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Paper

On the Spatial Pattern of Magnetic Fluctuations in the Cobar Area, NSW

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Abstract

Five recording magnetometers have been established in the Cobar area of NSW to examine the spatial uniformity (or otherwise) of natural fluctuations with time of the geomagnetic field. The Cobar area is a particularly suitable test area for such a study because of its history in the development and use of magnetic survey methods in the search for base metal ore deposits, and because magnetic fluctuations are now a limiting factor in the production of accurate aeromagnetic survey maps.

The magnetic fluctuations in the Cobar area are found to be not uniform, but appear affected by a current concentration in the vicinity of the east side of the Cobar basin. Thus changes as great as 25% in magnetic fluctuation amplitude are observed over distances of order 30 km (and may occur over even shorter distances). Some differences are also observed in the amplitude of the east-west component of the magnetic daily variation.

The phenomena are interpreted to indicate a geologic unit of good electrical conductivity (possibly the Cobar slate member of the Cobar Trough group) which runs along the eastern edge of the basin, and carries a concentration of the natural electric current flow induced in the earth.

Introduction

The present paper describes a reconnaissance study of fluctuations of the earth's magnetic field in the Cobar area, on the time scales of minutes, hours, and days. Fluctuations of the magnetic field occur when natural electric currents flow both external to the earth (in the ionosphere and beyond) and internal to the earth (in the crust and upper mantle). Such fluctuations are a fundamentally different phenomenon to the phenomenon of the magnetization of rock which gives rise to the stationary patterns of magnetic surveying.

However, fluctuations are a crucial factor in magnetic surveying, as they form a 'noise background' against which survey data are recorded. Thus an important part of magnetic survey practice has always been the correction of survey data for fluctuation effects. One modern procedure is to subtract a fixed base-station record from the record of the mobile survey instrument, and the accuracy of this technique will clearly depend upon the spatial uniformity of the magnetic fluctuations themselves. Examples of uniformity and non-uniformity in magnetic fluctuations for Australia, on a regional scale, have been reviewed in a previous paper (Lilley 1982).

Knowledge of magnetic fluctuation patterns is also relevant to exploration geophysics fundamentally, in contributing new geophysical information regarding the process of natural electromagnetic induction taking place in the earth. The local characteristics in a mineralized area of such large-scale natural electromagnetic induction have by no means been fully investigated, and relatively little is known of this subject in Australia. Thus the present project investigates the Cobar region as a suitable test area for reconnaissance observations.

As mentioned, natural geomagnetic fluctuations occur with a wide range of time-scales. The present paper describes relatively long period (low frequency) fluctuations. Audiomagnetotelluric ('AMT') measurements of natural electromagnetic induction in the Cobar area, at much shorter periods (higher frequencies), have recently been made by Professor K. Vozoff.

Magnetic methods at Cobar

The Cobar area of NSW has been an important mining field since 1869, when mineralization was first discovered in the region by surface prospectors. Because of associations of magnetic iron sulphide with more valuable base-metal sulphide ore, the field has long been a testing and proving ground for magnetic survey methods. [See, for example, Richardson (1948) and Barlow (1950).] With the development of airborne fluxgate magnetometers, the area was covered by a regional government survey (Spence 1961), and by some private surveys.

The development of proton precession magnetometers and transistor electronics enabled airborne surveying from lighter and more manoeuvrable aircraft, which could more closely emulate ground survey detail. One such development project was undertaken in Australia by the Bureau of Mineral Resources, choosing the Cobar area for a first trial survey in 1963 (Goodeve & Lilley 1963; Lilley 1964). A notable success from detailed aeromagnetic surveying resulted subsequently with the discovery by this method of the Elura orebody [see, for example, Wilkes (1979)]. For a comprehensive collection of papers on the exploration, discovery, evaluation and testing of the Elura deposit the reader is referred to papers in the volume edited by Emerson (1980), and to Gidley (1981).

The Elura experience drew attention to the question of magnetic fluctuations because it demonstrated the importance of relatively weak magnetic anomalies in mineral geophysics (the aeromagnetic anomaly detected over the Elura deposit was of strength some 45 nT), and so emphasized the importance of accurate aeromagnetic surveys. Traditionally the resolution of low-amplitude aeromagnetic anomalies had to some extent been regarded as the domain of the search for hydrocarbon deposits in sedimentary basins.

The Elura case history is also relevant to the present paper because it indicates quite generally the importance of geophysical methods in finding hidden gossans, and so underscores the necessity of continued research into the geophysics of mineralized areas.

The present study

Recording magnetometers were installed at five sites in the Cobar area, centred on Cobar airport. The positions of the sites are shown in Fig. 1, and more details are given in Table 1. The instruments are in effect temporary magnetic observatories, which each record fluctuations of the ambient magnetic field to an accuracy of 1 nT in three components: H to the magnetic north, D to the magnetic east, and Z vertically downwards. Fluctuations in the geographic directions of X to the north and Y to the east are computed from these other components, as are fluctuations in the total field F.

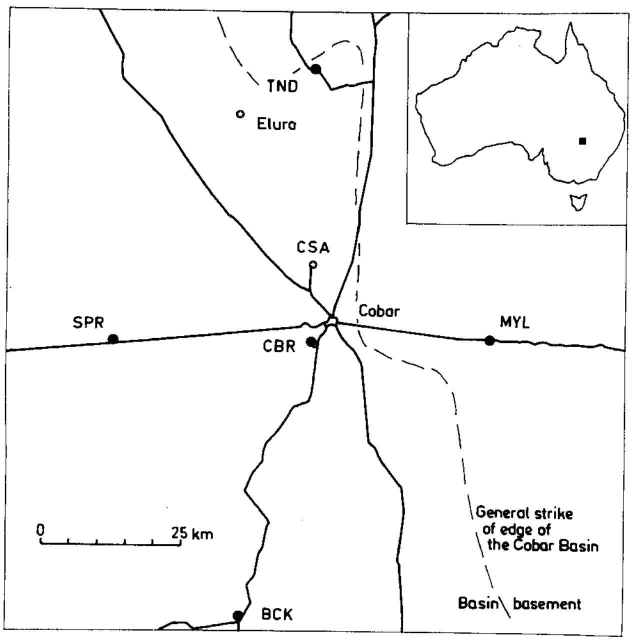

FIGURE 1
Map of the Cobar area, with sites of the five recording magnetometer installations marked by solid circles.

The instruments, to the design of Gough and Reitzel (1967), are described in particular by Lilley *et al.* (1975); a later version of the same instrument, with improvements, is described by Kuppers and Post (1981). Upon installation the instruments are buried in the ground, and powered by a car battery; recording is on photographic film. Taking readings every 10 s, a film lasts for three weeks of unattended operation, while if readings are taken every minute recording time is extended to four months.

TABLE 1

Code	Station	Latitude	Longitude
BCK	Buckambool	31° 59′	145° 40′
CBR	Cobar Airport	31° 32′	145° 48′
MYL	Meryula	31° 32′	146° 08′
SPR	Springfield Tank	31° 32′	145° 26′
TND	Tindarey	31° 06′	145° 48′

A substantial data base of simultaneous magnetic recordings is now held for the sites shown in Fig. 1. The records cover a great range of magnetic activity, from 'quiet days' (regarded as optimum for regular magnetic surveying) to severe storms (during which magnetic survey operations would normally be suspended). With these records it is possible to investigate the differences between the fluctuations at the different sites, and thus to estimate how accurately the record of a base station recording say at Cobar airfield could be used to subtract time fluctuations from the record of a survey aircraft operating near any of the other four recording stations.

The five sites occupied do not cover the Cobar area thoroughly; they do however form a reconnaissance net for magnetic fluctuation patterns in the area.

Examples of the data recorded will now be presented and discussed.

Data

The event of 26 October 1982 of north-west polarization

Figure 2a shows a simple 'sudden commencement' event as recorded at the five stations, and Fig. 2b shows this event differenced with respect to Cobar. That is, the records for the Cobar site (chosen arbitrarily as the central station of the net) have been subtracted from the records of the other four sites, in each component.

As can be seen from inspection of the figures, the basic signal of strength of order 40 nT is uniform across the net in the horizontal components of field (X and Y) to within several nanoteslas.

The event of 23 November 1982 of north-east polarization

A smooth substorm event recorded at the five sites is shown in Fig. 3, chosen for its predominantly north-east polarization. That is, the direction of strongest horizontal field change is quite different (north-east quadrant as against north-west quadrant) to that of Fig. 2.

As in Fig. 2b, Fig. 3b shows the signals differenced with respect to Cobar. There is now more character in the differenced signals, a result which will be discussed below.

The quiet day of 14 December 1982 of east polarization

The diurnal variation during a 'quiet day' recorded by the net is shown in Fig. 4a, and its differences, again with respect to Cobar, are shown in Fig. 4b.

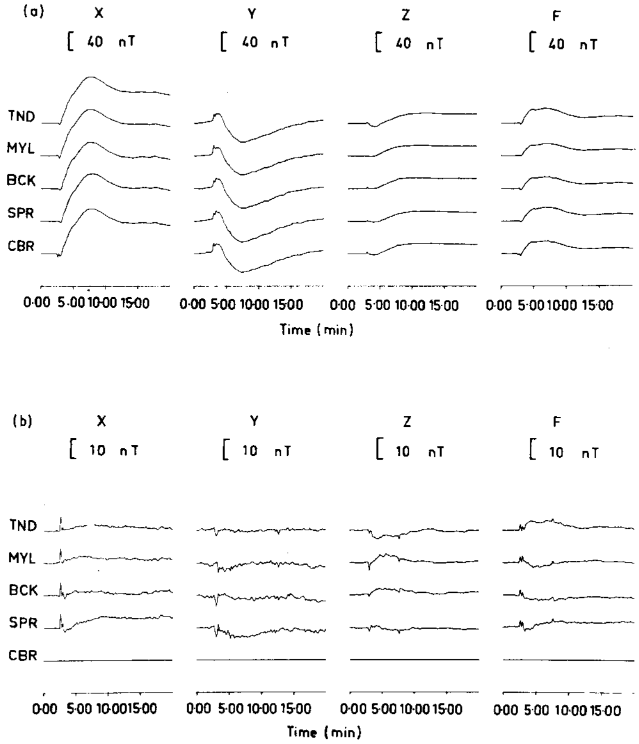

FIGURE 2

(a) The event of 26 October 1982 UT as recorded at the five stations. The starting time for all records is 0 hr 26 min UT. (b) The data of Fig. 2a when the relevant Cobar record is subtracted from each trace. Note the change in vertical scale by a factor of four between Fig. 2a and Fig. 2b.

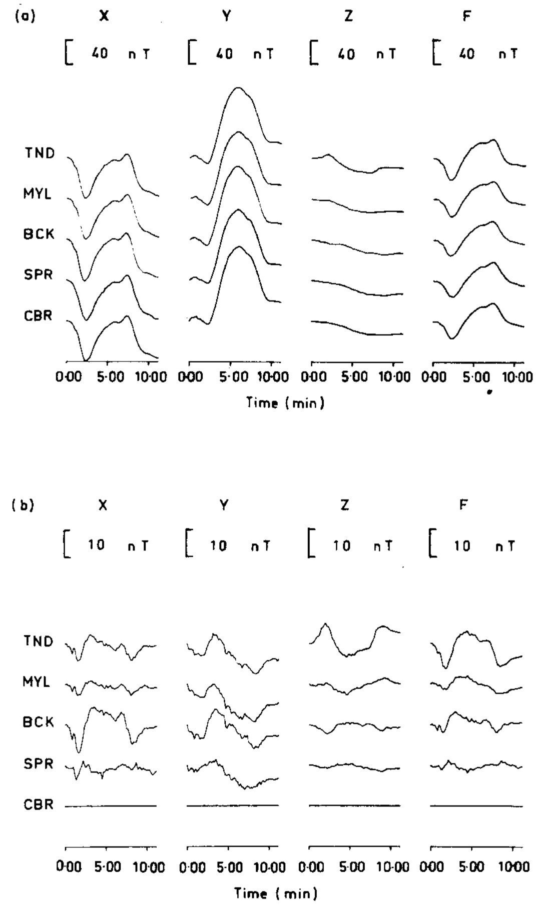

FIGURE 3

(a) The event of 23 November 1982 UT as recorded at the five stations. The starting time for all records is 23 hr 06 min UT. (b) The data of Fig. 3a when the relevant Cobar record is subtracted from each trace. Note the change in vertical scale by a factor of four between Fig. 3a and Fig. 3b.

The strongest horizontal signal for the quiet day is in the Y component, corresponding to an east-west horizontal polarization.

Figure 4b shows some variation in the strengths of the Y components for the various stations, as differenced with respect to Cobar. This phenomenon will be included in the discussion below.

Interpretation

Directions of electric current flow accompanying the magnetic events

The signals shown in Figs 2, 3 and 4 are the result of electric current flow outside the earth (mainly in the ionosphere, the 'primary' field) and also within the earth (the induced or 'secondary' field). The physics of the generation of the primary electric currents external to the earth in the ionosphere is understood to be a large-scale global phenomenon. Especially over midlatitudes (as for Australia) the current flow is likely to be smooth and spatially uniform.

Such variation as is evident on the differenced Figs 2b, 3b and 4b can therefore be taken to be a consequence of non-uniformity or spatial variation in the induced electric current flow in the ground. The characteristic of the observations which may be exploited most directly is that the horizontal magnetic field components (X and Y) will be most affected at positions vertically above a concentration of current in the ground. The maximum effects in the vertical field component (Z) will be offset to the sides of a current concentration. A first interpretation of the records of Figs 2, 3 and 4 may thus be made as follows.

In Fig. 2a, the main magnetic field change is an increase in the north-west quadrant, with a positive X signal and a negative Y signal. The direction of associated electric current flow, from basic considerations will (to first order) be perpendicular to the magnetic field change and thus comprise a pulse of current directed north-east external to the earth, together with a pulse of current directed south-west within the ground. Relative to Figs 3b and 4b, the differences in Fig. 2b are small, and it is deduced that such a south-west current flow in the ground is relatively uniform.

In Fig. 3a, the main magnetic field change is an increase in the north-east quadrant, so that the main current flow in the earth will be a pulse to the north-west. The differences in Fig. 3b indicate that such a north-west current flow is notably less uniform than the south-west current flow for the event in Fig. 2.

In the quiet day records, shown in Fig. 4a, (note that this figure covers a much longer time span than Figs 2 and 3) the main magnetic field change is in the Y component and comprises an increase first to the west, then to the east. The corresponding electric current pulses in the ground will be first to the south, then to the north. The differences in Fig. 4b indicate variations of up to 10 nT in the strength of the Y diurnal signal, of strength 120 nT.

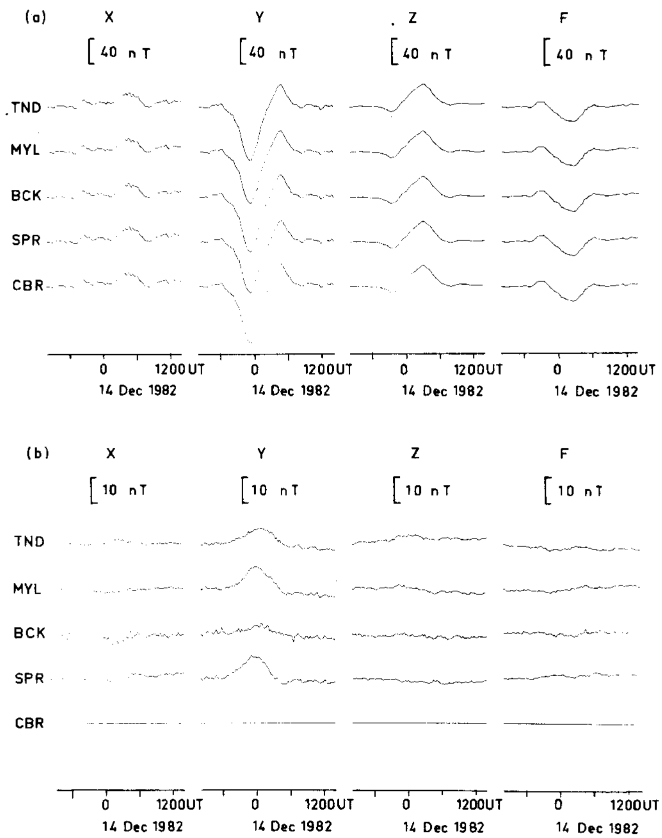

FIGURE 4

(a) The quiet day of 14 December 1982 as recorded at the five stations. The records shown are for the 24 hours from 14 hr 00 min UT on 13 December to 14 hr 00 min UT on 14 December 1982. (b) The data of Fig. 4a when the relevant Cobar record is subtracted from each trace. Note the change in vertical scale by a factor of four between Fig. 4a and Fig. 4b. Note also the considerable change in horizontal scale between Fig. 4 and Figs 2 and 3.

Interpretation in terms of concentration of electric current flow

The data of Figs 2, 3 and 4 may be given a first order interpretation in terms of a concentration, along the edge of the Cobar Basin, of electric current induced in the earth. Thus Fig. 2 shows a lesser effect as its induced current flow is across the Basin boundary, while Fig. 3 shows a greater effect because it has a substantial component of current flow parallel to the Basin boundary. Although it is perhaps unexpected for such a local effect to be evident in a long-period fluctuation like the daily variation, the phenomenon may in fact be most clear in Fig. 4, supported as it is mainly by a south-north current flow. Thus, in Fig. 4, the stations MYL and SPR (east and west of the basin boundary) are interpreted as normal stations, and TND, BCK and CBR (nearer the basin boundary) are interpreted as anomalous stations.

Discussion

Effect of the edge of the Cobar Basin

Natural magnetic fluctuations in the Cobar region show a spatial pattern suggesting control by the edge of the Cobar basin. The simple model is envisaged of natural electric current in the ground being concentrated along the edge of the basin, presumably in some rock formation of high electrical conductivity (such as the Great Cobar slate?). Such a structure selectively enhances fluctuations which are supported by a current flow parallel to it.

Spatial pattern of fluctuations in the total field F

Such an interpretation is based particularly on horizontal magnetic component data. For magnetic survey purposes, especially aeromagnetic, the important component is the 'total field' component F, also shown in Figs 2, 3 and 4. The F signal contains a moderate contribution from X, a negligible contribution from Y, and a major contribution from Z: thus the F differences in Figs 2b, 3b and 4b reflect particularly the Z differences though for reasons of convention they are of opposite sign.

A further characteristic of the records shown is the variety of causes of the Z signals in Figs 2a, 3a and 4a. In Fig. 2a the general increase at all stations of Z with a positive X and a negative Y is likely to be an expression of the 'coast effect' due to the continent-ocean boundary at the coast of NSW, away to the south-east. In Fig. 3a the Z signals are relatively weak (as the horizontal field is not polarized 'across the coast' and so does not create a coast effect), and in Fig. 3b the differences in Z (and so F) may be attributed to more local effects.

In Fig. 4a the substantial Z signal is usual for the magnetic daily variation in inland Australia (it may be different near coasts) and is associated in part with the fact that the diurnal fluctuation is of much longer duration than the sub-storm events in Figs 2 and 3. Thus the F differences in Fig. 4b are smooth, as the variations in the Y differences do not contribute to F.

Local or regional induction

A question not addressed in the present paper is that of whether the induction is local or regional, though this question is very topical in the wider literature on geomagnetic induction. However, the observation may be made, particularly concerning Fig. 4, that such a variation over a distance of 30 km for a very long-period disturbance appears to be evidence of the local channelling (essentially according to Ohm's law) of a current flow induced on a much larger scale.

Evidence of strong telluric signals

Strong telluric noise has been reported for the Cobar area by crews working there with electrical prospecting equipment (Emerson 1980). Such noise may be at much higher frequencies than the fluctuation events reported here, and at such higher frequencies the pattern of local geomagnetic induction may be different. However, it is appropriate to examine the present results for any relevance to the reported telluric noise.

The present study indicates some non-uniformity in telluric current patterns, but very strong local concentrations would be needed to give abnormally high noise (say noise increased by a factor of ten) on electrical surveys. Thus the present evidence of some current concentration does not necessarily explain or account for the reports. The present interpretation model does, however, predict that any unusually strong telluric signal near the edge of the Cobar Basin should be 'polarization dependent'. That is, it should be a maximum for magnetic fluctuations occurring in the north-east sector, and a minimum for magnetic fluctuations occurring in the north-west sector.

The point may be made that in a study to find the cause of telluric noise, information on any consistent horizontal polarisation which the noise might have, and information on its power spectrum, would provide powerful clues. Further, knowledge of the direction of any consistent noise polarization would enable survey lines to be designed with this factor in mind.

Conclusions

The present paper is based on an inspection of recorded data. The records from the present stations should yield more information upon further analysis, especially of any frequency dependence of the phenomena described, and also concerning correlations between vertical and horizontal field fluctuations.

However, clarification of geological effects in such a situation may require a greater density of observing sites. The net of five stations used in the reconnaissance study described has shown that significant geomagnetic fluctuation differences do occur on the scale studied.

Acknowledgments

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