52 West Beaver Creek Road, Unit 14
Richmond Hill, ON CANADA L4B 1L9
Tel: 905-764-8008 Fax: 905-764-2949
Email: info@gemsys.on.ca
Web: www.gemsys.ca

Advantages of Magnetic Gradiometers

Gradiometers have shown that they can offer a high degree of immunity from diurnal and minor magnetic storm activity in the ambient magnetic field; they can enhance near-surface, small or weakly magnetic anomalies; and they can provide obvious improvements in spatial resolution over the total field measurement alone.

A gradiometer is ideal for locating small, near surface anomalies, and is therefore very useful in archeological, geotechnical and environmental mapping. A further advantage is that a vertical gradiometer may be deployed without a base station magnetometer, as this component of the magnetic field is normally free of diurnal variations.

One of the sensors used for the gradient measurement also can be used to obtain total field data - providing a complete set of data for analysis and interpretation.

Small Target Detection

It is appropriate to introduce the idea of the anomaly frequency spectrum as it pertains to the search for small or weak magnetic targets. When surveying the magnetic field in high gradient areas, the low frequency component or long wavelength anomalies caused by the juxtaposition of magnetic surface and sub-surface geology can often overpower and obscure the subtle response due to small or weakly magnetic targets.

When producing a calculated vertical gradient map, low and mid-range frequency components can be replicated well, but the high frequency component is often filtered out because of its proximity to the noise envelope and therefore the small or weakly magnetic targets are often eliminated.

The gradiometer has much greater spatial resolving power compared to the single sensor, total field magnetometer, making it an ideal tool for locating small targets. However, a gradiometer requires two or more sensors with extremely high sensitivity and stability.

The Overhauser magnetometer is an excellent choice, not only because of its high sensitivity (0.015 nT/√Hz). Other advantages are the absolute value of the proton precession measurement and the inherent stability of the counting mechanisms.

52 West Beaver Creek Road, Unit 14
Richmond Hill, ON CANADA L4B 1L9
Tel: 905-764-8008 Fax: 905-764-2949
Email: info@gemsys.on.ca
Web: www.gemsys.ca

Time-Varying Effects

Another problem encountered when just measuring total field are the micropulsations and variations in the field caused by transient magnetic effects originating outside the earth's field (such as sunspot activity). The micropulsation magnitude and interval can sometimes be comparable to an anomaly produced by a small target - giving a clear possibility for error.

We can use a base station magnetometer to record the time variations in the magnetic field. These can be subtracted from the results produced by the survey magnetometer during post processing. In this instance, the sensor with the fixed position would, in effect, record only the time variations caused by the super imposed, short-term micropulsations, in addition to the daily diurnal pattern. Another method is to use a base station network to correct the survey results.

Whether base stations or tie lines are used, the correction process assumes that linear variation of the magnetic field has taken place between correction points on the network. Time variations in the magnetic field rarely approach linearity, particularly at higher latitudes.

The use of vertical gradiometers for magnetic mapping effectively removes the time variations in the magnetic field map without having to establish base stations, networks or tie lines and is the only insurance against elimination of the high frequency component that contains the small or weakly magnetic targets.

Resolution and Geological Significance

An advantage of gradient measurements, arising from the ambiguity present in all potential field measurements, is the suppression of broad regional changes in the magnitude of the magnetic field - the long wavelength component. With gradiometer measurements, the local variations are enhanced, making small and weakly magnetic targets recognizable. Gradiometer surveys are particularly useful in areas that are geologically complex.

In sedimentary environments, the short wavelength component of the data is usually of low power reflecting a few small targets and minor changes in magnetic susceptibly within the sedimentary section. In some environments, particularly in areas that have experienced sour gas migration, interaction of the sour gas with trace elements within the sediments often leads to magnetite formation.

Because the sour gas migrates along permeable areas, such as faults, small amounts of magnetite are preferentially formed along fault zones, and, therefore, these zones will produce weak magnetic anomalies. The magnetic gradiometer is useful in these areas as a tool for mapping these weak anomalies, and thus directly mapping faults, and other porous structures within the sedimentary section.

52 West Beaver Creek Road, Unit 14
Richmond Hill, ON CANADA L4B 1L9
Tel: 905-764-8008 Fax: 905-764-2949
Email: info@gemsys.on.ca
Web: www.gemsys.ca

Simultaneously, the total field data may be used to map depth to basement and basement magnetic structure and lithology.

Cultural Mapping

Mapping or searching for buried ferrous objects usually involves small or weakly magnetic target identification. The gradient measurement is a helpful tool because gradient anomalies have an inherently greater spatial resolution than the total field. The following approximations can be quite helpful in quickly estimating the depth to a target or, conversely, for calculating the sensitivity requirement for the gradiometer.

Total field Approximation | Gradient Approximation

$$T \cong \frac{M}{z^3} \quad \text{(dipolar source)} \qquad \frac{dT}{dz} \cong \frac{-3M}{z^4} \cong \frac{-3T}{z}$$

$$T \cong \frac{M}{z^2} \quad \text{(monopolar source)} \qquad \frac{dT}{dz} \cong \frac{-2M}{z^3} \cong \frac{-2T}{z}$$

where T is the total field residual amplitude of the target, M is the magnetic moment (I_I x k, induced field in nT x magnetic susceptibility contrast per unit volume - ignoring the remnant magnetic component), and z is the depth to the source.

The advantage of knowing these equations is that the depth to a magnetic source can be predicted simply through measurement of the total field and gradient (i.e. without knowing the physical properties of the target).

Note:

Using Total Field Amplitudes, horizontal pipes have a half width rule in near vertical magnetic fields of $Z = 2X_{1/2}$ and vertical pipes have a half width rule in near vertical fields of $Z = 1.3X_{1/2}$. The value of half the X distance at half the amplitude is a rule of thumb that is handy for estimating the depth from the shape of the Total Field Anomaly.

Vertical pipes can be considered monopoles and horizontal pipes, a line of dipoles that is a “monopole like” field if the magnetic field is at a high angle and can be represented by modifying the above Total Field Approximations to:

52 West Beaver Creek Road, Unit 14
Richmond Hill, ON CANADA L4B 1L9
Tel: 905-764-8008 Fax: 905-764-2949
Email: info@gemsys.on.ca
Web: www.gemsys.ca

Vertical Pipe: $$T \cong \frac{M}{z^2} \cong \frac{kIA}{z^2} \cong \frac{kI\pi Dt}{z^2}; \quad \frac{dT}{dz} \cong \frac{-2T}{z} \cong \frac{-2kI\pi Dt}{z}$$

Horizontal Pipe: $$T \cong \frac{M}{z^2} \cong \frac{2kIA}{z^2} \cong \frac{2kI\pi Dt}{z^2}; \quad \frac{dT}{dz} \cong \frac{-2T}{z} \cong \frac{-2kI\pi Dt}{z}$$

where D is the pipe diameter and t represents the wall thickness.

The magnetic susceptibility of pipe depends on the hardness of the steel, which when in a non-oxidized condition, is usually between 5 and 50 cgs units or higher.

EXAMPLE:

We are searching for buried pipe, which has a 15.24 cm in diameter with an average depth of 5 meters to the middle of the pipe from the mid point of the two vertical sensors, in a 50,000 nT field. The pipe has a wall thickness of 0.635 cm.

The amplitude of the horizontal pipe anomaly will be 60 nT and that of the vertical pipe, 30 nT.

Depth (m)	Suscpt (CGS)	Vertical (nT) Pipe ($1/r^2$)	dT/dz (nT)/m V Pipe (1/r) (peak to peak)	Horizonal (nT) Pipe ($2/r^2$)	dT/dz (nT)/m H Pipe (1/r) (peak to peak)	Vertical ($X_{1/2}$) (m)	Horizontal ($X_{1/2}$) (m)
1	5	760	1520	1520	3040	0.77	0.5
2	5	380	380	740	740	1.54	1.0
5	5	30	12	60	24	3.85	2.5
10	5	7.6	1.52	15.2	3.04	7.69	5.0
20	5	3.8	0.38	7.4	0.74	15.38	10.0

The table indicates that the vertical pipe has a slightly broader total field anomaly than the horizontal pipe for a given depth - but half the amplitude. In reality, each section of pipe will have a different remnant magnetic component. Therefore, caution must be exercised when interpreting the results. Sign reversals over well stems are not uncommon.

52 West Beaver Creek Road, Unit 14
Richmond Hill, ON CANADA L4B 1L9
Tel: 905-764-8008 Fax: 905-764-2949
Email: info@gemsys.on.ca
Web: www.gemsys.ca

Selected Bibliography

Goh, Rocque, 1972, A Marine Magnetic Survey in the Mackenzie Bay / Beaufort Sea Area, Arctic Canada; M.Sc. Thesis, Department of Geophysics, The University of British Columbia, Vancouver B.C., Canada.

Grant, F.S. and West, G.F., 1965, Interpretation Theory in Applied Geophysics, McGraw-Hill Book Company.

Reford, M.S., 1964, Magnetic Anomalies Over Thin Sheets: Geophysics, V. 29, pp. 532-536

Breiner, S, 1973, Applications Manual for Portable Magnetometers: Geometrics, p. 58.