Mackenzie Delta: A Case of One Residual Gravity Anomaly and 16 Dry Exploration Wells

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Abstract

Summary

The importance of integrating a detailed gravity data into the process of selecting well locations for exploration drilling is illustrated by this example from the Mackenzie Delta area. Residualization of the Bouguer gravity field revealed a long (~ 95 km) residual gravity anomaly striking parallel to and downdip from the regional-scale Eskimo Lakes Fault Zone (ELFZ). The shape, structural position, evidence from three public-domain seismic sections and results 2-D gravity modeling are consistent with interpretation of this anomaly as a gravity signature of a detached faulted megablock. Six significant oil and gas discoveries were reported within this block. The exploration drilling success ratio could be higher as 16 of 27 dry wells were drilled in high-risk areas: 10 wells - on the edges of residual anomaly (which defines the main body of a detached block), and 6 wells – immediately west of ELFZ from where the detached block moved downdip. Comparison with a known oil-bearing structure associated with a detached block (Grand Banks – Hibernia, offshore eastern Canada) is also shown.

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 faulting underlaying the Mackenzie Delta (Lane, 2002).

Extensional block faulting often results in a downslope sliding of large rock masses along listric faults. Large blocks of detached rock masses create lateral contrasts in subsurface distribution of rock densities and, accordingly, generate gravity anomalies. Residualization (i.e. calculation of residual anomalies of the original 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 80x110 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 and in its lower part by results of deep refraction seismic and regional gravity modeling (Stephenson et al., 1994).

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 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 instrumental drift, theoretical gravity, free-air, onshore Bouguer, elevation variations (terrain correction), ocean bottom variations and ice thickness (offshore Bouguer correction); b) leveled and gridded at 1 km grid cell size; c) mapped as the Bouguer gravity field.

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

Data enhancement and 2-D gravity modeling

Residualization is a conventional method of enhancing gravity anomalies associated with elements of subsurface structure. The residual Bouguer anomaly is usually obtained as a difference between the original Bouguer gravity field and its regional approximation. In our study, the regional approximation was obtained by 5 km upward continuation of the Bouguer field.

Figure 2 shows the residual Bouguer gravity anomaly west of the Eskimo Lakes Fault Zone overlain with three public-domain seismic lines (AA, BB, CC) and discovery wells.

A 2-D gravity model was built along the seismic line AA (Morell, 1996). We used the posted vertical time and depth scales to estimate interval velocities and, via Gardner equation, rock densities in four upper layers. The basement density and basement depth were taken from the model by Stephenson et al. (1994). The density of the upper of two bottom layers was varied until the model response fitted the observed gravity.

Figure 3 shows the principal profiles over 2-D gravity model (a), final depth model with interval densities (b), and seismic section along the line AA (c). The seismic section, interpreted by Morell (1996), shows a low-relief (~ 150 m) block-faulted anticline structure of the pre-Mesozoic age immediately west and downdip from the Eskimo Lakes Fault Zone (on the right). Six gas discovery wells, one oil well and two dry wells drilled into this structure are shown.

Residual gravity anomaly and exploration wells

There is a certain correlation pattern between the shape and magnitude of the residual gravity anomaly, considered in this study, and distribution of discovery and dry wells. Figure 4 shows oil and gas discoveries and dry wells (red triangles) in the study area on top of the residual Bouguer gravity anomaly. Five of seven oil and gas discoveries are on the same trend of the residual gravity highs that closely correlate with local structural highs shown on three public-domain seismic sections. 10 dry wells were drilled on the edges of the residual gravity anomaly away from its high values. Another 6 dry wells were drilled immediately west of the Eskimo Lakes Fault Zone (ELFZ) from where the reservoir, apparently, moved downdip as a part of the detached block.

Conclusions

Based on the integrated analysis of six datasets (detailed and regional gravity, reflection and deep refraction seismic, wells and 2-D gravity modeling), we can make the following conclusions:

1. Residual gravity anomaly, considered in this study, is a gravity signature of a new, previously unrecognized structure. It is a detached megablock 95 km long at the depth of about 4000 m.
2. The detached block includes both the pre-Mesozoic and basement rocks.
3. 16 of 27 dry exploration wells drilled in high-risk areas: 10 wells - on the edges of residual anomaly, away from its high values that define the main body of a detached block, and 6 wells – immediately west of ELFZ from where the detached block moved downdip.
4. There are new opportunities for exploration in the undrilled areas of the southern half of the residual anomaly.

References

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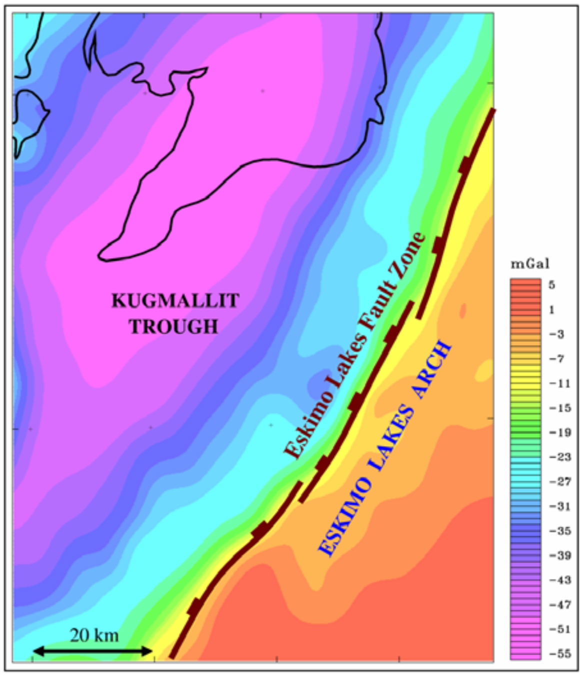

Figure 1. Bouguer gravity field and major tectonic elements.

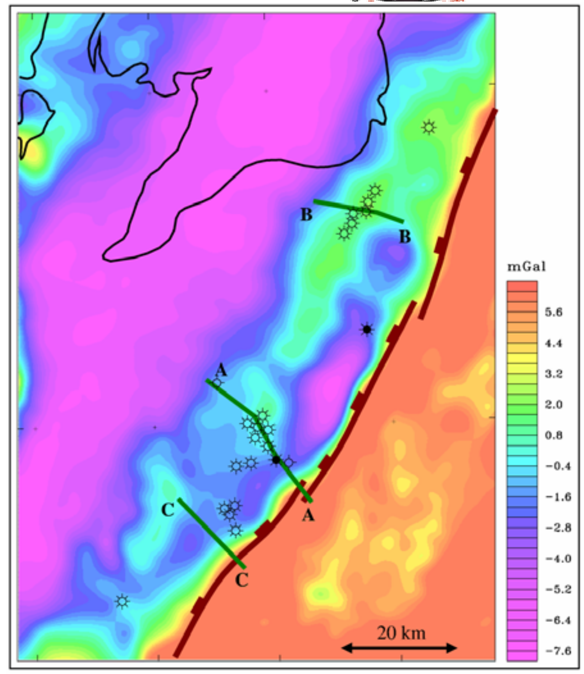

Figure 2. Residual Bouguer anomaly with seismic lines and discovery wells.

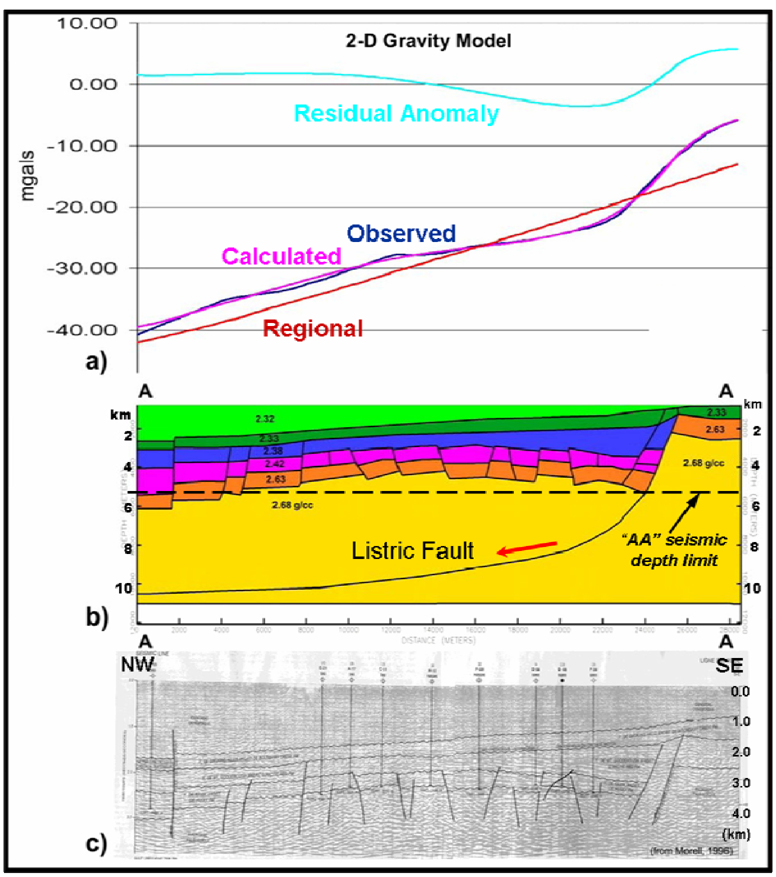

Figure 3. 2-D gravity model: a) principal profiles; b) final model; c) seismic section AA

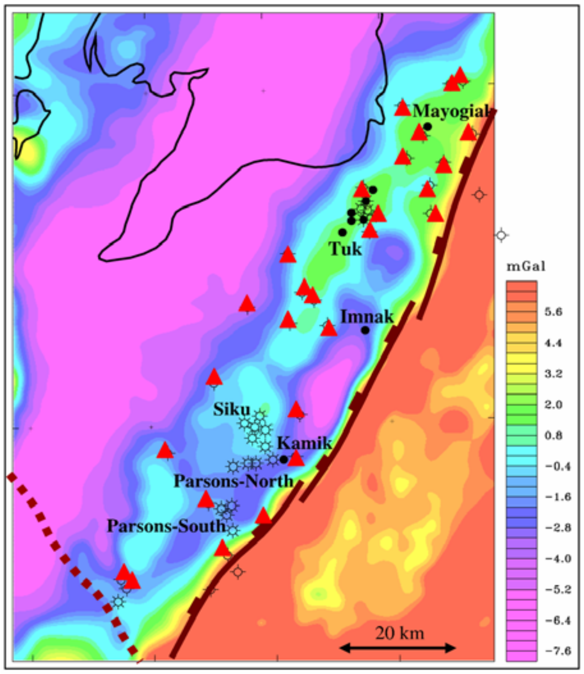

Figure 4. Residual Bouguer anomaly with discoveries and dry wells.