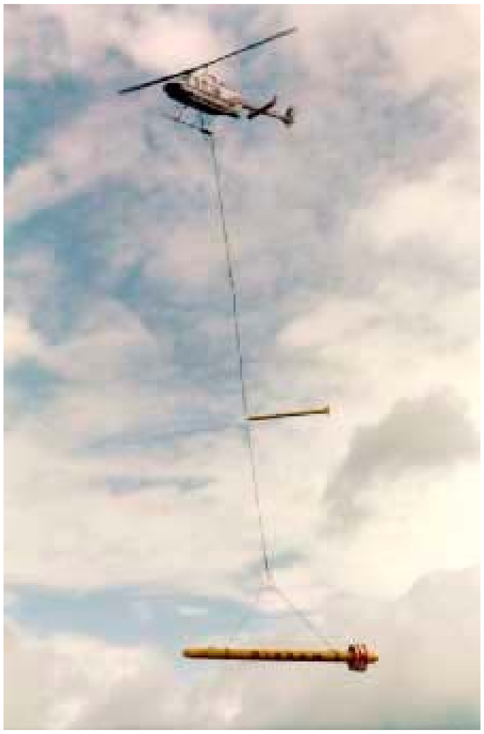
D4: Airborne EM methods (frequency domain)

D4.1 Example of primary and secondary magnetic fields

- In airborne EM exploration, the TX and RX are often quite close together, and at a significant elevation above the target.
- This example is similar to D3.2, except that the TX-RX offset is much less than the distance from the TX to the target.
- Both the primary field and secondary field decay with distance as $1/r^3$ from the TX and conductor, respectively.
- Thus the secondary field at the RX is **much weaker** than the primary field at the RX. Typically the secondary magnetic field is a million times weaker than the primary magnetic field. This can cause problems measuring the secondary magnetic field (see Geophysics 424 is interested in the details).
- DIGHEM is a commonly used airborne EM system with TX and RX in a cylindrical bird carried below a helicopter.
- Assume that the secondary magnetic field is **in phase** with the primary magnetic field.
- In this example, we are assuming that the host rock is a perfect resistor. Thus we are assuming that the EM signals travel from TX to conductor and conductor to RX **without attenuation**.

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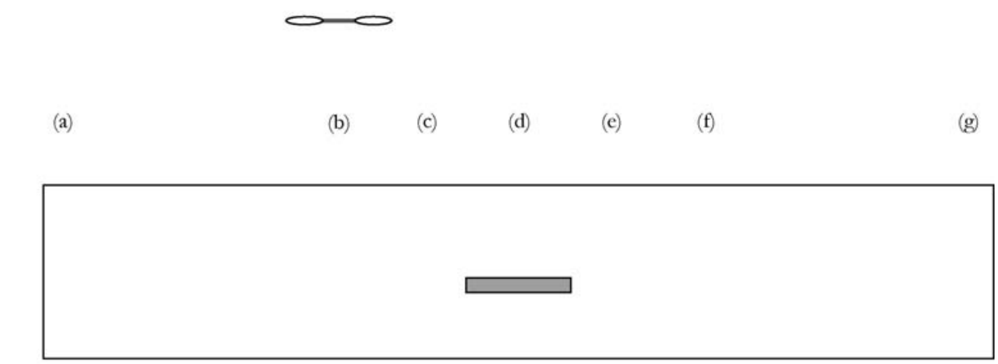
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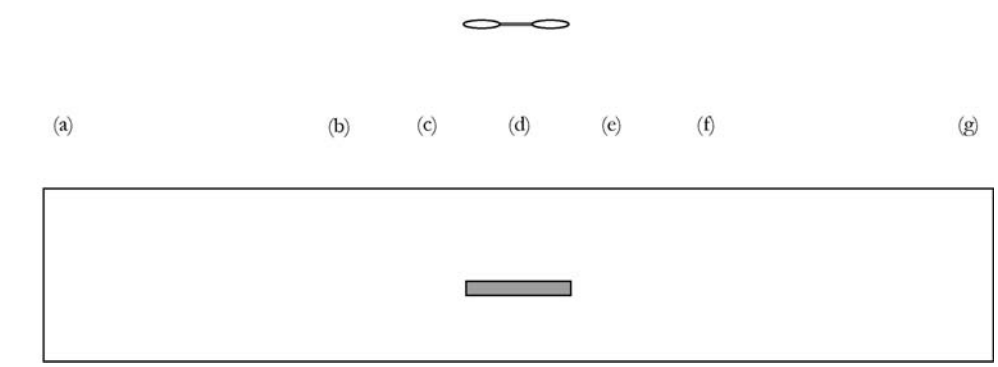
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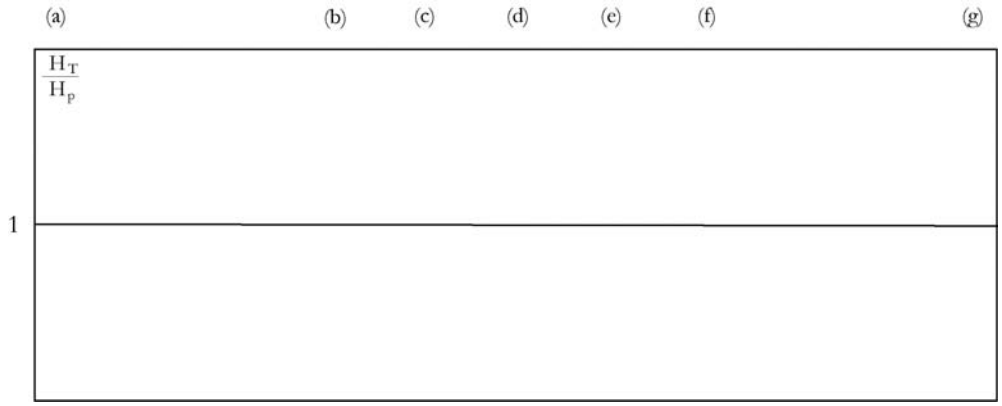


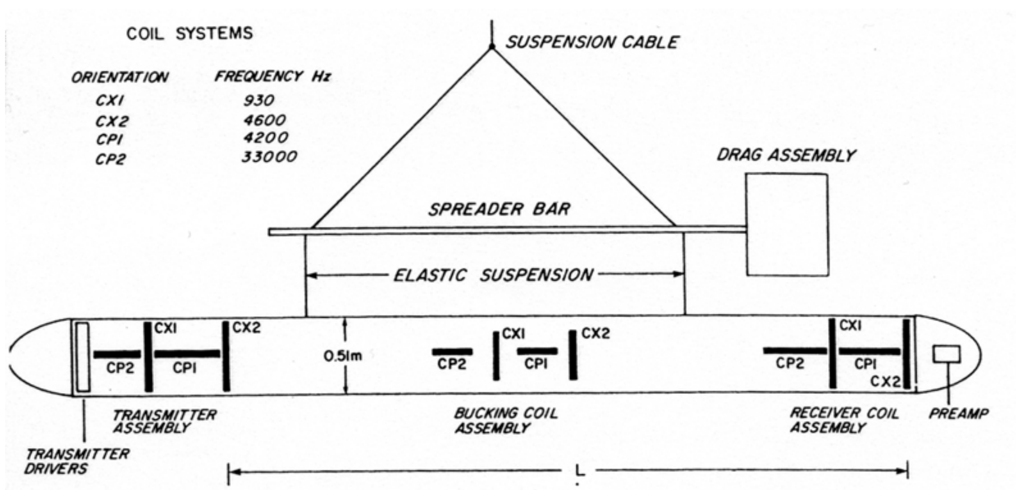
C4.2 Instrumentation for airborne EM surveys

- Compared to ground based EM systems, the vertical distance from the TX-RX system to the target is large. This makes the in-phase and quadrature anomalies quite small. The value of the secondary field is typically measured in parts-per-million (ppm) of the primary magnetic field.

- Bucking coil used to suppress the primary magnetic field at the RX. This allows a weak secondary field to be detected in the presence of a strong primary field.

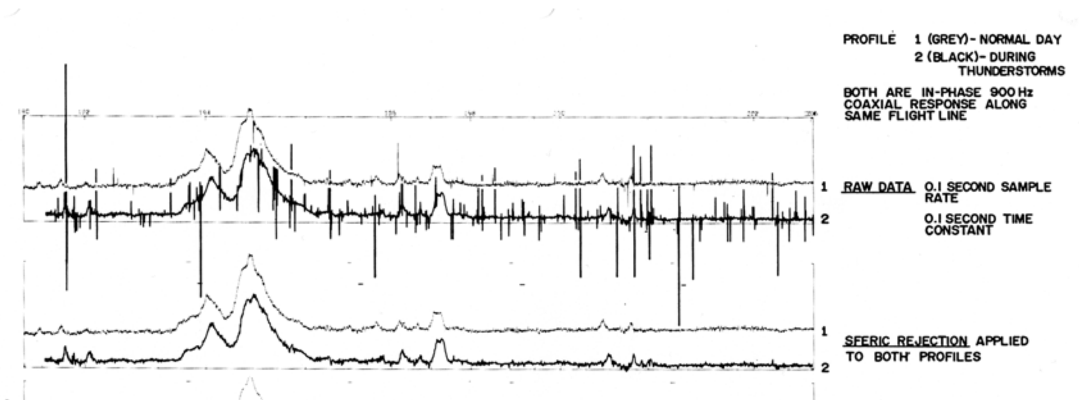
- Multiple coil configurations are used. This allows 9 combinations of TX and RX to be used. These will couple differently with different conductor geometries.

- Multiple frequencies give estimate of depth variation of conductivity. Palacky and West (1991), Figure 11.



- Measurements can be contaminated by EM noise, such as lightning strikes (also called spherics). See Palacky and West, (1991), Figure 14. The top panel of the figure shows the same line recorded on a normal day and one with a lot of thunderstorm activity.   Lower panel shows same profiles after filtering.

  Signal in a magnetotelluric survey is noise in an airborne EM survey!!!!!!!!



- Flight lines collected on a grid. Palacky and West (1991), Figure 19. Typical anomaly map from Aerodat survey in Quebec. This shows variation of in-phase and quadrature secondary fields.

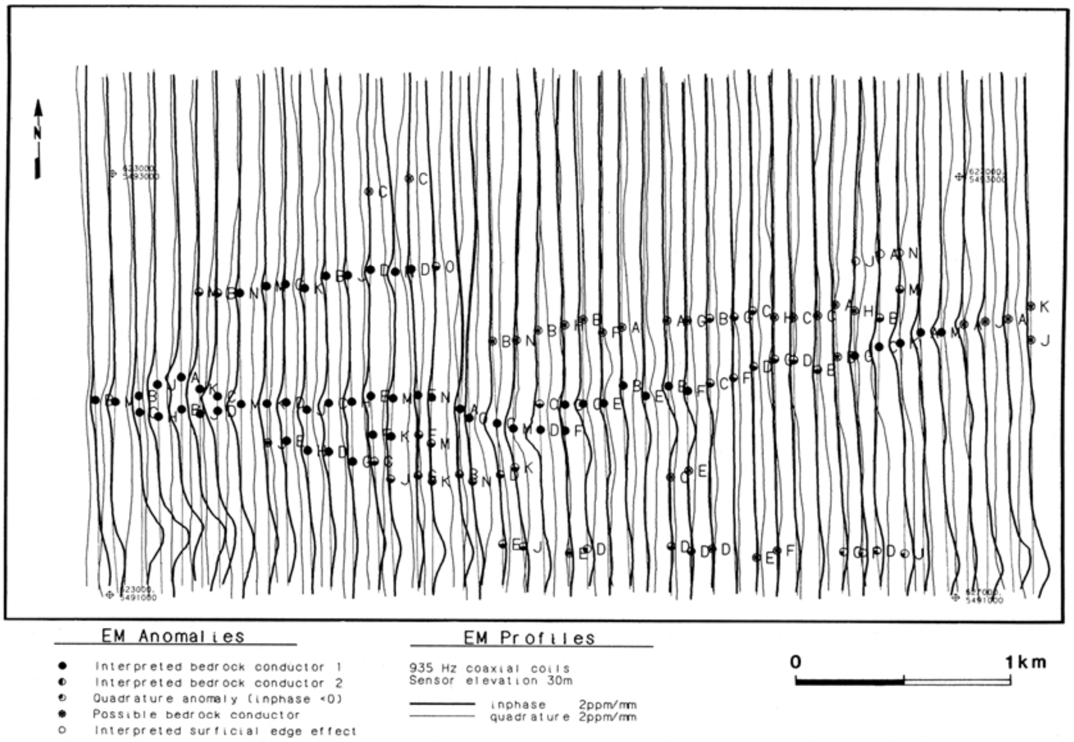


Fig. 19. Map of stacked profiles obtained in the course of a helicopter AEM survey in the Casa Berardi area, Quebec. In-phase and quadrature EM data and interpreted bedrock conductors are shown (courtesy of Aerodat Ltd.).

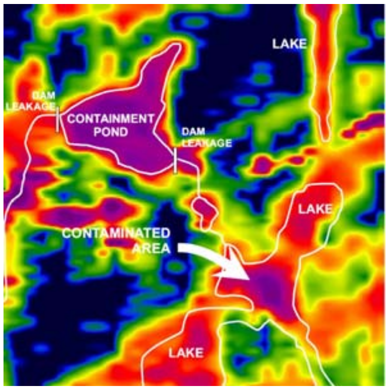
- Depth of penetration depends on TX-RX distance, frequency and the skin depth.
- Measuring weak secondary magnetic fields in the presence of the primary magnetic field is difficult.
- Very strong conductors have small quadrature response. Thus the best targets in mineral exploration are the most difficult to detect with frequency domain EM!
- Multiple frequencies can be used to estimate conductivity – depth variations.
- Data displayed as

  (a) secondary field / primary field as ppm or

  (b) ground (terrain) conductivity map as in D2 (EM31, EM34 etc)

<u>D4.3 Environmental and groundwater surveys</u>

- Saline groundwater contamination (contaminated water is conductive). This problem can also occur during oil extraction or as a consequence of irrigation.

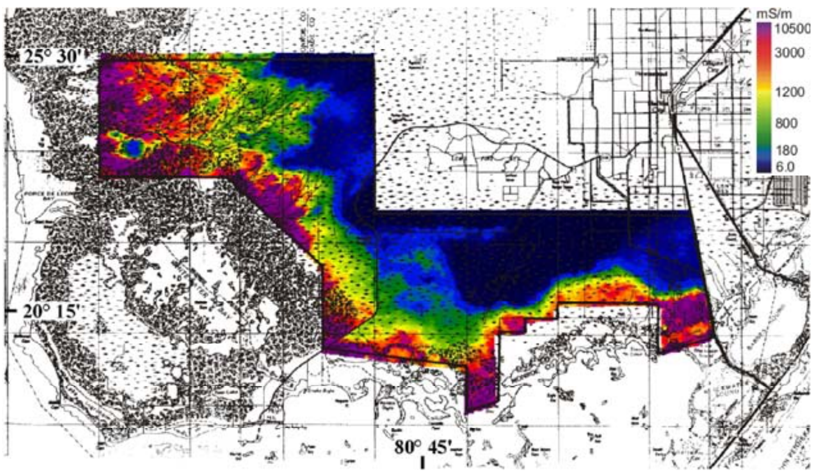


- Ground conductivity map derived from a DIGHEM survey.
- This example on the left shows leakage from tailings ponds at a mine.

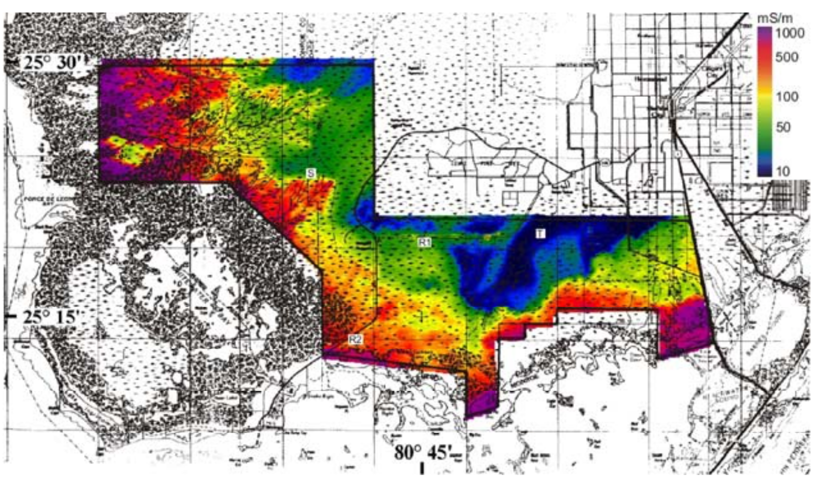
http://www.fugroairborne.com.au/service/images/env_downloads/CONTAMINANT_MAPPING.pdf

- Contamination of ground water by organic liquids. These include both light and dense non-aqueous phase liquids (LNAPLS and DNAPLS) such as hydrocarbons and CCl_4 and are generally resistive.

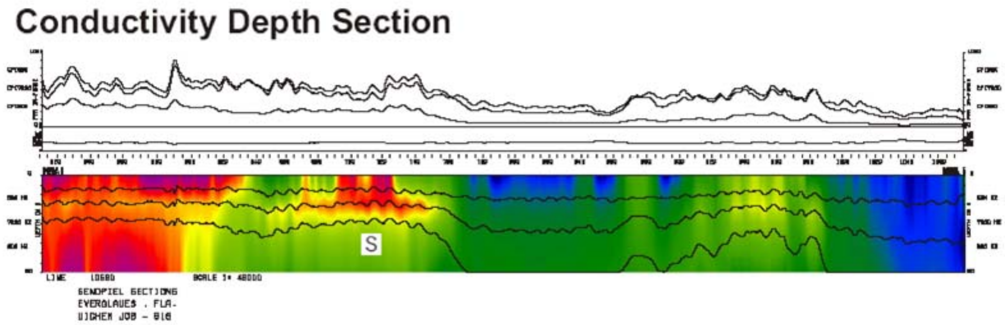
- Mapping salinity of groundwater, especially with regard to salt water intrusion



56 kHz DIGHEM survey in the Everglades



7.2 kHz DIGHEM survey in the Everglades



http://www.fugroairborne.com.au/service/images/env_downloads/EVERGLADES.pdf

See examples http://www.fugroairborne.com.au/service/images/env_downloads/

D4.4 Geotechnical applications

- DIGHEM data can be used to map the depth of topsoil, and avoid bedrock during the construction of pipelines.

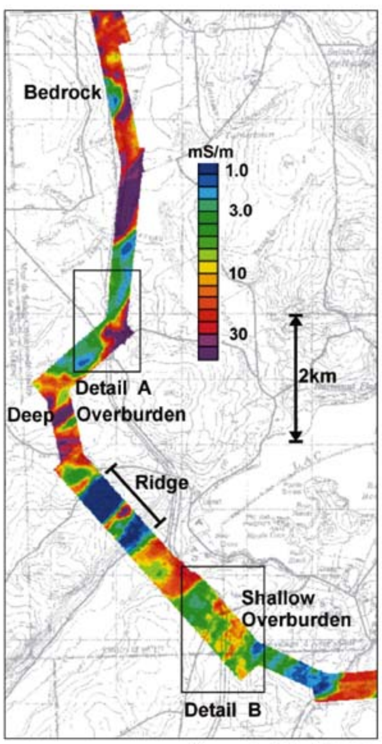


Figure 2: Block 22-26

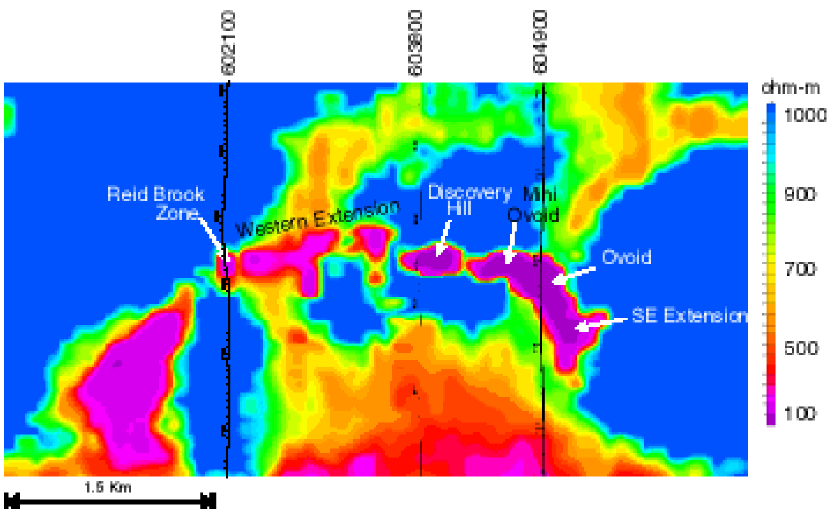
http://www.fugroairborne.com.au/resources/case_studies/engineering/pdfs/PipelinePlanning.pdf

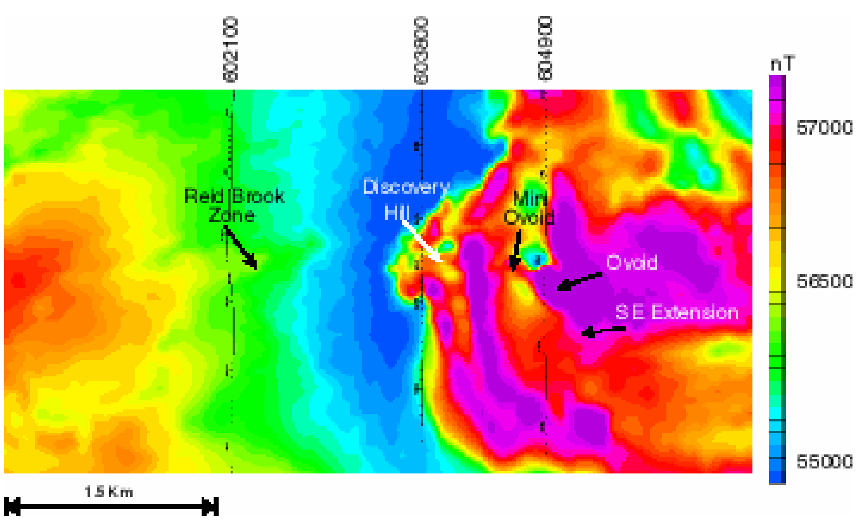
Can also map paleochannels prior to construction (or for groundwater exploration)
http://www.fugroairborne.com.au/service/images/env_downloads/PALEO_CHANNEL.pdf

D4.5 Mineral exploration

- Frequency domain EM techniques were originally developed for mining applications. The first systems were ground based (and are still used today), but the real value has been proven in airborne EM techniques where huge areas can be covered very quickly.

- DIGHEM data from Voisey's Bay, which is a very large massive sulphide deposit in Labrador



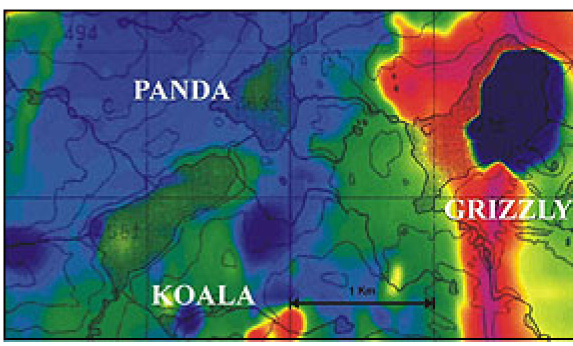


http://www.fugroairborne.com.au/resources/case_studies/minerals/voiseys.html

D4.6 Kimberlite exploration with DIGHEM

- As discussed in previous section on magnetics, kimberlite pipes will exhibit both induced and remnant magnetization. Depending on the age of the pipe, the remnant magnetization can be either normal or reversed.

- The magnetic anomaly is due to a combination of induced and remnant magnetization. This can result in a positive, negative or zero anomaly, as is the case for pipes at Ekati Mine. Grizzly pipe has a negative magnetic anomaly and Panda has a small positive anomaly. Koala pipe shows a weak anomaly.

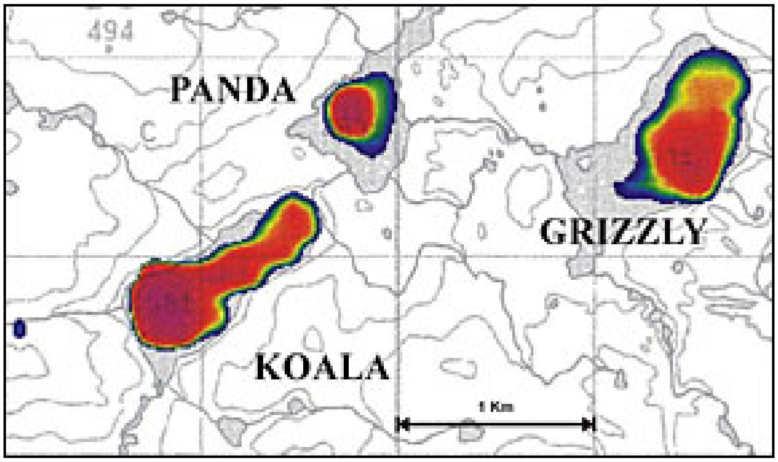


- Kimberlite pipes are often characterized by a low resistivity zone at the surface, as the pipe weathers to clay.

- Erosion by glaciers often forms a lake that saturates the clay with water.

- The Ekati Diamond Mine is exploiting five economic kimberlite pipes in the Lac de Gras region of the NWT (Panda, Koala, Misery, Fox and Leslie). BHP Billiton mining operations at the **Koala Pipe** are shown above.

- Airborne EM data can provide an alternative way of locating kimberlite pipes. The apparent resistivity map calculated from the 7200Hz coplanar data of the DIGHEM survey (see below) clearly shows the economic pipes in this data block. The Koala and Panda kimberlite pipes give clear EM anomalies, and are also underneath lakes.



More details can be found at :

http://www.fugroairborne.com.au
http://www.mining-technology.com/projects/ekati
http://ekati.bhpbilliton.com