Gravity signature of a buried detached megablock: an example from the Mackenzie Delta area

Serguei A. Goussev, Robert A. Charters, and John W. Peirce,*
Geophysical Exploration & Development Corporation (GEDCO)

Summary

Calculation of residual anomalies of the Bouguer gravity field in the Mackenzie Delta region, northern Canada, has revealed a long (~ 95 km) quasi-continuous anomaly striking parallel to and downdip from the Eskimo Lakes Fault Zone. The shape, structural position, seismic signature on three public domain seismic sections, and the results of 2-D gravity modeling are consistent with the interpretation of this anomaly as a response of the Bouguer gravity field to a rollover structure associated with a detached, faulted megablock. Six significant oil and gas discoveries have been reported within this block.

Introduction

During the Mesozoic (late Jurassic-early Cretaceous) time, the continental rifting in the Mackenzie Delta region produced large, regional-scale structures, including the Kugmallit Trough and Eskimo Lakes Fault Zone. The latter is a zone of major listric normal faulting underlaying the Mackenzie Delta (Lane, 2002).

Extensional block faulting often results in a downslope sliding of large rock masses along the listric faults. Large blocks of detached rock masses create lateral contrasts in subsurface distribution of rock densities and, accordingly, generate detectable gravity anomalies. Data enhancement techniques, like calculation of residuals of the Bouguer gravity field, can make these anomalies visible and correlatable.

The study was focused on the Kugmallit Bay region north of the Mackenzie River delta and covers the area of about 80 × 110 km. Three public domain seismic sections (Lane, 2002; Morell, 1996) have been incorporated into our interpretation. 2-D gravity modeling along one of them was constrained in its upper part by the seismic and well data.

Gravity Data Acquisition and Processing

The gravity data used in this study was acquired by Photogravity Surveys Ltd. in the mid-1970s and includes both land (onshore) and on-ice (offshore and lakes) observations. Station intervals in the study area varied from 200 m along the survey lines to about 3 km in gaps and between survey lines.

The acquired data were a) corrected for the instrumental drift, the Earth's homogeneous structure (theoretical gravity, free-air and onshore Bouguer corrections), high-elevation variations (terrain correction), ocean bottom variations and ice thickness (offshore Bouguer correction); b) levelled and gridded at 1 km grid cell size with a minimum curvature algorithm; c) mapped as the Bouguer gravity anomaly.

Figure 1 shows the Bouguer gravity field overlain with a shore line and known major tectonic elements in the study area: Kugmallit Trough, Eskimo Lakes Fault Zone and Eskimo Lakes Arch.

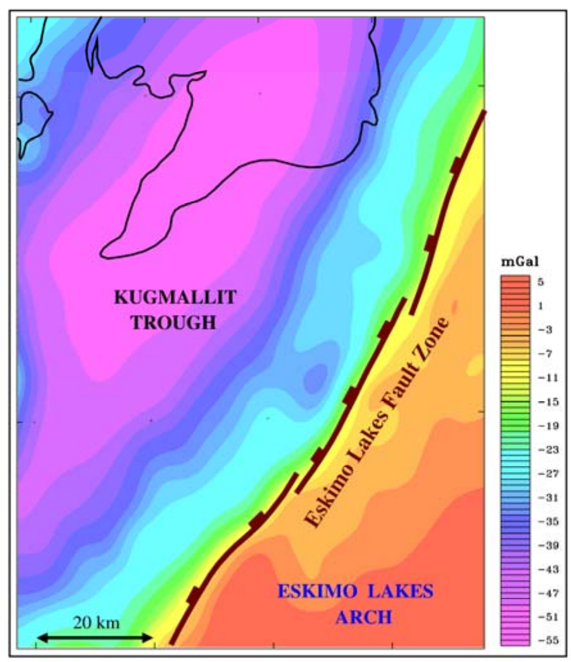

Figure 1: Bouguer gravity anomaly and major tectonic elements in the study area

Data Enhancement and 2-D Gravity Modeling

Residualization is a conventional method of enhancing gravity anomalies associated with elements of the subsurface structure. The residual Bouguer anomaly is usually obtained as a difference between the original Bouguer anomaly field and its regional approximation.

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Figure 2 shows the 4-th order residual Bouguer anomaly obtained by subtracting the best fit 4-th order polynomial surface from the original Bouguer anomaly field. The residual anomaly under consideration is labelled. The Eskimo Lakes Fault Zone (ELFZ) is also shown.

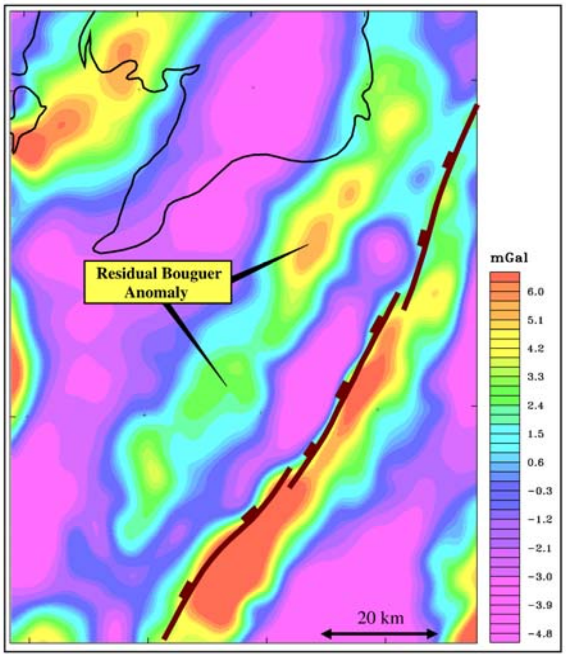

Figure 2: 4th order residual Bouguer gravity anomaly and Eskimo Lakes Fault Zone

Results of residualization can often be ambiguous: depending on the order of polynomial approximation (or other types of a regional field approximation), different anomalies can be enhanced. In our case, similar anomalies appear downdip from the ELFZ on several different order residuals. They all seem to be in the same location, i.e. independent from the order of polynomial approximation of a regional component of the Bouguer gravity field.

To illustrate this observation, we stacked all seven calculated residual grids (from 3-d order to 9-th order). The result is shown on Figure 3. The stacked residual anomaly is in the same location as the 4-th order residual (Figure 2). The irregular shape of this anomaly is better visible. Separate wells and their clusters show significant oil and, mostly, gas discoveries (from NE to SW: Mayogiak, Tuk, Imnak, Siku, Kamik, Parsons North, Parsons South and Ikhil). Three dark green lines (AA, BB, CC) are locations of the public domain seismic sections.

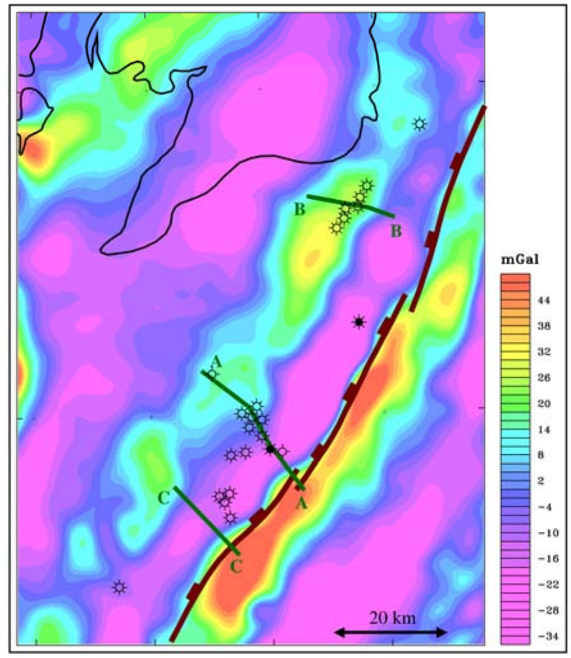

Figure 3: Stacked residual Bouguer gravity anomaly with seismic lines and discovery wells

A 2-D gravity model was built along the seismic section AA (Figure 4). Figure 4a shows the principal profiles over this model: observed gravity (blue), calculated gravity (magenta), regional approximation with the 4-th order polynomial (red) and 4-th order residual anomaly (cyan). The final 2-D gravity model is shown on figure 4b. The posted vertical time and depth scales were used to calculate interval velocities and, via the Gardner equation, densities in four upper layers. The densities of two bottom layers have no control and were varied until the model response fits the observed gravity. Figure 4c is the seismic section AA. Its interpretation (Morell, 1996) was used to constrain the upper part of the model. It shows a low-relief (~150 m) rollover anticline structure at its right (eastern) end, as well as a block-faulted signature of a detached block of the pre-Mesozoic age. Six gas discovery wells, one oil well and two dry wells drilled into this structure are shown.

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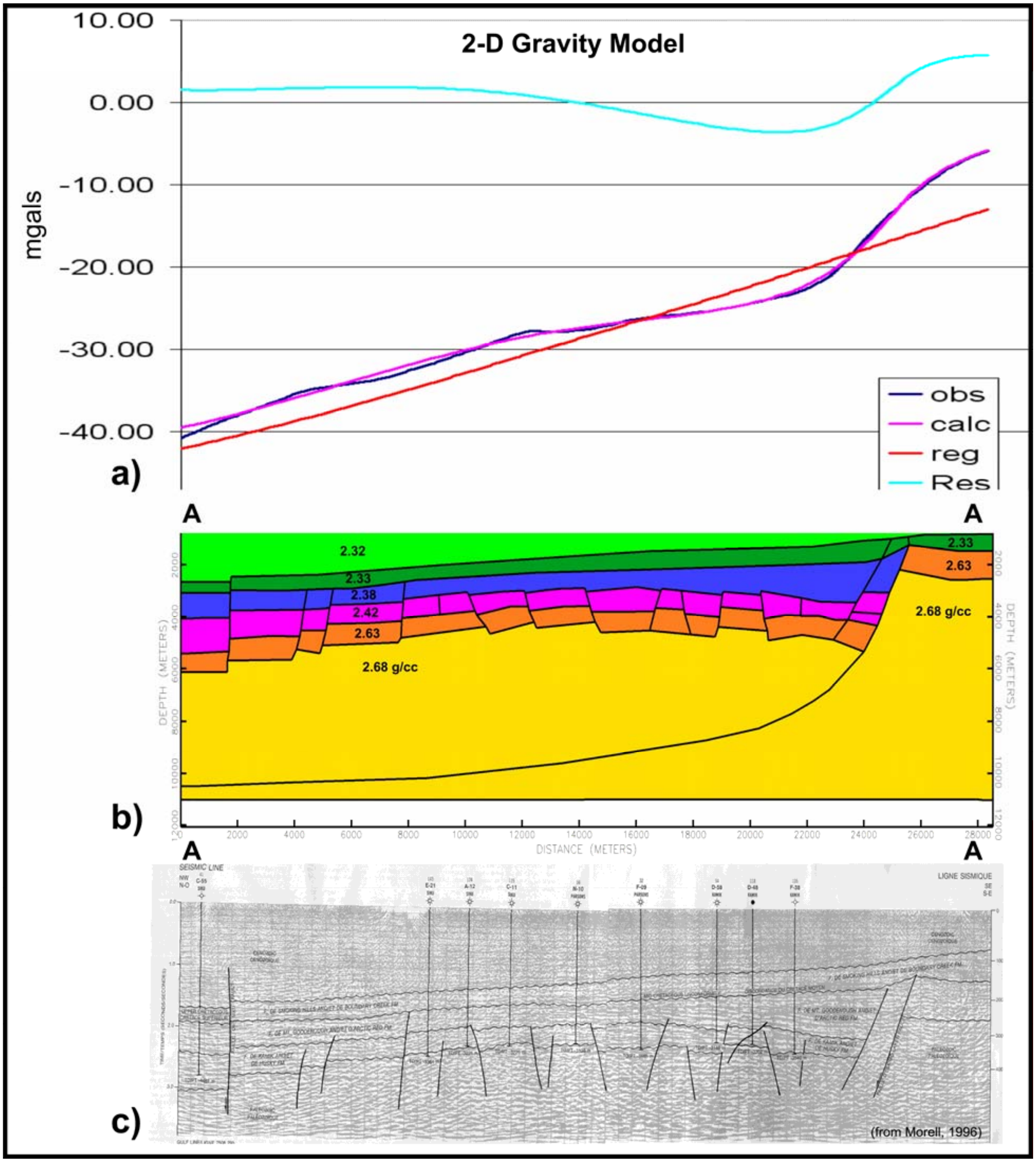

Figure 4: 2-D gravity model: a) principal profiles; b) final model; c) seismic section AA

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Conclusions

We can conclude, based on similarity of character, that continuous residual gravity anomaly (which has been adequately sampled) is associated with the same type of subsurface structure over the whole area of its correlation. Based on this, we conclude that the residual gravity anomaly, considered in this study, represents a response of the Bouguer gravity field to the presence of a rollover structure associated with a detached pre-Mesozoic megablock of about 95 km length (Figure 3).

This conclusion is consistent with three public domain seismic sections and results of the gravity modeling. The 2-D gravity model provides a first-iteration geological model of the detached faulted megablock and can be updated with more recent seismic data and/or information from the deeper penetrating wells.

The integrated interpretation of gravity and seismic data shows new opportunities for drilling along the length of the identified structure.

References

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