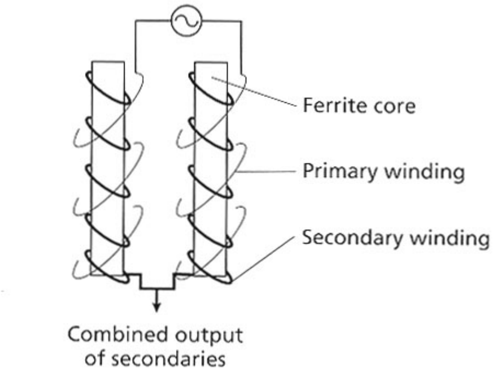
325 D5 Instrumentation and data collection techniques

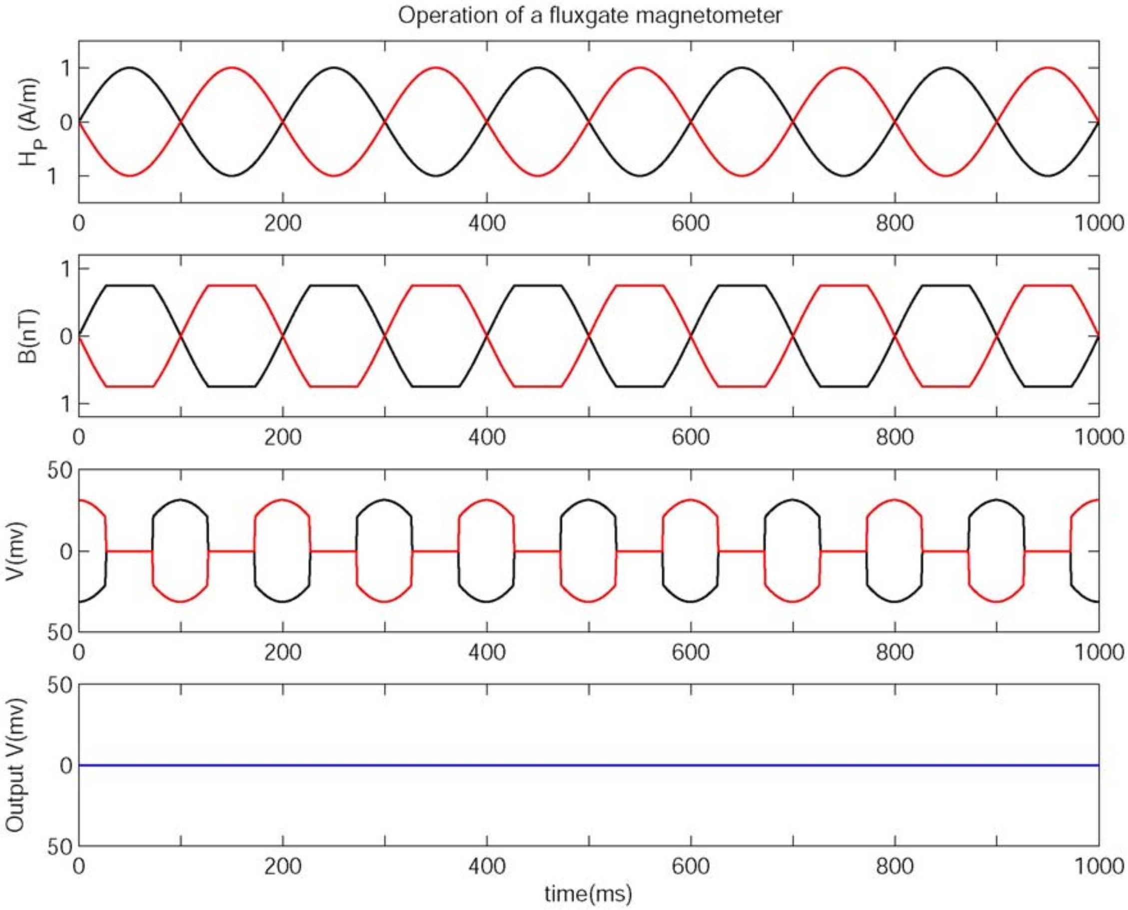
D5.1.1 Flux gate magnetometer

Telford p.75-76

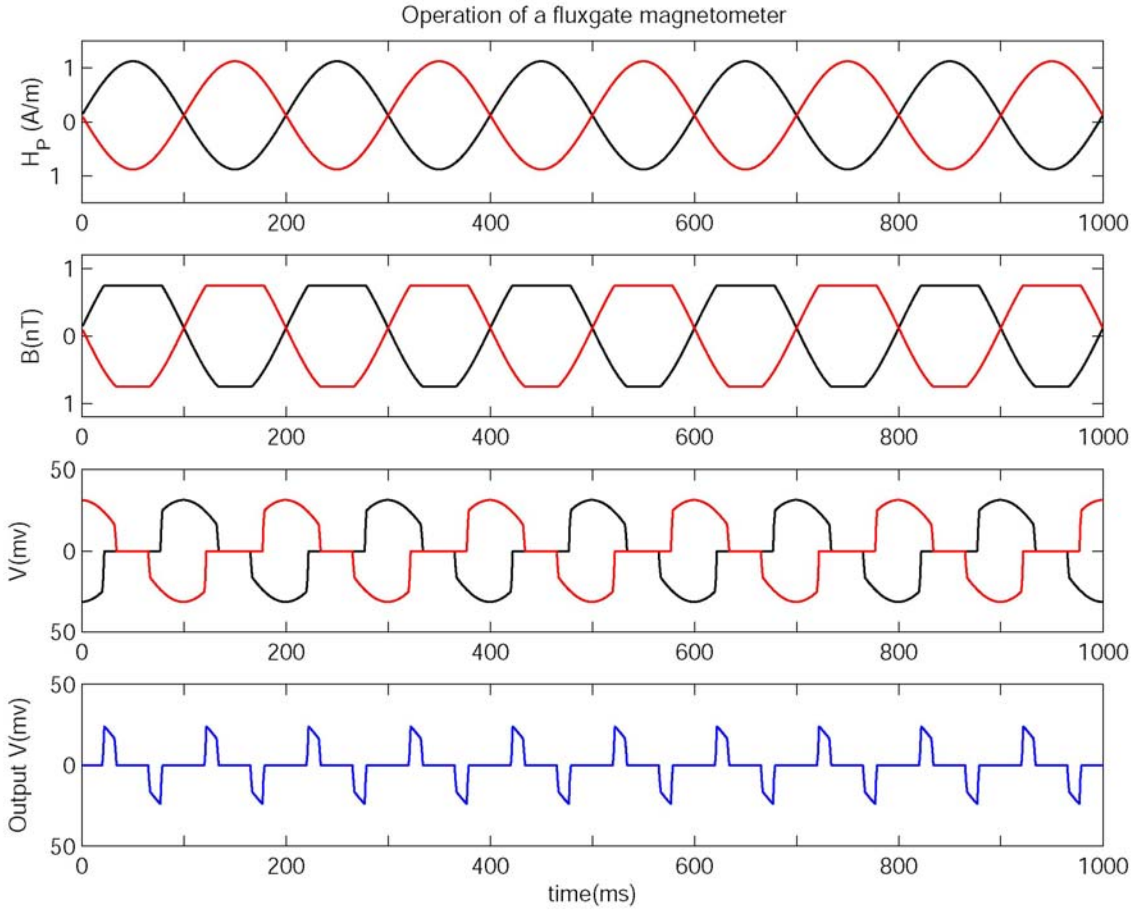


The primary windings magnetize the two magnetic (ferrite) cores, in opposite spatial directions (one up and the other down). The cores are made of a highly permeable magnetic material that **saturates** during each oscillation of the primary magnetic field (H_P). This can be seen in the plot of B where the tops and bottoms of the sine curve have been flattened.

The secondary windings detect the effect of the flux density (B) in each core through the voltage (V) induced by the changing magnetic flux. This occurs through electromagnetic induction. In the case shown below, there is no external magnetic field and the output from the left and right cores cancels exactly. Thus the total **output** voltage is zero.



When an external magnetic field is present, this symmetry is broken. In this case the cores saturates earlier in each cycle when a positive H_P is applied. The voltages in the secondary windings do not cancel and a set of output voltage pulses is detected.

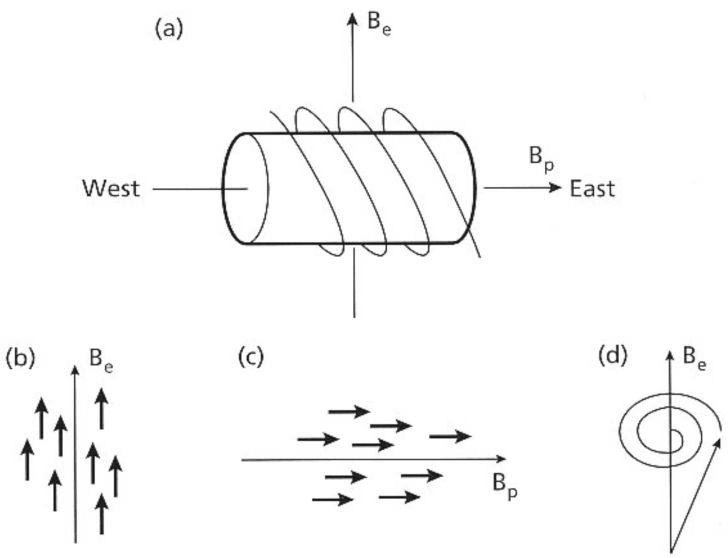


It can be shown that the magnitude of the voltages pulses is proportional to the applied (external) magnetic field.

Note that a fluxgate magnetometer measures the magnetic field **component** parallel to the axes of the cores.

D5.1.2 Proton precession magnetometer

Telford p.77-78



This instrument uses a cylinder shaped bottle of protons. These protons can be conveniently found in paraffin or other hydrocarbons. The protons have a small magnetic moment and are naturally aligned with the Earth's magnetic field (B_e) as shown in (b). When a stronger magnetic field (B_p) is applied, the protons will be aligned in this new direction (c). When the applied magnetic field is removed (d) the protons re-align with the Earth's magnetic field. As they re-align, they **precess** around the direction of B_p and emit low frequency radio signals. The Larmor precesion frequency of these signals is proportional to the strength of the magnetic field.

Note that:

- The proton precession magnetometer measures the **total magnetic field** (not individual components). This has the advantage that the sensor does not need to be oriented prior to measurements being made. This allows a magnetometer to be placed in a bird that is towed behind an aircraft or in a moving backpack.

- Axis of the cylinder should not be exactly parallel to the Earth's magnetic field.

- Power lines can interfere with the operation of the magnetometer, since they also emit low frequency EM signals.

- This measurement technique is quite similar to NMR in chemistry.

D5.1.3 Alkali vapour magnetometer

- These magnetometers use **changes in the frequency splitting** of optical spectral lines of elements such as rubidium, caesium or potassium to measure the magnetic field. This is governed by the Zeeman effect.

- Typically measure 10 times per second with precision of 0.01 nT or lower.

- Now the most widely used magnetometer in airborne surveys.

- Errors in survey limited by positioning errors rather than magnetic field measurements.

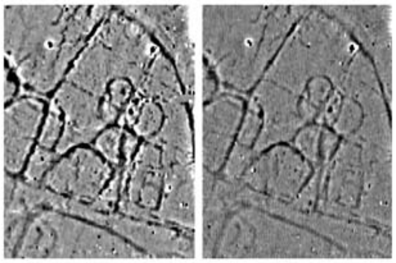
- Typical HRAM (High resolution aeromagnetic surveys) use these instruments. Elevation is 40-80 m and line spacing 200-500 m. This has allowed aeromagnetic exploration to be used in studies of the subtle magnetic anomalies generated by sedimentary rocks with small (but variable) magnetite contents. See examples in D6 from North Slope of Alaska, Canadian Cordillera and Weyburn, Saskatchewan. Example from Finland below.

D5.1.4 Magnetic gradiometers

- By placing one magnetometer above another, the vertical gradient of the magnetic field (dF/dz) can be measured. The high precision of modern instruments means the spacing only needs to be 1-2 m. This has several advantages

- By computing (dF/dz)/F, temporal variations in the external magnetic field can be effectively removed from the data. This is illustrated in the data example below (panel f), and this provides an alternative way to remove time variations (if the base station fails!)

- dF/dz can be more sensitive to dipole anomalies in the Earth than long wavelength features in the regional magnetic field.



1m gradiometer 0.5m gradiometer

D5.2 Field techniques

D5.2.1 Ground-based magnetic surveys

- Typically use a proton precession magnetometer (~ 1nT sensitivity)
- The operator must be liberated of all metal objects (especially their keys and money!)
- Survey is made along a profile or grid. Crossovers allow the internal consistency of the data to be evaluated.
- Locate profiles with surveying, or better to use an instrument with integrated GPS such as the one illustrated above.

Time corrections

In section D3 we saw that changes in the Earth's magnetic field occur with timescales of minutes, hours and days. This clearly complicates magnetic exploration. Suppose that as a magnetometer is moved along a survey line, and the measurements change with position. How can we tell if this is due to a magnetic body in the Earth below, or due to oscillations in the magnetosphere?

A simple solution

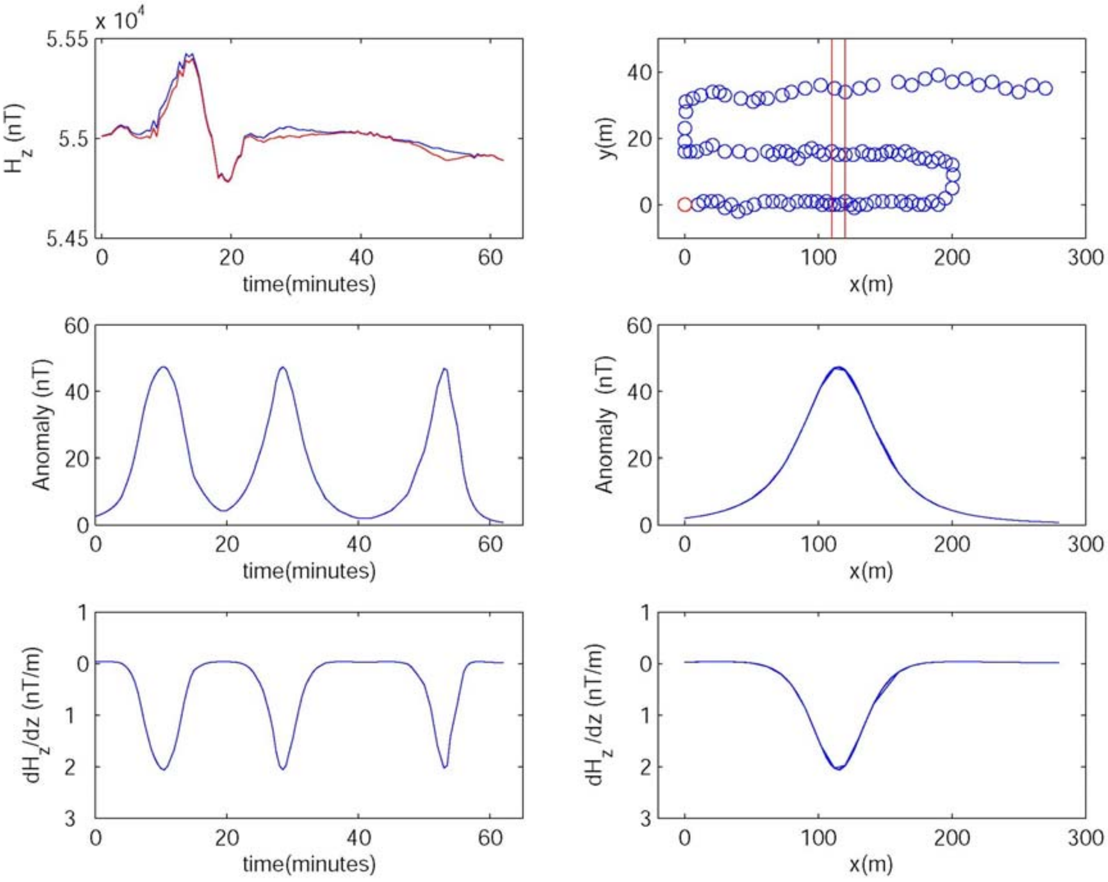
Choose a reference (base) station in the survey area and return to this location at least once per hour to check for temporal variations. During a magnetic storm, this may not be enough as the magnetic field changes very quickly. This is especially true in high magnetic latitudes.

A much better solution

A much better option is to leave a second magnetometer at the base station in a continuous recording mode. In the figure below the **red line** shows magnetic field data at the fixed base station and the **blue line** shows data measured by the moving magnetometer.

Between 10 and 20 minutes a significant change in the magnetic field is observed. Is this a major ore body, or simply a small geomagnetic signal from activity in the magnetosphere?

After the magnetic data has been collected, the difference between the base station and the moving station can be computed. This is labeled as the **anomaly** in the figure below.



Note that the survey crosses the anomaly three times, but with the operator walking at different speeds. When plotted with time on the horizontal axis, this gives the impression that the anomaly has different widths. However, when plotted with distance on the horizontal scale, the three anomalies are identical.

Instrument drift

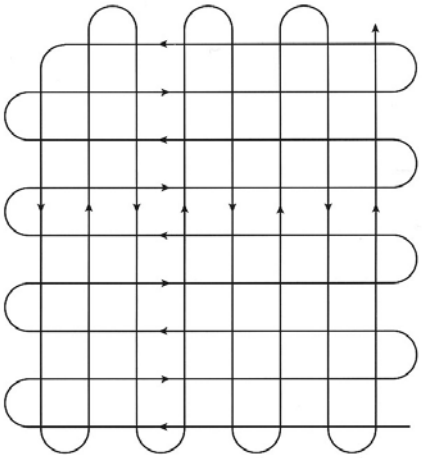
- Instrument drift is not a serious problem in magnetic surveys (this is quite different to the situation in gravity exploration. Why?)

Spatial corrections

- It is possible to correct for latitude and elevation but these corrections are generally smaller than typical magnetic field anomalies. They are only important if the survey has a large spatial extent.

- The effect of topography can be important, such as when measurements are made in a narrow valley or canyon.

D5.2.2 Aeromagnetic surveys



- Profiles flown with line spacing 100 m to several kilometers. Elevation is typically 100-1000 m

- Alkali vapour magnetometer is used with accuracy as low as 0.01 nT

- Continuous recording base station used to remove temporal variations.

- Cross lines used as internal check that these effects have been consistently removed.

- Need to use a special non-magnetic aircraft (left) or put the magnetic sensor in a towed bird (centre).

- Flight path can be located with radar, altimeter or by taking aerial photos. GPS now makes this much more accurate and simpler.

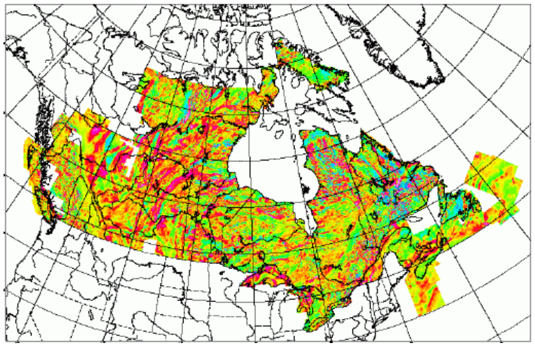
- Magnetic field data is usually corrected to a common elevation with upward or downward continuation.

- In areas with significant topography, **draped surveys** can be flown at constant elevation above the surface (need helicopter in steep terrain)

- With total field measurements the motion of the aircraft or bird is not serious

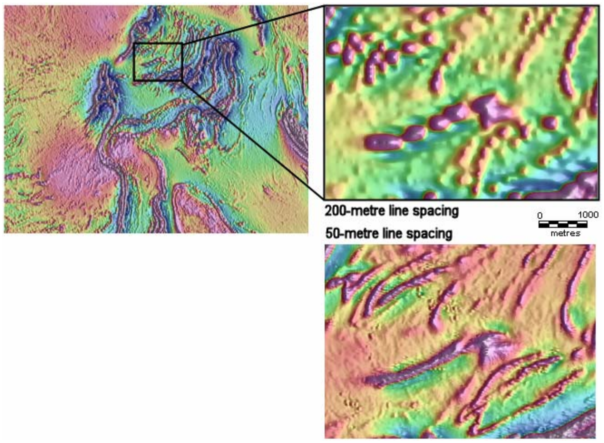
- Gives rapid coverage and works well in areas where access is difficult on ground (both in remote wilderness areas or urban environment)

- Magnetometer is further from target than in ground surveys, so lower sensitivity to small (but still economic) ore deposits.



- The magnetometer is further from target than in ground surveys, so the sensitivity is slightly lower. However, with alkali vapour magnetometers small ore deposits and features in sedimentary rocks can be mapped..

- High resolution aeromagnetic (HRAM) surveys are now the standard field technique and use a **dense line spacing** and **low flight elevation** to give detailed information about subtle, sub-nanotesla magnetic field anomalies. Examples from Geological Survey of Finland at *http://www.gsf.fi/aerogeo/eng0.htm*



D5.2.3 Marine magnetic surveys

- The proton precession magnetometer needs to be as far from a metal ship as possible. This is usually in a plastic fish that is towed behind the ship.

- Marine surveying is slower and more expensive than airborne surveying, so not widely used in commercial offshore exploration.

- However, magnetometers are routinely towed behind survey ships and have revealed many details of the structure of ocean basins (*e.g.* magnetic stripes produced by seafloor spreading)