Using images in a geological interpretation of magnetic data

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Many types of images can be produced from the magnetic data which are now routinely acquired for regional geological studies and mineral exploration. Different images enhance different features that enable the informed regional/exploration geologist to make full use of the data. Unfortunately, not all of the image types are readily available to the geologist, so vital geological information may remain untapped.

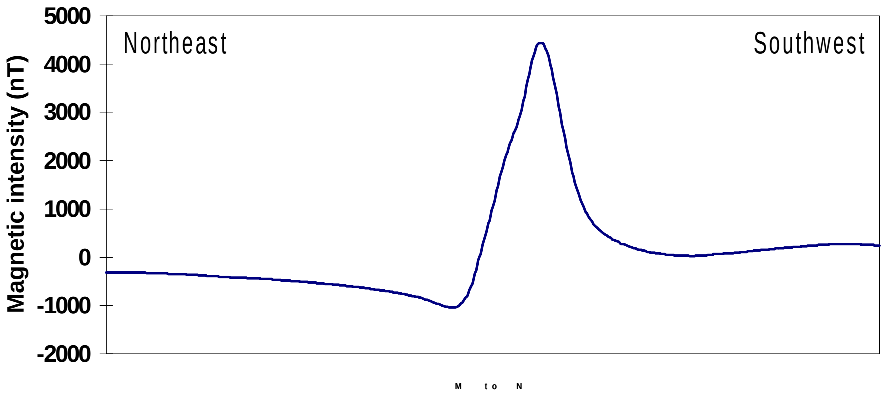


Fig. 20. Profile along line M–N crossing the highly magnetic BIF unit in Figure 21e. The asymmetry of the anomaly suggests that the unit dips to the northeast.

In this paper, we discuss the geological information that can be interpreted from magnetic data, and share our experiences of using images, in particular:

- the images used for the solid-geology interpretation of the Nabberu 1:250 000 Sheet area at the northeast margin of the Yilgarn Craton in Western Australia (Liu 1997: *AGSO Research Newsletter*, 27, 23–24), and
- anomaly-slope-enhanced images produced from a new method.

Lithostructural units

The geological interpretation of magnetic data involves identifying lithostructural units and structural features, all of which are best shown on a solid-geology map. For this purpose, images are the primary tool, although profile data are still needed for modelling. Magnetic lithostructural units define the lithological and structural features that can be interpreted from the magnetic data. Each lithostructural unit corresponds to a magnetic source or group of sources with characteristic magnetic patterns defined by the intensity and geometry of its magnetic sources. For many units, boundaries correspond to discontinuities in magnetic patterns, or sudden/sharp changes in intensity.

Owing to the different types and amounts of magnetic minerals they contain, different lithologies have different magnetic intensities, so they can be interpreted from a total magnetic intensity (TMI) image (Fig. 21a). Also, a considerable amount of structural information, particularly at macroscales, can be obtained from the distribution and geometry of magnetic sources. For a structural interpretation, it is important to determine the distribution and geometry of individual magnetic anomalies. Some apparently single, large anomalies are actually composites of several smaller ones. Special processing involving calculations of vertical derivatives may be needed to reveal individual anomalies. Vertical derivatives of TMI enhance high-frequency anomalies by 'sharpening' them. The first vertical derivative (Fig. 21b) appears to be most useful because it sharpens anomalies but does not enhance much of the noise in the data. For some composite anomalies, the second vertical derivative may have to be calculated to reveal further details, but this process also significantly enhances noise in the data. For some anomalies, an automatic-gain-control image may reveal additional structural information by amplifying and resolving weak signals (Rajagopalan & Milligan 1995: *Exploration Geophysics*, 25, 173–178). Many other image enhancement methods are available to assist resolving specific geological problems (Milligan & Gunn 1997: *AGSO Journal of Australian Geology & Geophysics*, 17, 63–75).

Our experience suggests that a TMI image (Fig. 21a) and a structurally enhanced (e.g., vertical derivative) image (Fig. 21b) are a useful combination for identifying different lithostructural units from the magnetic data.

Reduction to the pole

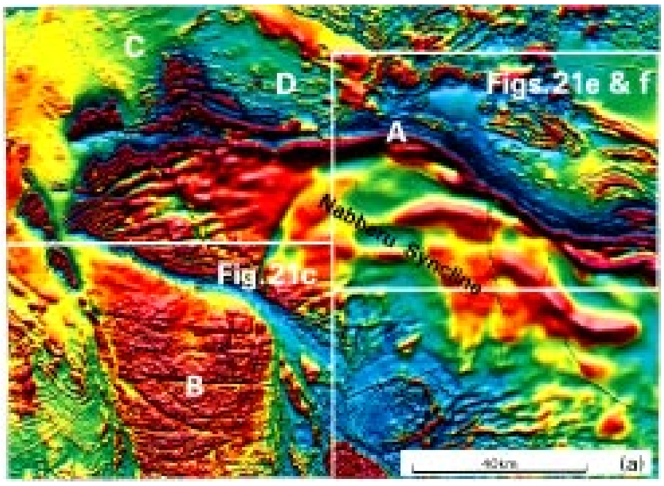
For individual magnetic anomalies, it is important to determine the location and geometry of their sources. For planar sources, their attitudes — vertical or dipping (and dip angle) — are important criteria. For this reason, magnetic data generally need to be reduced to the pole, particularly for areas close to the magnetic equator, in order to remove the asymmetry in magnetic anomalies due to the inclination of the Earth's magnetic field. Reduced-to-the-pole (RTP) data place anomalies directly above their sources. This is consistent with the assumption that the magnetisation of the rocks in an area is by induction and no significant permanent magnetisation occurs in a direction other than that of the Earth's magnetic field. This assumption appears to hold for the Nabberu area because the images show no smearing 'comet tails', which occur where the assumption does not hold (MacLeod et al. 1993: *Exploration Geophysics*, 24, 679–688). Omitting this step can produce incorrect positions and geometries of geological features, particularly east-trending ones.

Colour and greyscale images

Colour images (Figs. 21a, d, and f) show anomaly magnitudes and long-wave-length features particularly well. However, small and low-magnitude anomalies may not be evident in colour images. The positions of colour changes are not only dependent on the positions, magnitudes, and widths of anomalies but also on how the data are assigned colours in image processing. Different colour lookup tables effect different colour distributions in an image. Furthermore, the human eye is easily distracted by the different colours (Fig. 21d). Consequently, the widths and boundaries of anomalies are hard to determine on colour images. A greyscale image (Fig. 21b) is more useful for showing fine details and locating anomaly boundaries. Even so, greyscale images do not give much indication of the magnitudes of anomalies.

Anomaly slope images and contour maps

None of the images described above clearly defines the precise position of an



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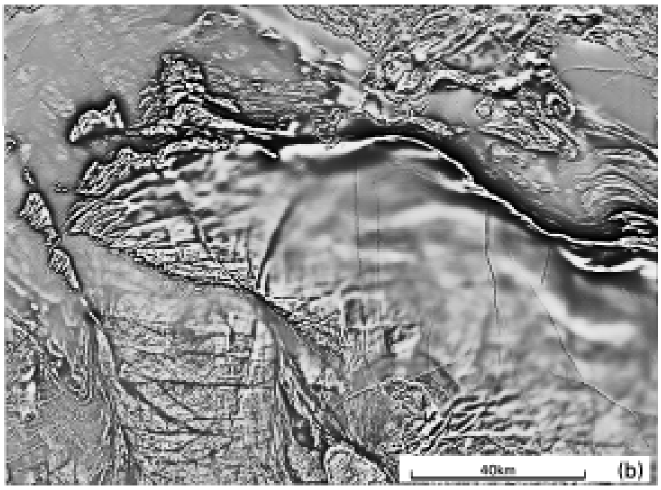

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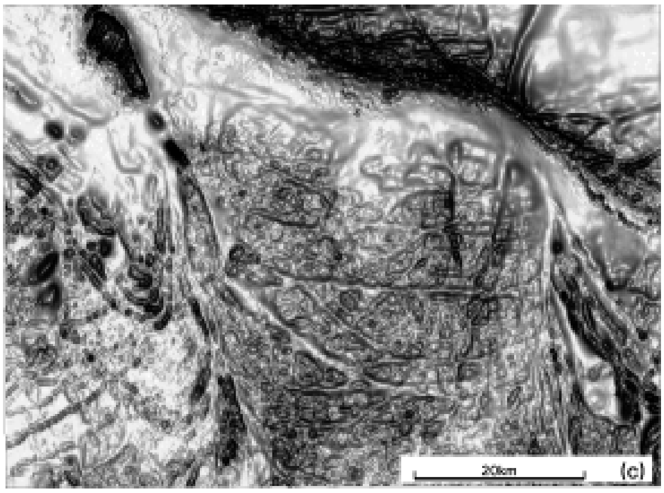

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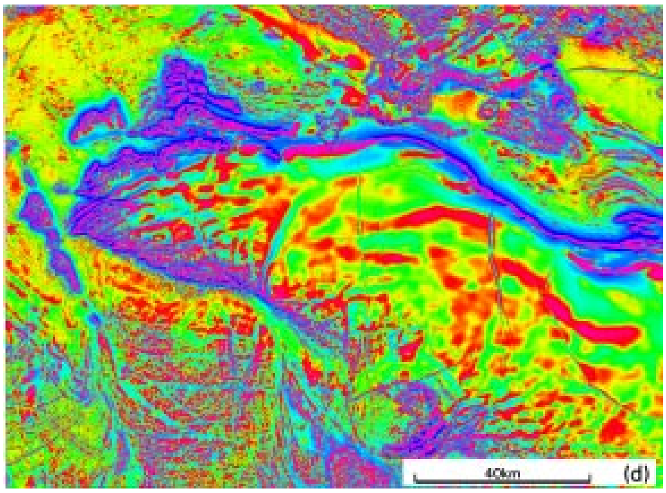

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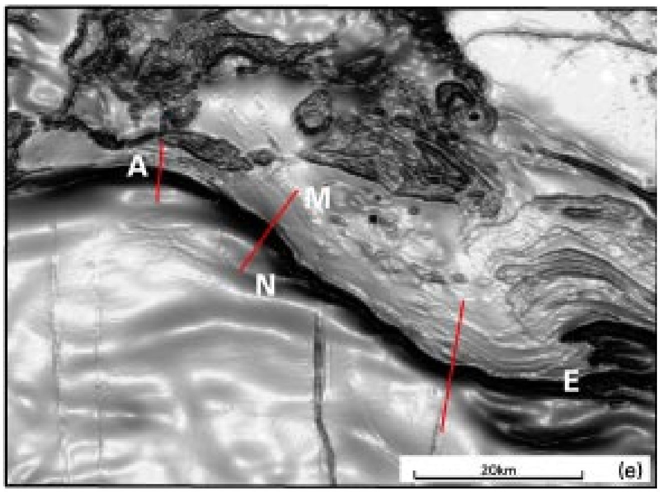

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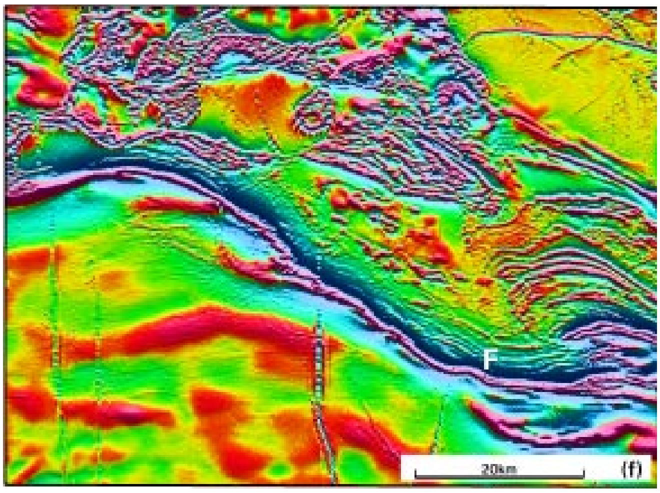

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Fig. 21. ***(a)*** **Total magnetic intensity image (TMI) of the Nabberu 1:250 000 Sheet area (data reduced to the pole for all images in this paper). This is a composite image based on the HSI (hue, saturation, intensity) colour model (Milligan et al. 1992: *Exploration Geophysics*, 23, 219–224). It was derived from a colour image of TMI as hue and a greyscale image of TMI with northerly illumination as saturation and intensity. It combines the advantages of both colour and greyscale images with the highlight of features by illumination. *(b)* Greyscale image of the first vertical derivative of TMI for the Nabberu 1:250 000 Sheet area. *(c)* Greyscale anomaly-slope-enhanced TMI image of the Merrie area (compare with the southwest part of Fig. 21a). Anomaly peaks and valleys are bright (white), whereas slopes of anomalies show varying degrees of grey shades to black. The darker the shade, the steeper the anomaly. *(d)* Colour image of the first vertical derivative of TMI for the Nabberu 1:250 000 Sheet area. *(e)* Greyscale anomaly slope-enhanced TMI image of the Mount Cecil Rhodes area (northeast part of Fig. 21a). The BIF unit from positions 'A' to 'E' is much darker on the south side. This suggests that the unit dips north. Profile data from positions 'M' to 'N' are shown in Figure 20. *(f)* Colour composite image of the first vertical derivative of TMI with northerly illumination of the Mount Cecil Rhodes area (same area as Fig. 21e). Image produced by the same method as Figure 21a.**

anomaly's peak, which is important for correlating the anomaly with its geological source — particularly a linear one. Contour maps are traditionally used for this purpose. Although contour density helps determine the dip direction of an anomaly, contour maps have limitations because any chosen contour interval presents a compromise between showing high and low anomalies. In addition, unlike images, contour maps do not maintain data continuity.

We recently developed an anomaly-slope-enhancement method which produces images (Figs. 21c and e) that reflect the slopes and preserve the symmetry/asymmetry of an anomaly. In a greyscale image produced by this method, flat areas (e.g., peaks and valleys of anomalies) are shown as bright (white), while slopes are shown as various shades of grey to black; the darker the shade, the steeper the anomaly. The positions of both high and low anomalies can be precisely located. This method, therefore, facilitates close correlation of anomalies with their geological features. It also enables the dip direction of a planar source to be determined from the relative darkness and gradient on both sides of the anomaly. If a dyke-like planar source dips to the north, for example, the northern side of the anomaly will appear lighter than the southern side on the image. Because the symmetry/asymmetry of the anomalies is maintained in this type of image, it reflects a non-biased presentation of the enhanced structural features, unlike illuminated images, which highlight features at high angles to the illumination direction (Fig. 21c, compare with the southwest part of Fig. 21a). Therefore, this type of image assists a more objective structural interpretation.

Interpretation of the Nabberu area

Most lithostructural units in the Nabberu area are readily discernible from a colour TMI image for intensity (lithological) information (Fig. 21a) and a greyscale image of the first vertical derivative of TMI for structural information (Fig. 21b). Anomaly-slope-enhanced images (Figs. 21c and e) are useful for structural interpretations and locating the positions of anomalies. Some illustrated examples follow.

The highly magnetic banded iron formation (BIF) of the Earaheedy Group ('A' in Fig. 21a; cf. 'A' to 'E' in Fig. 21e) defining the Nabberu Syncline has a moderate to steep dip on the northern limb, is gently dipping to subhorizontal on the southern limb, and youngs to the south. However, the anomaly is much darker on the southern side of the BIF from positions 'A' to 'E', suggesting that the bulk of the unit here dips north to northeast. This is confirmed by a profile across the anomaly (Fig. 20). Therefore, the bulk of the BIF here is overturned, dipping north but younging south; southerly dips, however, are apparent locally (Leech et al. 1977: Geological map, Nabberu 1:250 000 Sheet, Geological Survey of Western Australia).

A large granitoid body in the southwest of the Sheet area appears purple–red in the image ('B' in Fig. 21a). It abuts and underlies the hinge of the Nabberu Syncline, and continues to the northwest of the Sheet area but with lower magnetic intensity (shown in yellow and greenish blue — e.g., at position 'C').

The magnetic pattern in the area around 'D' (Fig. 21a) shows features that can be attributed to both the highly magnetic BIF unit and the underlying granitoid. The low magnetisation of the area as shown in the TMI image (Fig. 21a) is attributed to the underlying granitoid. However, the linear east-trending anomalies in this area are similar to that of the BIF west and south of this area (Figs. 21a and b). These features led Liu (1997) to interpret the magnetic BIF in area 'D' as thin.

Further detailed interpretation can be done with more specifically processed images. Pseudo-illumination can highlight some features, particularly low-magnitude anomalies that may not be evident in images without illumination. Thus, in area 'F', north of the highly magnetic BIF (Fig. 21f), several small, low-magnetic anomalies trend subparallel to this unit. They are clearly shown in the northerly illuminated image of the first derivative of TMI (Fig. 21f), but are less evident in images without illumination (Fig. 21b). Recognising such differences, the interpreter should be aware of a potential bias due to the illumination, which highlights features at high angles to the direction of its source. For example, in the Merrie area, structures are oriented in all directions, as shown in the anomaly-slope-enhanced image (Fig. 21c), which shows a non-biased presentation of structures. In the northerly illuminated TMI image of Figure 21a, however, east–west trending features are enhanced at the expense of anomalies in other directions. Therefore, for illuminated images, several illumination directions/angles may be needed to highlight features trending in different directions. Even so, a geological interpretation of magnetic data should not rely solely on illuminated images, which should be used in conjunction with other images in order to present a balanced representation of key geological features.

Concluding remarks

Although many types of images can be produced from magnetic data, two or three types provide most of the geological information that can be obtained from the data. They include a colour TMI (RTP) image, a greyscale vertical derivative of TMI (RTP) image, and a greyscale anomaly-slope-enhanced image of TMI (RTP). As interpretation becomes more specific, other types of images may be produced for interpreting geological detail.

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