MRF/451

Editor: D.W. Emerson | Vol. 19, Nos 1/2 | March/June 1988
Guest Editor: M. P. Middleton

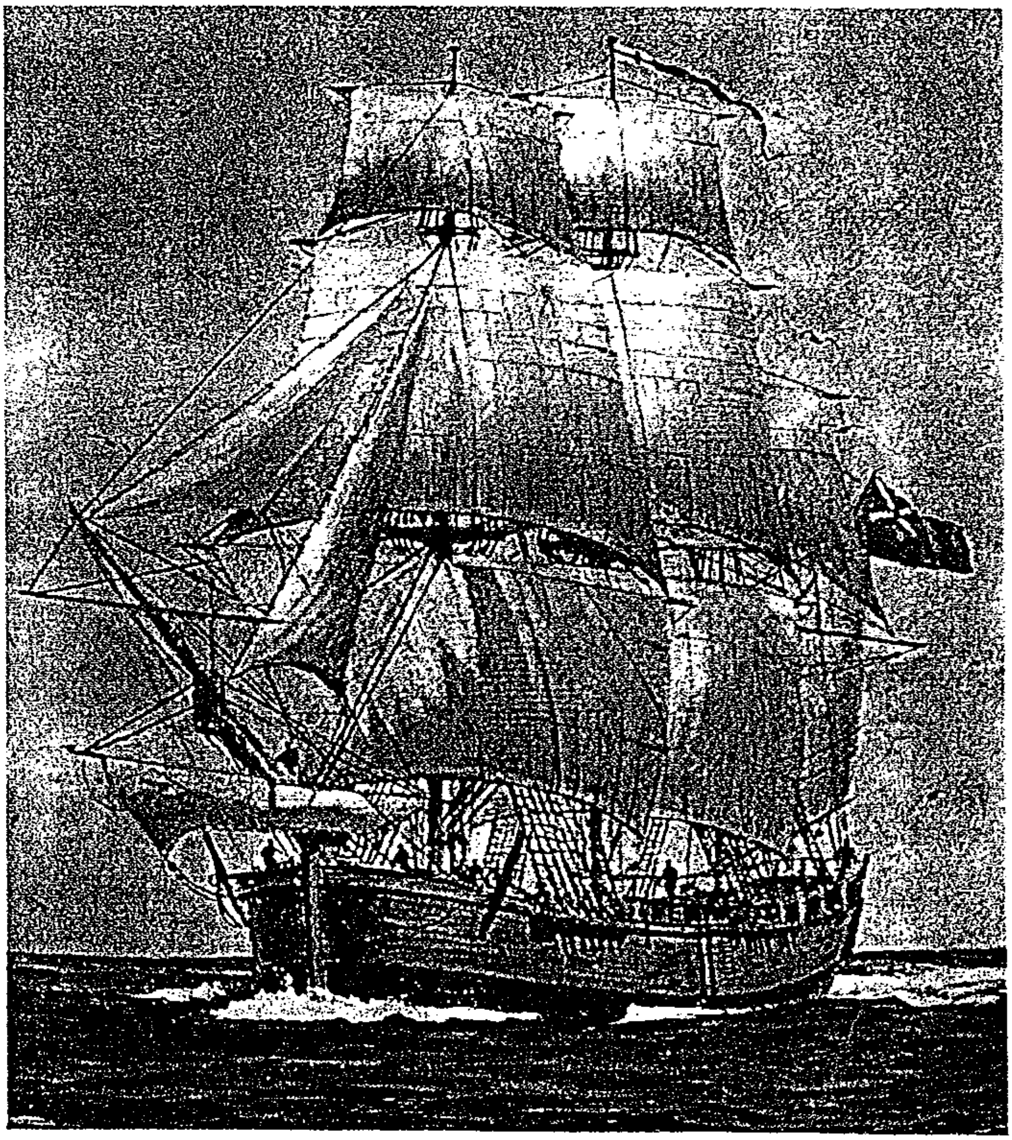
EXPLORATION GEOPHYSICS

THE BULLETIN OF THE AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

ASEG/SEG INTERNATIONAL GEOPHYSICAL CONFERENCE & EXHIBITION

ADELAIDE, FEBRUARY 14–21, 1988

EXTENDED ABSTRACTS



1788 - 1988
Australia Bicentenary
Voyage of Discovery

Conference Theme: *'Leave nothing unattempted in '88'*

Registered by Australia Post Publication No. NBP 0424

ISSN 0812-3985

Interpretation of Magnetics Using Magnetic Property Data—Case Histories from Australia

D. A. Clark

CSIRO Division of Mineral Physics and Mineralogy
PO Box 136, North Ryde, NSW 2113
Australia

Summary

Although magnetics is the most widely used geophysical method in hard rock mineral exploration, interpretation of the data suffers from inherent non-uniqueness. Ignorance of the magnetic properties of magnetic rock units may lead to faulty interpretation, with expensive consequences. Several examples of interpretations which have been assisted by magnetic property measurements will be presented. Applications include siting drill holes in order to maximise the probability of intersecting the target and testing whether intersected material explains the anomaly. Factors which may have to be considered include the remanence direction and Koenigsberger ratio (particularly for volcanics, basic plutonic rocks and pyrrhotite-bearing rocks), the age of remanence relative to folding, and susceptibility anisotropy (particularly for banded-iron formations and certain orebodies). Palaeomagnetic cleaning and data analysis techniques are essential for extracting maximum information from samples.

Discussion

The depositional sequence in the Lower Proterozoic Hamersley Basin consists of a thick sequence of volcanics overlain by the chemical sediments of the Hamersley Group, including a total thickness of approximately 1 km of banded iron formations (BIFs), in turn followed by predominantly clastic sequences. The Turner Syncline is a major structure, strongly mineralised on its eastern flank, which is the site of the giant Tom Price haematite orebody. The magnetic signatures of the Turner Syncline are not explicable in terms of induced magnetisation parallel to the present field. The anomalies were examined in the light of the magnetic properties of the BIFs. The Hamersley Group contains four major BIF units separated by iron-rich shale units. The Dales Gorge member of the Brockman Iron Formation has been intensively studied and subdivided into alternating BIF and shale units for which magnetite contents have been determined by Ewers and Morris (1981).

Previous attempts to determine the remanent magnetisation of the BIFs were not successful because surface samples were affected by weathering and lightning strikes, producing scattered NRM directions and highly variable intensities. My co-worker, Dr P. W. Schmidt, and I circumvented this problem by sampling fresh orientable drill core from the Dales Gorge member, Joffre member and Weeli Wolli formation, and by judicious application of palaeomagnetic cleaning techniques to these samples, as well as to surface samples (Clark and Schmidt, 1986a). Fresh drill core was available from two localities with different structural attitudes, allowing application of a palaeomagnetic fold test to determine whether the remanence was acquired before or after folding. Earlier studies of the volcanics underlying the Hamersley Group had shown that the NRM of mildly metamorphosed rocks is dominated by a pre-folding component whereas rocks which have undergone greenschist facies metamorphism have an NRM dominated by a syn-folding component (Schmidt and Embleton, 1985).

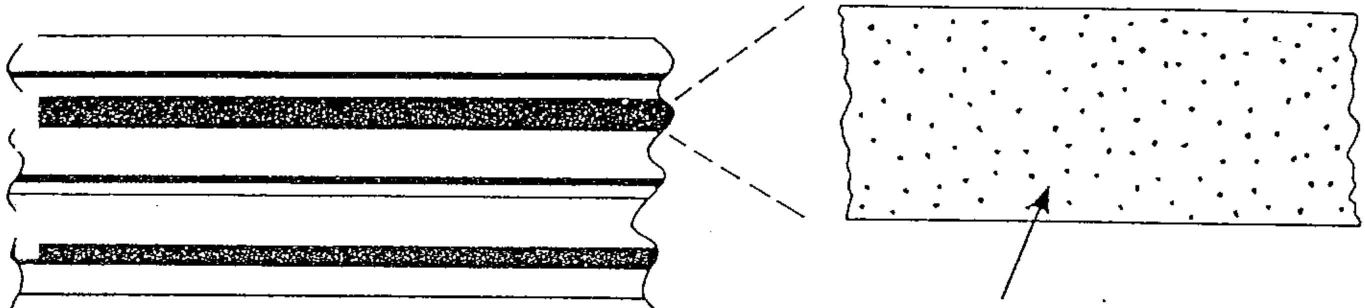
Remanence directions obtained from drill core samples which come from areas of low metamorphic grade clearly indicate pre-folding acquisition of remanence. The pre-folding component is directed NW and is sub-horizontal. Pre-folding remanence differs substantially in its influence on magnetic anomalies from post-folding remanence (Clark and Schmidt, 1986b).

The Turner Syncline is in an area of high metamorphic grade. The direction of the post-folding metamorphic overprint in the area is known to be in the NW quadrant with shallow negative inclination. This direction is quite close to the pre-folding direction, referred to the palaeohorizontal (although the two directions are, statistically speaking, significantly different). Thus flat lying BIFs across the basin are found to have a fairly consistent NW sub-horizontal to shallow up direction. The Koenigsberger ratio (Q value) is about 1—2. This implies that remanence must be considered in magnetic interpretation of the structure of the BIFs.

The measured susceptibility anisotropies of the BIFs are very high, typically 2–4, indicating that anisotropy has a major influence on anomaly form. There is a serious sampling problem, however, in measuring anisotropy on small specimens, given the mesoscopic scale of inhomogeneity of BIFs which gives rise to the textural anisotropy. As a check, a theoretical calculation of the susceptibilities of the Dales Gorge member, parallel and perpendicular to bedding was made. The results obtained are shown in Fig. 1 and served as a check on the representativeness of the measurements.

Very high anisotropy can greatly change the observed anomaly over a thick dipping tabular body. The shape of the anomaly arising from induced magnetisation is independent of dip over a wide range of angles, although the anomaly amplitude is sensitive to dip and changes sign as the normal to the plane of the body crosses the Earth's field direction. This behaviour is quite different to that of an isotropic body with the same geometry.

Because of the strength and consistency of direction of the remanence it must also be taken into account. As the remanence is generally sub-horizontal the effective Q is very sensitive to strike. For NW striking bodies the effective Q is very small, whereas for NE striking bodies it is a maximum.



$$k = \frac{fk_i}{1 + N(1-f)k_i}$$

$$k_= = f_L k$$

$$k_\perp = \frac{f_L k}{1 + 4\pi k}$$

$$A = k_= / k_\perp = 1 + 4\pi k$$

$$A \gtrsim 3$$

$$k_= \simeq 0{\cdot}1\ G/Oe$$

FIGURE 1
agnetic anisotropy of BIF.

Taking all these factors into account we were able to explain ie strike and dip sensitivity of the observed anomalies over the Turner Syncline (Clarke and Schmidt, 1986b).

igure 2 shows the calculated anomaly over a NW striking mb, using geological information on the location, thickness, strike and dip of units on this limb. The calculated anomaly matches the observed profile very well. Note the ifference between the true 'total field' anomaly (ΔB_m) and ie conventional approximation to it (ΔB_T), which is the anomalous field vector projected onto the regional eomagnetic field direction. This discrepancy arises because f the magnitude of the anomalies, which significantly perturb the local field direction (Emerson *et al.*, 1985).

he contrasting signature observed over the SE limb which trikes E–W is shown in Fig. 3. Note that the prominent high over the outcropping BIF units becomes an asymmetric low due to the change in strike and a shallower dip. The dashed rofile corresponds to an equivalent geometry, but assumes re-folding (instead of post-folding) remanence, and does not fit the observed signature as well. This suggests that the remanence of the BIFs in the Turner Syncline is predominantly ost-folding.

Using the measured magnetic properties we were able to atisfactorily account for the rather perplexing signatures bserved over a well mapped structure. We expect that this will enhance the confidence with which buried structures can be interpreted in the Hammersley Basin.

'he next case history which I will discuss is from the Cobar area of NSW. The particular locality of interest is Magnetic Ridge which is a well-defined linear trend between the Great Cobar and CSA Mines. Known orebodies in the area are magnetic and the Elura orebody was discovered by magnetics within the same horizon. Hole DD80 MR2 was drilled to test a prominent magnetic high within this trend. The hole intersected a zone of disseminated pyrrhotite but the observed susceptibilities are far too low to account for the observed anomaly.

Because the bedding planes were clearly visible in the core and were oblique to the core axis it was possible to orient samples using the knowledge that the DDH azimuth is perpendicular to strike and that the formations dip very steeply in this area. The Q values of the oriented core samples are high, as is typical for pyrrhotite-bearing rocks, but variable and the NRM directions are either well-grouped in the SW quadrant with steep negative inclination or else are distributed along a girdle. The NRM directions of specimens from examples of the two types of sample are shown in Fig. 4. It was therefore difficult to estimate the overall contribution of remanence to the total magnetisation.

The distribution of remanence intensities and directions was readily explicable after palaeomagnetic cleaning resolved the NRMs into soft and hard components. Soft components were invariably normal, directed SW up, whereas hard components of different samples could have either polarity.

Having resolved the NRM vectors into components a simple model was constructed. Details are given in Fig. 5. The model is based on an empirical relationship between the susceptibility and intensity of each remanence component. For each type of sample the NRM intensities of specimens are approximately linearly related to their susceptibilities, suggesting that both susceptibility and remanence simply

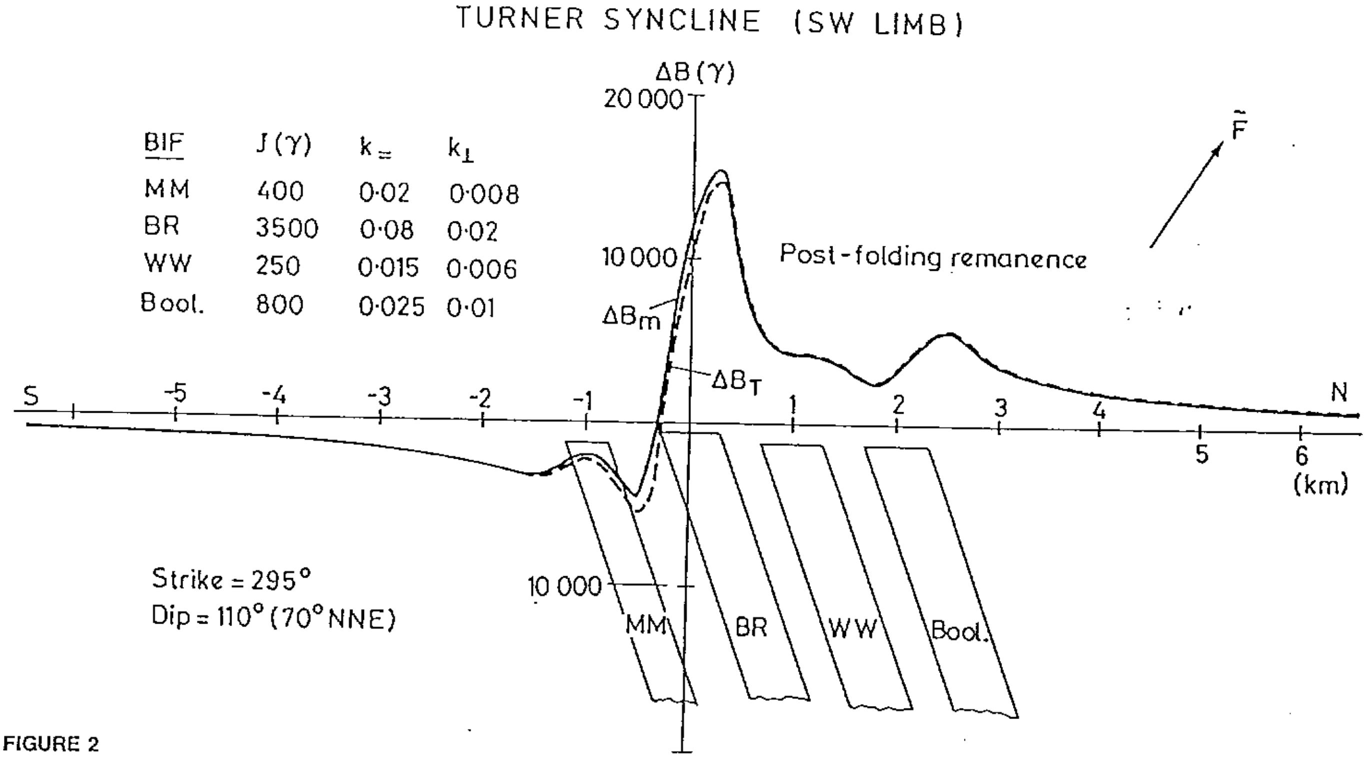


FIGURE 2
Theoretical magnetic anomalies over a NW-striking limb of the Turner Syncline.

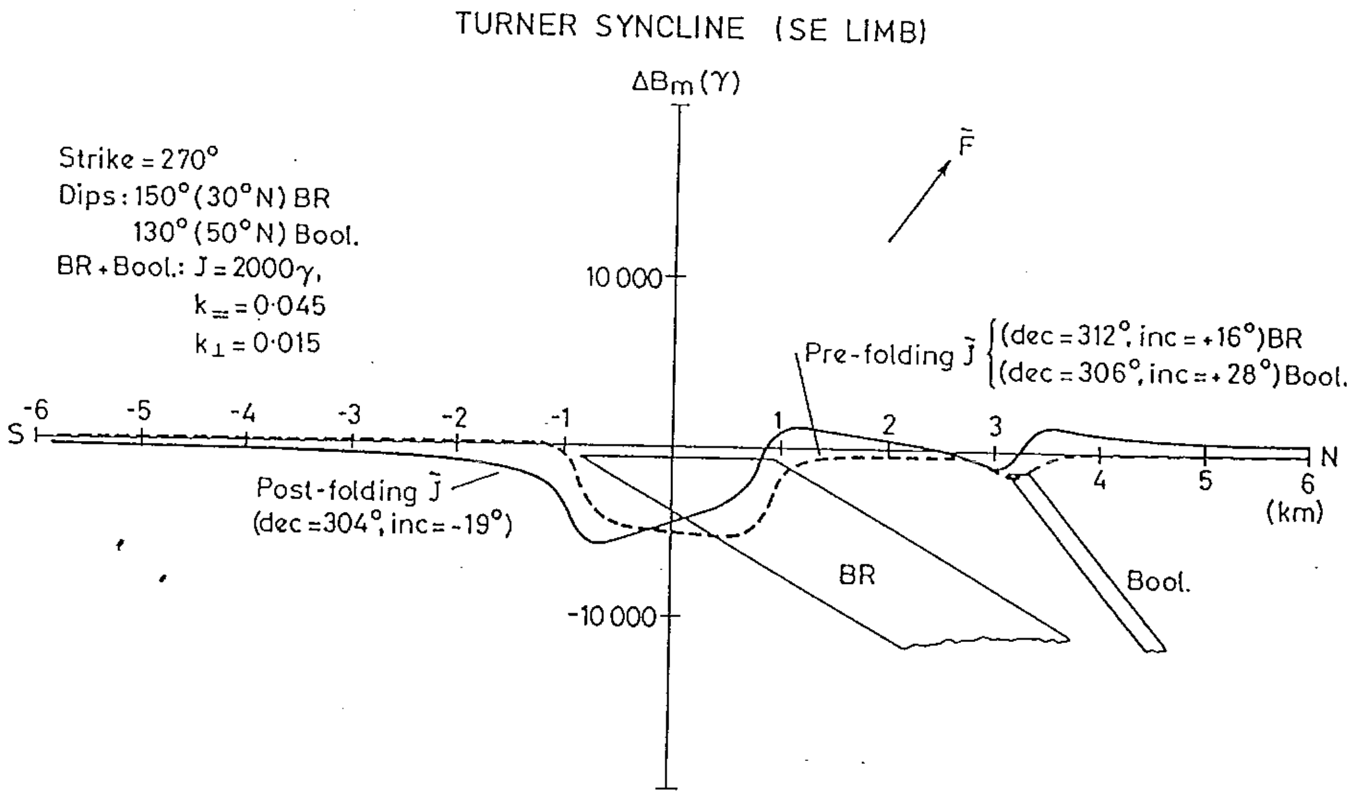


FIGURE 3
Theoretical magnetic anomalies over the SE limb of the Turner Syncline.

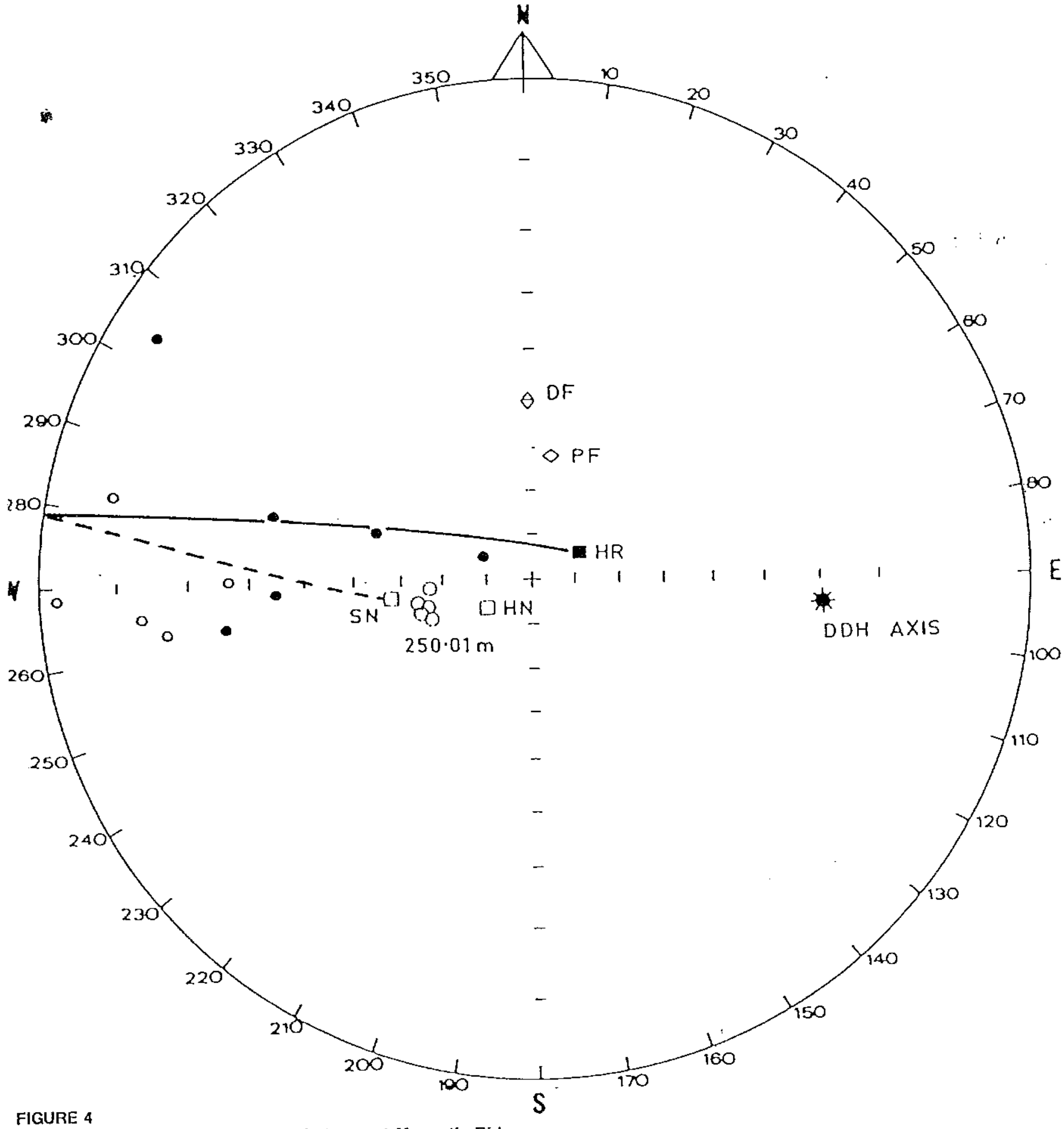


FIGURE 4
NRM directions from different sample types at Magnetic Ridge.

reflect the volume fraction of pyrrhotite in the specimens because the intrinsic Koenigsberger ratios of the components carried by the pyrrhotite grains are fairly consistent from specimen to specimen. Note that the susceptibilities of these metasediments are sufficiently low that the paramagnetic susceptibility of the silicate minerals, which corresponds to the $J = 0$ intercept of the linear $J - k$ relationship, must be considered in calculating the magnetisation contrast between the zone of higher pyrrhotite content and the surrounding rocks which contain a low background pyrrhotite content (this applies only below the base of oxidation).

Using the magnetisation contrast derived from the model and the geometry determined from drilling the theoretical anomaly was calculated and compared to the observed anomaly (Fig. 6). The calculated anomaly has the right general form but is too large by about 30%, partly because the finite strike length has been neglected. Reducing the magnetisation contrast appropriately, the shape of the observed anomaly is quite well matched. The agreement between the theoretical and observed anomalies is satisfactory, given the limited sampling, and demonstrates clearly that the remanence of the intersected zone can account for the anomaly. Note that the

$$\left.\begin{array}{l} k = k_{para} + k_{ferro} \\ Q = \dfrac{J_{NRM}}{k_{ferro}F} \end{array}\right\} \quad J_{NRM} = (k - k_{para})\, QF \quad \text{(SINGLE COMPONENT)}$$

LINEAR REGRESSION OF J_{NRM} ON k (ZONE 2)

			SN + HN	SN + HR
SLOPE	⇒	Q	29	5
INTERCEPT	⇒	k_{para}	46×10^{-6}	56×10^{-6}

$$\therefore\ k_{para} \simeq 50 \times 10^{-6}\ \text{G/Oe}$$

$$Q_{soft} \simeq 17$$

$$Q_{hard} \simeq 12$$

MAGNETISATION CONTRAST

$$\left.\begin{array}{ll} \text{ZONE 1}: k = 90 \times 10^{-6} \Rightarrow & J_{NRM} = 71 \times \dfrac{90-50}{140-50} \\ \text{ZONE 2}: k = 140 \times 10^{-6}\ , & J_{NRM} = 71\gamma \end{array}\right\} \begin{array}{l} \Delta k = 50 \times 10^{-6}\ \text{G/Oe} \\ \Delta J_{NRM} = 39\gamma \end{array}$$

FIGURE 5
Magnetisation model for the CSA Siltstone at Magnetic Ridge.

anomaly due to induced magnetisation alone is negligible compared to the observed anomaly. On the other hand, neglecting the 'background magnetisation' of the surrounding rocks would produce a calculated anomaly which was much too large. The conclusion is that the observed anomaly is explained by the zone of disseminated pyrrotite and it is unlikely that a discrete source, a possible orebody, has been missed. Relying on susceptibility measurements alone would have suggested that the anomaly had not been fully tested, requiring further drilling.

These case histories, and many others, demonstrate that substantial improvements to magnetic interpretation can result from magnetic petrophysical studies. Neglecting the effects of susceptibility anisotropy of BIFs and certain banded ores may lead to substantial errors. More generally, remanence is often an important factor which should not be neglected when attempting quantitative modelling for determination of structure or for testing of anomalies. Reliable determination of representative in situ remanence vectors requires full analysis of remanence components using palaeomagnetic cleaning techniques. The importance of ascertaining the time of remanence acquisition relative to folding has not been recognised sufficiently. For folded rocks, pre-folding remanence produces signatures which differ greatly from those associated with post-folding remanence.

References

Clark, D. A. & Schmidt, P. W. (1986a)—'Magnetic properties of the banded-iron formations of the Hamersley Group, W.A.', CSIRO Restricted Investigation Report 1638R.
Clark, D. A. & Schmidt, P. W. (1986b)—'Geological structure and magnetic signatures of Hamersley BIFs', CSIRO Restricted Investigation Report 1639R.
Emerson, D. W., Clark, D. A. & Saul, S. J. (1985)—'Magnetic exploration models incorporating remanence, demagnetisation and anisotropy: HP41C handheld computer algorithms,' *Explor. Geophys.* 16, 1–122.
Ewers, W. E. & Morris, R. C. (1981)—'Studies of the Dales Gorge Member of the Brockman Iron Formation, Western Australia', *Econ. Geol.* 76, 1929–1953.
Schmidt, P. W. & Embleton, B. J. J. (1985)—'Pre-folding and overprint magnetic signatures in Precambrian (~2.9–2.7 Ga) igneous rocks from the Pilbara Craton and Hamersley Basin N.W. Australia', *J. Geophys. Res.* 90, 2967–2984.

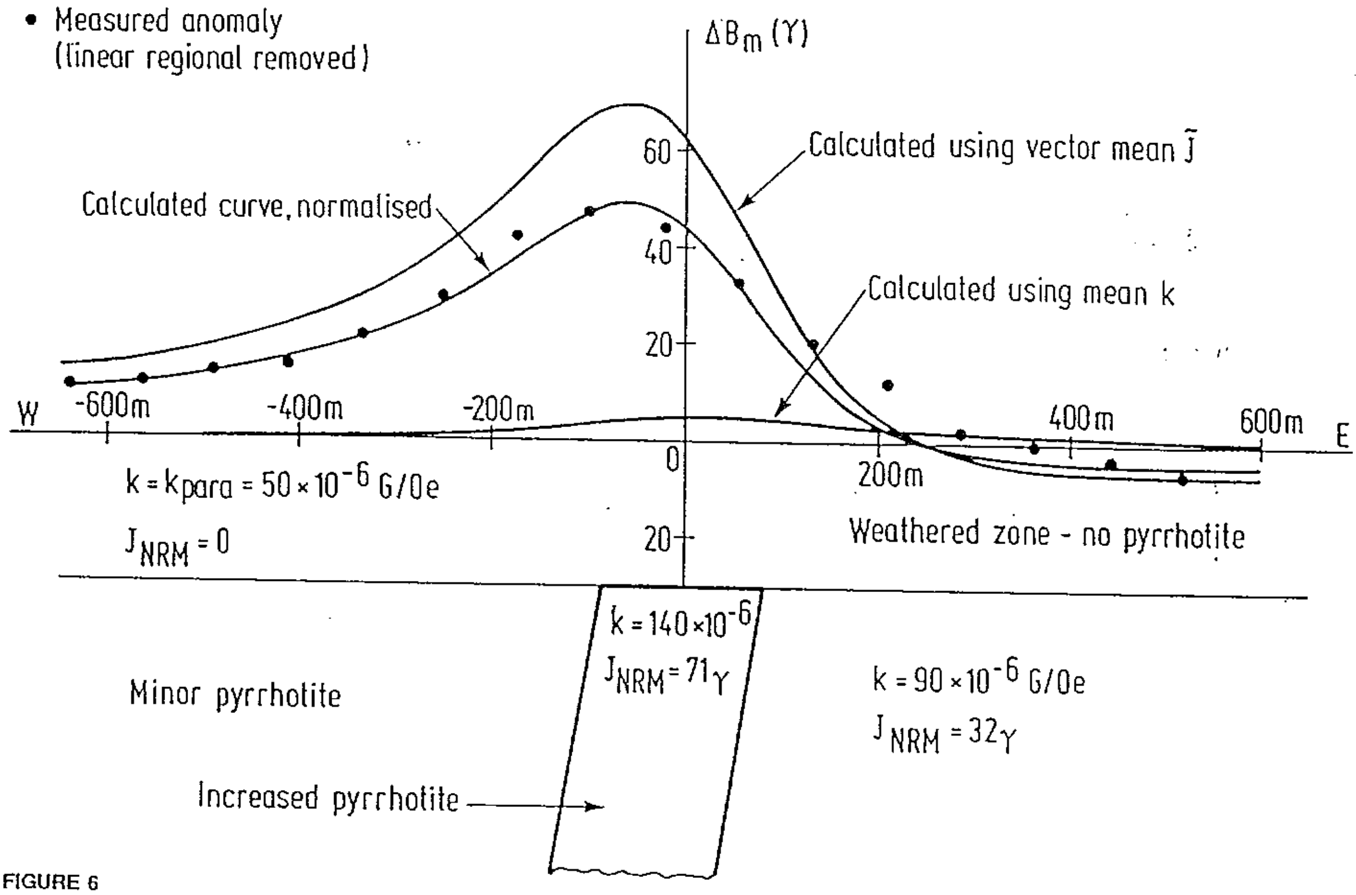


FIGURE 6
Theoretical and observed magnetic anomalies, Magnetic Ridge.