# Expanding Foothills Exploration in Muskwa-Kechika:
# An Integrated Approach using full Tensor Gravity Gradiometry,
# Magnetic Gradiometry, LIDAR, Digital Mapping & GIS

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## Summary

In the summer of 2005, ARKeX Ltd. in conjunction with JEBCO Seismic Canada began acquiring an airborne geophysical survey over Muskwa-Kechika (MK) covering 3,000 sqkm of the Rocky Mountain Foothills, British Columbia. The survey was completed in 2006 and the data acquired provides the explorationist with previously unattainable high resolution airborne gravity gradiometry, magnetic gradiometry and LIDAR data. This combined dataset reveals new and detailed information of geologic structures over this expansive area. Through qualitative and quantitative interpretation of the dataset, shallow and deep structural targets are readily imaged, even beneath 1.5km of terrain. This project represents state-of-the-art deployment for Airborne Gravity Gradiometry (Air-GG). The way in which the data was acquired, processed and interpreted represents a significant deviation from existing methodology. In this paper, we demonstrate the advantages of the dataset by focusing on the exploration history of a well drilled in 1993. The target, a deep Mississippian carbonate play in the Debolt Formation, 4km beneath the surface. Using qualitative and quantitative interpretation techniques, we demonstrate, with hindsight, that the addition of Air-GG to the 'then' exploration data-pool would have significantly increased the probability of technical success.  We therefore discuss how we can use this example as an analogue to help explore in other areas of MK while avoiding costly mistakes.

## Introduction

The MK survey is located along the thrust front of the eastern Rocky Mountains. Most E&P is currently limited to the low lying foothills. The survey was specifically flown to target two working plays, (i) shallow rotated fault blocks, Triassic in age and (ii) deeper anticline structures associated with the Debolt formation, Mississippian in age.

The ARKeX Airborne Gravity Gradiometry (Air-GG) data was acquired over MK using a Lockheed-Martin built instrument. Magnetic gradiometry, photometric and LIDAR data was also acquired using the same platform. Acquisition and processing methodology was significantly modified to accommodate flying in such rugged topography and due to the inherent sensitivity of the instrument, LIDAR was deemed necessary to help correct for topography, the largest near source effect.
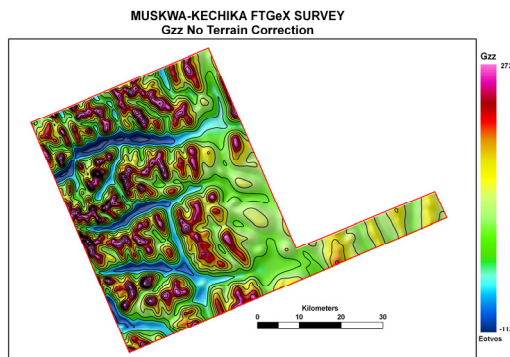


Gzz, the vertical derivative of the gravity gradient shows a detailed map of topography. The first density contrast that the instrument 'sees'.
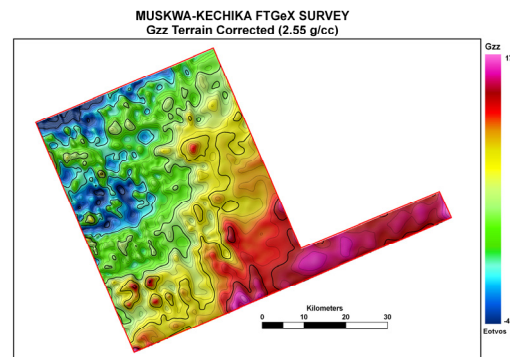


Gzz processing stage 1: after applying a simplified terrain correction. The final dataset used for interpretation (processing stage 4), incorporates a more sophisticated terrain correction workflow.

## The Case Study

In 1993, the Thunder-Cypress well (A-065-D/094-B-15) was spudded. The authors of this paper know very little regarding the well history, but what is clear is that after some initial difficulties, the well was sidetracked to the southwest. The well was chasing a thrust anticline Debolt play some 3 to 4km below the surface. Presumably the well location in this rugged terrain would have been chosen using traditional exploration methods, such as detailed geological mapping, 2D cross section rebalancing and possibly sparse 2D seismic data. Whether the well was deemed a success or not, is beyond the scope of this paper. Instead we assess the impact that Air-GG could have had on the placement of the well location, if it were commercially available at that time.

The figures above and below show the Gzz signal before and after terrain correction. The application of a detailed terrain correction is highly important given that the terrain accounts for 85-90% of the total Gzz signal. The underlying geological structures, imaged in the terrain corrected Gzz signal, appear to have no resemblance to topology. This is because the topography is dominated by piggy back thrusts within the Triassic and pre-Triassic Units. By removing the terrain signal, the resultant Gzz anomaly reflects deeper sources (i) base, lower Triassic (ii) Permian and (iii) Debolt Carbonates.
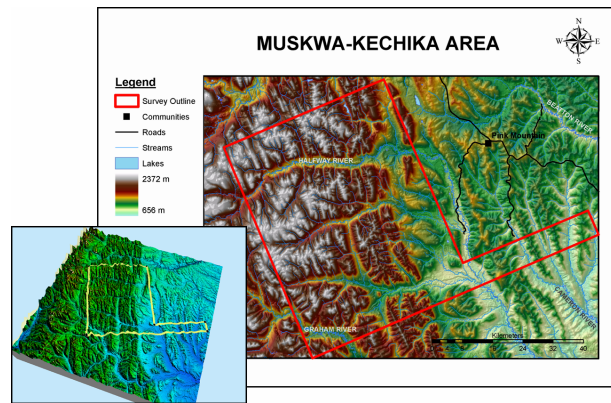
Qualitative Interpretation: Using detailed feasibility modeling of rebalanced cross sections, we calculated the typical gravity gradient anomaly wavelength and amplitude that should be targeted to image Debolt level structure.  The figure below shows a filtered Gzz anomaly map that specifically targets the Debolt. Filtering the data in this manner is crudely akin to depth slicing down through the entire earth section. The Gzz high (in red) outlines a large anticline structure that is bounded to the north and south by cross cutting east-west wrench faults. By using other gravity gradient tensor components such as Gxx, Gyy, Gxz, Gyz, the location of structures can be mapped in fine detail. Gxx and Gxz are particularly good at mapping the thrust front and backsides of piggyback anticlines. Gyy and Gyz are good at locating the position of cross cutting wrench faults.

Quantitative Interpretation: In order to model the Debolt structure in three dimensions, it is necessary to constrain as many parts of the earth model as possible. Using gravity gradient and magnetic gradeint 3D forward, inversion and back-stripping techniques, combined with sophisticated GIS analysis, we eliminated signal resulting from (i) terrain, (ii) Cretaceous-Triassic interface and (iii) base Triassic. The only remaining gravity gradient signal component of the earth section therefore arises from the exploration target, the Permian – Debolt interface. Using ARKeX's proprietary inversion software this 'residual' signal was then used to generate a 3D surface of the Top Debolt. An unconstrained inversion was performed on the optimized interface, meaning that no other data was used to position the layer in 3D space. The net effect of the modeling workflow is that the optimised layer produces a Top Debolt structure contour map. Combining the optimised surface with the qualitative interpretation therefore provides a detailed map of the Thunder-Cypress play (final figure).
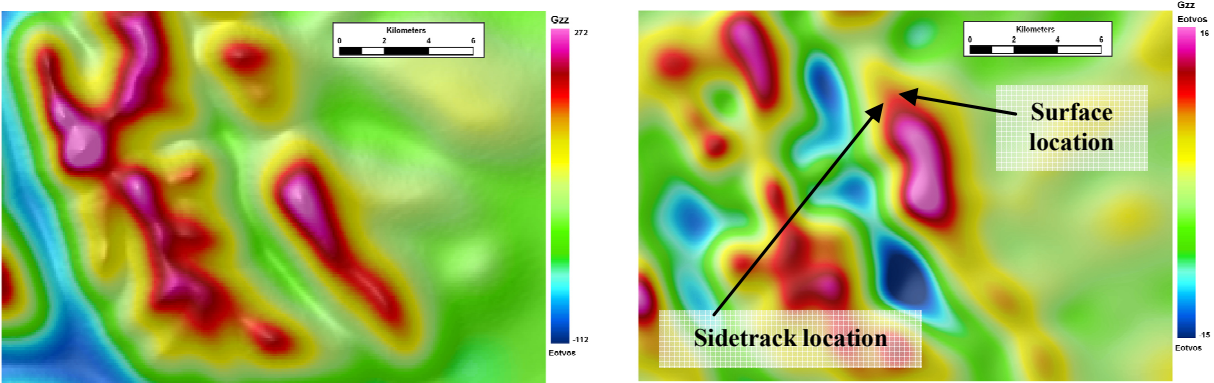
*Gzz before correcting for near source terrain effects (left) and after Terrain correction and filtered to target deeper Debolt level structure (right). Also displayed are the surface positions of the Thunder-Cypress Well location and final sidetrack*

Air-GG was not commercially available at the time of spudding the Thunder-Cypress well. It is clear that if it were available, the dataset would have undoubtedly added important geological knowledge to the understanding of the G&G team. The final figure (below) clearly shows that the well could not have been drilled in a worse location. It has been located along the plane of a bifurcating wrench fault clearly identified in the Air-GG dataset. Furthermore, the Air-GG analysis shows that the main structure lies some 2 km to the SSE, suggesting that the sidetrack deviation was chasing dip data that indicated an anticline axial plane further to the south. If this is the case, then the dip data indicated a smaller anticline west of the main structure. The figure below also indicates the importance of having a dataset that can differentiate between surface geology and structures at depth. Topography reflects outcropping geology (Cretaceous and Triassic rocks) and when constructing re-balanced cross sections, it is difficult to estimate the position and size of any structure that exists beneath thrust planes that extend to the surface. The figure below shows the Debolt structure contour map on an image of the topography. Little resemblance is made between topography and the Debolt structure.

## Conclusions

It is clear that acquiring Air-GG prior to spudding the Thunder-Cypress well would have caused the asset team to rethink their exploration strategy. Interpretation of the data shows that target structures often bear no resemblance to surface structure. Debolt-level structures are often masked by thrust planes located shallower in the earth section. Furthermore, analysis of sparse 2D seismic data has corroborated this observation, as well as suggesting, that when not overprinted by shallow structures, the axial-plane of Debolt anticlines are often shown to be shifted significantly from axial planes mapped at the surface in Triassic and Cretaceous units.

Exploration in this area of Muskwa-Kechika is extremely high risk. Seismic acquisition is difficult and prohibitively expensive. We identified many seismic sections already acquired, which could have been better positioned with the addition of Air-GG to (i) avoid wrench faults (many east-west lines step over and back a wrench fault) and (ii) hit main target structures (too many lines were observed to clip target flanks). The ARKeX/Jebco survey suggests that using Air-GG as a complimentary exploration tool to seismic data can be a powerful exploration workflow. Using inversion and back-stripping techniques, along with qualitative mapping of target wavelengths to produce a first pass structure contour map, Air-GG could be used as an initial screening tool, high grading areas for seismic acquisition. Having acquired the seismic, Air-GG can then be used to

help image complex structure in areas where the seismic data is unclear. Furthermore, the seismic data could be used to provide constraint to the gravity gradient inversion modelling process. This would provide a more robust earth model on which to plan an exploration program. Finally this project is in its infancy. Having produced a structural map over the entire Muskwa-Kechika survey area, outlining potential targets with similar signature to the Thunder-Cypress play has been relatively straight forward. Initial analysis indicates several large Debolt level structures around which a seismic acquisition program is planned. To date, Air-GG has demonstrated that it can identify structural targets, position effectively seismic, provide useful information on field appraisal while reducing drilling costs.
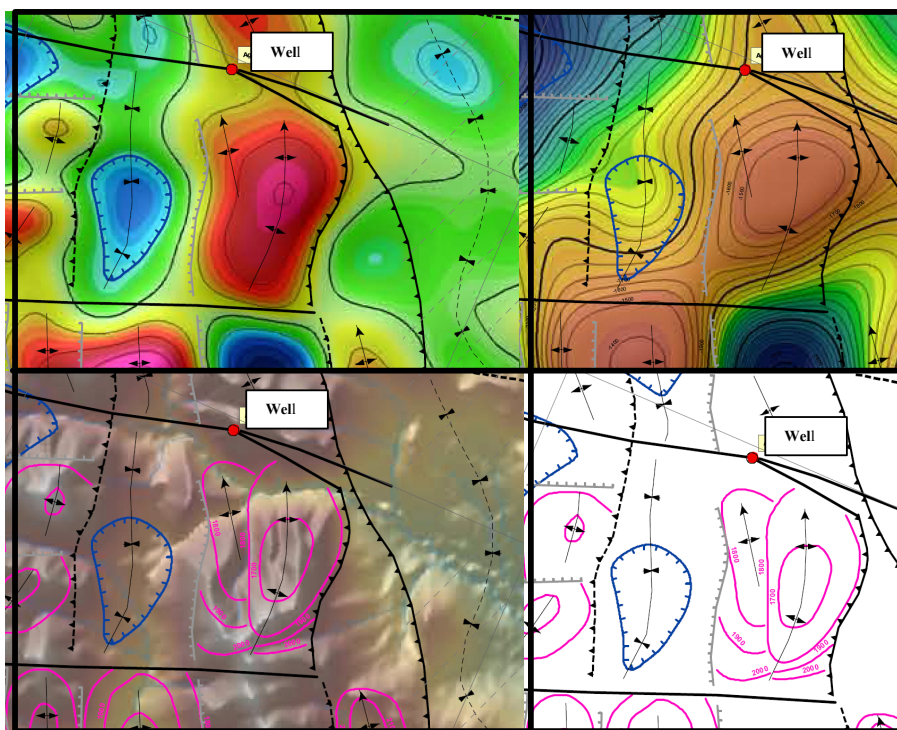


Qualitative and quantitative interpretation targeted at Debolt level. (Clockwise from top left). (i) Gzz with qualitative interpretation. (ii) Debolt inversion solution (in meters) with interpretation. (iii) Debolt structure map and (iv) Debolt structure map on topography. (see text for explanation).

### References

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