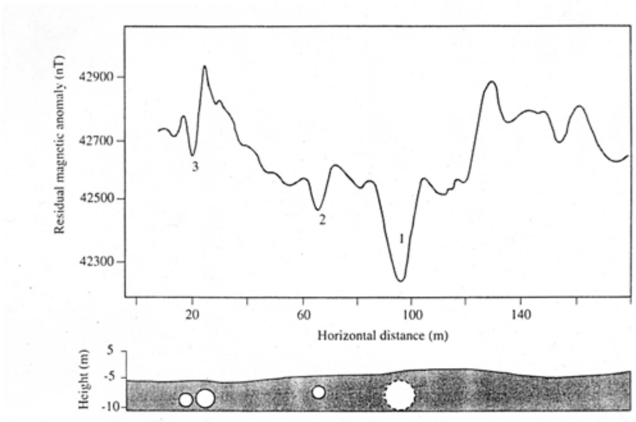
Geophysics 224
D6: Common applications of magnetic exploration methods

D6.1 Detection of voids

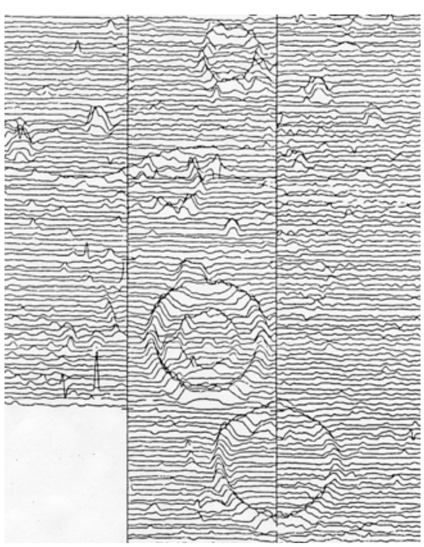
● The air in a cave has $k = 0$. If the host rock has a non-zero magnetic susceptibility, then a magnetic anomaly will be observed at the surface. What will be the **sign and shape** of the anomaly over a cylindrical lava tube in a basalt lava flow?

● Ground-based magnetic surveys have been used in Hawaii to locate **lava tubes** prior to developing agriculture or construction.



● **Tunnels** can be detected through their **negative susceptibility contrast**, as described above (case study at Teotihuacan in Mexico described by Arzate *et al*, 1990)

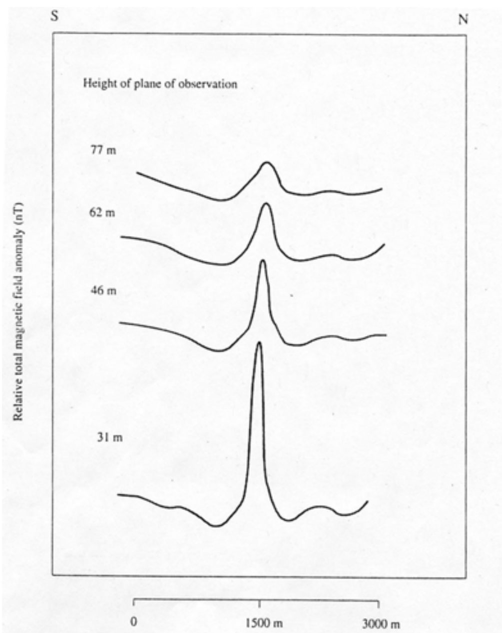
D6.2 Archaeology

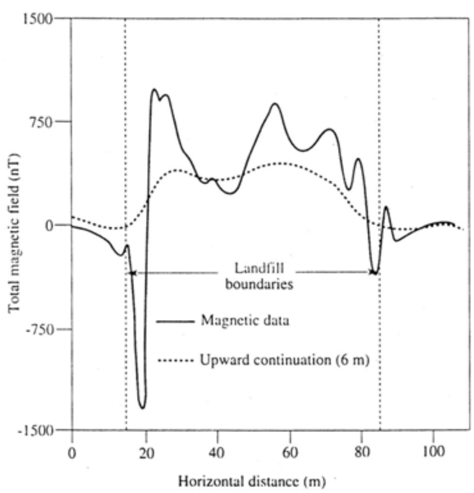


● Disturbing the soil can produce a small change in the magnetic susceptibility. This can permit the detection of foundations, graves or ditches (Clark, 1986)

● Buried metal objects can be detected through induced or remnant magnetization

D6.3 Environmental geophysics





- locating buried metal objects in landfills (55 gallon oil drums, pipes etc)

- locating disused well casings. Why does the anomaly change with aircraft elevation?

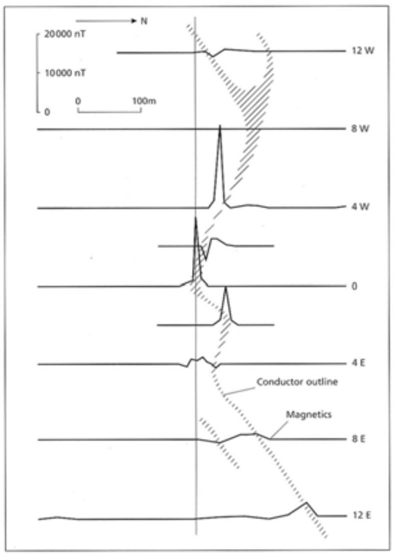
- Mapping landfill boundaries (Roberts *et al*, 1990).

- Note that **upward continuation** is a mathematical technique that computes the magnetic field at a higher elevation than that at which the data were collected.

- Why is the upward continued data smoother than the ground level data?

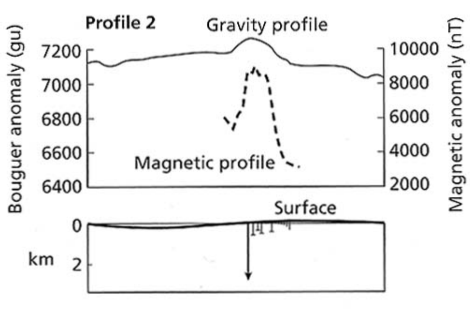
D6.4 Mineral exploration

- ore bodies can have a high magnetic susceptibility and may exhibit both induced and remnant magnetization. These anomalies can easily be detected at aircraft elevations and thus aeromagnetic exploration is a good reconnaissance tool for minerals.



● Example from Quebec (Kearey figure 7-25). The ore body is also electrically conductive, and is well defined by two geophysical surveys (electrical and magnetic)

● Remember that haemitite is antiferromagnetic and produces a negligible magnetic anomaly.

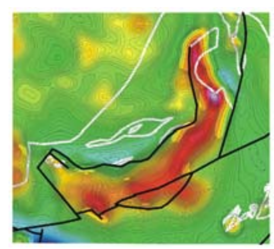


● Combined gravity and magnetic surveys sometimes help define if a magnetic anomaly represents a significant ore deposit. (Kearey figure 7-28).

● What is the physical basis of this technique?

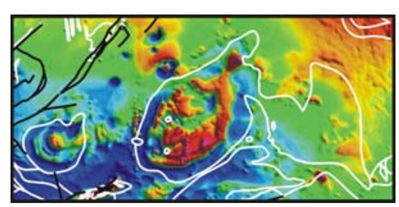
Examples from Atlin, British Columbia

Ultramafic body in Surprise Lake Valley
P = peridotite (k = 88.5 x 10^{-3} SI)
M = metabasalt k = 0.41 x 10^{-3} SI)



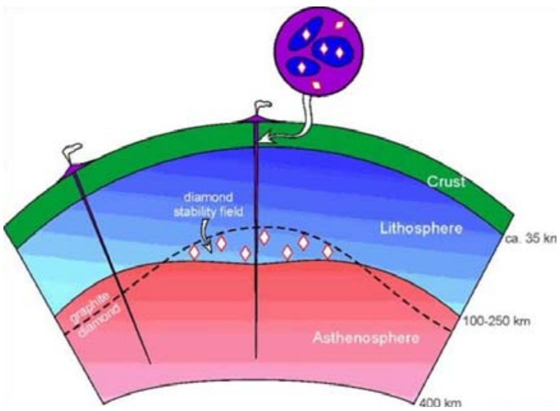
Mapping plutons and their associated mineralization.
Previous geological mapping was revised.

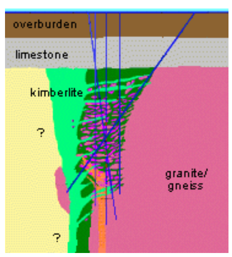
Magnetic field data courtesy of Carmel Lowe, Natural Resources Canada.



D6.5 Diamond exploration

Locating kimberlite pipes





Kimberlites are volcanic rocks that originate at depths of 100-200 km in the asthenosphere and move rapidly to the surface. If they originate in the **diamond stability field**, they can bring diamonds to the surface. Aeromagnetic data are widely used to locate kimberlite pipes.

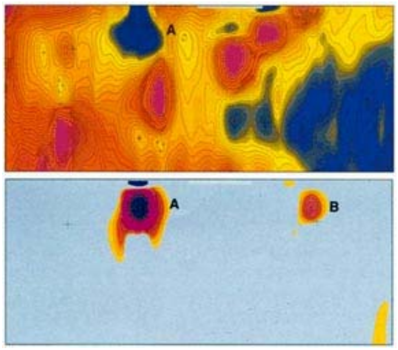
Kimberlite usually contains more magnetite than the host rock in the Slave Province and produces a **positive** magnetic anomaly. However a **negative** magnetic anomaly occurs if: (a) the host rock is more magnetic (contains more magnetite) or (b) the pipe has a (reversed) remnant magnetization. If these effects cancel, the pipe can produce a **weak**, or near zero, anomaly.

Extra information can be gained from airborne electromagnetic (EM) surveys (more details in Geophysics 424 next year). This is essentially a way of measuring shallow electrical resistivity from a moving aircraft or helicopter. Two factors make this a viable exploration technique:

(1) Kimberlite has a lower electrical resistivity than the host rock
(2) Kimberlites weather and produce clay, with a low resistivity. If eroded, a lake forms, also producing a lower resistivity.

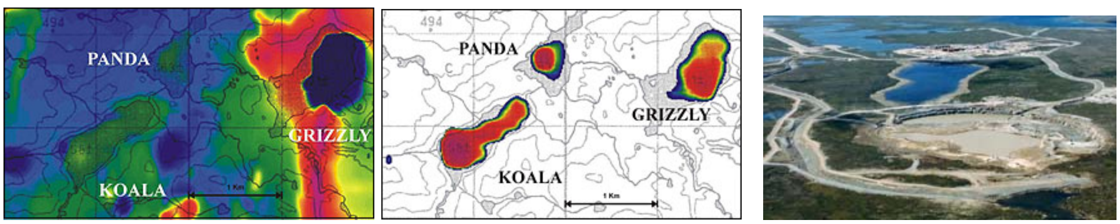
"*Because kimberlite pipes exhibit variable anomalies on both electromagnetic and magnetic data, the best approach to mapping them is to simultaneously collect EM and magnetic data from a low flying platform. The DIGHEM system collects both data sets from a sensor at 30m altitude, sampling about every 3m.*" http://www.fugroairborne.com.au

(a) Point Lake Kimberlite, NWT



First kimberlite pipe discovered in NWT by airborne magnetics and EM. Note the negative magnetic anomaly (top). There is also a strong response in the EM data (GEOTEM channel 7, off-time)

(b) Ekati Mine, Lac de Gras, NWT



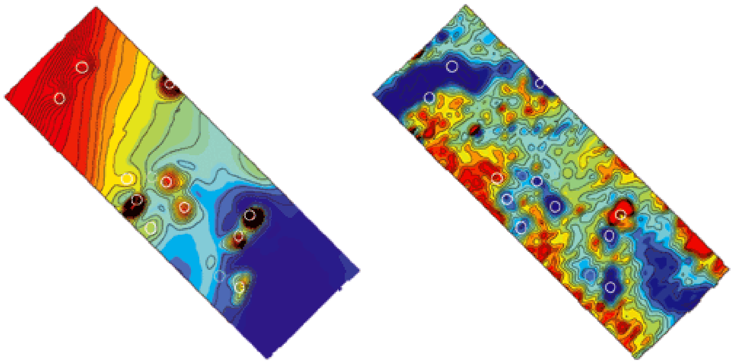
The Ekati Diamond Mine is exploiting five economic kimberlite pipes in the Lac de Gras region of the NWT. The pipes are named Panda, Koala, Misery, Fox and Leslie. BHP Billiton mining operations at the Koala Pipe are shown on the right.

Magnetic data: Left panel shows that the Grizzly pipe has a negative magnetic anomaly and Panda has a small positive anomaly. Koala and Fox pipes show weak anomalies.

Airborne EM data: The apparent resistivity map (centre), calculated from the 7200Hz coplanar data of the DIGHEM survey, clearly shows the economic pipes in this data block. The Fox pipe (south west corner) has the most distinct anomaly, and coincides almost exactly to the overlying lake. The Koala and Panda pipes give clear anomalies, and are also underneath lakes.

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

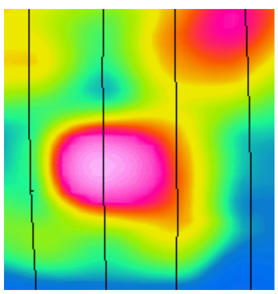
(c) Fort à la Corne kimberlites, Saskatchewan



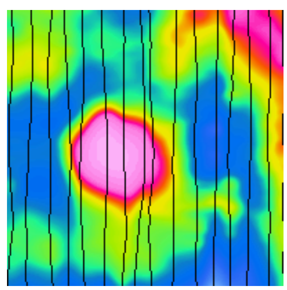
Located beneath 100 m of sedimentary rocks and glacial overburden with no surface expression. Magnetic data are shown on the left and coincident GEOTEM data shown on right.

www.fugroairborne.com

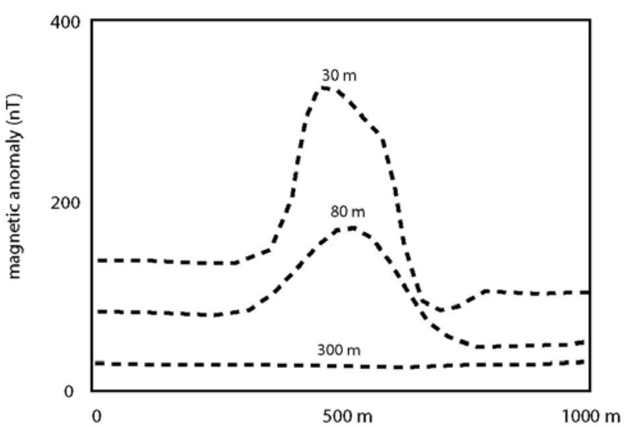
(d) James Bay Lowlands From Hogg and Munro (2000)



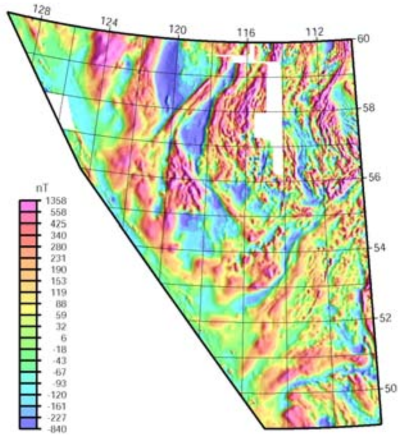
80 m elevation



30 m elevation



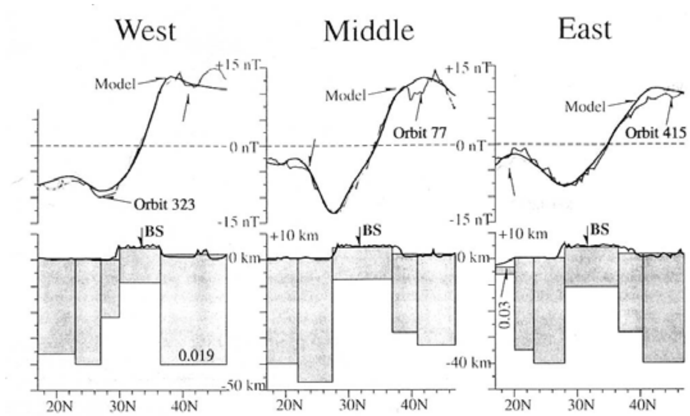
D6.6 Regional crustal structure



Alberta Basement: The crystalline basement rocks in Alberta date from the Archean and Proterozoic. However, they are covered by the sedimentary rocks of the Western Canada Sedimentary Basin and cannot be studied directly. The basement rocks have been mapped through potential field data (magnetic and gravity) and analysis of rocks recovered form the bottom of oil wells (Pilkington *et al*, 2000).

Even if the origin of the magnetization is not resolved, the character of the aeromagnetic anomalies can be used to determine the extent of a geological province. The direction of the magnetic anomalies can also reveal the geological strike of these rocks.

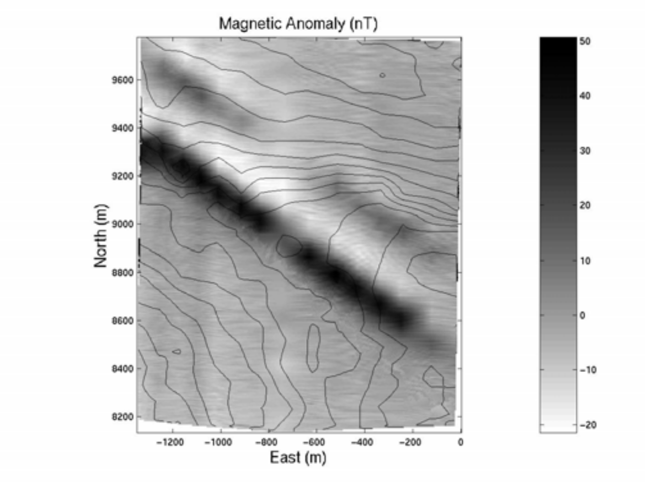
Tibetan Plateau: Several geophysical techniques have suggested that unusually high crustal temperatures exist beneath the Tibetan Plateau. How will this alter the susceptibility of the crustal rocks? Good coverage with magnetic data in Tibet is hard to obtain on the ground (no roads) and aeromagnetic data coverage is not widely available.



In the 1990's a low orbit satellite (MAGSAT) was used to map the Earth's magnetic field. (Why in low orbit?) Analysis of these data by Alsdorf and Nelson (1999) reveal a pronounced magnetic low over Tibet? Can this magnetic low be explained on the basis of high crustal temperatures and partial melting?

D6.7 Dike location

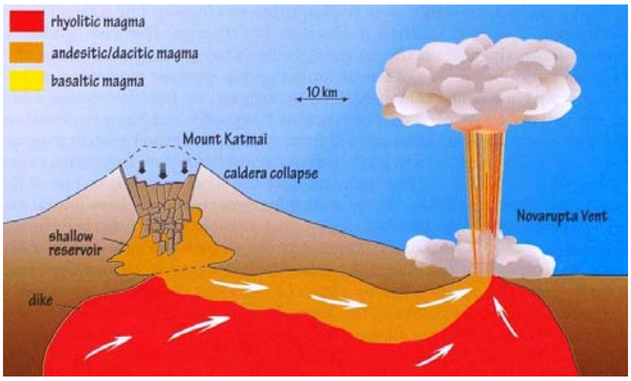
Southern Alberta

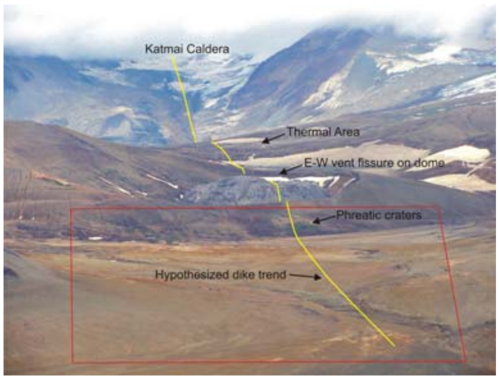


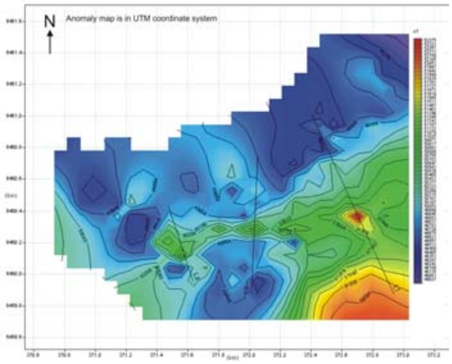
These data were collected during the University of Alberta Geophysics field school in Southern Alberta. Shading shows magnetic field anomaly in nanteslas. Contour lines show surface elevations. The magnetic anomaly is due to a shallow dike.

Katmai Volcano, Alaska

The goal of the magnetic survey was to determine if a dike connects Mt. Katmai and Novarupta. Both erupted in the 1912 eruption, but the plumbing of this volcanic system is still unknown.

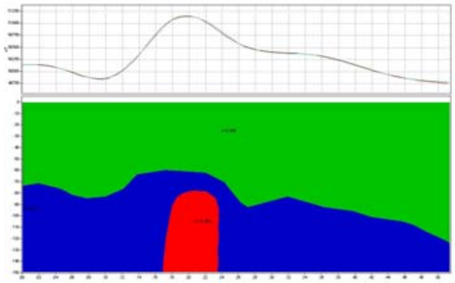






Magnetic anomaly map: Note the east-west magnetic high (approximately 1000 nT) that is coincident with the hypothesized dike trend.

These data are the results of fieldwork by Graham Hill and John Eichelberger, Alaska Volcano Observatory, University of Alaska, Fairbanks.



Model for western profile: 2-D model with variable magnetic susceptibility that fits data for one of the profiles.

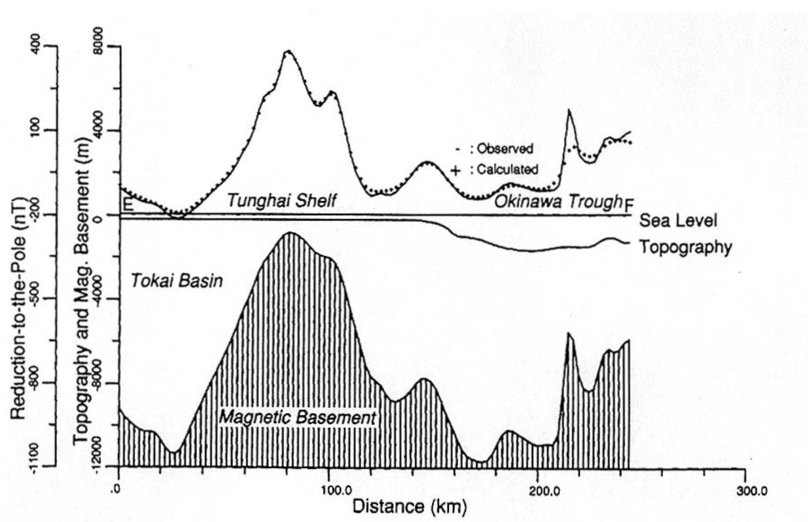
Sedimentary basement	*k=0.004*
Pyroclastic flow	*k=0.002*
Rhyolite dike	*k=0.01*

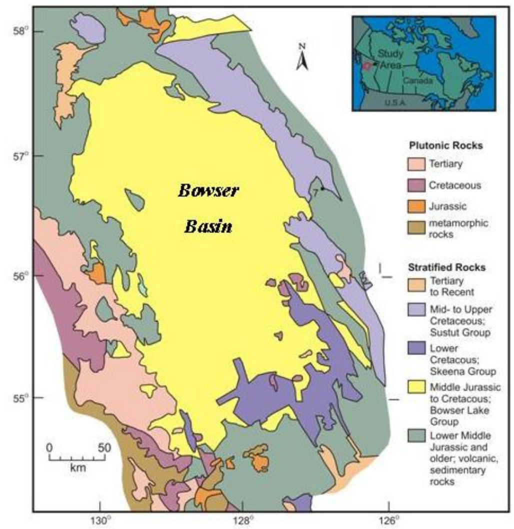
D6.8 Hydrocarbon exploration with magnetic data

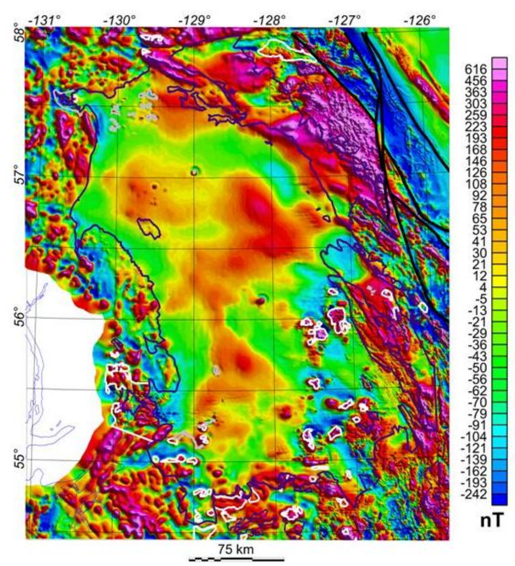
● A summary of the state-of-the-art in oil and gas exploration can be found in Gibson and Millegan, 1998. While oil and gas are not magnetic, useful information can be obtained from magnetic exploration, since it can define the local geology.

● Magnetic data can be used to define the depth of **magnetic basement**. The magnetic basement is usually the crystalline basement and knowledge of the depth is useful in hydrocarbon exploration since it gives information about the overlying sedimentary rocks (depth, location of faults etc).

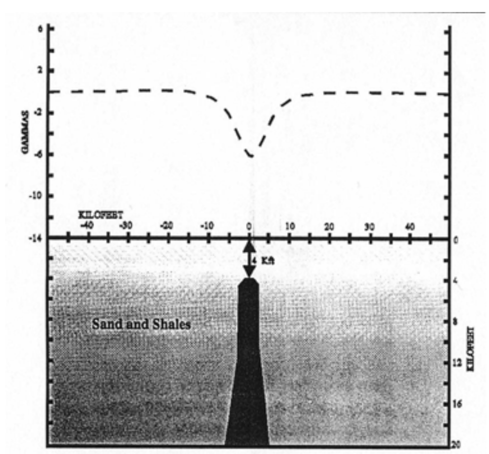
Example: East China Sea, Okuma *et al*, in Gibson and Millegan, 1998, pages 59-62







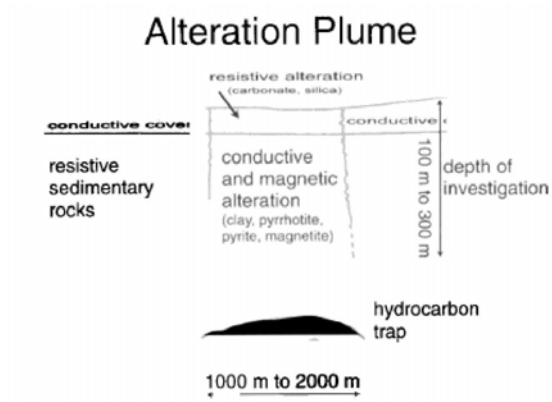
● The Bowser Basin in British Columbia is currently being evaluated for hydrocarbon potential. Note that spatial extent is defined from the magnetic data. Magnetic anomalies have longer wavelengths within the basin (why?). Magnetic field data courtesy of Carmel Lowe, Natural Resources Canada.

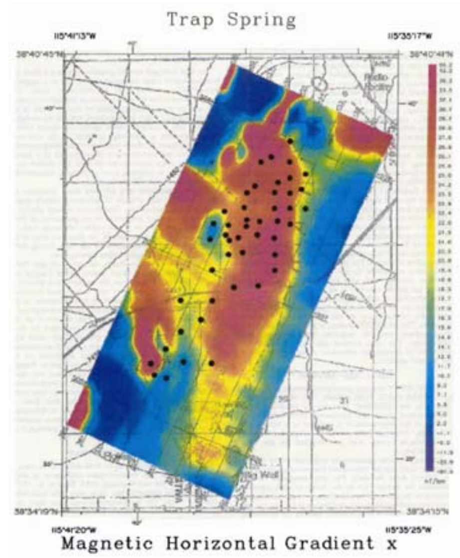


● Salt is **diamagnetic** and thus produces an anomaly of negative sign compared to a paramagnetic rock. This allows the geometry of salt diapirs to be defined from very accurate magnetic field data.

Example: Gulf of Mexico Continental slope, Corine Prieto, in Gibson and Millegan, 1998, pages 14-16

● As oil seeps to the surface from a trap, it can **alter** the rocks through which it flows. This can change the near-surface magnetic susceptibility. Attempts to locate these altered regions have been made with magnetics, and other airborne geophysical data.





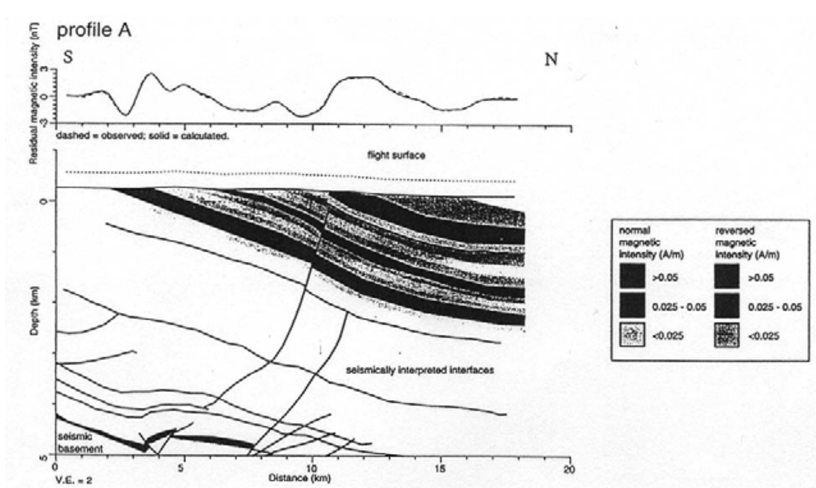
Example: ALTREX method, J. Rowe *et al*, Gibson and Millegan, 1998, pages 124-129

Note discussion of this effect by **Machel** and Burton (1991)

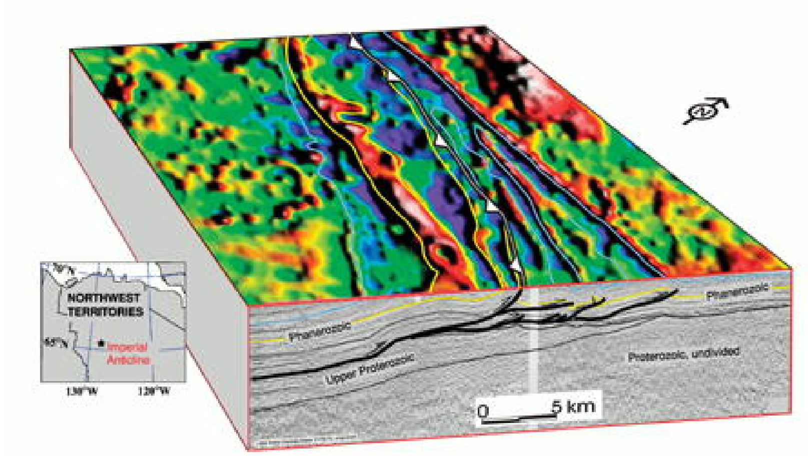
- Generally sedimentary rocks have low magnetic susceptibilities and do not exhibit a strong induced or remnant magnetization. Sedimentary rocks can develop a weak remnant magnetization during deposition.

In **detrital remnant magnetization** (DRM), magnetic mineral grains are oriented by the Earth's magnetic field as they are deposited. With very sensitive magnetometers (alkali vapour) and accurate navigation in a high resolution aeromagnetic (HRAM) survey, the remnant and induced magnetization can be detected and interpreted.

Example: ANWR, North Slope of Alaska, Phillips *et al*, in Gibson and Millegan, 1998, pages 130-134

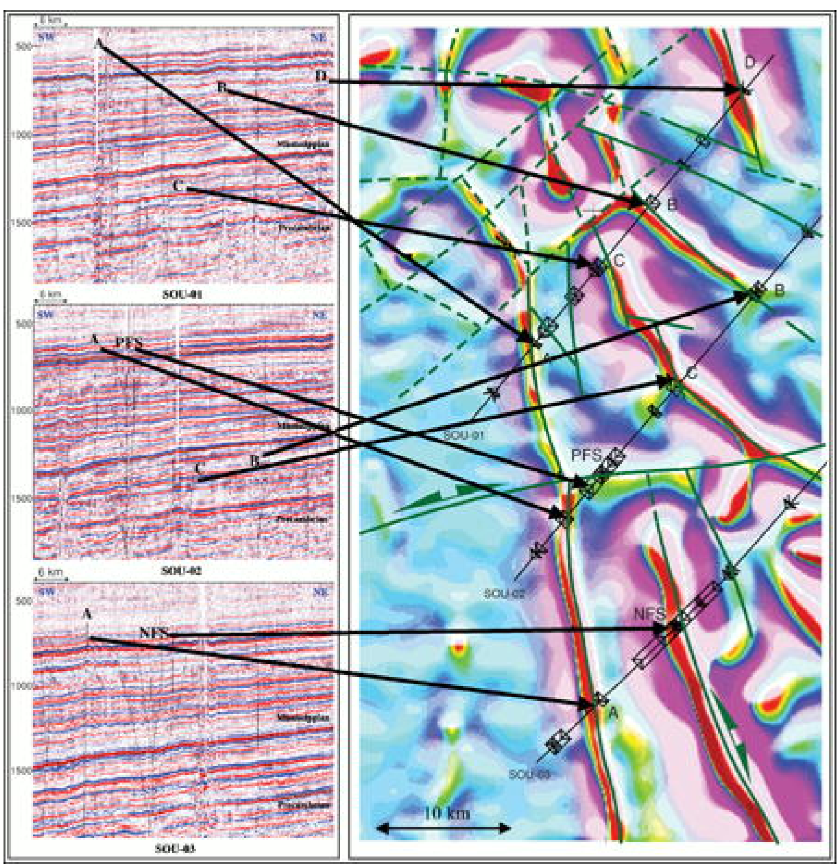


Example : Northern Canadian cordillera, shown in Nabighian et al., (2005)

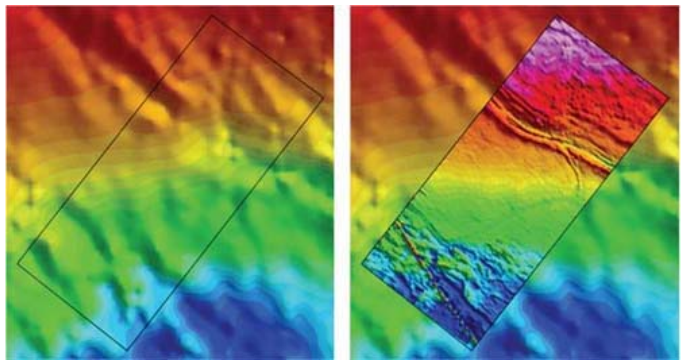


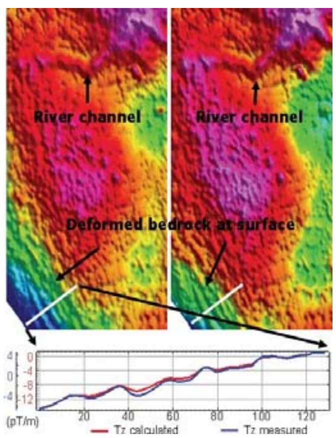
In this case, the magnetic data can be used to map faults, in between the widely spaced seismic reflection lines.

Example: Weyburn carbon dioxide sequestration project, shown in Nabighian et al., (2005). The prescence a sedimentary layer with more magnetite than the background allows faults to be mapped in HRAM data. The seismic data are essential to ground truth the magnetic field data in this case.



Example : Mushayandebvu and Davies, 2006. Magnetic gradients in WCSB



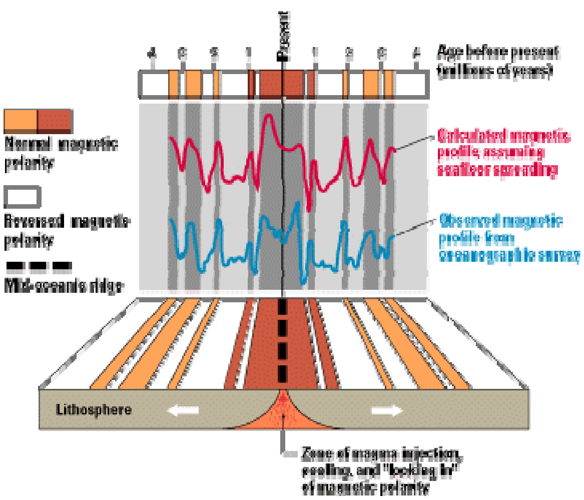


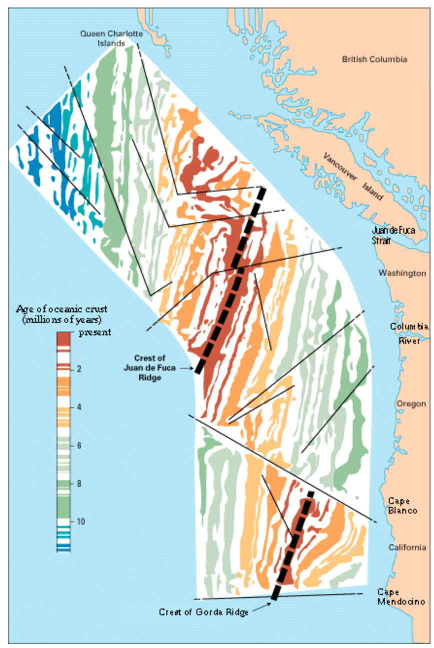
D6.9 Seafloor magnetic anomalies

- As new oceanic crust is formed at mid-ocean ridges, it is magnetized in the direction of the Earth's magnetic field. For basalt, this remnant magnetization is usually stronger than the induced magnetization.

- As the plates move away from the ridge, they carry a record of the magnetic field polarity at the time the crust was formed.

- These so-called **magnetic stripes** were a key piece of evidence in the development of plate tectonic theory. By combining the history of the magnetic field reversals with radioactive dating, the age of oceanic crust can be determined from the magnetic field anomalies.





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