The Magnetisation of the Elura Orebody, Cobar, NSW

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Summary

Petrophysical sampling of the steeply plunging, roughly pipe-like Elura Zn–Pb–Ag orebody demonstrates a dominantly remanent magnetisation with steep negative inclination; the magnetisation is carried by central monoclinic pyrrhotite lenses. The remanence data suggests a mid-Cretaceous low grade thermal overprint possibly related to final cooling associated with minor uplift. Susceptibilities are high, averaging about 4200 × 10^{-6} cgs (about 52 800 × 10^{-6} SI), and markedly anisotropic with k_1:k_2:k_3 = 1.6:1.2:1.0. The anisotropy reflects a preferred crystallographic orientation of pyrrhotite grains — the basal planes are vertically oriented suggesting plastic flow or crystal growth in a vertical direction. The high susceptibilities coupled with a Koenigsberger Ratio of 9·4 produce a ground magnetic anomaly 140 gammas (nT) in magnitude. This anomaly can be simply and correctly modelled by vertically plunging ellipsoids using equations that incorporate remanence, anisotropic susceptibility, and demagnetisation.

Introduction

The Elura Zn–Pb–Ag orebody is located 43 km NNW of Cobar and is the northernmost known deposit in the Cobar mineral field (Emerson, 1980). The orebody has an associated 45 γ aeromagnetic anomaly which was the first clue to its discovery.

Twenty-eight oriented block samples were collected from four different rock types within the orebody. The collection comprised 16 samples of pyrrhotitic ore, four of pyritic ore, four of siliceous ore and four host rock samples (Tonkin, 1985).

Remanent magnetisation is the dominant contributor to the Elura magnetic anomaly. The pyrrhotitic ore, which forms the central magnetic core, has an intense natural remanent magnetisation (NRM) which is consistently directed steeply upwards. Other ore types, and the host rocks, have negligible magnetisation. NRM directions of specimens from pyrrhotitic ore samples are plotted in Fig. 1. The average NRM intensity for the 16 samples is 22 700 μG and the mean bulk susceptibility is 4 230 × 10^{-6} G/Oe. The corresponding Koenigsberger ratio is 9.4, indicating that the induced magnetisation is only a minor component of the total magnetisation and that interpretation based on measured susceptibilities alone would lead to serious errors.

Alternating field and thermal demagnetisation of selected specimens demonstrated that the NRMs are essentially monocomponent, dominated by a single remanence with

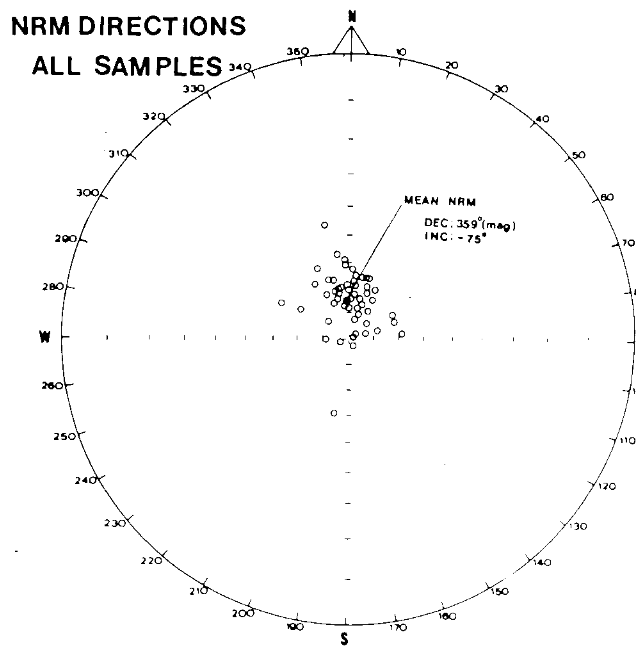

FIGURE 1
NRM directions for pyrrhotitic ore samples.

mean direction: dec = 358°T, inc = −78°, with small amounts of randomly directed isothermal components ('palaeomagnetic noise' due to exposure to stray magnetic fields).

The well-defined cleaned remanence direction (α_{95} = 5°) is statistically indistinguishable from the mean NRM direction (dec = 359°, inc = −75°, α_{95} = 3°) which lies ~15° from the present field direction and ~25° from the present dipole direction. Thus the difference between the remanence direction and either the instantaneous or time-averaged recent field directions is statistically significant, indicating that the NRM is not a viscous remanence acquired recently. The palaeopole position calculated from the cleaned remanence direction is Lat = 50°S, Long = 150°E, (A_{95} = 9°) which is consistent with acquisition of remanence either during the Late Carboniferous-Late Permian or the mid-Cretaceous. The earlier age would be consistent with acquisition during post-metamorphic cooling, but the normal polarity of the magnetisation suggests that a mid-Cretaceous (~100 Mya) age of the remanence is more probable (Clark, 1983a). Monoclinic pyrrhotite, due to its low Curie temperature, is a sensitive detector of low grade thermal events. The remanence of the Elura orebody may relate to final cooling, possibly associated with minor uplift, during the Cretaceous. Evidence of a low grade thermal overprint, of similar age, carried by pyrrhotite-bearing samples from the CSA Siltstone in the Cobar area has been discussed by Clark (1983b). A regional event of this nature should be reflected in the remanence of pyrrhotite-bearing rocks throughout the area.

The susceptibility of the pyrrhotitic ore is markedly anisotropic, exhibiting a pronounced magnetic lineation (axis of maximum susceptibility) which is subvertical, with mean direction dec = 210°, inc = +83°. The corresponding susceptibility is 6 210 $\times 10^{-6}$ G/Oe. The susceptibility normal to this axis is almost isotropic and has an average magnitude of 4 370 $\times 10^{-6}$ G/Oe. The anisotropy has negligible effect on the magnetic anomaly because the total magnetisation is dominated by remanence, but it does reflect a preferred crystallographic orientation of pyrrhotite grains and it therefore has interesting implications for the structure and geological history of the orebody. The magnetic fabric of the pyrrhotitic ore indicates a preferred vertical orientation of basal planes, with c-axes randomly distributed within the horizontal plane. Such an arrangement reflects either plastic flow in a vertical direction during deformation of the orebody or crystal growth in a stress field with axial symmetry and a vertical axis of maximum tension.

Preliminary models of the Elura orebody, based on the distribution of pyrrhotitic ore (the cores of the orebody) shown in mine sections, were constructed and theoretical total field anomalies were calculated at the surface and compared to observed ground magnetic profiles over the orebory. The pyrrhotitic cores are vertical pipe-like bodies. Prolate ellipsoids, and later slightly triaxial ellipsoids (Emerson *et al.*(1985), Clark *et al.* (1986)) were chosen as appropriate geometric forms for modelling these bodies.

The magnetic properties of the models were simply taken to be equal to the average values determined for the samples. Agreement between calculated and observed anomalies was quite satisfactory, indicating that the magnetic properties of the orebody have been well characterised by the sampling. Minor adjustments to the dimensions of the models produced an excellent match between theoretical and observed ground magnetic profiles, with the only discrepancies being attributable to magnetic noise due to shallow sources within the lateritic soil cover (see Figs. 2, 3 and 5).

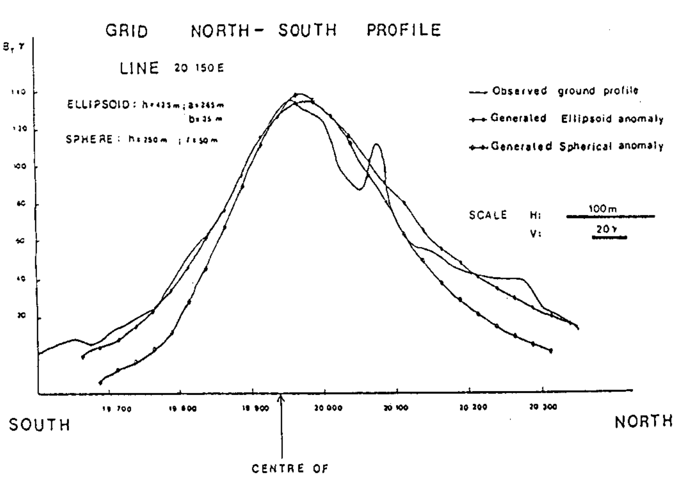

FIGURE 2
Comparison of observed ground magnetic anomaly with theoretical anomalies for ellipsoid and sphere models.

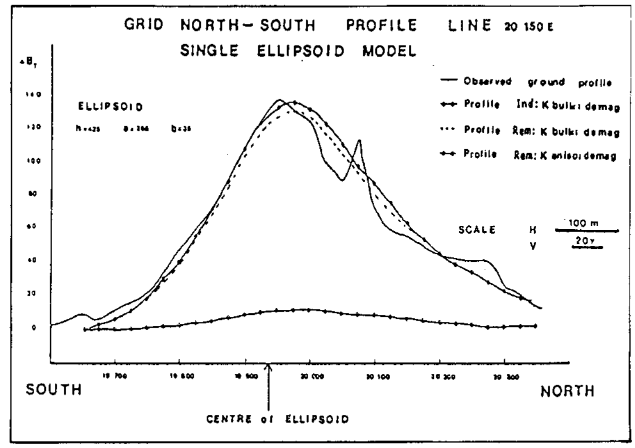

FIGURE 3
Observed and theoretical anomalies including (solid diamonds) and excluding (open diamond) remanence.

Figure 2 shows that a vertically plunging body of considerable depth extent matches the shape of the observed anomaly better than a compact body, by comparing signatures due to an elongated prolate ellipsoid and a sphere. Figure 3 demonstrates that the induced magnetisation, calculated from the measured susceptibilities, makes only a minor contribution to the anomaly. The geometry of a refined model, incorporating two ellipsoids which correspond to separate pyrrhotitic cores within the orebody, is shown in Fig. 4. Figure 5 shows that the two cores are not resolved as separate bodies at ground level. Thus the simpler models, which represent the pyrrhotitic ore distribution by a single, vertical elongated ellipsoid are quite satisfactory for most purposes. Ellipsoids are certainly more appropriate forms for modelling many orebodies than either spheres or sheet-type models.

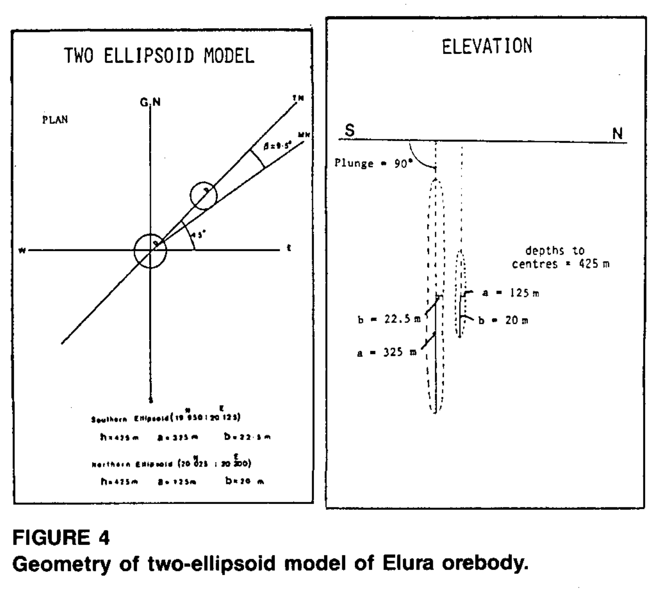

FIGURE 4
Geometry of two-ellipsoid model of Elura orebody.

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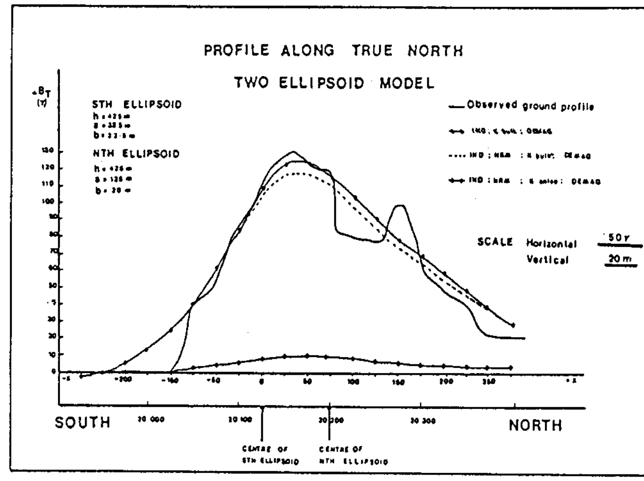

FIGURE 5
Observed and theoretical anomalies for the two-ellipsoid model.

Radar Probing Through 600 Metres of Zechstein Salt

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Summary

Two radar systems were used to conduct tests in a European salt mine. Both systems obtained very good results. An electromagnetic wave speed of 122 m/μs in salt was measured in this particular mine. Using the first system, Bravo, for long range probing, several areas that appeared to contain many anhydrite stringers and other areas that appeared to have good, clean salt were found. Bravo obtained a maximum range of 592 m. At a few locations the Bravo antennas were moved in azimuth in order to pin-point the location of a particular reflection. At one of these stations, a reflection that corresponded to a known anhydrite stringer was located.

With the second system, Foxtrot, which was used for short range, high resolution tests, a primary and a multiple signal were recorded from a known anhydrite layer below the mine's salt floor. At another station, Foxtrot obtained a maximum range of 47 m. The salt used for the Foxtrot tests was not as pure as in other locations within the mine. The authors believe that Foxtrot tests at other locations might yield probing distances up to 70 or 80 m.

Introduction

Two radar systems were used to probe into rock salt in a European salt mine. The 'Bravo' system transmits at 230 MHz with a peak power output of 30 kW. Its intended use was to probe in advance of mining for large anhydrite stringers. The second system, 'Foxtrot', which operates at 4300 MHz, was intended for short range, high resolution profiling, such as mapping a known anhydrite layer that lies below the salt floor of the mine. Both of these systems have been used successfully in salt mines through North America (Unterberger, 1974; Unterberger, 1978; Unterberger, 1983; Cavanaugh, 1984). In a potash mine in Brazil, Foxtrot was able to record and follow a potash-tachyhydrite interface beneath the mine floor and had a maximum range of 19.2 metres (Lopez-Aguilar, 1986). Since the Brazilian potash contained a relatively large amount of water, however, transmission tests of the Bravo system were unsuccessful.

The present tests were conducted in the Zechstein Salt, which is a layer of dry rock salt that lies 800 m below the surface at the study location. Above the salt deposit lies a layer of shale, and below the salt lies a 12 to 15 m thick layer of Kreuzsalz, which contains sulfate. Anhydrite, limestone, and coal deposits lie below the Kreuzsalz. Anhydrite stringers also extend throughout the salt deposit. The operators of this salt mine wanted to use the radar systems to help them avoid mining into large anhydrite deposits.

Testing equipment

A block diagram of the Bravo system is shown in Fig. 1. The Bravo system is a modified APN-3 Short Range Navigation system that was originally designed for navigational use in airplanes during World War II. It is still used today for position locations of ships during marine seismic studies. Both the receiver and transmitter use a two-bay array of YAGI antennas, which produce a 3 db beamwidth of ± 11.5° in the H-plane during salt transmission.