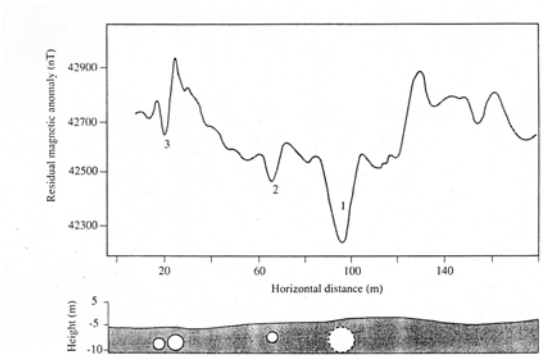
Geophysics 325
D7: Applications of magnetic exploration methods

D7.1 Detection of caves and tunnels

- The air in a cave has susceptibility, $k = 0$. If the host rock has a non-zero magnetic susceptibility, then a magnetic anomaly will be observed at the surface.

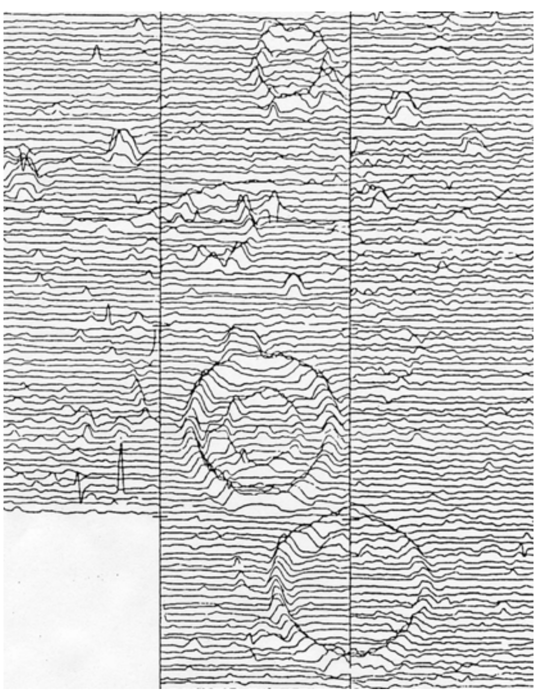
  What will be the sign and shape of the anomaly over a cylindrical lava tube in a basalt lava flow?

- 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)

D7.2 Archaeology

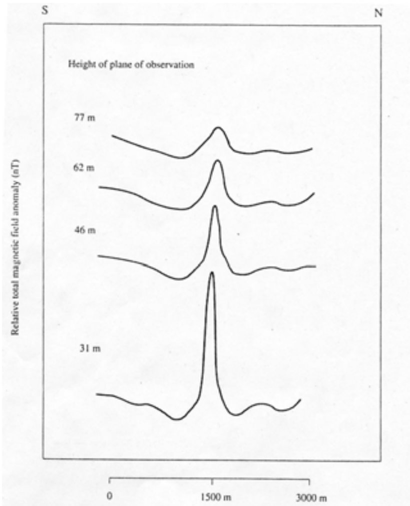


- Buried metal objects can be detected through induced or remnant magnetization

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

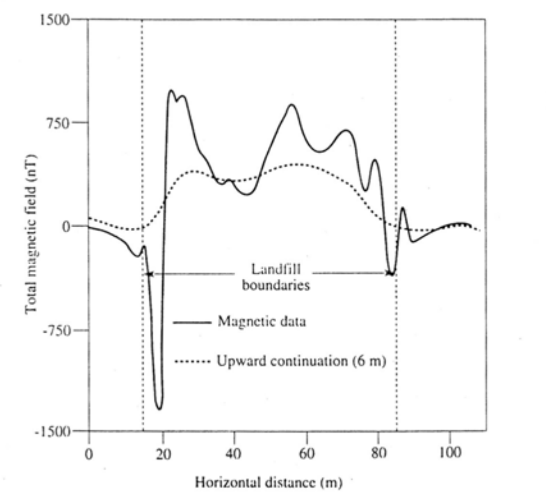
D7.3 Environmental geophysics

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



●locating disused well casings.

●why does the magnitude and shape of the magnetic anomaly change with aircraft elevation?



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

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

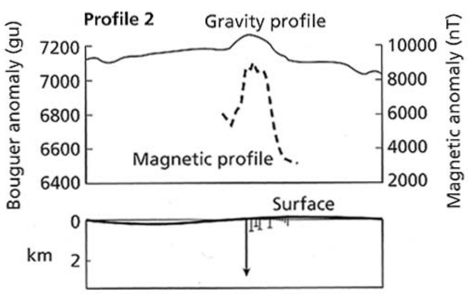
●Why is the upward continued data smoother than the ground level data?

D7.4 Mineral exploration

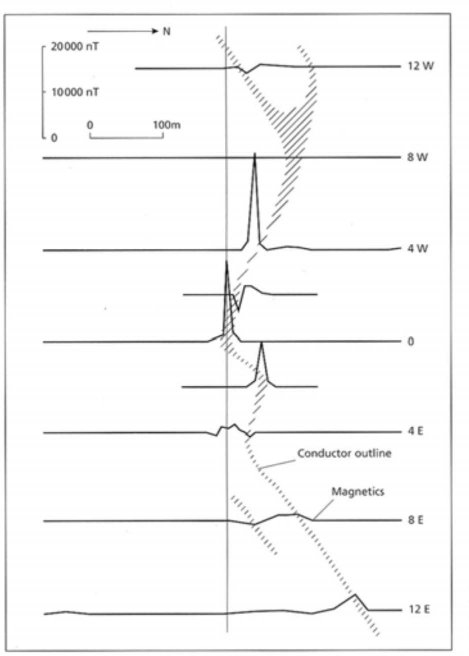
- Iron ore bodies can have a high magnetic susceptibility and may exhibit both induced and remnant magnetization. These anomalies can easily be detected at aircraft elevations and thus aeromagnetic exploration is a good reconnaissance tool for minerals.

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

- Asbestos can be located with magnetic exploration, since it often occurs in ultrabasic intrusive rocks that are rich in magnetite. Example from Matheson, Ontario (*e.g.* Telford page 116).



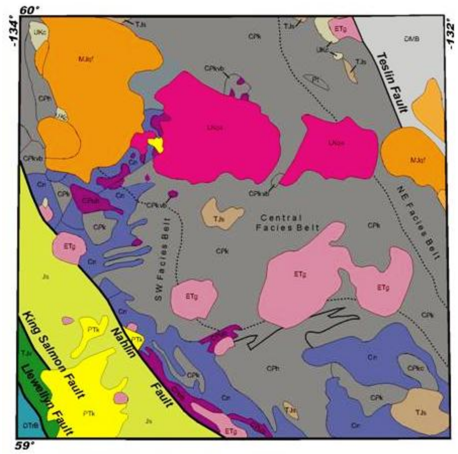
- Combined gravity and magnetic surveys sometimes help define if a magnetic anomaly is a significant ore deposit. How does this work? (Kearey Figure 7-28).

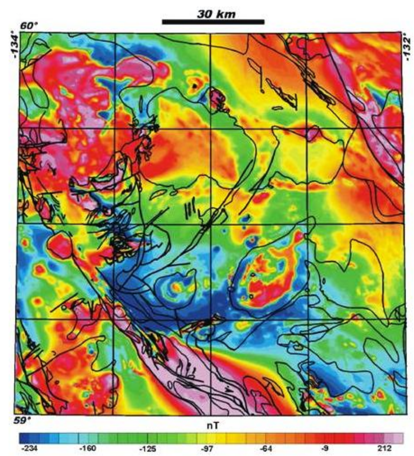


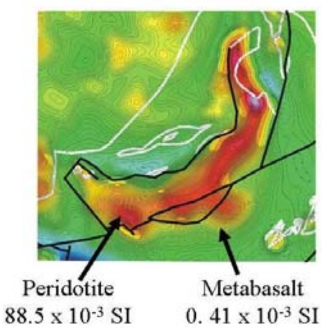
- Example from Quebec (Kearey Figure 7-25). The ore body is also electrically conductive, and detected by a frequency domain electromagnetic survey. More details of this technique will be described in Geophysics 424.

Note that the anomaly is well defined by **two** geophysical surveys (electrical and magnetic).

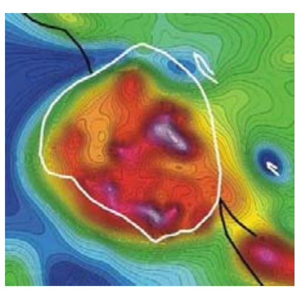
● Examples from the Atlin Geoscience Project, British Columbia. The goal of this project is to develop continued mineral exploration in this historic mining district. Magnetic field data courtesy of Carmel Lowe, Natural Resources Canada, Sidney, B.C.



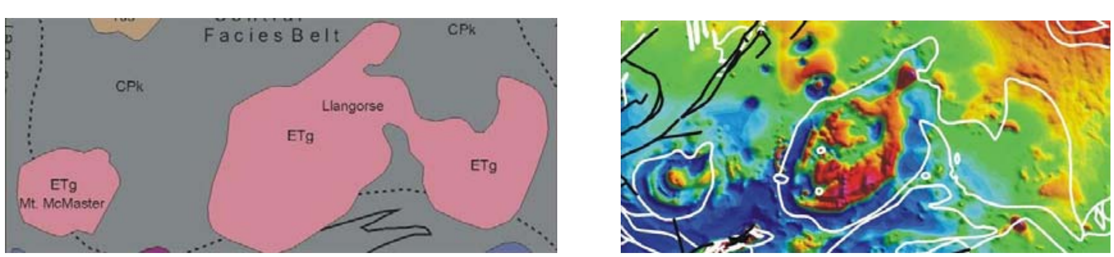




(1) Ultramafic body in Surprise Lake Valley

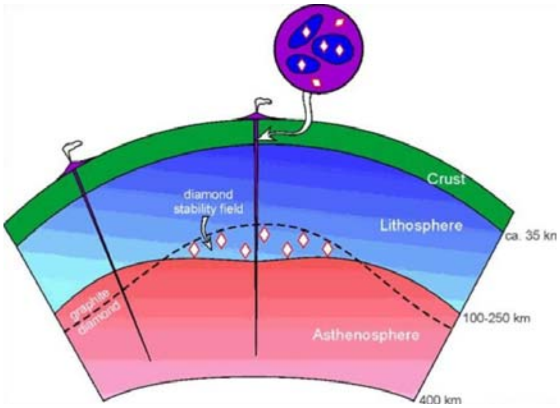


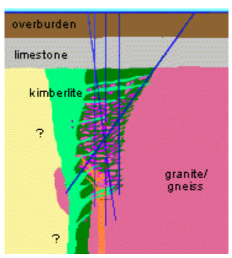
(2) Birch Mountain Pluton



(3) Mapping plutons and their associated mineralization. Previous geological mapping was revised on the basis of this magnetic survey.

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 or below the **diamond stability field**, they can bring diamonds to the surface. Aeromagnetic data are widely used to locate kimberlite pipes.

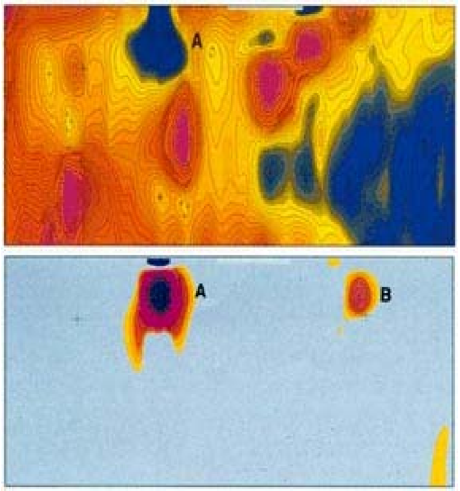
Kimberlite usually contains more magnetite than the host rock in the Slave Province and produces a **positive** magnetic anomaly. However a **negative** magnetic anomaly occurs if: (a) the host rock is more magnetic (contains more magnetite) or (b) the pipe has a (reversed) remnant magnetization. If 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 the top of the pipe is eroded by the ice sheet, a lake forms, also producing a lower resistivity.

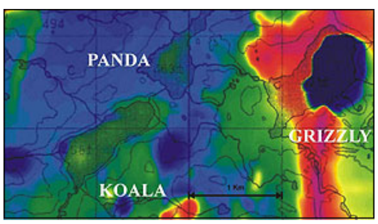
"*Because kimberlite pipes exhibit variable anomalies on both electromagnetic and magnetic data, the best approach to mapping them is to simultaneously collect EM and magnetic data from a low flying platform. The DIGHEM system collects both data sets from a sensor at 30m altitude, sampling about every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

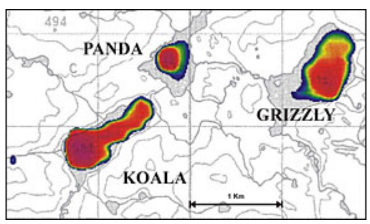
Point Lake Kimberlite, NWT



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)

Ekati Mine, Lac de Gras, NWT





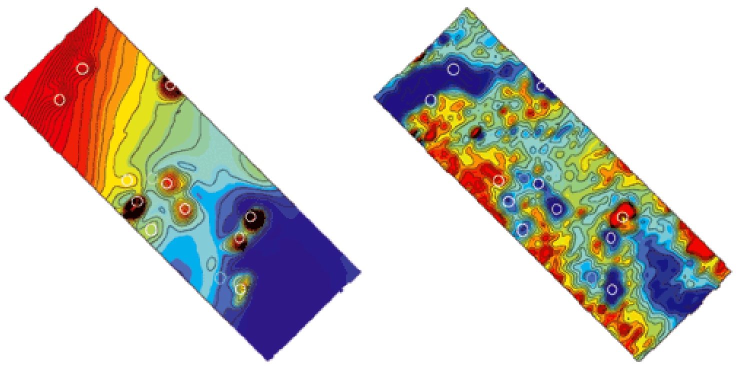
The Ekati Diamond Mine is exploiting five economic kimberlite pipes in the Lac de Gras region of the NWT. The pipes are named Panda, Koala, Misery, Fox and Leslie. BHP Billiton mining operations at the Koala Pipe are shown on the right.

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

Fort à la Corne kimberlites, Saskatchewan

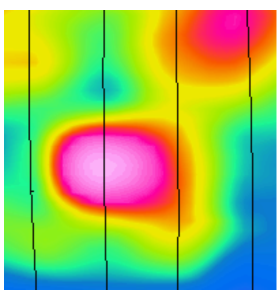


Located beneath 100 m of sedimentary rocks and glacial overburden with no surface expression. Magnetic data are shown on the left and coincident GEOTEM data shown on right.

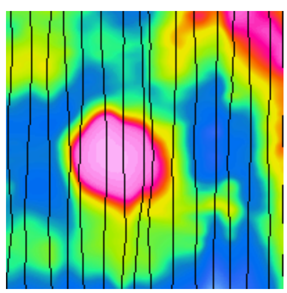
www.fugroairborne.com

James Bay Lowlands Kimberlites

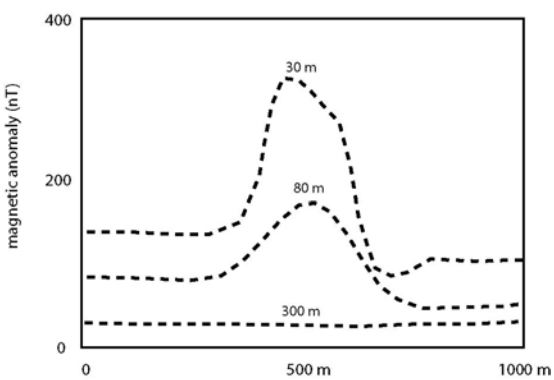
From Hogg and Munro (2000)



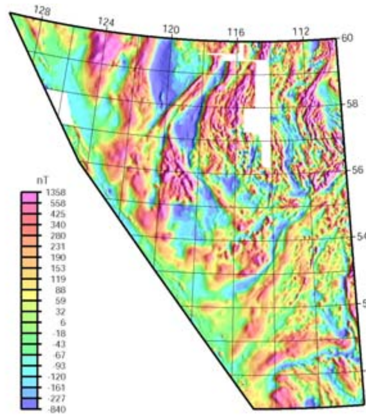
80 m elevation



30 m elevation



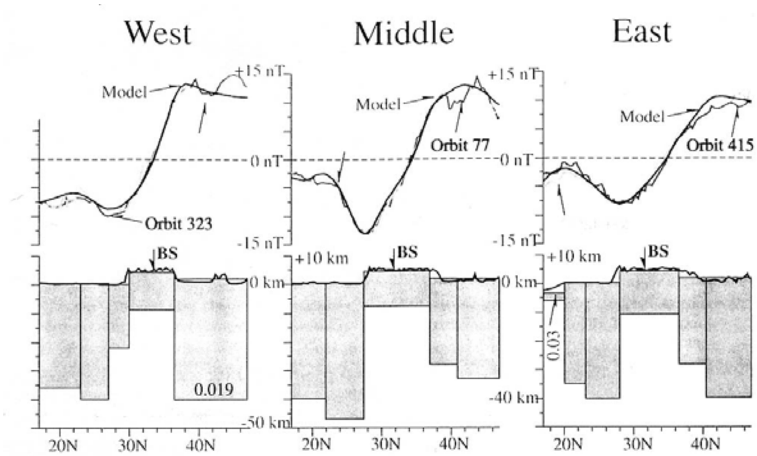
D7.5 Regional crustal structure



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).

Generally, zones of higher magnetic susceptibility correspond to magnetic highs in the aeromagnetic anomaly map. 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 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 magnetic 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?

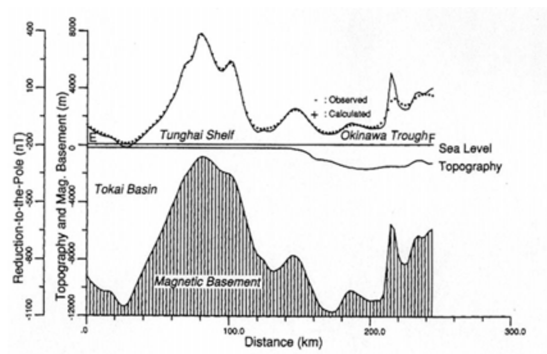
D7.6 Hydrocarbon exploration with magnetic exploration

● A good 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 geological structures that may form source rocks or potential hydrocarbon reservoirs.

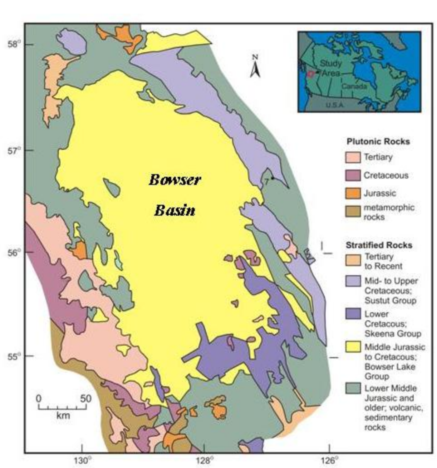
D7.6.1 Thickness and extent of sedimentary basins

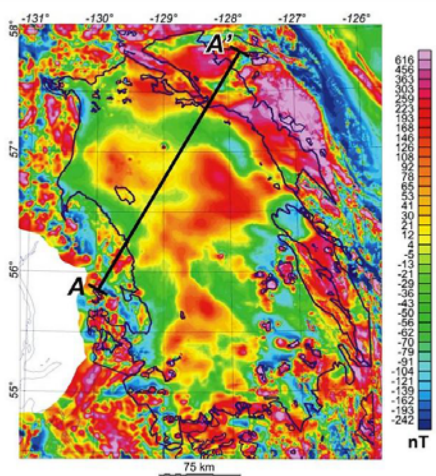
● Magnetic data can be used to define the depth of crystalline (magnetic) basement. This gives information about the overlying sedimentary rocks (depth, location of faults etc)

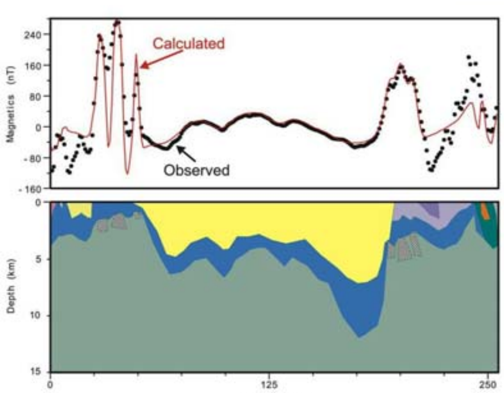
Example: East China Sea, Okuma *et al*, in Gibson and Millegan, 1998, pages 59-62



● *Example*: Bowser Basin in Central BC. Magnetic field data courtesy of Carmel Lowe, Natural Resources Canada.

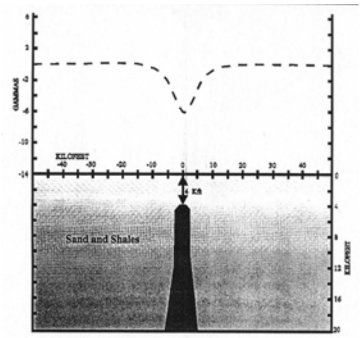






D7.6.2 Geometry of salt structures

- 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



D7.6.3 Direct detection of alteration associated with hydrocarbon seeps

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

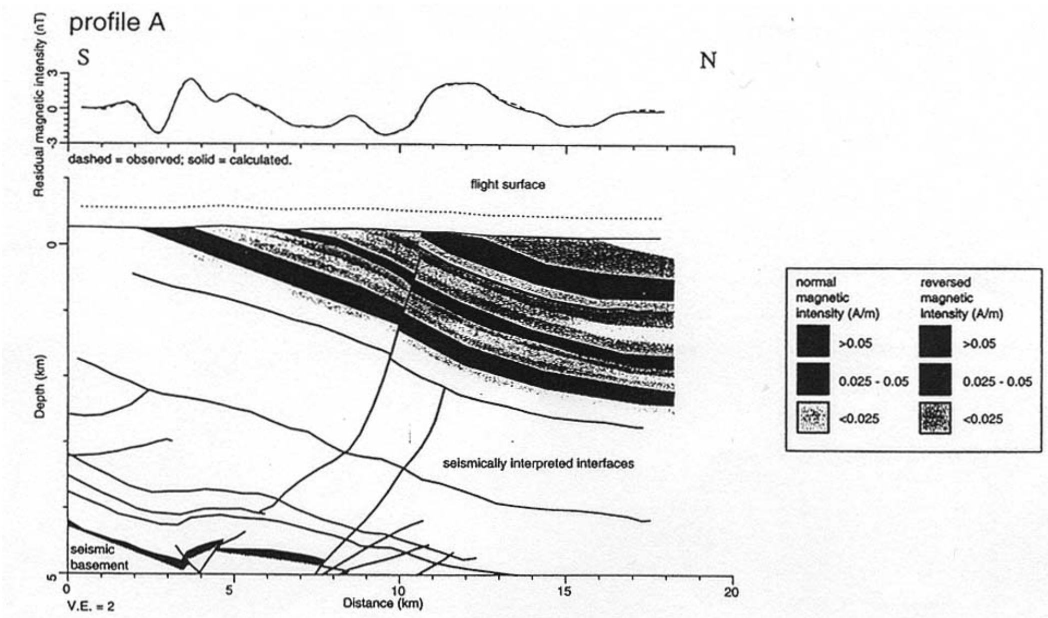
D7.6.4 Structure within sedimentary packages

- 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.

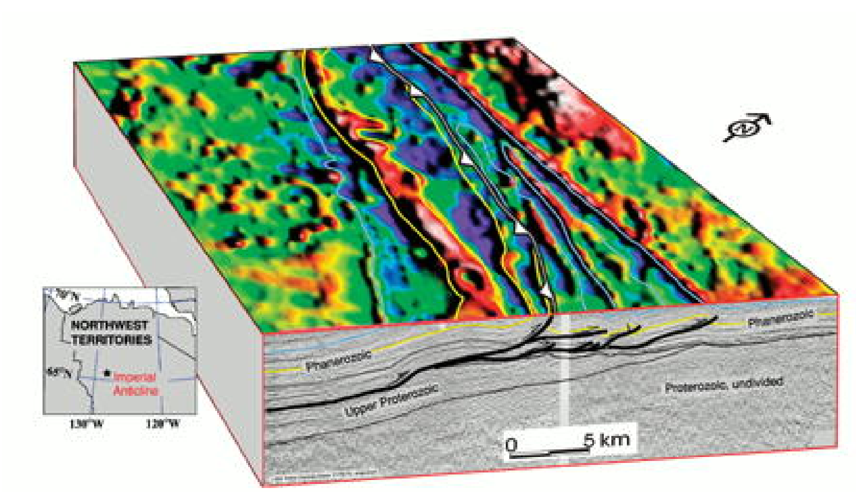
  In **detrital remnant magnetization** (DRM), magnetic mineral grains are oriented by the Earth's magnetic field as they are deposited.

  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.

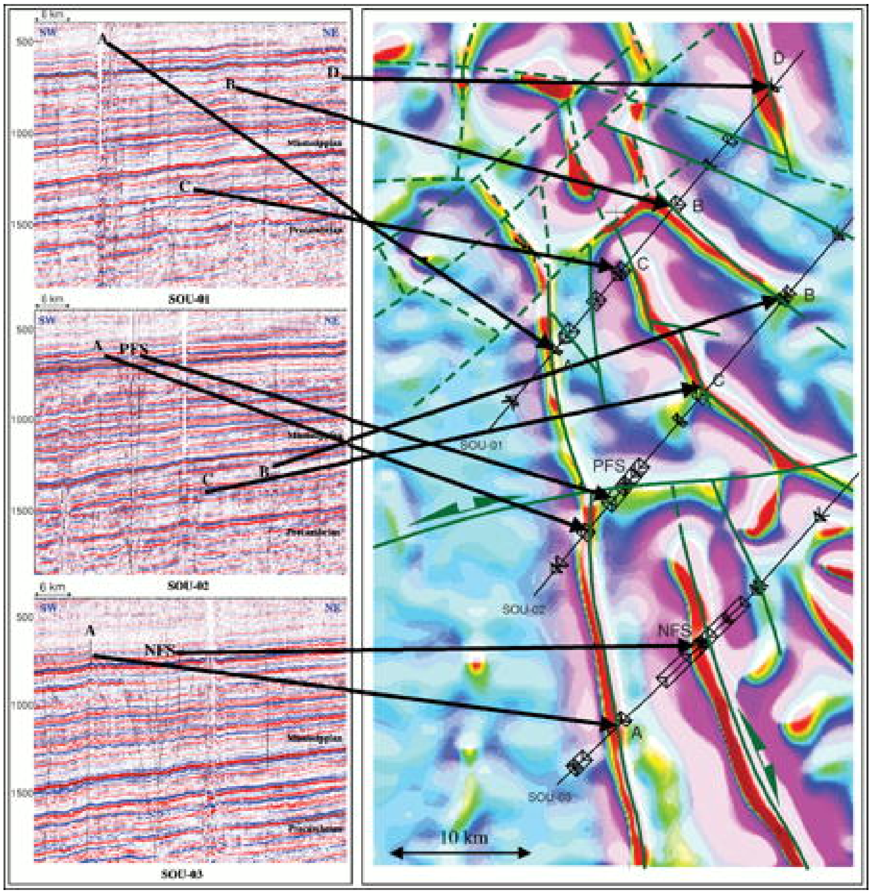


Example : Northern Canadian cordillera, shown in Nabighian et al., Geophysics, (2005)



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

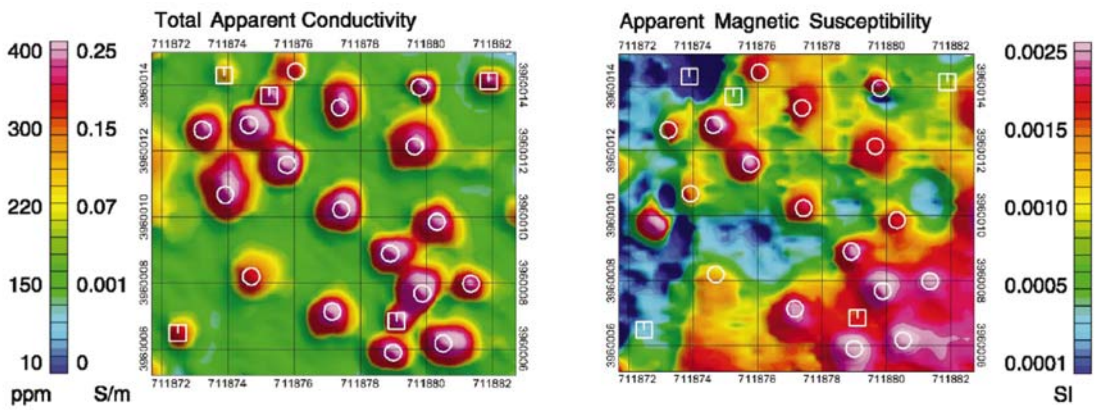
Example : Weyburn carbon dioxide sequestration project, shown in Nabighian et al., Geophysics, (2005). The prescence a sedimentary layer with more magnetite than the background allows faults to be mapped in HRAM data. The seismic data are essential to ground truth the magnetic field data in this case.



D7.7 Detection of unexploded ordinance (UXO)

Magnetic surveys can be used to look for unexploded ordinance (UXO) and for clearing minefields. However magnetic methods are not as effective as electromagnetic (EM) methods in this task for the following reasons:

(1) Not all metal objects are ferromagnetic. Copper and aluminum will not be detected. This is illustrated below in a figure from Huang and Won (2003). This shows magnetic and EM surveys over a test site. Circles show ferrous targets and squares show non-ferrous targets.



(2) Geological noise causes many **false positives** in magnetic surveys for UXO. This is clear in the above figures where there is a lot of background variability in the apparent magnetic susceptibility. In contrast the background apparent conductivity is quite uniform.

(3) Magnetic field data has very **little sensitivity to the shape** of a buried object. The shape is invaluable in determining the nature of the target (e.g. shell, mine, bomb etc)

For a broader view of the role of shallow geophysics in weapons inspections, see the article by Won et al (2004) in The Leading Edge.

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