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MAGNETIC PROPERTIES OF ROCKS FROM THE HERBERTON TINFIELD, QUEENSLAND, AND EXPLORATION IMPLICATIONS

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Fig. 1 AF Cleaning of selected SV25 specimens. Stereographic plot of vector directions with open symbols denoting upper hemisphere (negative inclinations), closed symbols lower hemisphere (positive inclinations). Squares denote NRM directions, circles are successive cleaned directions. Note stability of remanence direction for SV25J-I (site 3). SV25D-I (site 1) SV25P-I (site 4) have multicomponent NRMs, but AF demagnetisation removes soft overprint and isolates stable direction close to SV25J-I direction.

1. INTRODUCTION

In August 1978 a group of four AMIRA collaborators agreed to sponsor a three-year research programme conducted by the CSIRO Division of Mineral Physics on the application of rock magnetic studies to interpretation of magnetic surveys.

As part of the programme for 1979 Peko-Wallsend Ltd proposed an investigation of the magnetic properties of rocks from the Irvinebank area within the Herberton tin-field in north-east Queensland.

The primary aim of the study was to obtain remanence and susceptibility data which could assist modelling of anomalies and thus better define drill-targets. Subsidiary aims included investigation of the relationship between surface sample and fresh rock properties, and testing of the hypothesis that the observed negative magnetic anomalies are due to rocks remagnetised by contact metamorphism associated with emplacement of the upper Palaeozoic granites during a period of reversed polarity of the geomagnetic field. Confirmation of the hypothesis would enable extrapolation of remanence directions from rock units near the magnetic anomaly to the causative body itself.

2. FIELD WORK

Surface sampling of rocks from 7 prospects was carried out over 3 days in November 1978 by Dr B.J.J. Embleton and Dr P.W. Schmidt of the CSIRO in collaboration with Mr R.H. Duffin of Geopeko. Attempts were made to sample as close as possible to the magnetic features of interest, subject to the accessibility of good outcrop. In several cases the rocks sampled were weathered and therefore may be unrepresentative of the rock type.

Details of the sampled rock types and sample locations are given in Table 1. In addition to the surface samples, several drill core samples from the Surveyor 5 and Surveyor 24 prospects were provided by Geopeko.

3. LABORATORY PROCEDURES

Remanent intensities and directions were measured on a Digico balanced fluxgate spinner magnetometer and susceptibilities on a Digico bulk susceptibility bridge with operating frequency 10 kHz, except for a pyrrhotite bearing sample which was measured on a CSIRO designed susceptibility bridge with excitation frequency 217 Hz. The Digico susceptibility instrument is unsatisfactory for rocks of high conductivity.

4. DISCUSSION OF RESULTS

4.1 Surveyor 25 - Featherbed Volcanics

Samples of quartz-feldspar porphyry associated with a prominent aeromagnetic low were collected from 5 sites corresponding to samples SV25A-D, SV25E-H, SV25I-M, SV25N-P and SV25Q-S. Samples from site 5 (Q-S) were not in situ.

As only surface samples were collected the measured magnetic parameters could be affected by weathering and lightning strikes. Weathering may involve alteration of the magnetic minerals leading both to changes in bulk susceptibility of the near-surface rock and to the acquisition of a chemical remanence component superimposed on the primary remanenence. Lightning strikes can usually be recognised by the occurrence of intense NRMs (high Koenigsberger ratios) with very scattered directions. The magnetisation component due to lightning (an isothermal remanent magnetisation or IRM) is in general magnetically softer than a primary thermoremanence (TRM) and can therefore be cleaned out by AF demagnetisation, isolating the original magnetisation direction.

Stability tests consisting of alternating field and thermal demagnetisation runs were made on pilot specimens from each of the sites. The results are summarised in Table 2.

Considered together with the magnetic parameters quoted in Table 3, it appears that the samples from site 1, and to a lesser extent site 2, are anomalous in their magnetic properties. Although the magnetic mineral content of rocks from all sites is similar, as evidenced by the relative uniformity of susceptibility values, the scatter of NMR directions and the intense but highly variable NRM intensities, corresponding to high but variable Koenigsberger ratios, suggest that sites 1 and 2 are affected by lightning and that the raw remanence data from these sites should be omitted from the interpretation.

AF cleaning has been partially successful in removing lightning induced components, although some specimens do not appear to possess a stable magnetisation. One sample from site 1 possesses an anomalous NRM directed vertically upwards, but cleans up to a reversed direction consistent with the cleaned directions from other sites. Thermal cleaning is commonly found to be ineffectual against IRM overprinting and this is observed with the anomalously magnetised samples from sites 1 and 2.

The tightly clustered directions obtained from site 3, together with the stability of the directions to AF and thermal demagnetisation, suggest that only one remanence component is present apart from, possibly, a small viscous magnetisation which is removed by thermal cleaning. The magnetisation is ancient and presumably acquired either during initial cooling of the rocks or during subsequent metamorphism associated with emplacement of granites.

The evidence suggests that the bulk of the rock unit away from the influence of surface effects bears a stable reversed remanence dominating the induced magnetisation, and directed approximately (180°, +50°). Neglecting the results from sites 1 and 2, which are considered anomalous, a representative value of the remanent intensity should be of the order of 1,000 micro Oersteds (100 gammas). The observed negative anomaly appears to be explained on the basis of these results and lends support to the hypothesis that cleaning can remove surface effects and isolate a representative remanence direction.

The palaeomagnetic pole calculated from the cleaned direction is (145°E, 77°S) with an estimated cone of confidence of 20°. The sampling is inadequate for a thorough palaeomagnetic study and complete laboratory treatment has not been carried out for all specimens. However from the Paleozoic Apparent Polar Wander Path for Australia given by Embleton (1980) the palaeomagnetic pole position appears to be more consistent with a lower Carboniferous magnetisation than with a Permo-Carboniferous primary or overprint magnetisation. This tends to support the geological evidence from field relationships that the Featherbed Volcanics are older than the Elizabeth Creek granite, conflicting with the geochronology (Black, et al. 1978) which indicates the volcanics are younger than the granite. Conclusions based on the palaeomagnetism must be very tentative because it is likely that secular variation has not been averaged out due to the limited sampling of the unit.

Thermomagnetic analysis of SV25 samples reveals that the dominant magnetic mineral in these rocks has a Curie temperature of approximately 620°C which is well above that of magnetite (580°C). This suggests the presence of an oxidised (cation-deficient) titanomagnetite, also known as titanomaghaemite. The Curie temperature could also correspond to a composition of about 5% ilmenite in solid solution with haematite, but this possibility is incompatible with the relatively high susceptibility and low coercive force of the main magnetic carrier in this rock. The presence of some haematite is indicated by the stability of remanence directions up to 650°C, which is above the Curie point of the major magnetic component.

Some of the magnetic carrier is destroyed by heating to above 500°C for 40 minutes, as evidenced by a drop in the susceptibility of specimens which have been thermally demagnetised to this temperature, and most of the magnetic material has broken down after heating in air at 700°C for 15 minutes. The observed effect of heat treatment is probably due to inversion of cubic titanomaghaemite to the corresponding rhombohedral phase.

4.2 Surveyor 24 - Brecciated Hornfelsed Sediments

For this prospect oriented surface samples of the sediments were collected from 4 sites and unoriented drill core was available from DDH S/1 at depths of 146 m, 154 m, 164 m, 167 m and 174 m. In addition outcrop of the adjacent Elizabeth Creek Granite was sampled at one site.

Whilst the surface samples appear similar to the deeper sediments they are unrepresentative of the magnetic properties at depth. This shows up clearly in the down-hole susceptibility survey. Weathering is thought to be responsible for the negligible susceptibility and remanence of the surface samples. This could be verified by checking if there is a visible coincidence of the bottom of the oxidised zone and the sudden appearance of magnetite in the sediments at a depth of 22 metres. Remanence directions from the surface samples are very scattered and the low intensities preclude cleaning.

The fresh rocks at depth are fairly magnetic with a peak remanence value of 2,640 x 10^{-6} Oe at a depth of 154 metres, quite close to the magnetic target. The remanence directions are ambiguous as the samples are unoriented, but it can be stated that the NRM vectors are roughly perpendicular to the drill core axis.

The contributions of remanence and induction in producing the observed anomaly are comparable, and the anomaly form will depend on the remanence direction.

Two samples of granite (SV24I-J0)collected from the southern part of the anomaly were badly weathered and consequently non-magnetic.

4.3 Surveyor 5 - Sediments

Oriented surface samples and unoriented drill core were tested. All specimens were non-magnetic with the exception of one specimen cut from drill core at depth 105 m containing a vein of sulphide mineralisation. This vein consisted mainly of pyrrhotite and had a very high conductivity (of the order of 100-200 mho/m), high susceptibility (0.03 emu at 217 Hz) and intense, fairly soft, remanence (NRM roughly 0.4 Oersted, perpendicular to core axis). Samples at depths of 107.5 m and 201 m were effectively non-magnetic.

The magnetic anomaly is unaccounted for both by the surface sampling and the drill hole data. The remanence directions of surface samples, if stable, may be indicative of the remanence direction of the far more intensely magnetised causative body if the remanence is associated with contact metamorphism of the area. The NRM directions of the sandstone samples SV05A-G are reversed with an average direction of roughly (200°, $+50^{\circ}$), which is reminiscent of the Featherbed Volcanics. This direction is ancient and suggests the magnetisation may date from the last high temperature thermal event, with which the magnetic body at depth could be associated. A tin pipe formed during emplacement of the Elizabeth Creek granite is likely to have retained a primary magnetisation and a remanence direction of (200°, $+50^{\circ}$) would account for the polarity of the observed anomaly. This magnetisation direction could therefore be tried in modelling and, if the assumptions of this interpretation are correct, could better define a target.

However, it would only take quite a small, compact pyrrhotite bearing body with remanence of the order found in the vein at 105 m to produce the observed anomalies down-hole and at the surface.

The quartzite samples (SV05H-I) and the shale (SV05J) have normal NRM directions close to the present field. This suggests that any ancient magnetisation has been viscously overprinted, or else chemically remagnetised during recent weathering.

4.4 Surveyor 6 - Sediments

Surface samples only were tested. As for Surveyor 5 these were all virtually non-magnetic. The low intensity NRMs exhibited normal, reversed and hybrid directions. A cryogenic magnetometer would be necessary for cleaning tests on these samples to try to isolate a primary direction.

4.5 Surveyor 14 - Sediments

Only surface samples were available. Low susceptibilities and remanent intensities were found. The NRM directions of the quartzite samples (SV14A-D) were normal and for the feldspathic sandstone (SV14E-H) were reversed. As for the other sedimentary rocks the NRMs were so weak that residual intensities after cleaning would be too small to measure on the Digico equipment.

4.6 Surveyor 23 - Volcanic Agglomerate

Surface samples were found to be fairly magnetic and fresh rock may have an emu susceptibility of 500-1,000 x 10^{-6}, probably with induction dominating remanence although both will contribute significantly to the anomaly. The NRM directions are scattered about a mean direction horizontal with declination 130° with cone of confidence 50°.

This large scatter is indicative of multicomponent magnetisation and the hybrid mean direction suggests that both normal and reversed components are present. Thermal and, to a lesser extent AF, cleaning tends to preferentially remove a normal component and the cleaned directions, whilst still fairly scattered, are better grouped than the NRMs with a mean direction approximately (180°,+40). Again then is evidence of a stable reversed magnetisation in the rocks of the Irvinebank area.

4.7 Surveyor 27 - Elizabeth Creek Granite

Oriented surface samples were collected from two sites corresponding to SV27A-B and SV27C-D. The latter samples were visibly more weathered and were non-magnetic. Their residual NRM directions were present field, assuming the samples were in situ.

The site 1 samples were magnetic with remanence dominating induction. Fresh rock may have a remanent intensity around 2,000 micro-oersteds (200 gammas). The NRM directions are scattered about a mean direction which is roughly horizontal with declination 65°, and are very stable to magnetic and thermal cleaning. As it is not certain that the samples were in situ, this hybrid-looking direction must be suspect.

5. CONCLUSIONS

1. The magnetic parameters determined from surface sampling at prospects SV25, SV23 and SV27 indicate the likely causative rock types of the anomalies and should place constraints on the modelling of these anomalies. If, in the light of the magnetic property measurements, the form and magnitude of the observed anomalies can be explained on the basis of known lithology, the exploration potential of the prospect is greatly downgraded.

On the other hand, at prospects SV5, SV6, SV14 and SV24 outcropping lithologies were shown to be incapable of accounting for the observed anomalies. In the case of SV24 the surface samples were unrepresentative of the rock at depth, possibly due to weathering, and the anomaly can be explained on the basis of the magnetic parameters of the drill-core samples. However at SV5 it appears likely that some explanation other than disseminated magnetite and/or pyrrhotite in the sediments is required to account for the observed magnetic response. A discrete mineralized zone is indicated by the magnetics, particularly the down-hole measurements, when the magnetic property measurements are taken into account.

2. The measurements on the SV25 samples are very relevant to the problem of the applicability of surface sampling to magnetic interpretation. At a number of sites the primary TRM acquired by the Featherbed volcanics had been inhomogeneously overprinted by surface effects, leading to a large scatter in NRM intensities and directions. Attempting to apply NRM measurements from these sites to modelling would have been confusing

and misleading. In particular had lightning-affected normally magnetised samples been the majority of those collected, a positive anomaly would have been expected over the unit, rather than the negative anomaly observed.

However application of standard palaeomagnetic cleaning techniques succeeded in demonstrating that the variability in raw remanence was due to unstable secondary components, which are attributed to surface effects, and that a hard, ancient reversed thermoremanence could be isolated which is thought to predominate away from the surface and which explains the negative magnetic anomaly.

It is recommended that surface samples generally be subject to full analysis of multicomponent magnetisations so that the maximum information about the magnetic history of the outcropping rocks can be extracted.

3. It was not possible to definitively test the hypothesis that the Irvinebank rocks acquired a reversed thermoremanence during metamorphism associated with emplacement of the Elizabeth Creek granite, because no fresh, definitely in situ granite samples were collected. The results from SV25A-D suggest that unweathered granite is capable of retaining a stable magnetisation and that in situ samples might define the direction of the Earth's magnetic field at the time of formation.

There is evidence of reversed magnetisation components in sedimentary rocks at a number of prospects (e.g. sandstones at SV5 and SV14 and SV23). Cleaning might isolate a reversed direction dating from the time of metamorphism, provided the very weak magnetisations could be accurately measured by a cryogenic magnetometer.

It can in any case be surmised that ore bodies may have retained a reversed Carboniferous direction which could be reflected in a negative anomaly (for $Q > 1$). At the time of intrusion of the Upper Carboniferous Elizabeth Creek Granite the Australian palaeomagnetic pole was at 49^{o}S, 140^{o}E ($A_{95} = 10^{o}$) based on three poles in Irving (1966). At Herberton this corresponds to a direction of (187^{o}, $+72^{o}$), assuming the field was reversed, which was the case throughout Permo-Carboniferous time. In the absence of other data this direction could be tried in modelling of negative anomalies.

6. REFERENCES

L.P. Black, D.H. Blake and J.A. Olatunji - "Ages of granites and associated mineralisation in the Herberton tinfield of northeast Queensland" B.M.R. Journal of Australian Geology and Geophysics, 3, 173-180, 1978.

B.J.J. Embleton - "Pre-Cenozoic palaeomagnetism of Australia and Antarctica" (Contribution to Study Group 3 of Working Group 10, International Commission for Geodynamics) 1980.

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TABLE 1

SAMPLE LOCATIONS (± 5m)

Surveyor 24			
SV24A	10 055N	10 250E	hornfelsed brecciated sediments
SV24B	10 055N	10 250E	" " "
SV24C	10 055N	10 250E	" " "
SV24D	10 030N	10 260E	" " "
SV24E	10 030N	10 260E	" " "
SV24F	10 030N	10 285E	" " "
SV24G	10 030N	10 285E	" " "
SV24H	10 030N	10 285E	" " "
SV24I	9 920N	10 245E	granite
SV24J	9 920N	10 245E	"
Surveyor 23			
SV23A	9 985N	9 595E	volcanic agglomerate
SV23B	9 985N	9 595E	" "
SV23C	10 025N	9 610E	" "
SV23D	10 045N	9 620E	" "
SV23E	10 045N	9 620E	" "
Surveyor 27			
SV27A	9 940N	10 160E	granite
SV27B	9 940N	10 160E	"
SV27C	9 825N	10 150E	"
SV27D	9 825N	10 150E	"
Surveyor 14			
SV14A	10 495N	10 730E	quartzite
SV14B	10 500N	10 750E	"
SV14C	10 500N	10 775E	"
SV14D	10 490N	10 800E	"
SV14E	10 580N	10 810E	felspathic sandstone
SV14F	10 580N	10 810E	" "
SV14G	10 580N	10 810E	" "
SV14H	10 580N	10 810E	" "
Surveyor 5			
SV05A	9 930N	9 960E	weathered buff sandstone
SV05B	9 930N	9 960E	" " "
SV05C	9 930N	9 960E	" " "
SV05D	9 930N	9 960E	" " "
SV05E	9 930N	9 960E	" " "
SV05F	9 930N	9 960E	" " "
SV05G	9 930N	9 960E	" " "
SV05H	10 025N	9 920E	quartzite
SV05I	10 025N	9 905E	"
SV05J	9 890N	9 930E	shale

.../2 (continued)

TABLE 1 (continued)

Surveyor 6			
SV06A	15m from adit entrance		felspathic sandstone
SV06B	10m from adit entrance		breccia
SV06C	5m from adit entrance		micaceous mudstone
Surveyor 25			
SV25A	9 730N	10 290E	quartz feldspar porphyry
SV25B	9 730N	10 290E	" " "
SV25C	9 730N	10 290E	" " "
SV25D	9 730N	10 290E	" " "
SV25E	9 725N	10 380E	" " "
SV25F	9 725N	10 380E	" " "
SV25G	9 725N	10 380E	" " "
SV25H	9 725N	10 380E	" " "
SV25I	9 300N	10 035E	" " "
SV25J	9 300N	10 035E	" " "
SV25K	9 300N	10 035E	" " "
SV25L	9 300N	10 035E	" " "
SV25M	9 300N	10 035E	" " "
SV25N	9 350N	10 030E	" " "
SV25O	9 350N	10 030E	" " "
SV25P	9 350N	10 030E	" " "
SV25Q	10 030N	10 100E	" " "
SV25R	10 030N	10 100E	" " "
SV25S	10 030N	10 100E	" " "

TABLE 2

CLEANING OF FEATHERBED VOLCANICS

	NRM DIRECTIONS	AF CLEANED DIRECTIONS	THERMAL CLEANED DIRECTIONS
SITE 1	Very scattered Average (0°,+40)	Directions wander randomly or clean up to reversed direction	Directions unchanged up to 650°C
SITE 2	Scattered around (220°,+50°)	Tend to move towards (180°, +50°)	Move slightly towards reversed direction
SITE 3	Well grouped around (180°, +60°)	Very stable (180°,+60°)	Stable. Move to (180°+50°)
SITE 4	Fairly scattered Average (180°, +40°)	Move to (180°,+50°)	Move towards (180°,+50°)

TABLE 3

MAGNETIC PARAMETERS

SITE	Average susc. (cgsx10^{-6})	Susc. Range (cgsx10^{-6})	Average NRM (O_ex10^{-6})	NRM Range (O_ex10^{-6})	Average Q	Range in Q	No. of Specimens
SV05A-J	15	5-40	5	0-15	0.5	0-4.3	27
SV06A-C	8	5-10	2	0-5	0.3	0-0.8	6
SV14A-H	8	0-30	10	0-140	4	0-15	16
SV23A-E	630	340-830	140	30-500	0.4	0.1-1.3	7
SV23F	15	15	6	5-7	0.8	0.7-0.9	2
SV24A-H	25	5-90	5	0-40	0.2	0-0.8	10
SV24I-J	5	5	0	0	0	0	2
SV25A-D	430	300-660	7110	1100-26030	34.1	7-117	9
SV25E-H	340	180-590	5040	1470-12450	30.3	12-57	11
SV25I-M	210	150-290	840	720-980	8.1	6-10	12
SV25N-P	140	110-190	440	300-880	6.0	5-9	8
SV25Q-S	600	380-730	1660	1600-1710	4.7	4-5	3
SV27A-B	1090	670-1850	1950	320-5050	4.3	0.4-10	10
SV27C-D	3	1-6	2	2	1.6	1-4	6
S5(DDHS/1)	23	20-25	5	0-5	0.4	0-0.4	8
S24(DDHS/1)	1380	560-2640	960	300-2740	1.2	0.7-2.1	7

62 samples

Notes:

1. The Koenigsberger ratio Q has been calculated assuming a value of 0.5 Oersteds for the Earth's field at Herberton.

2. The averages are arithmetic means