AIRBORNE AND GROUND MAGNETICS

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1. OVERVIEW

Magnetics is a geophysical survey technique that exploits the considerable differences in the magnetic properties of minerals with the ultimate objective of characterising the Earth's sub-surface.

The technique requires the **acquisition** (Horsfall, 1997) of measurements of the amplitude of the **magnetic field** at discrete points along survey lines distributed regularly throughout the area of interest.

The magnetic field, whose amplitude is measured, is the vector sum of;

1. the Earth's **main field** which originates from dynamo action of conductive fluids in the Earth's deep interior (Merrill, et al., 1996);
2. an **induced field** caused by magnetic induction in magnetically susceptible earth materials polarised by the main field (Doell and Cox, 1967);
3. a field caused by **remanent magnetism** of earth materials (Doell and Cox, 1967); and,
4. other (usually) less significant fields caused by solar, atmospheric (Telford, et al., 1976) and cultural influences.

It is the induced and remanent fields that are of particular interest to the regolith geoscientist because the magnitudes of these fields are directly related to the **magnetic susceptibility,** spatial distribution and concentration of the local crustal materials. Fortunately only a few minerals occur abundantly enough in nature to make a significant contribution to the induced and remanent fields. The most important of these is magnetite and to a lesser extent ilmenite and pyrrhotite (Clarke, 1997, Telford, et al., 1976).

Once the main field and the minor source effects are removed from the observed magnetic field data via various **data reduction and processing** methods (Luyendyk, 1997), the processed data serve as an indicator of the spatial distribution and concentration of the magnetically significant minerals. At this point the data are **enhanced and presented** (Milligan and Gunn, 1997) in readiness for their analysis. Most importantly the analysis ultimately leads to an **interpretation** (Gunn, et al., 1997a, Mackey, et al., 2000) of structure, lithology, alteration, regolith and sedimentary processes, amongst many other factors.

The geological ingredients that can be interpreted from magnetic surveys are those that influence the spatial distribution, volume and concentration of the magnetically significant minerals. It is important to realise that the magnetic data serve only as an indicator because it is generally not possible to ascertain a definitive, unambiguous and direct lithological or structural interpretation.

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2. DATA ACQUISITION

General

The magnetic field is usually measured with a total field magnetometer. The most common instrument in use today is the caesium vapour magnetometer. Observations are made at regular intervals (generally between 1 to 7 metres) along a series of **traverse lines** of constant azimuth and spacing. Observations are similarly made along **tie lines** oriented perpendicular to the traverse lines. Tie lines are necessary to assist in the removal of temporal variations in the main field. Tie lines are usually spaced ten times further apart than traverse lines.

Data may be acquired close to ground level (ground magnetics) either via a person carrying a magnetometer or with a magnetometer mounted on a motor vehicle such as a quad motorcycle or four-wheel drive. Alternatively airborne magnetics (aeromagnetics) can be acquired via mounting the magnetometer on a fixed wing aircraft or a helicopter. Fixed wing acquisition is preferred due to the lower cost, however helicopters are necessary where the terrain is rugged.

While data are being collected along the survey lines a **base station magnetometer** also measures the magnetic field at a stationary point. These data serve as an estimate of the temporal variation of the main field, which is subtracted from the survey data. The base station magnetometer is also used to identify **magnetic storm** events (where the magnetic field is varying rapidly due to disturbances in the ionosphere/magnetosphere). On such occasions data acquisition is suspended (or data re-acquired) because the estimate of the temporal variation is less accurate at a distance from the base station.

2.2 Survey design

Survey specifications are normally determined by consideration of several factors. Some specifications are discussed below.

1. A trade off between cost and the required detail determines the traverse line spacing – smaller line spacing equates to higher cost but also higher resolution. The distribution and shape of the magnetic sources to be mapped is important. Since narrow features have narrow anomalies they may not be resolved if the line spacing is too coarse. Conversely, deeper sources have broader anomalies (though more subtle), accordingly it is not always necessary to use a fine line spacing if the sources are deep. Common airborne traverse line spacings in use today range from 400m in regional mapping programs through to 200 m, 100 m and down to 50 m for detailed mapping projects at prospect scale. Finer lines spacing (down to 20 m) are sometimes employed in special circumstances. Ground magnetic surveys usually have traverse line spacings from 25 to 50 metres. Finer spacings are also possible if necessary.

2. Maximum information is extracted when survey lines are oriented perpendicular to the geological strike (or at least to the structures of most interest).

3. Flying height is always ultimately determined on the basis of safety. The main factors affecting the safety of a particular flying height is the ruggedness of the terrain and the climbing capability of the aircraft. Other than the safety factor it is generally best to carry out surveys at a constant, and lowest possible, terrain clearance. However, due to the difficulty of processing, and interpreting data acquired at highly variable clearances, it is better to choose a flying height that the aircraft can comfortably maintain rather than a height that is difficult to maintain and results in significant variation in flying height. Flying height and line spacing are often considered linked to the extent that it is desirable to have lower flying heights with finer line spacings. This is to maintain better spatial resolution of anomalies along flight lines to reflect the better resolution between flight lines. Standard combinations of line spacing and flying height are 400 m/80 m, 200 m/60 m, 100 m/60 m and 50 m/40 m.

3. DATA REDUCTION AND PROCESSING

Data reduction and processing is the series of steps taken to remove both signal and spurious noise from the data that are not related to the geology of Earth's crust. This process thereby prepares the dataset for interpretation by reducing the data to only contain signal relevant to the task. These steps are summarised below.

1. **Magnetic compensation** removes the influence of the magnetic signature (remanent, induced and electrical) of the aircraft on the recorded data. This is often done in real time on-board the aircraft.

2. **Data checking and editing** involves the removal of spurious noise and spikes from the data. Such noise can be caused by cultural influences such as powerlines, metallic structures, radio transmissions, fences and various other factors. This step will ideally include systematic and detailed viewing of all data in graphical profile form to ensure instrumental and compensation noise is within tolerance.

3. **Diurnal removal** corrects for the temporal variation of the earth's main field. This is achieved by subtracting the time-synchronised signal, recorded at a stationary base magnetometer, from the survey data. This procedure relies on the assumption that the temporal variation of the main field is the same at the base station and in the survey area. Best results are obtained if the base station is close to the survey area, the diurnal variation is small and smooth and electromagnetic induction effects are minimal (Lilley, 1982, Milligan, 1995).
4. **Geomagnetic reference field removal** removes the strong influence of the earth's main field on the survey data. This is done because the main field is dominantly influenced by dynamo action in the core and not related to the geology of the (upper) crust. This is achieved by subtracting a model of the main field from the survey data. The Australian or International Geomagnetic Reference Field (AGRF or IGRF) is generally used for this purpose. This model accounts for both the spatial and long period (>3 year) temporal variation (secular variation) of the main field (Lewis, 2000).
5. **Tie line levelling** utilises the additional data recorded on tie lines to further adjust the data by consideration of the observation that, after the above reductions are made, data recorded at intersections (crossover points) of traverse and tie lines should be equal. Several techniques exist for making these adjustments. Luyendyk (1997) gives a detailed account of the commonly used techniques. The most significant cause of these errors is usually inadequate diurnal removal because of the assumptions stated above.
6. **Micro-levelling** is used to remove any errors remaining after the above adjustments are applied. These are usually very subtle errors caused by variations in terrain clearance or elevated diurnal activity. Such errors manifest themselves in the data as anomalies elongate in the traverse line direction. Accordingly they can usually be successfully removed with directional spatial filtering techniques (eg. Minty, 1991).

4. GRIDDING

Data are recorded along traverse lines that are never perfectly straight or equally spaced and the sampling rate along the lines is much denser than across the lines. It is usually desirable to interpolate these data (profile data) onto a regular lattice or grid. This procedure is known as gridding and permits further algorithms and image processing techniques to be applied to the processed data. Several gridding techniques are commonly used (eg. Briggs, 1974, Fitzgerald, et al., 1997).

In most cases the data are interpolated onto a grid with a cell size of one fifth or one quarter of the line spacing. It is important to note that in the vast majority of cases, gridded data do not contain the full information content that is contained in the original profile data because it is under sampled in the flight line direction during gridding. Hence it may be necessary to use profile-based presentations of the data as well as grid-based presentations in order to retrieve maximum information.

5. PRESENTATION

Although post processing and enhancement are the next logical steps in the sequence, it is convenient first to address presentation techniques. There are several methods of presenting magnetic data (both pre and post enhancement), some of which are summarised below.

1. **Stacked profiles** are line-based maps in which all lines of data are plotted as XY graph style profiles. Each profile is geographically located beside each other. The X axis of each profile is along the line of best fit through the survey line and the Y axis is at right angles to that. This is the oldest form of presentation but still has the advantage of being able to show detail that cannot be shown in grid-based presentations due to loss of information (in the gridding process) in the flight line direction. One disadvantage of this type of presentation is that it is usually difficult to choose a single vertical scale and base level that is appropriate (optimised) for all of the displayed data. However there are pre-processing methods such as high pass and automatic gain control filtering that can be applied to alleviate this problem. Stacked profile plots are likely to be a useful form of presentation for regolith studies because the high sampling rate along lines is not compromised by the necessity for gridding as in contouring and imaging.

2. **Contour** maps have traditionally been a popular way of presenting gridded data. These maps have largely been replaced by images in recent years. Like stacked profiles it can be difficult to choose a single contour interval suitable for all the data. Where recognition of absolute amplitudes of anomalies is important these presentations are important. Many interpreters continue to use contours because they are superior to images when gradients of anomalies are to be used in determining dips of structures.

3. **Images** are the most common style of presentation today. Images are essentially a presentation in which individual pixels in the image are colour (or greylevel) coded according to some attribute of the gridded data being imaged. The advantage of images is that they are capable of showing extremely subtle features not apparent in other forms of presentations. They are also quickly manipulated in digital form, thereby providing an ideal basis for GIS based on screen interpretation. Milligan, et al. (1992) and Milligan and Gunn (1997) provide useful descriptions of these techniques as applied to magnetic data.

4. **Bipole plots** are a further form of presentation that have particularly relevant application in regolith studies due to their ability to resolve subtle detail (Gyngell, 1997). Similarly to stacked profiles, this method is applied to profile data but employs colour coded bar graphs where the colour represents polarity and length represents amplitude of an enhanced attribute of the data (Mudge, 1991).

6. POST PROCESSING AND ENHANCEMENT

Enhancement and post processing includes a range of transformations of the processed data that assist in its interpretation. These transformations usually either simplify the anomalies, make features of particular interest more prominent at the expense of others or make an attempt to relate the measured field to rock properties.

Post-processing techniques are based on the well-known theory of magnetic fields. The most important of these are summarised below and the reader should refer to Milligan and Gunn (1997) for an excellent overview of their application.

1. **Reduction to the pole** simplifies the interpretation of anomalies by removing the asymmetry introduced due to its induction by the inclined main field. The main field is only vertical (and induced anomalies symmetric) at the north and south magnetic poles. As the name suggests reduction to the pole transforms the data to that which would be measured at the magnetic poles. This simplifies the anomalies by centring anomalies over the causative magnetic body rather than being skewed and offset to one side.

2. **Vertical and horizontal derivatives** quantify the spatial rate of change of the magnetic field in vertical or horizontal directions. Derivatives essentially enhance high frequency anomalies relative to low frequencies.

3. **Upward and downward continuation** of magnetic data transforms the data to that which would be observed on different surfaces either above or below the actual observation surface. Upward continuation thus tends to attenuate the effect of near surface sources relative to deeper sources. Downward continuation has the opposite effect.

4. **Analytic signal** transformations combine derivative calculations to produce an attribute that is independent of the main field inclination and direction of magnetisation as well as having peaks over the edges of wide bodies. Thus a simple relationship between the geometry of the causative bodies and the transformed data are observed.

These transformations need to be applied and interpreted with careful consideration of their in-built assumptions. For instance downward continuation to a surface below the magnetic sources is not valid and reduction to the pole assumes there is no remanent magnetisation. Additionally there are some practical limitations to their application, for example high order derivatives and downward continuation tend to amplify noise and other errors in the data.

Other types of transformations known as enhancements, which are not necessarily based on the fundamental theory of magnetic fields, can be applied. Some typical examples follow.

1. **Artificial illumination** is a method of visually enhancing image data so that if the magnetic data were a surface, it is illuminated as if the sun was shining on it from a certain azimuth and elevation (Pelton, 1987). Otherwise know as sun angle or hill shade enhancement this method is excellent for making high frequency subtle features easily identifiable. Figure 1 is an example of an artificial illumination enhancement.

2. **Frequency selective filtering** is used to selectively remove, attenuate or amplify the effect of a certain band of frequencies. Such filters include high pass, lowpass and bandpass filters. They are important to the extent that, given a particular geometry, shallow sources have a higher frequency content than deep sources. Thus it is an important method of differentially enhancing the effects of sources at different depths.

3. **Directional filtering** enhances anomalies trending in particular directions. Such a technique is useful where subtle yet important trends need to be mapped but are complicated or even obscured by trends in other directions. To an extent artificial illumination acts as a directional filter because anomalies trending perpendicular to the sun angle are preferentially enhanced.

4. **Regolith filters** have been designed (Dauth, 1997, Gunn, et al., 1997b) which aim to specifically separate the effect of regolith materials from basement material.

5. **Automatic gain control** (Rajagopalan and Milligan, 1995) is an amplitude filtering method that has great application in the identification of subtle anomalies. It works on the principle of equalising the power of the signal in a moving window passed over the dataset; thus it attenuates strong anomalies and amplifies weak anomalies. This filter can be particularly useful in regolith studies because regolith materials often have a low magnetic susceptibility.

6. **Statistical filters** such as averaging and median filters can also be used to remove spurious noise or to smooth anomalies to make them more interpretable.

7. **Textural filtering** is a method that responds to the shape, size and continuity of adjacent anomalies (Dentith, et al., 2000). Because assemblages of regolith material usually have a characteristic textural appearance, textural filtering has application in regolith studies.

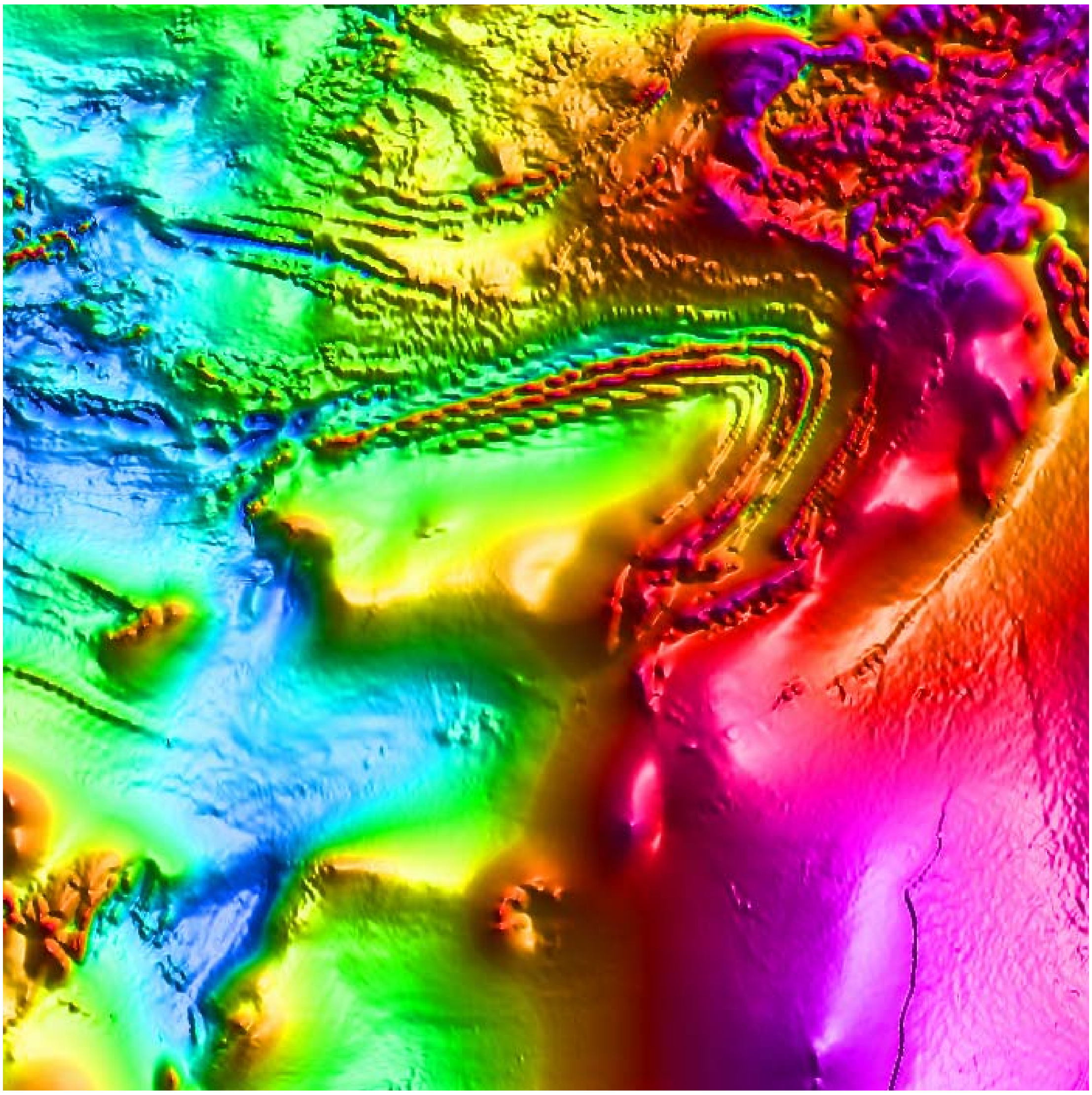

Figure 1. Colour image of magnetic data reduced to the pole with artificial illumination from the northeast. The data are from a portion of regional airborne survey in the Flinders Ranges of South Australia, flown with 400-metre line spacing and 80 metre terrain clearance. The image covers an area of 70 x 70 km. The data allow direct mapping of structures (folding and faulting).

7. APPLICATIONS

Analysis of the magnetic data and their various enhancements via a suite of qualitative and quantitative methods results in an interpretation of the sub-surface geology. Most interpretation schemes utilise a broad qualitative interpretation of the complete dataset with detailed quantitative methods applied on certain anomalies to test the validity the interpreted source.

Qualitative interpretation relies on the spatial patterns that an interpreter can recognise in the data. Faults, dykes, lineaments and folds are usually easily identified (eg. Figure 1). Intrusive bodies are often recognised by virtue of the shape and amplitude of their anomalies. Palaeolandscape features such as buried volcanic flows and palaeochannels usually show distinct dendritic pattens. Figure 2 shows the delineation of maghemite filled palaeochannels in the West Wyalong district of New South Wales. Magnetic units or assemblages with anomalous susceptibilities can often be directly mapped by recognition of domains with a characteristic magnetic signature. After correlation with additional information direct lithological inferences can sometimes be drawn. Weathering and alteration can also be interpreted where these processes have either depleted or enriched the magnetite content (Gunn and Dentith, 1997). Recognition of reversely polarised anomalies due to remanently magnetised rocks can be useful in differentiating volcanic flows of various ages. Dauth (1997) demonstrates how magnetic data gives insights into regolith processes through an example of the identification of maghemite-rich lateritic weathering products. Gunn, et al. (1997a) give a detailed overview of qualitative interpretation techniques and the types of geological entities that can be mapped by magnetic data.

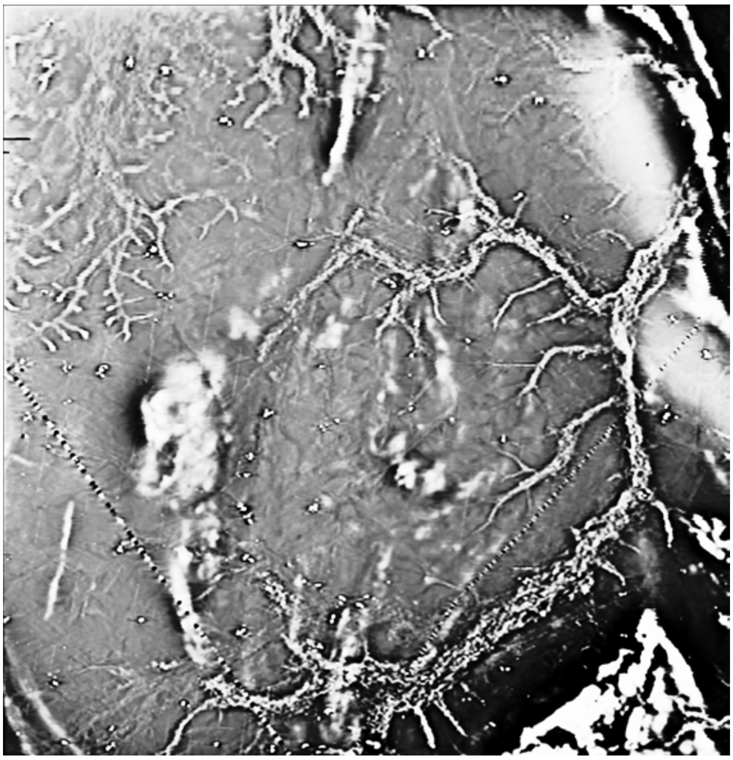

Figure 2. Greyscale image of the first vertical derivative of magnetic data reduced to the pole. The data are from a portion of detailed survey flown near West Wyalong in New South Wales, with 50-metre line spacing and 50 metre terrain clearance. The image covers an area of 17 x 22 km. The obvious dendritic patterns are characteristic of palaeochannel and volcanic flows. In this case they relate to maghemite filled palaeochannels (Mackey, et al., 2000). Several cultural anomalies relating to buildings, fences and powerlines are also evident in the image.

Qualitative interpretation may be complemented with several forms of quantitative interpretation that seek to provide useful estimates of the geometry, depth and magnetisation of the magnetic sources. Broadly categorised as curve matching, forward modelling or inversion, quantitative techniques rely on the notion that simple geometric bodies, whose magnetic anomaly can be theoretically calculated, can adequately approximate magnetic more complex bodies. Gunn (1997) provides a subjective review of the more important techniques.

The simplest of these are the so-called "rules of thumb" and curve matching methods. Rules of thumb are simple approximate empirical rules that relate a magnetic body's depth, shape and magnetisation to certain parameters measured manually from profile plots of its anomaly (Blakely, 1996). Curve matching is slightly more sophisticated because in this case the interpreter matches parameters measured from plots to "type" curves (eg. Naudy, 1970, Parker Gay, 1963) that have been published for various types of simple geometric bodies. Although these methods are conceptually simple they are tedious to apply and have generally fallen from favour.

Forward modelling is a trial and error process whereby;

1. A geometric body (model) is chosen to approximate the real geological body to be modelled.

2. The theoretical magnetic anomaly of the model is calculated and compared to the measured anomaly.

3. Adjustments are made to the parameters that define the model and the anomaly is recalculated until the calculated and observed anomalies match or "fit" to the interpreter's satisfaction.

Geometric bodies such as ellipsoids, plates, rectangular prisms, polygonal prisms and thin sheets can all be calculated. For example faults are often modelled using a thin sheet model. In this case the parameters that describe the model are the depth to the top, dip, strike and magnetisation contrast thickness product. Complex bodies can be built by superposing the effects of several simple bodies. Assumptions about the strike length, azimuth and depth extent are used in formulating the forward modelling algorithms; accordingly interpreters need to be cautious and use the appropriate model for each situation otherwise erroneous results will occur. Figure 3 is a quantitative model from Mackey, et al. (2000) in which a near surface palaeochannel deposit and deeper volcanic units are modelled.

Like most other geophysical methods, magnetics is ambiguous to the extent that there are an infinite (although not all geologically plausible) number of models that have the same magnetic anomaly. Hence if a model is forward modelled and it fits the observed anomaly, it is not proof that the model is correct. Irrespective of this, forward modelling is a method that has stood the test of time and is probably the single most useful quantitative technique in use.

Inversion is a procedure in which a geological model, whose theoretical magnetic anomaly matches (within some tolerance) the observed magnetic field, is determined by an automated process. There are two ways this can be achieved, known as linear inversion and iterative or non-linear inversion.

Linear inversion is possible only where the theoretical magnetic anomaly of the model can be formulated in terms of a system of linear equations where the model parameters are the unknowns. In this case the model parameters are determined by solving the system via standard linear algebra methods. Linear inversion is restrictive since it can only be applied to relatively simplistic models. Linear inversion has been applied in several useful schemes for susceptibility mapping (eg. Bott, 1967).

Iterative or non-linear inversion is more widely applicable because it can be used with models that are more geologically realistic. The technique is essentially the same as forward modelling except that an automated routine is used to determine the adjustments to be made to the model parameters. Also a calculated measurement of fit, such as RMS or chi-squared error is used in place of an interpreters visual inspection. Several different schemes exist for determining the adjustments, some of which use random search methods and others that use downhill minimisation methods. Both linear and iterative inversions suffer from the effects of ambiguity in the solution. This is recognised where geologically implausible models are produced while the fit is very good. Constraints can be placed on the model parameters using *a priori* information in these cases.

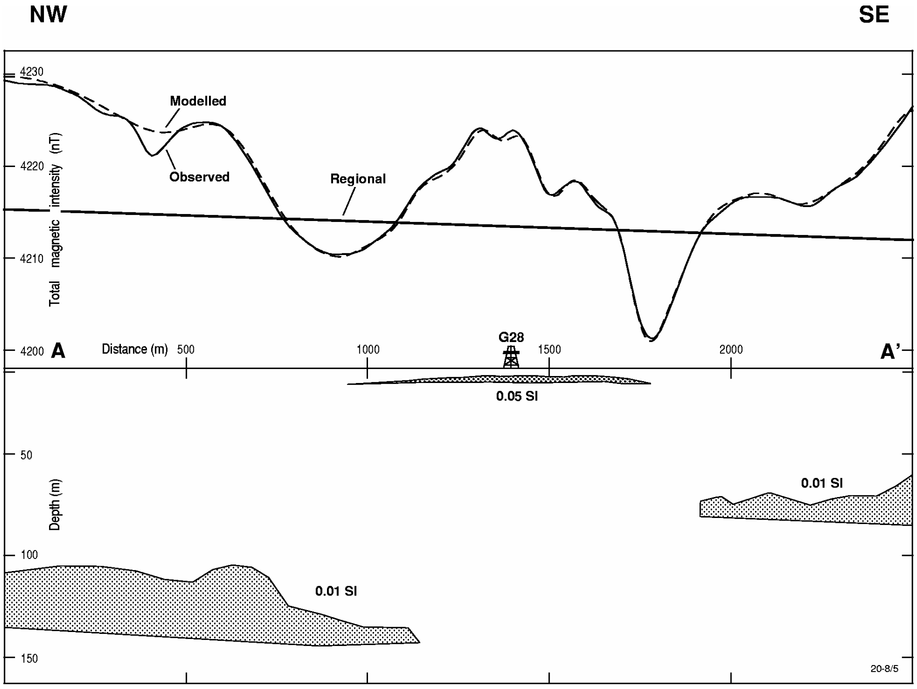

Figure 3. Forward modelling from Mackey, et al. (2000) in which a near surface palaeochannel deposit and deeper volcanic units are modelled. In this case, polygonal shapes approximate each body. The theoretically calculated (modelled) anomaly fits the observed anomaly well, indicating that this model is a possible cause of the observed anomaly.

Many automated routines exist for estimating the depth to basement. These routines cannot distinguish between magnetic sources in the basement and magnetic sources in the regolith and are more correctly termed depth to magnetic source routines. Gunn (1997) gives a detailed description of several of these. Popularly used techniques include Naudy curve matching, Phillips' autocorrelation method, Werner deconvolution, Euler deconvolution and spectral depth estimates. Although these are automated methods, careful consideration of the results is required, because many assumptions are made about the shapes of the causative bodies.

8. PROBLEMS AND LIMITATIONS

The greatest limitation of the magnetic method is the fact that it only responds to variations in the magnetic properties of the earth. Accordingly, many characteristics of the sub-surface that a regolith geologist wishes to delineate are not resolvable by the magnetic method because there is no associated change in the distribution of magnetite.

While novice interpreters may be able to easily identify some geological units, structures and characteristics from magnetic datasets, highly experienced interpreters are usually required to extract the subtle information contained in the data.

The inherent ambiguity in magnetic interpretation is problematic where several geologically plausible models can be attained from the data. Interpreters must be aware of this limitation and be prepared to use any available ground truth information or other datasets to decrease the ambiguity.

Cost

Airborne surveys are almost always priced on a dollar per line kilometre basis. In recent years fixed wing survey prices have generally been between \$4.50 to \$6.00 per kilometre for medium to larger size surveys (7,000 km or larger). Small surveys usually attract a price premium and may cost up to \$8 or \$12 per kilometre. Helicopter surveys are usually three to five times more expensive than fixed wing surveys and will cost up to \$35 per kilometre. Airborne acquisition prices will usually include gamma-ray spectrometric data.

Ground surveys are more time consuming and more expensive. Because ground conditions and access play a major part in production rates, prices are often quoted on a per day basis. A reasonable guide is \$1,500 per day per two-person crew. Such a crew may acquire 40 km per day (\$37.50 per km) in easily traversed country, whilst they might only achieve 20 km per day (\$75 per km) in heavily vegetated country with numerous physical obstructions.

Non-production charges are also incurred as part of the data acquisition cost to account for production delays that are not in the control of the contracting company (stand-by charges). These are usually due to bad weather or magnetic storms. These charges are around \$1,000 to \$2,000 per airborne crew per day. Most companies will include a mobilisation/demobilisation fee as a one off charge to cover the overhead of setting up a new field base.

Apart from the dollars per kilometre rate the major influence on the cost of a survey is the traverse line spacing. As a general rule of thumb the number of line kilometres can be calculated as follows;

$$line\ kilometres = \frac{1000 \times (1 + \dfrac{traverse\ line\ spacing\ in\ metres}{tie\ line\ spacing\ in\ metres}) \times area\ in\ square\ kilometres}{traverse\ line\ spacing\ in\ metres}$$

For example for a 300 square kilometre (20 x 15 km) survey area with a traverse line spacing of 200 metres and tie line spacing of 2,000 metres, the total line kilometres will be;

$$line\ kilometres = \frac{1000 \times (1 + \dfrac{200}{2000}) \times 300}{200} = 1650km\,.$$

Service Providers

Several companies in Australia offer magnetic data acquisition and processing services. The major companies are listed below.

1. Fugro Airborne Surveys - aeromagnetics
2. Universal Tracking Systems - aeromagnetics
3. Geophysical Technology Limited - ground magnetics and aeromagnetics)
4. Ultra Mag - ground magnetics
5. Baigent Geosciences - magnetic data processing, presentation
6. Pitt Research - magnetic data processing, presentation
7. Geoimage - presentation
8. Quadrant Geophysics - ground acquisition, some processing
9. Solo Geophysics - ground acquisition, some processing
10. Elliott geophysics - ground acquisition, some processing

11. Southern Geoscience Consultants - some processing, presentation
12. GPX Airborne Surveys - airborne acquisition, processing
13. GPX - ground acquisition, some processing.

Choosing between ground magnetics and aeromagnetics

Some comparative pros and cons of ground magnetics and aeromagnetics are summarised below.

1. Aeromagnetics has lower costs per line kilometre ($5-9/km compared to $50-80/km).

2. Aeromagnetic data are acquired more rapidly (eg. 1800 km/crew/day compared to 30 km/crew/day).

3. There are few access difficulties in aeromagnetics unless the survey area is in a built-up area where flying restrictions apply or in rugged terrain where a helicopter is necessary, thereby increasing the per line kilometre cost by three to five times. Ground magnetic surveys can suffer where access to private property is difficult or ground conditions are unfavourable, such as where there is dense vegetation, fences or watercourses.

4. Higher spatial resolution can be achieved and more subtle anomalies can be detected with ground magnetics because line spacings and sample distances are usually smaller and the measurements are made nearer to the magnetic sources.

5. Near surface magnetic sources are more readily resolved with ground magnetic surveys (Gyngell, 1997). Hence where the objective of the survey is the very detailed delineation of narrow magnetic sources in the top 20 metres, ground magnetics will probably be the method of choice. Conversely, strong magnetic sources at or near the surface, commonly caused by ferruginous pisoliths, may mask more subtle deeper sources – although delineation of the pisoliths may be of equal importance to the regolith geoscientist.

9. CONCLUSION

The magnetic method is a powerful tool that can be successfully applied in regolith studies. Since magnetics provide a relatively direct mapping of the abundance of magnetic minerals, it also serves as a useful indicator of lithology, structure, weathering and alteration processes. The method is mature and inexpensive technology. Australia has several experienced contracting companies and a competitive industry.

Airborne and ground magnetics have various advantages and disadvantages but airborne magnetics will be the method of choice unless subtle near surface anomalies are crucial. Routine data reduction and processing methods exist but need to be applied with rigour. There are several variations on enhancement and presentation methods that need to be selectively applied depending on both the data and the aim of the project. Specialised enhancements have been developed for dealing with regolith materials.

Qualitative interpretation is based on recognition of spatial patterns within the data. Many geological entities such as faults, folds and intrusions can often be easily identified whilst more skilled interpreters may be required to distinguish the probably more subtle effects of weathering. Direct lithological interpretation is usually not possible without additional information. Several quantitative methods exist that can estimate the depth, geometry and magnetisation of simple geometric bodies that could produce the observed anomaly. Ambiguity is an inherent property of magnetic data, accordingly all quantitative interpretations need to be reviewed with caution.

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