Conductivity Anomalies in Australia and the Ocean Effect

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Time variations in the magnetic field are generally a planetary, rather than a local, phenomenon. However it has been known for some years that variations with a time scale of tens of minutes differ remarkably at observatories not far apart. This is especially true of the vertical component. This difference is usually ascribed to gradients in underground conductivity. From what we know of the conductivity distribution it seems likely that these gradients are in the upper mantle.

There are many ways of studying these regional differences in magnetic variations. The method we have adopted in Australia is to establish correlations in the simultaneous changes in the three elements during bays and similar variations. Usually there is a definite correlation at each station which often differs from that at a neighbouring station. This method has the advantage that a large network of stations operating simultaneously is not necessary. It gives a statistical rather than a synoptic picture of the phenomenon.

We find that generally there is a tendency for the vertical component to increase when the horizontal components change in a particular horizontal direction, and to decrease when the horizontal components change in the opposite direction. Often this correlation is sufficiently good that the amount of vertical variation is proportional to the component of the horizontal variation in that particular direction. Both the direction which correlates with maximum vertical change and the ratio of vertical to horizontal change vary from station to station, even when the stations have similar latitudes and are not far apart.

If you divide a magnetogram into intervals of, say, 20 minutes, then by measuring the changes in the three elements during each of these intervals you can define a vector representing the change in the magnetic field during that interval. The directions of these change vectors can be plotted on a polar diagram like that shown in the left hand part of figure 1. In these diagrams the upper circle is used to plot a point corresponding to a vector with an upward (or negative) vertical component, and the lower circle for a vector with a downward vertical component. The
centre of the upper circle represents vertically up, and the centre of the lower circle vertically down. Horizontal directions are indicated around the circumference of the circles. Thus the point \( P \) represents a direction south-east and \( 20^\circ \) above the horizontal and \( Q \) represents a direction north-west and \( 40^\circ \) below the horizontal.

On the right hand side of figure 1 are plotted a number of points for 20 minute intervals at Darwin, in northern Australia. Notice that there is a strong tendency for the field to change upward when it changes to the west and downward when it changes to the east. When the horizontal components of the variation are north or south there is little vertical variation. Roughly the amount, as well as the direction, of the vertical variation depends on the simultaneous horizontal variation. So the correlation between the variations in the elements at this station could be stated by two parameters; one is the horizontal direction corresponding to an upward variation, namely west, and the other is the ratio of vertical to westward change, in this case about 0.6.

Figure 2 is a map of Australia, and the surrounding region, in which these two parameters, at various stations, are indicated by arrows. The direction of the arrow indicates the horizontal direction which correlates positively with upward vertical change and the length of the arrow indicates the ratio of vertical to horizontal variation. For instance at Darwin the arrow points almost west and its length corresponds to a ratio of 0.6. The shorter the arrow the smaller the vertical variation compared to the horizontal. For instance at Alice Springs the vertical field changes very little in intervals of the order of 20 minutes, even for large horizontal variations. Small vertical variations are typical of most inland stations.

The most obvious feature of this map is that all the arrows at coastal stations point towards the ocean, i.e. the field tends to change in an upward direction when it changes towards the ocean. This is very well shown by the stations around the south-west corner. The dashed line is the 1000 fathom contour. At Kuyper north of Java the direction of the arrow is not towards the shallow sea to the north but towards the closest deep ocean to the south.

This coastal effect is not confined to Australia. In fact it occurs on almost all fairly straight coastlines near deep water. One explanation which comes immediately to mind is that eddy currents induced in the conducting sea water modify the field in this way near coastlines. However an ocean is more than a mass of salt water. The coastal effect may well be due to a systematic difference between the conductivity in the mantle under oceans and continents.

It is very important to try to decide between these two possible explanations. In an attempt to do so we have built a model of the earth, a kind of terrella, in which the oceans are represented by sheets of copper bent to lie on the surface of a sphere. A uniform highly conducting core, at a depth of 600 km is simulated by a sphere of aluminium with a radius of 0.9 times that of the terrella. The primary field is introduced by a coil of wire wound in the form of the current function which is thought to produce bays, and held slightly outside the sphere in the place corresponding to the ionosphere. The invariant parameter of the problem is the magnetic Reynolds number.
Fig. 2 "Map of Australian region showing directions of magnetic variations"
where $a$ is some length parameter, for instance the radius of the sphere, $\mu$ is the permeability, $\sigma$ the conductivity and $T$ the period of the time dependent field. Our model is scaled down in length by a factor of about $10^7$, which makes it 45 inches in diameter. It is non-magnetic, so $\mu$ does not change. The ratio of the conductivity of copper to that of sea is also about $10^7$, therefore to keep this parameter constant we have to scale down the time by a factor of $10^7$. This reduces a period of 40 minutes to 0.5 millisecond, which is the period corresponding to 2 kc. When an alternating current of this frequency is fed into the primary coil the direction of the resulting magnetic field at any point can be found with a small search coil.

In July I received the results of the first measurements made with this terrella. They are very preliminary, and require checking in a number of points, but I think the results are generally valid and worth presenting.

The main point to emerge so far is that the conductors in the terrella modify the field much less than do the conductors present in the earth. This is particularly so at inland stations. For example at Alice Springs the terrella indicates fields which are almost vertical for some orientations of the primary coil. In reality the variations of the field at Alice Springs are never more than $10^\circ$ from the horizontal. This infers that the depth at which the conductivity of the mantle becomes large is much less than 600 km. Apart from this the effect of the copper oceans appears to be too small to explain the coastal effect.

Figure 3 shows the polar diagram for Carnarvon (on the west coast of Australia) obtained from the terrella and from magnetograms. Notice that there is a greater scatter of points for the terrella. Secondly the horizontal direction which correlates best with an upward change in the vertical component is south-west rather than west, as it is in reality. Now the primary field, in temperate latitudes, is directed upwards towards the pole and downwards towards the equator, so the terrella results for Carnarvon indicate that the copper oceans are having an effect in the right sense, but the effect is less than that of the conductors on the earth. Figure 4 is a similar pair of diagrams for Brisbane, on the east
coast of Australia. In this case the terrella points lie upwards to the south-east, but at Brisbane itself the upward field correlates with an eastward rather than a south-east horizontal change.

The last example is from Kakioka, in Japan, which has a magnetic latitude of about 30°N. Figure 5 shows the direction of the primary variation field for that latitude, derived from the terrella with no conductors. As mentioned earlier, it points upward to the pole, i.e. to the north. Figure 6 shows the corresponding patterns for Kakioka Observatory. On the left hand side are the terrella results for the position of Kakioka. In spite of the copper sheet representing the Pacific Ocean the field is still generally upward to the north and downward to the south. However the actual field at Kakioka, which is shown on the right hand side of figure 6, is completely different. The variation field moves upward to the south and downward to the north.

As I have said the terrella requires considerable refinement and the results require checking, but the preliminary conclusion is that sea water in the oceans, with a highly conducting core at a depth of 600 km, cannot explain either the coastal effect or the very low vertical component usually found at inland stations. So there is some hope that even at coastal stations magnetic measurements may contribute to our knowledge of the upper mantle.

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