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Note. Both polarization ellipses shown rotating in wrong direction

A Polarization-sensitive Magnetic Variation Anomaly in South Australia

LARGE two-dimensional arrays of magnetometers, recording time-varying magnetic fields from ionospheric currents, have been used to study local variations in the electrical conductivity of the upper mantle, especially in the tectonically active regions of western North America[1–5]. Electrical conductivity of ultrabasic silicates is related exponentially to temperature through semiconduction mechanisms[6], and is related also to partial melting. Compositional conductivity anomalies also exist[7], and magnetometer array studies supplement and extend information from heat-flow measurements in mapping anomalously hot regions of the upper mantle and their boundaries with colder mantle under shield regions. Such thermal mapping gives one approach to the study of global tectonics within continents.

The first two-dimensional magnetometer array study in Australia was carried out in 1970. The positions of the magnetometers are shown by dots in Figs. 1 and 2. The array, 25 instruments arranged in three lines, was placed in South Australia and western New South Wales with its centre at the northern Flinders Ranges. These mountains run north–south and lie east of Spencer Gulf, the conspicuous indentation of the coastline centred in the maps (Figs. 1 and 2). The array was located with the help of information from heat-flow, geochronology, seismicity and geology, suggesting that the Flinders Ranges might be a surface expression of the boundary between the western ancient shield and the eastern, tectonically active and younger province. The initial hypothesis was that the upper mantle under Australia might be like a mirror image of that under the United States, with a colder, less conductive upper mantle in the west and higher temperatures under the eastern region.

The magnetometers, of an inexpensive type with inaugurated two-dimensional arrays[8], were located at airstrips, in most cases on sheep or cattle stations. Installation and servicing were by light aircraft. A large quantity of data was secured from magnetic storms and sub-storms, and will be considered in detail later. Here we report an anomaly in the variation fields of a type not encountered before, and offer an explanation.

In previous array studies[1,4] it has proved useful to draw contoured maps of the amplitudes and phases of Fourier transforms of the magnetograms, at periods at which the ionospheric source currents provide adequate input to the array. When this is done for substorm events recorded by the South Australian array, a closed maximum in the vertical component (Z) amplitude appears prominently in the centre of the array for transforms of some events at some periods (Fig. 1) but is absent from the fields of other events. Indeed the Z anomaly comes and goes even for transforms at different periods from a single data set (Figs. 1 and 2). This variability of the anomaly contrasts with the invariable presence of North American anomalies at the Southern Rocky Mountains[1,2], at the Wasatch Front[1,2], in the North American Central Plains[4,5] and at the Northern Rockies[4,5].

Induction in conductive structures in the upper mantle is chiefly by the horizontal components of the incident field, which are in general several times larger than the vertical component. The reason for this is well understood; it is a consequence of reinforcement of tangential fields and reduction of radical field by induction in the highly conductive middle mantle[6]. Given the dominance of the horizontal components in the induction process, the polarization of the horizontal field will be important[9,10]. In general the polarization will be elliptical. For simplicity we consider the special case of a plane-polarized time-varying magnetic field making angle θ with a straight conductor in the Earth. Current induced will be proportional to the transverse magnetic field, and so to sin θ; anomalies in the vertical and transverse horizontal components will always be present unless $\theta = 0$, but will vary in magnitude as sin θ. This is consistent with the presence of the North American anomalies already listed, in all variation fields recorded.

In a curved conductor (Fig. 3) a field polarized with magnetic vector normal to the central, curved part of the conductor induces in-phase EMFs in all parts of the conductor, a large current flows and a vertical field anomaly appears inside the fractional-turn coil. With the orthogonal polarization the EMFs induced on either side of the centre are in phase opposition: the current and Z anomaly will be small. The polarization ellipses for the horizontal fields are shown in Figs. 1 and 2, and their major axes are indeed in the directions which would account for a polarization-sensitive Z anomaly in terms of a curved conductor running north–south under or near the Flinders Range and east–west just north of the array.

In general terms, a polarization-sensitive anomaly requires a three-dimensional configuration of conductors. The curved conductor is one such. Another configuration is important: that of two crossed but unconnected straight conductors (Fig. 4). An incident field will generate Z amplitude anomalies in the opposed pair of angles within which the horizontal magnetic vector lies. In the other two angles the vertical fields of the two currents are out of phase and the anomaly will be small.

The conductive configuration which produces the South Australian anomaly may be closer to the crossed-conductor model than to the curved conductor. With crossed conductors currents will be induced in both, and will produce amplitude anomalies in the transverse horizontal component above each conductor, for any polarization (Fig. 4). In both Fig. 1 and Fig. 2 there is evidence of maximum in the north–south field X in the northern part of the array, indicating east–west current there; and an anomaly in Y in the eastern part of the array indicating north–south current there; these anomalies are present for both polarizations shown. This is consistent with the crossed-conductor model rather than the curved conductor. The phase maps (not shown) also support the crossed-conductor model. At $T = 35$ min, at which there is a large Z amp-

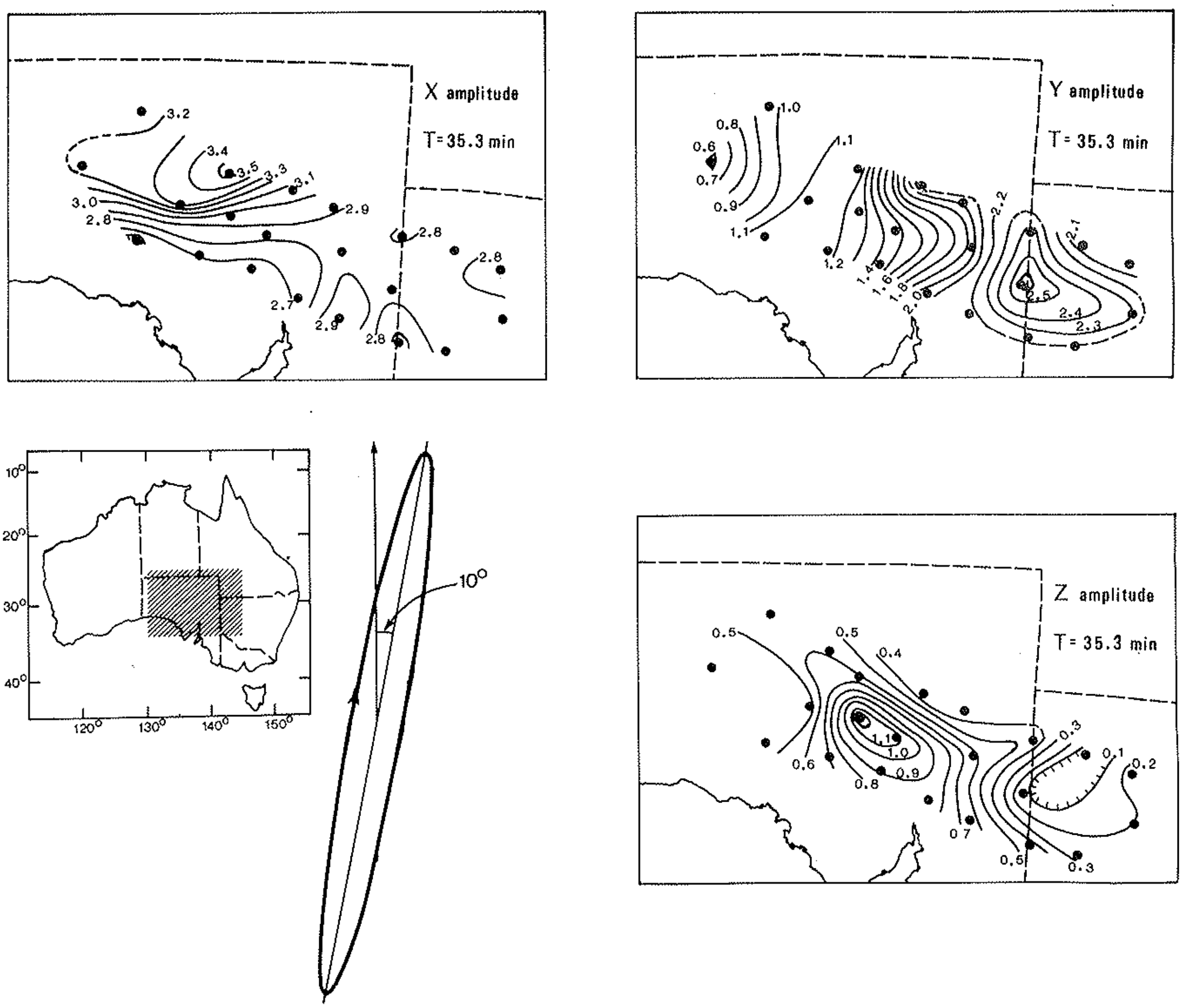

Fig. 1 Amplitudes (in arbitrary units) at period 35 min of Fourier transforms of magnetograms of a magnetic disturbance on October 16, 1970, recorded by the South Australian magnetometer array. X is the geographic northward horizontal component of the variation field, Y the eastward horizontal component and Z the downward vertical component. Dots show magnetometers.

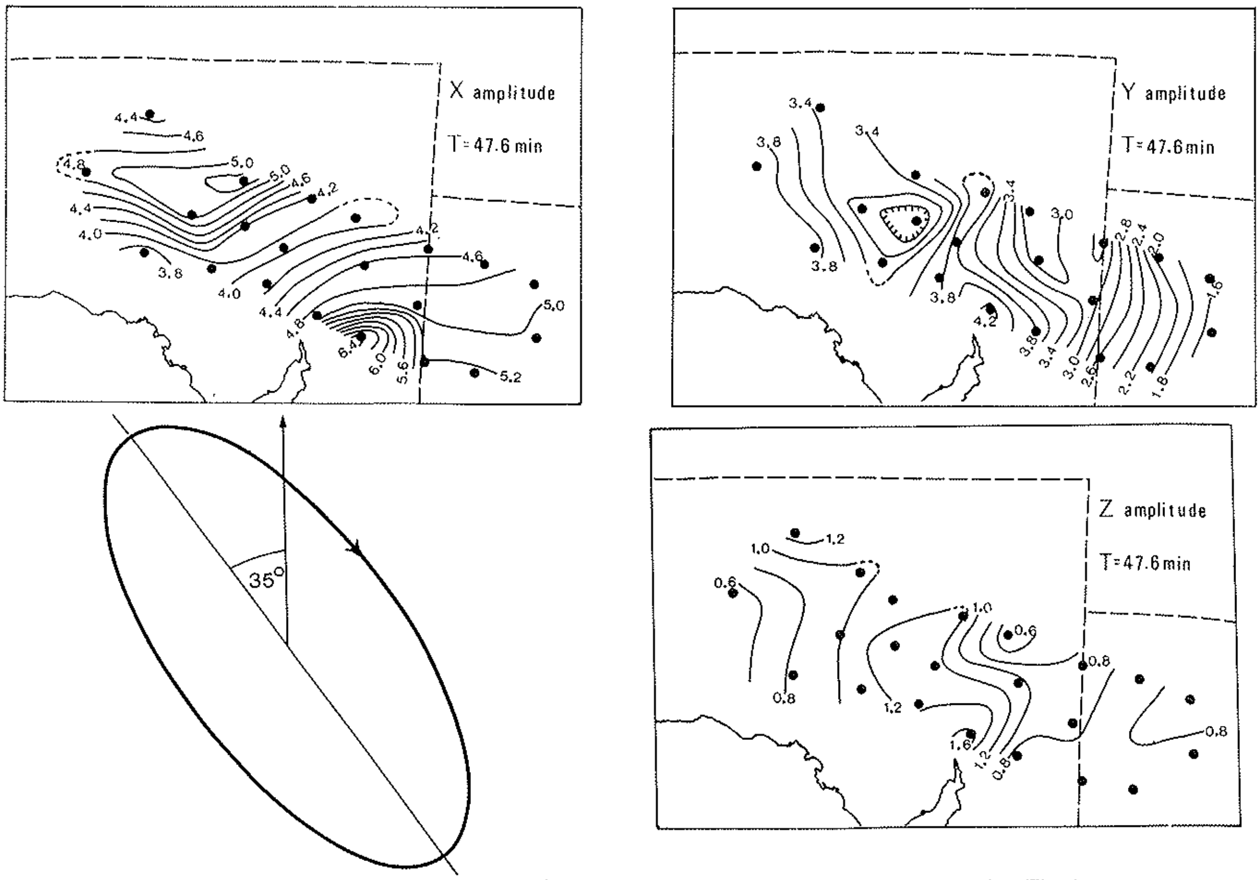

Fig. 2 Amplitudes of Fourier transforms at period 48 min of the magnetograms related to Fig. 1.

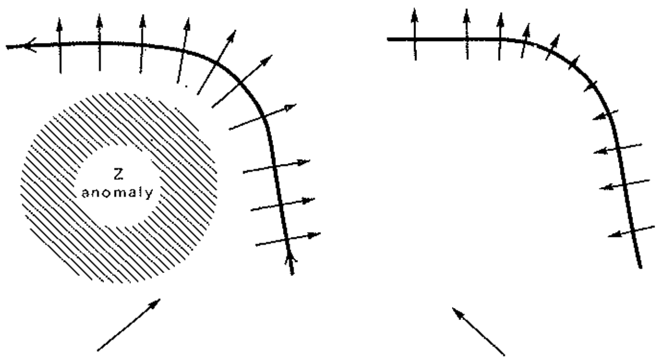

Fig. 3 Induction in a curved conductor by plane-polarized magnetic fields. The arrows represent either the magnetic field B or dB/dt. Left, induction in common phase along conductor gives large current and vertical-field anomaly. Right, no current and no anomaly.

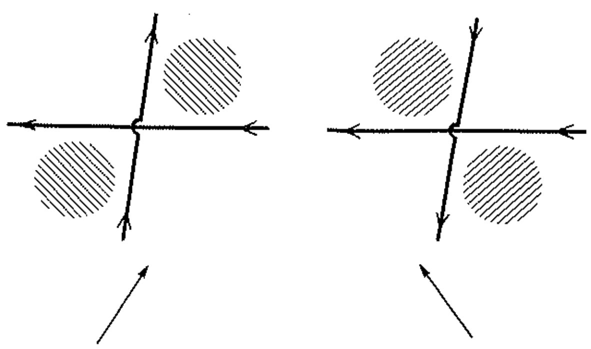

Fig. 4 Induction by plane-polarized magnetic fields in crossed conductors. Arrows represent B or dB/dt. Shading indicates vertical-field anomalies where the fields due to the conductors add in phase.

litude anomaly (Fig. 1), X in the north and Y in the east of the array differ in phase by only 56° whereas the corresponding phase difference is 132° at period 48 min, for which the Z amplitude map shows no anomaly.

Many possible conductive structures must be considered in relation to the South Australian anomaly. One that merits consideration is that of a conductive step in the upper mantle running north–south under the Flinders, and an east–west conductor near the northern limit of the array, perhaps in the crust. Study of the anomalies in three components and over a wide range of periods and polarizations may be expected to eliminate some of the options. Work along these lines is proceeding.

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