successful algorithms will probably be those which have the tightest and most seamless interfaces with seismic workstation interpretation tools.

## References

- Bell, R. E., Anderson, R., and Pratson, L., 1997, *Gradiometry spinning into Gultrends*: The American Oil & Gas Reporter, 40, 90-93.
- Bell, R. E., Anderson, R., and Pratson, L., 1997, *Gravity gradiometry resurfaces*: The Leading Edge, 16, 55-59.
- Bell, R. E., Pratson, L. F., Anderson, R., and Biegert, E. K., 1995, *Gravity gradiometry: Applications to basin analysis*: 1995 Fall Meeting Abstracts, American Geophysical Union, F143.
- Biegert, E., Herring, A., Brett, J., Dosch, D., Affleck, C., Grierson, A., White, J., Bell, R., Pratson, L., Anderson, R., Korn, B., Phair, R., and Gale, P., 1995, *Comparisons of 3-D marine gravity gradiometry data and conventional marine gravity data survey in the Mississippi Canyon area, Gulf of Mexico*: 1995 Fall Meeting Abstracts, American Geophysical Union, F144.
- Dransfield, M. H., 1995, *Invariants of the gravity gradient tensor for exploration geophysics*: 1995 Fall Meeting Abstracts, American Geophysical Union, F143-F144.
- Jekeli, C., 1988, *The gravity gradiometer survey system (GGSS)*: EOS Transactions, American Geophysical Union, 69, 105-117.
- Jordan, S. K., 1978, *Moving-base gravity gradiometer surveys and interpretation*: Geophysics, 43, 94-101.
- Klingele, E. E., Marson, I., and Kahle, H.-G., 1991, *Automatic interpretation of gravity gradiometric data in two dimensions: vertical gradient*: Geophysical Prospecting, 39, 407-434.
- Marson, I., and Klingele, E. E., 1993, *Advantages of using the vertical gradient of gravity for 3-D interpretation*: Geophysics, 58, 1588-1595.
- Odegard, M. E., 1995, *Processing and interpretation of gravity gradiometer data*: 1995 Fall Meeting Abstracts, American Geophysical Union, F144.
- Pederson, L. B., and Rasmussen, T. M., 1990, *The gradient tensor of potential field anomalies: Some implications on data collection and data processing of maps*: Geophysics, 55, 1558-1566.
- Phair, R., and Korn, B., 1995, *Exploration usage of gravity component maps in the Gulf of Mexico*: 1995 Fall Meeting Abstracts, American Geophysical Union, F143.
- Pratson, L. F., Bell, R., Anderson, R., Dosch, D., White, J., Affleck, C., Grierson, A., Korn, B., Phair, R., Biegert, E., and Gale, P., 1995, *Results from a high-resolution, 3-D marine gravity gradiometry survey over a buried salt structure, Mississippi Canyon area, Gulf of Mexico*: 1995 Fall Meeting Abstracts, American Geophysical Union, F144.
- Vasco, D. W., and Taylor, C., 1991, *Inversion of airborne gravity gradient data, southwestern Oklahoma*: Geophysics, 56, 90-101.

