Gravity gradiometry in resource exploration

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Although gravity gradiometry was among the first geophysical methods used successfully in resource exploration (see the article by Bell and Hansen in this issue), it is a term that is probably unfamiliar to many because the technique fell from favor in the 1930s. However, it recently became the subject of intense interest and discussion within the potential field community because its advocates believe it represents a technical improvement over conventional vertical component gravimeter surveys.

The conventional gravimeter measures a single component (the vertical component) of the gravity field vector. In contrast, a gravity gradiometer can measure up to five of the nine terms in the gravity field's gradient tensor which completely describes the anomalous gravity field gradient. Gradiometer proponents believe that the increased information inherent to gradiometer measurements can enhance geologic interpretations made with gravity data.

Another, and very appealing, advantage of the gradiometer is its greater immunity to the large translational accelerations which adversely affect conventional gravimeters in dynamic environments (e.g., ships and aircraft). Such accelerations, which are difficult to distinguish from geological-based gravitational accelerations (Einstein's equivalence principle), are a major source of error.

However, conventional marine and airborne gravity surveying is highly developed and, although the gravimeter is exceedingly complex and intricate, it is less complicated than some gravity gradiometers. Consequently, the former is more economic and more robust in the field. In addition, the existing commercial base of gravimeters is substantial whereas only a few commercial gravity gradiometer systems exist. Furthermore, interpretation of gravimeter data is well advanced while that of the gradiometer is in its infancy. The more favorable operational economics/logistics ensure that the use of gravimeters will continue for some time and that the use of gravity gradiometry will continue at a much lesser scale

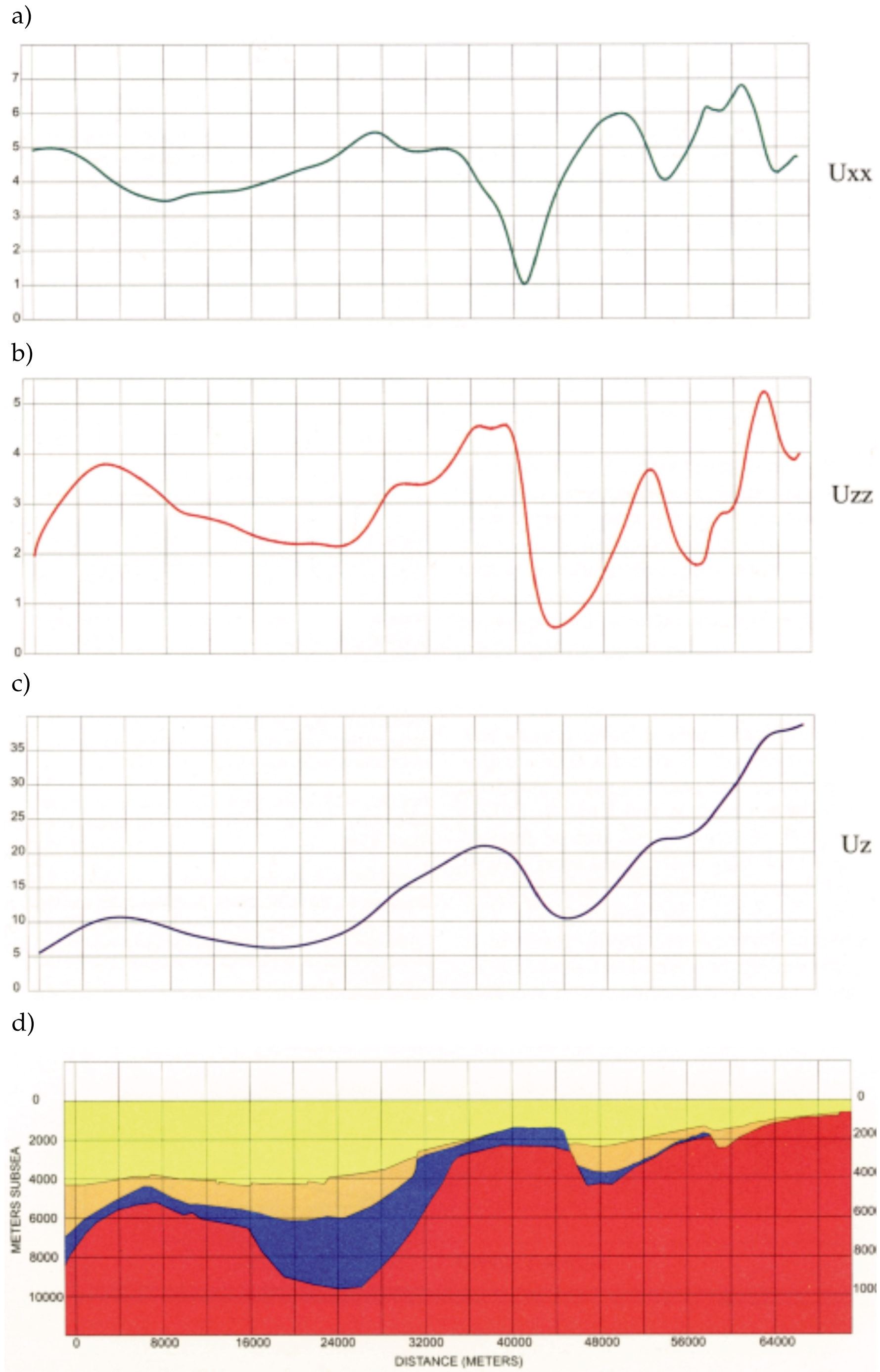

Figure 1. Comparison of gradiometer data with conventional vertical gravity data for a simulated measurement at sea level for the geologic situation having the cross-section in the bottom panel (d). Shown above it are the gradiometer horizontal gravity gradient (a), the gradiometer vertical gravity gradient (b), and the conventional gravity anomaly (c). Density contrasts related to structuring within the sedimentary section (yellow, ocher, blue) and the igneous basement (red) cause the simulated gravity anomalies. The greater sharpness and separation of the gradiometer anomalies show the increased resolving power obtainable in principle with this technology.

until the latter technique proves that it can provide (cost effectively) data that are more useful. Can it? Possibly. The remainder of this article will discuss some ways that gravity gradiometer data enhance geologic evaluation of exploration prospects.

Advantages of gravity gradiometry data. Gravity anomaly enhancement maps, routinely created to assist interpretation at both the regional and prospect scale, sometimes use gradients that are calculated from conventionally measured vertical-component gravity anomaly data. *These quantities are directly measured in gravity gradiometer data*. Similarly, certain interpretation methods use quantities which, with gradiometer data, are available as measured rather than calculated factors. 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 improve the delineation of certain anomalies.

The following gravity (vertical component) anomaly enhancement maps, all used for fault/edge detection and structural/tectonic analyses, can be improved using gravity gradiometer data: vertical derivative anomaly; second vertical derivative anomaly; amplitude of horizontal gradient anomaly; and amplitude of total gradient (aka analytic signal) anomaly.

In addition, gravity gradiometry data promise improved quantitative modeling/analysis of geologic features. The following quantitative interpretation techniques benefit from gradiometer measurements: half-slope (aka Peters) method; Werner deconvolution; Euler deconvolution; and structural modeling.

Structural geology example. The advantage of gradiometer-acquired data is illustrated by Figure 1. The example shows an actual geologic cross-section from one of the marginal shelf basins in eastern Asia.

The conventional gravity anomaly (Uz) is shown, as are two of the gravity gradiometer components (Uzz and Uxx). Note how the two gradiometer measurements better emphasize the structural highs and lows as well as the bounding fault zones — all of this over a depth ranging from approximately 1000 to 6000 m 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. However, interpretation of gravity gradiometry data is presently immature in practice and application. Published interpretive efforts have appeared largely within only the last year or two.

However, many existing gravity and magnetic interpretation algorithms are easily and naturally adapted to the interpretation of gravity gradiometer data (see Klingele, and Marson and Klingele in "Suggestions for further reading"). 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. (see "Suggestions for further reading"). Ultimately, the most successful algorithms will probably be those which have the tightest and most seamless interfaces with seismic workstation interpretation tools.

Suggestions for further reading. Articles by R. E. Bell, R. Anderson, and L. F. Pratson which give excellent background on this re-emerging technology are "Gradiometry spinning into Gulf trends" (*The American Oil & Gas Reporter*, 1997) and "Gravity gradiometry resurfaces" (*TLE*, January 1997). The same authors and E. K. Biegert gave additional examples in "Gravity gradiometry: Applications to basin analysis" (*1995 Fall Meeting Abstracts*, American Geophysical Union).

Other interesting articles are "Comparisons of 3-D marine gravity gradiometry data and conventional marine gravity data survey in the Mississippi Canyon area, Gulf of Mexico" by Biegert et al. (*1995 Fall Meeting Abstracts*, American Geophysical Union); "Invariants of the gravity gradient tensor for exploration geophysics" by M. H. Dransfield (*1995 Fall Meeting Abstracts*, American Geophysical Union); "The gravity gradiometer survey system (GGSS)" by C. Jekeli (*EOS Transactions*, American Geophysical Union, 1988); "Moving-base gravity gradiometer surveys and interpretation" by S. K. Jordan (GEOPHYSICS, 1978); "Automatic interpretation of gravity gradiometric data in two dimensions: vertical gradient" by Klingele et al. (*Geophysical Prospecting*, 1991); "Advantages of using the vertical gradient of gravity for 3-D interpretation" by Marson and Klingele (GEOPHYSICS, 1993); "Processing and interpretation of gravity gradiometer data" by Odegard (*1995 Fall Meeting Abstracts*, American Geophysical Union); "The gradient tensor of potential field anomalies: Some implications on data collection and data processing of maps" by Pederson and Rasmussen (GEOPHYSICS, 1990); "Exploration usage of gravity component maps in the Gulf of Mexico" by Phair and Korn (*1995 Fall Meeting Abstracts*, American Geophysical Union); "Results from a high-resolution, 3-D marine gravity gradiometry survey over a buried salt structure, Mississippi Canyon area, Gulf of Mexico" by Pratson et al. (*1995 Fall Meeting Abstracts*, American Geophysical Union); and "Inversion of airborne gravity gradient data, southwestern Oklahoma" by Vasco and Taylor (GEOPHYSICS, 1991).

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