Benefits of a high performance airborne gravity gradiometer (HD-AGG™) for resource exploration

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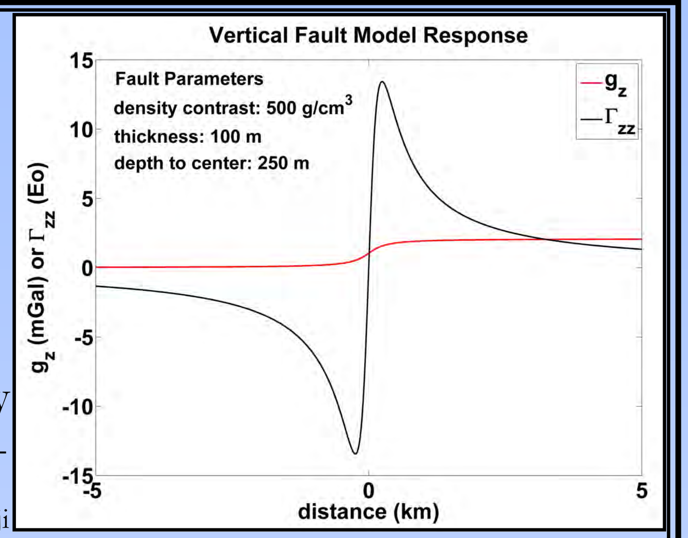
Gravity Gradiometry



The gravity gradient tensor of the Earth is given by:

$$\Gamma = \begin{bmatrix} \Gamma_{xx} & \Gamma_{xy} & \Gamma_{xz} \\ \Gamma_{yx} & \Gamma_{yy} & \Gamma_{yz} \\ \Gamma_{zx} & \Gamma_{zy} & \Gamma_{zz} \end{bmatrix} = \begin{bmatrix} \frac{\partial g_x}{\partial x} & \frac{\partial g_x}{\partial y} & \frac{\partial g_x}{\partial z} \\ \frac{\partial g_y}{\partial x} & \frac{\partial g_y}{\partial y} & \frac{\partial g_y}{\partial z} \\ \frac{\partial g_z}{\partial x} & \frac{\partial g_z}{\partial y} & \frac{\partial g_z}{\partial z} \end{bmatrix}$$

where (g_x, g_y, g_z) is the Earth's gravity vector. Gravity potential satisfies Laplace's equation ($\Gamma_{xx}+\Gamma_{yy}+\Gamma_{zz}=0$) and the gradient tensor is symmetric ($\Gamma_{ij}=\Gamma_{ji}$ for $i \neq j$). Gravity gradient has units of Eötvos (1 Eo = 0.1 mGal/km = 10^{-9} sec^{-2}).

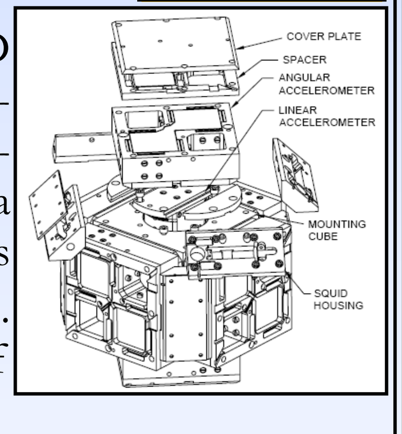
Gradiometry vs gravimetry? The figure above compares g_z and Γ_{zz} over a vertical contact. The gradient fields offer enhanced shorter wavelength information and are better at imaging shallower sources than the gravity vector components.

Gedex HD-AGG™ Target Performance

Gedex Inc is developing an airborne gravity gradiometer system, the High Definition Airborne Gravity Gradiometer (HD-AGG™), having a target noise level of 1 Eo/Hz$^{1/2}$ from 0.001 Hz to 1 Hz, or over wavelengths of 10s of meters to 10s of kilometers assuming aircraft speeds of 100 to 120 knots.

The Sensor

Superconducting mechanical components, sensing coils and SQUID amplifiers are required to build a gravity gradiometer having the lowest possible intrinsic noise and the highest possible material and circuit stability. The single-axis gravity gradiometer prototype uses a pair of matched angular accelerometers and provides measurements of the gravity gradient tensor diagonal element combination Γ_{xx}-Γ_{yy}. The full three-axis sensor (right) will also provide observations of Γ_{xx}-Γ_{zz} and Γ_{yy}-Γ_{zz}.

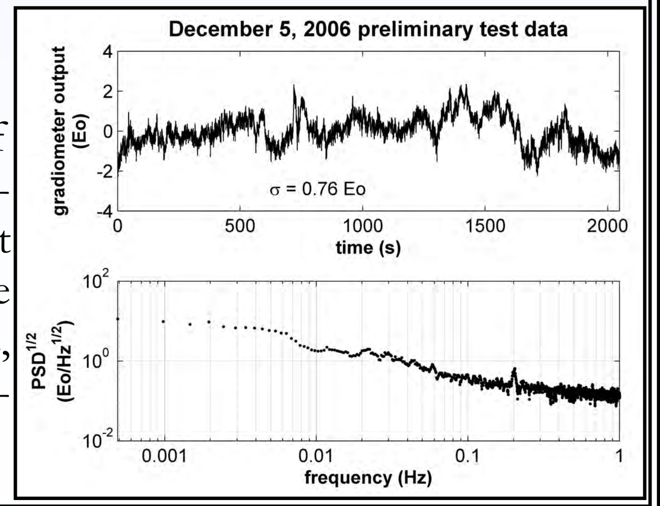


The Platform

The Gedex HD-AGG™ design incorporates a six-degree-of-freedom motion isolation sub-system (GeoMIM) intended to reduce errors associated with the down-conversion of high-frequency platform jitter outside the signal band to lower frequencies within the signal band. The platform design incorporates both passive and active isolation.

Quiescent Test Results

Gradiometer data were recorded at the University of Maryland (right). The square root of the power spectral density (PSD) is less than 1 Eo/Hz$^{1/2}$ from about 0.05 Hz to 1 Hz. With the gradiometer housed in the GeoMIM, custom temperature control electronics, and dynamics-related corrections, the target performance will be achieved in airborne mode.

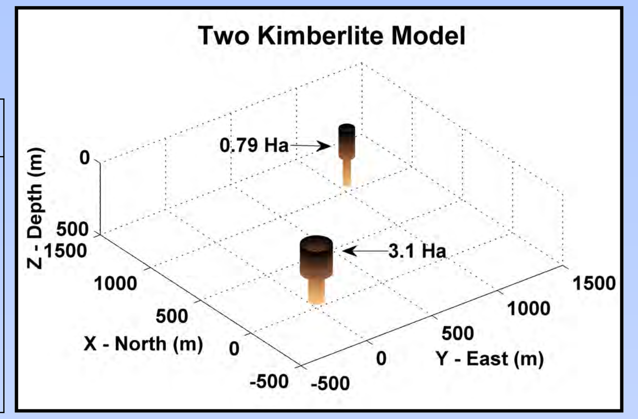


Kimberlite Exploration

Kimberlites are diamond-bearing pipe-like structures composed of an upper crater, a middle diatreme, and a root. The surface area of kimberlites ranges from 0.5 to 150 Ha. **The size of the kimberlite is not indicative of diamond content, i.e. whether or not it will be economic.**

Simulated AGG Surveys

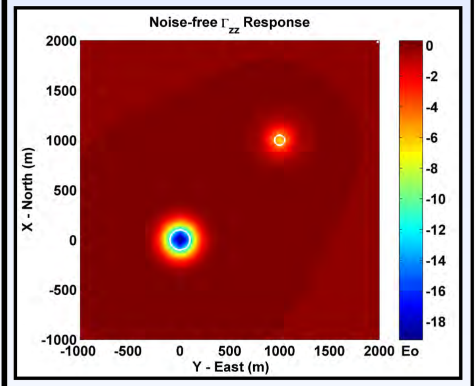
Survey parameters	
Traverse Line Spacing :	100 m
Control Line Spacing :	100 m
Ground Clearance :	100 m
Forward Speed :	100 knots
Data Sampling :	2 Hz (25.5 m)

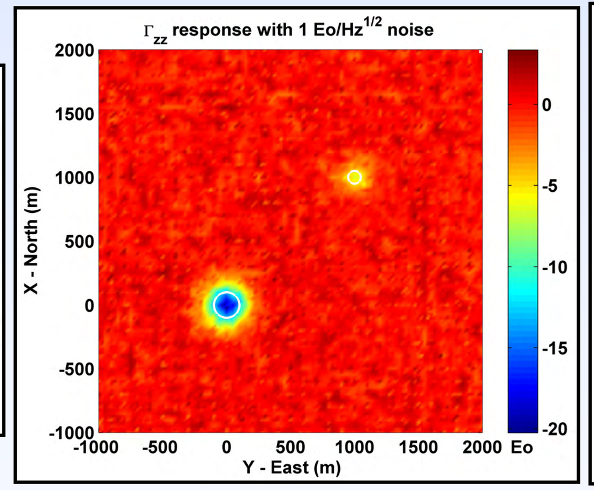


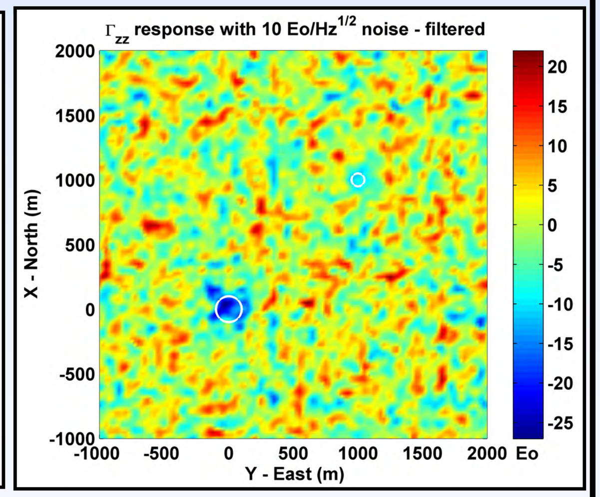
Two-Kimberlite Model	Thickness (m)	Density (g/cc)	Radius (m)	
			0.79 Ha	3.1 Ha
homogeneous overburden	50	2.0	N/A	N/A
heterogenous overburden	50	2.02-2.19	N/A	N/A
crater	200	2.25	50	100
diatreme	200	2.5	25	50
homogeneous host rock	N/A	2.6	N/A	N/A
heterogeneous host rock	N/A	2.21-2.64	N/A	N/A

Homogenoeus Overburden and Host Rock

The 10 Eo/Hz$^{1/2}$ noise level (filtered) approximates the performance of operational non-superconducting AGG systems in fixed-wing aircraft. The spatial filter is a radial cosine taper low-pass of order 2 with roll-off start wavelength of 500 m and stop wavelength of 50 m.

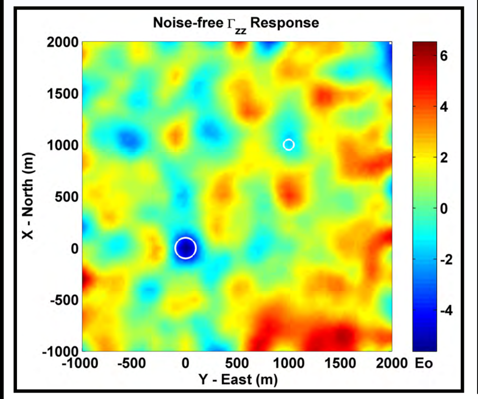


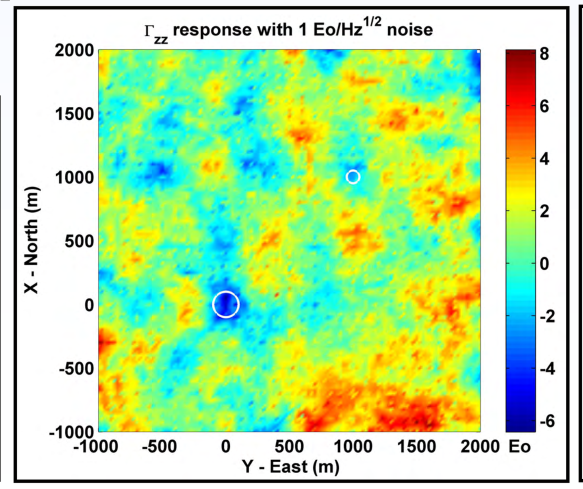


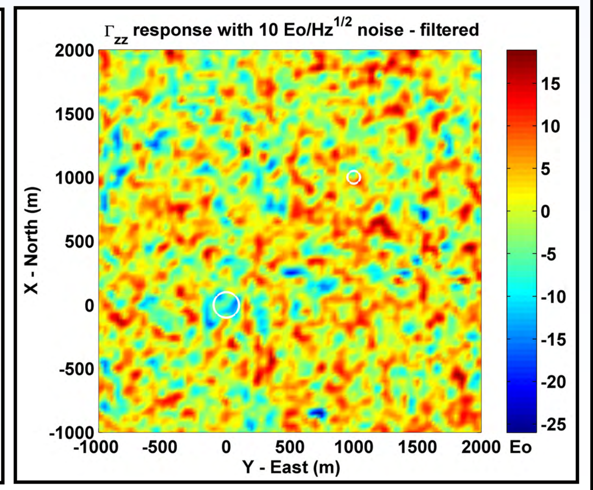


Heterogeneous Overburden and Host Rock

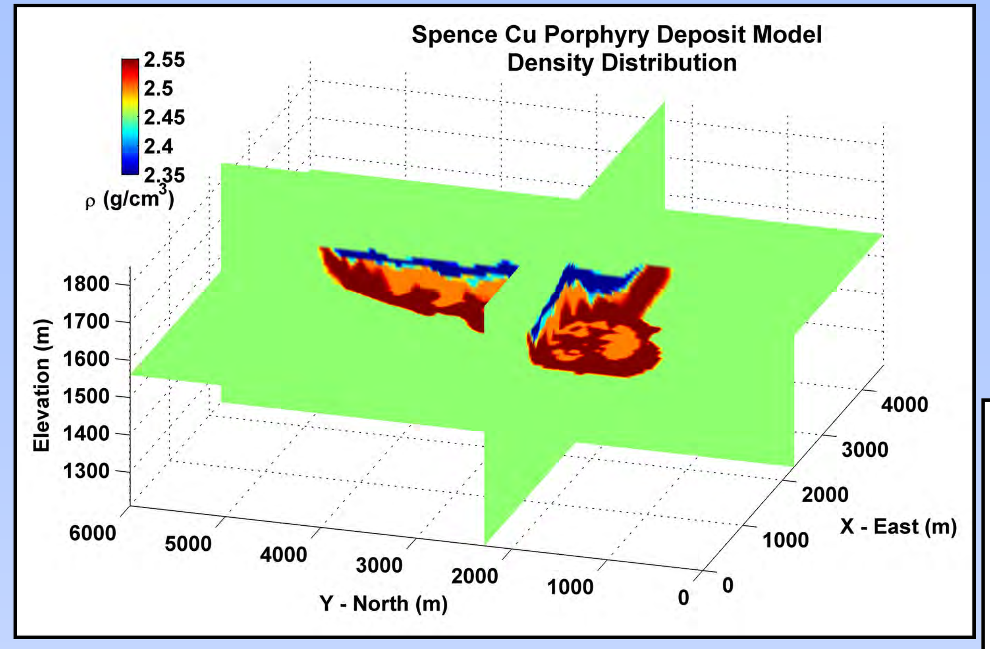
Combined interpretation of magnetic and gravity data are required to confirm the presence of kimberlites in heterogeneous media.





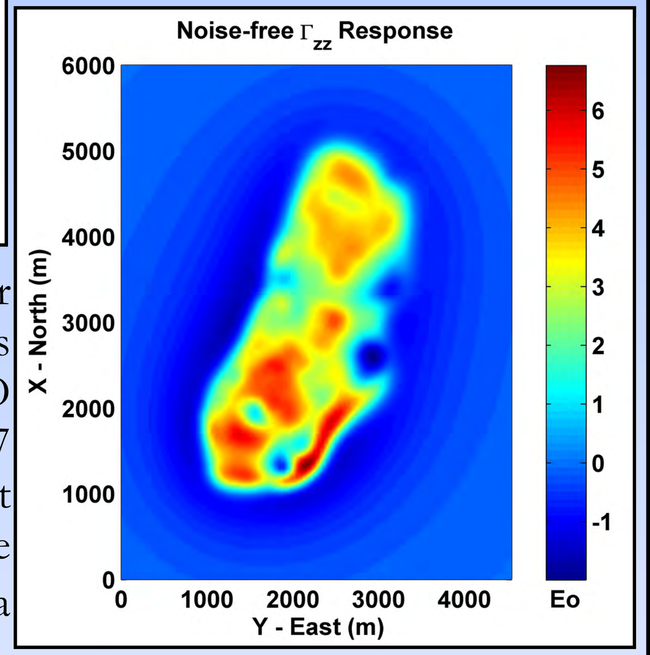


Orebody Delineation

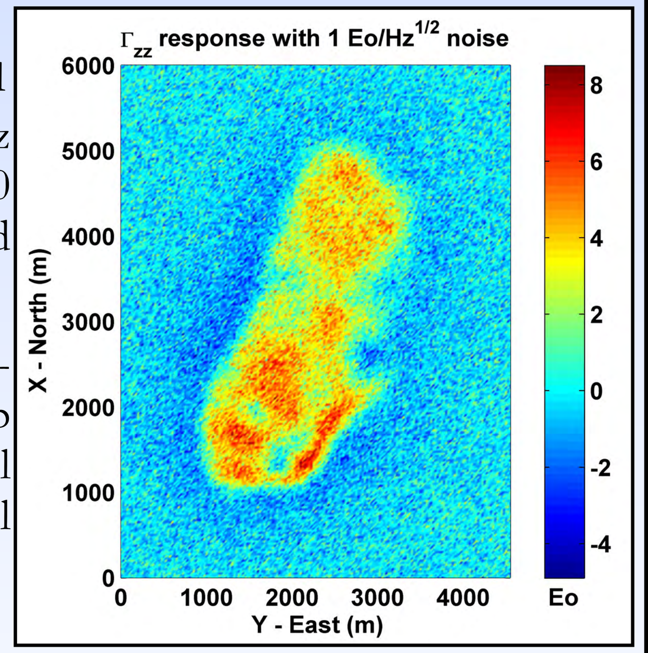


Lithology	Density (g/cc)
gravel	2.45
leach cap	2.35
oxide	2.42
supergene sulphides	2.50
mixed sulphides	2.50
hypogene sulphides	2.55
host rock	2.45

The Spence deposit is a supergene-enriched copper porphyry deposit located in northern Chile. This model was part of the Mira Geoscience Ltd CAMIRO project. The topographic relief has a maximum of 197 m and a standard deviation of 31 m. The highest point of the leach cap is less than 10 m below the surface topography. The Γ_{zz} response was computed on a drape surface 100 m above the ground.

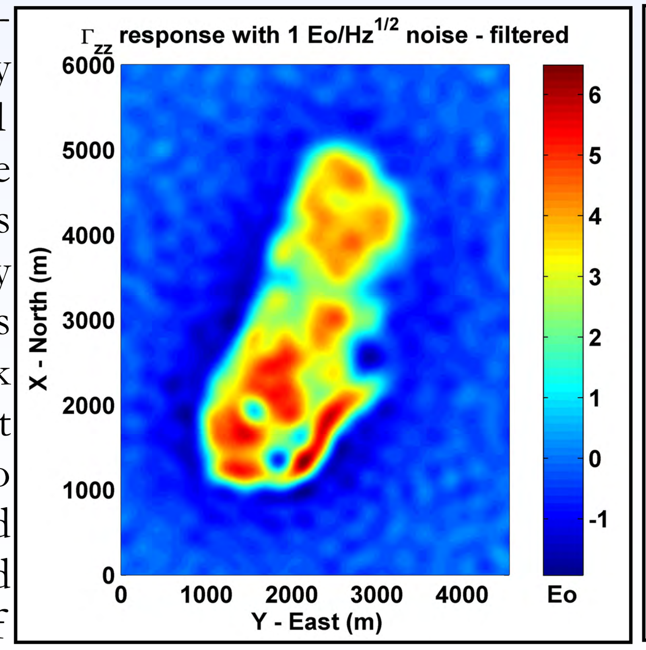


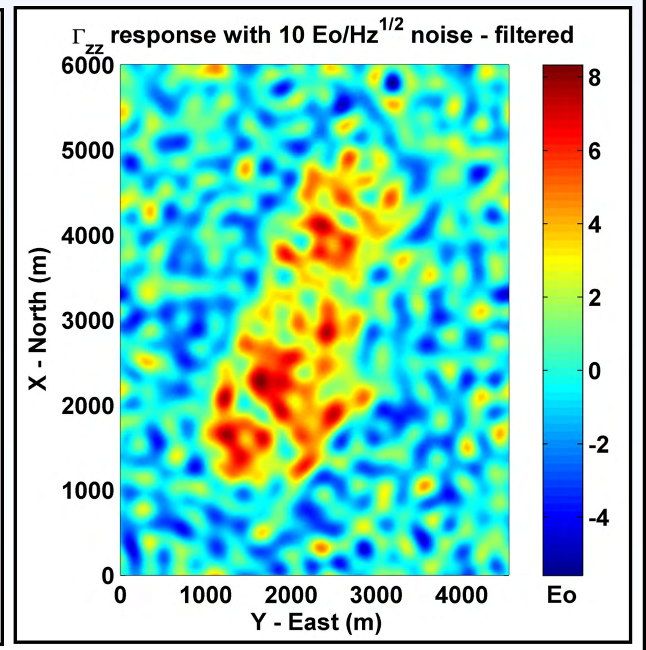
Grids of random normally distributed noise having 1 and 10 Eo standard deviations were added to the Γ_{zz} grid. This is equivalent to 1 Eo/Hz$^{1/2}$ noise and 10 Eo/Hz$^{1/2}$ noise up to 1 Hz assuming an aircraft speed of 50 m/s and a data sampling rate of 2 Hz.



The spatial filter is a radial cosine taper low-pass of order 2 with roll-off start wavelength of 700 m and stop wavelength of 300 m. The 10 Eo/Hz$^{1/2}$ noise level (filtered) approximates the performance of operational non-superconducting AGGs in fixed-wing aircraft.

Orebody delineation is significantly improved under 1 Eo/Hz$^{1/2}$ noise conditions. This level of accuracy and resolution is required if weak gravity gradient anomalies are to be interpreted qualitatively and desirable if stronger gradient anomalies are to be inverted for density distribution.





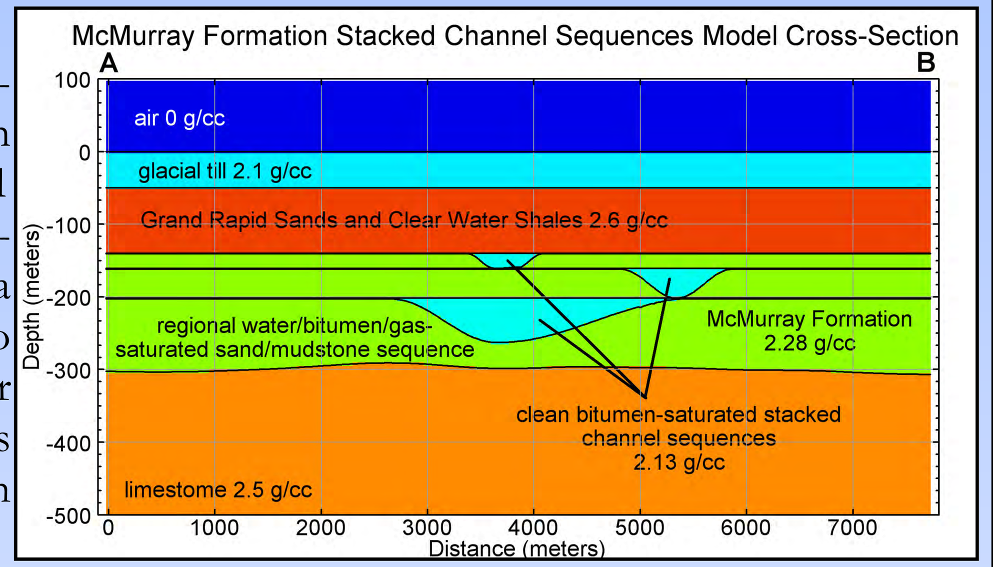
Oil Sands Application

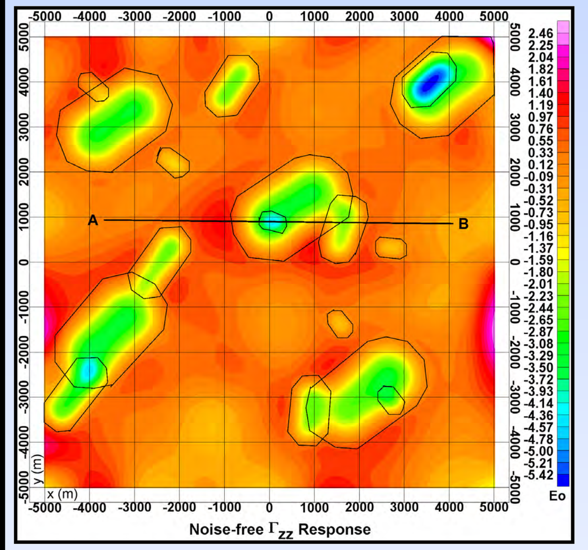
Target: Clean oil sands, i.e. poor in mudstone.

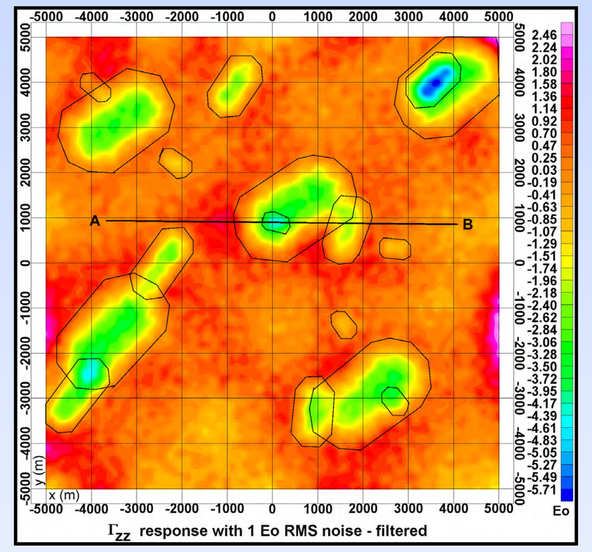
Channel Sequence	Depth (m)	Width (m)
Shallow (141 m)	20	500
Intermediate (162)	40	1000
Deep (203 m)	60	2000

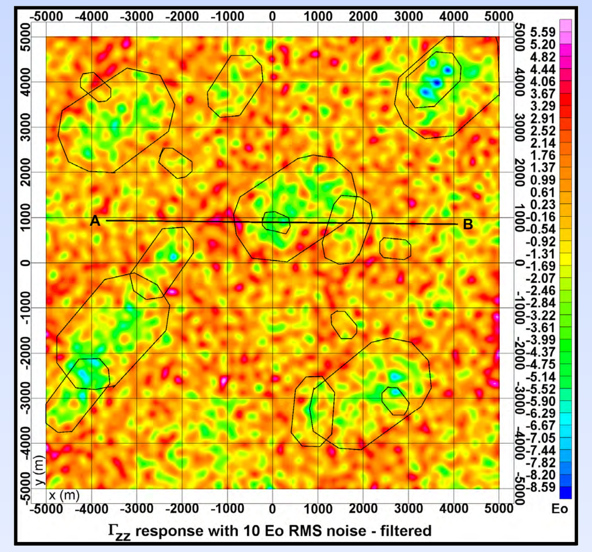
The limestone contact is situated between depths of 268 m and 300 m. Its relief has a standard deviation of 5 m.

The Γ_{zz} response (below left) was computed over flat topography at 100 m ground clearance. Noise equivalent to 1 Eo/Hz$^{1/2}$ and 10 Eo/Hz$^{1/2}$ up to 1 Hz assuming an aircraft speed of 50 m/s and a data sampling rate of 2 Hz was added to the noise-free response. The spatial filter consists of a radial cosine taper low-pass of order 2 with roll-off start wavelength of 500 m and stop wavelength of 200 m.









The 40m-deep/1000m-wide and 60m-deep/2000m-wide clean oil sand deposits are well detected at depths of 162 m and 203 m, respectively, under 1 Eo/Hz$^{1/2}$-equivalent noise conditions.

Conclusions

Variations in subsurface density are of direct interest in oil and gas and mineral exploration. Density contrast is a physical property indicative of the presence of a natural resource. Its detection by gravity gradiometry can make a substantial difference in **assessing economic potential**.

The HD-AGG™ is defined by its target performance under typical survey conditions. At target performance the HD-AGG™ will provide gravity gradient data with an **error standard deviation of 1 Eötvos** or better **at spatial resolutions of 50-60 meters** or better, from a fixed-wing aircraft, assuming speeds of 100 to 120 knots.

This performance level represents **an order of magnitude improvement** in gradient data accuracy and resolution compared to non-superconducting operational AGG systems. This provides improvement in detection and delineation of economic near-surface compact mass anomalies, and of deeper geological structure that would go undetected or be poorly resolved by operational AGG systems.

The HD-AGG™ performance is expected to **increase the number of applications** in oil and gas and mineral exploration. The benefits are **focused drilling programs and follow-up surveys, reduced exploration costs** and value created by **increased probability of discovery**.

De Beers Canada — De Beers, the world leader in diamond exploration and mining, has entered into a strategic, multi-year agreement with Gedex Inc. to apply its HD-AGG™ technology in the field.

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