The Influence of Continents and Oceans on Geomagnetic Variations

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Summary

During bays and similar magnetic variations the vectors representing changes in the geomagnetic field tend to lie on or close to a plane. The orientation of this plane varies from one observatory to another. At coastal observatories it almost invariably tilts upward towards the nearest deep ocean.

1. Introduction

In a previous paper (Parkinson 1959) polar diagrams were presented showing the directions of rapid magnetic variations at six Australian magnetic observatories. At each observatory the directions are not random, but tend to lie on a plane, called the "preferred plane".

In this paper similar results are derived for a further 21 observatories, 15 of which are outside Australia.

2. Orientation of the preferred plane

The technique of scaling and plotting the change vectors on to polar diagrams was similar to that described in the previous paper.* Because fewer data were available from many observatories, more latitude has been allowed in amplitude and duration of intervals. Any interval of duration between 5 and 60 minutes in which the magnitude of the change vector was more than 10 gammas, was plotted. This may account for the greater scatter in the polar diagrams than that found previously for the Australian observatories. Nevertheless in every case almost all points fall within 20 degrees of a great circle. This great circle defines the preferred plane. Its orientation was determined by inspection from the polar diagram. The vertical angle of tilt of the preferred plane was determined to the nearest 5 degrees and the horizontal direction of maximum slope to the nearest 22·5 degrees. The results are listed in Table 1. Generally the data do not warrant any more exact expression of the orientation of the preferred plane.

If the direction of tilt of the preferred plane is magnetic north–south there will be a correlation between H and Z traces on the magnetogram. If the direction of tilt is east–west there will be a correlation between D and Z traces. Often this correlation is amazingly detailed. Figure 1 shows an example of a magnetogram

*The first equation of that paper should read

$$\tan\theta = [(\Delta H)^2+(k\Delta D)^2]^{\frac{1}{2}}/\Delta Z$$

from Esperance, on the southern coast of Australia. Notice the very close correlation between the H and Z traces.

Results from all observatories are presented in Table 1. Observatories are listed in order of decreasing north latitude. The symbols coincide with those given in I.A.G.A. Bulletin No. 12K and subsequent quarterly lists of geomagnetic phenomena.

Table 1

Orientation of preferred plane

Observatory		Lat.	Long.	Direction	Tilt	No. of intervals	Year	Scatter	Notes
Vl	Valentia	52°N	10°W	W	40°	256	1958	mod.	
Mb	Memanbetsu	44°N	144°E	E	15°	46	1956	slight?	2
SM	S. Miguel	38°N	26°W	NW	3°	28	1958	slight?	1
Ka	Kakioka	36°N	140°E	S	30°	97	1956	great	2
Ho	Honolulu	21°N	159°W	W	30°	126	1949–51	great	
Mu	Muntinlupa	14°N	121°E	S	30°	135	1958	mod.	3
MB	M'Bour	14°N	17°W	WNW	20°	95	1958	mod.	
Ib	Ibadan	7°N	4°E	S	25°	—	—	—	3
Pa	Paramaribo	6°N	55°W	NNE	40°	92	1958	mod.	
Hn	Hollandia	2°S	140°E	N	35°	80	1958	mod.	
Ky	Kuyper	6°S	107°E	S	15°	51	1958	slight?	
PM	Port Moresby	9°S	147°E	SSW	35°	116	1958–60	mod.	
Hu	Huancayo	12°S	75°W	S	5°	36	1948	mod?	3
Dw	Darwin	12°S	131°E	WNW	30°	542	1957	mod.	
Tn	Tananarive	19°S	48°E	SE	10°	107	1958	slight	
AS	Alice Springs	24°S	134°E	SE	5°	70	1957	slight	
Ca	Carnarvon	25°S	114°E	W	30°	86	1959	slight	4
Br	Brisbane	27°S	153°E	E	25°	328	1960	great	
Wa	Watheroo	30°S	116°E	WSW	40°	71	1951	slight	
Kl	Kalgoorlie	30°S	122°E	SSW	10°	341	1960	mod.	
Td	Toodyay	32°S	116°E	SW	40°	176	1960	mod.	
Gn	Gnangara	32°S	116°E	WSW	35°	47	1957	slight	
Ep	Esperance	34°S	122°E	S	40°	376	1960	mod.	
Hr	Hermanus	34°S	19°E	SSW	45°	70	1958	mod.	
Ay	Albany	35°S	118°E	SSW	60°	231	1959–60	mod.	
To	Toolangi	38°S	145°E	S	10°	131	1955	mod.	
Am	Amberley	43°S	173°E	ESE	25°	81	1929–33	great	

Notes to Table 1.

1. The variation in the vertical component at S. Miguel is so small that intervals had to be chosen when it was unusually large. In only two instances was the variation in Z more than 6 gammas.

2. Variation at Japanese observatories has been described in detail by Rikitake & Yokoyama (1953).

3. Huancayo, Muntinlupa, and Ibadan are all affected by the equatorial electrojet. Consequently variations in the east component are always much smaller than those in the north component. Therefore the end of the geomagnetic vector moves along a line rather than a plane. The line is the intersection of the preferred plane with a north–south vertical plane. Where the preferred plane would be if variations in the easterly component were comparable with those in the northerly component, is difficult to say, but for Muntinlupa and Ibadan it would probably tilt upwards more or less towards the south. For Huancayo it might well tilt upwards towards the west.

4. Recordings were made at four different locations east of Carnarvon, and ranging from 20 to 60 miles from the coast. The latitude and longitude given are an average. No significant difference could be found between the locations.

The amount of scatter was estimated from the polar diagrams, using Valentia (see Figure 3A) as a standard. Those with appreciably less scatter are designated "slight", those with appreciably more scatter "great" and those with about the same scatter as Valentia are designated "moderate". In some cases the number of points is too small to give a reliable estimate of the scatter.

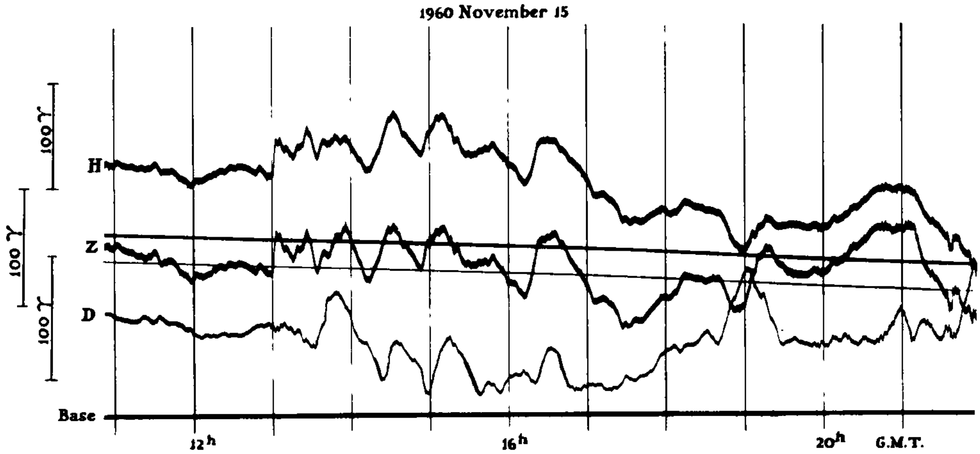

FIG. 1.—Sample of a magnetic trace recorded at Esperance (Ep) on 1960 November 15, showing the close correlation between variations in horizontal intensity (*H*) and vertical intensity (*Z*).

The sources of data for Table 1 are as follows:

Memanbetsu and *Kakioka:* Ionospheric Research Committee (1956).
Honolulu: U.S. Dept. of Commerce (1951–54).
Ibadan: Onwumechilli (1959).
Huancayo: Boletín Magnético del Instituto Geofí sico de Huancayo.
Amberley: N.Z.D.S.I.R. (1932, 1936).

Port Moresby, *Watheroo*, *Gnangara* and *Toolangi* are magnetic observatories operated by the Australian Bureau of Mineral Resources, Department of National Development.

Darwin was a temporary observatory operated by the Bureau of Mineral Resources during the I.G.Y.

Alice Springs, *Carnarvon*, *Brisbane*, *Kalgoorlie*, *Toodyay*, *Esperance* and *Albany* are locations in Australia at which Askania geomagnetic variographs were operated for a short time to investigate the regional pattern of magnetic variations.

Copies of magnetograms from *Valentia*, *S. Miguel*, *Muntinlupa*, *M'Bour*, *Paramaribo*, *Hollandia*, *Kuyper*, *Tananarive* and *Hermanus* were kindly supplied by the authorities operating those observatories (see Acknowledgments).

Figure 2 illustrates the orientation of the preferred plane for all observatories listed in Table 1. The arrow starting at the location of the observatory is the horizontal projection of the downward normal of the preferred plane. Its direction indicates the direction of maximum upward tilt of the preferred plane and its length is proportional to the sine of the angle of tilt; a short arrow corresponds to an almost horizontal preferred plane and a long arrow to a steeply tilting plane.

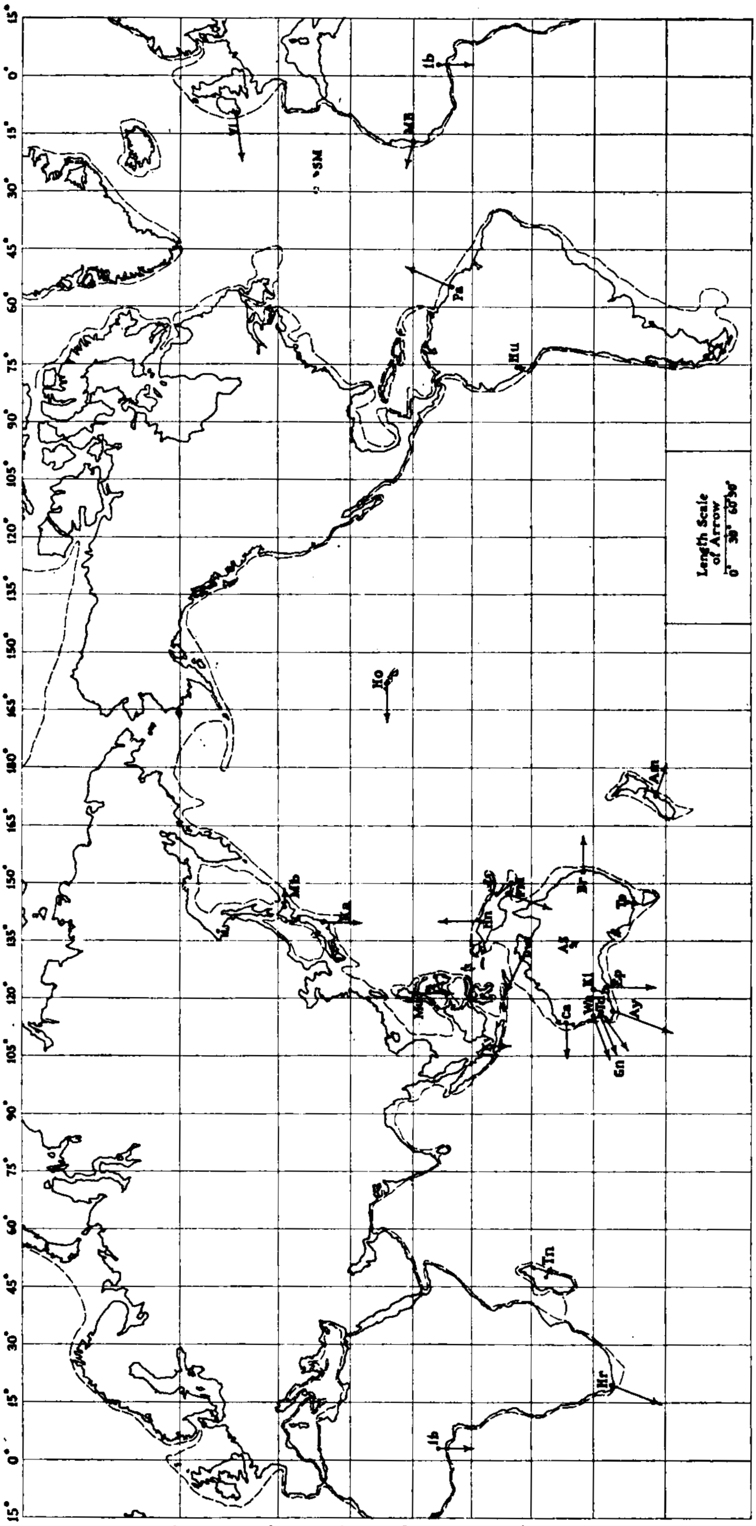

FIG. 2.—Orientations of preferred planes at observatories listed in Table 1. The significance of the arrows is explained in Fig. 3 and the text.

Figure 3A illustrates a typical polar diagram and the great circle on which the points tend to lie. Figure 3B shows the corresponding preferred plane looking north, the downward normal, and the horizontal projection of the downward normal, which is the arrow drawn in Figure 2.

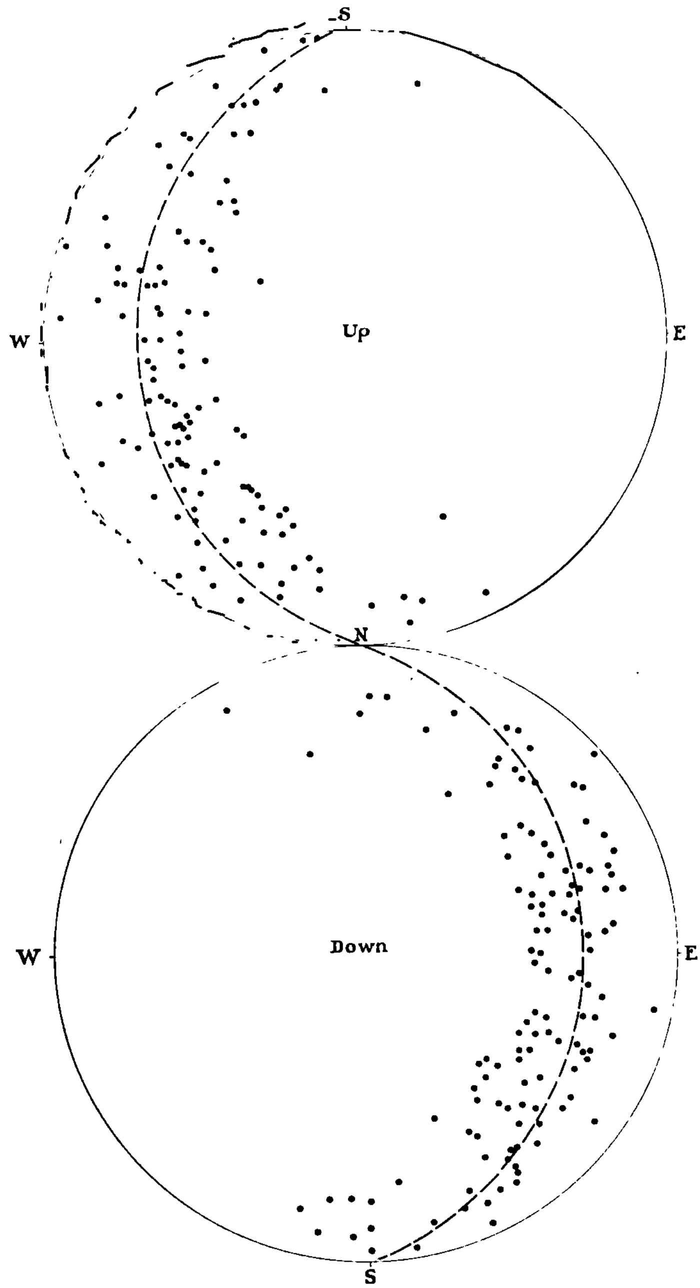

FIG. 3A.—Polar diagram showing the directions of 256 changes in the magnetic field at Valentia (Vl) and the great circle (dashed line) corresponding to the preferred plane of these changes. Directions are magnetic.

3. Discussion of results

The most obvious fact apparent from Figure 2 and Table 1 is that the arrows at almost all coastal observatories point towards the ocean, or more correctly towards the nearest deep ocean. The only exceptions are Memanbetsu (Mb), Kakioka (Ka), Muntinlupa (Mu), and Darwin (Dw). The edge of the continental shelf is complicated in all these cases. Wherever the edge of the continental shelf is straight for hundreds of kilometres the arrow is almost at right angles to it and points towards the ocean. Because Huancayo is affected by the electrojet it cannot be considered a significant exception.

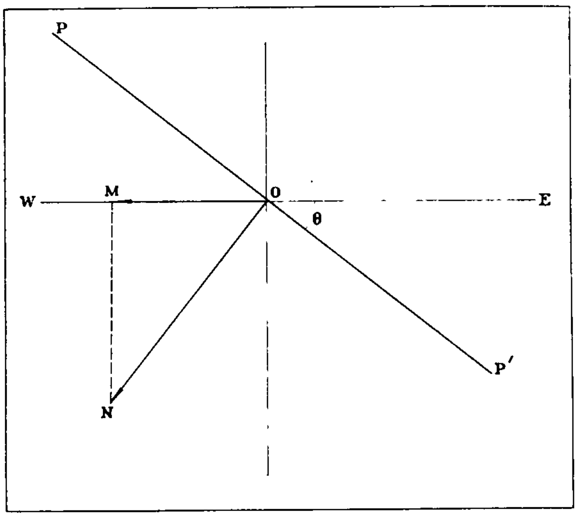

FIG. 3B.—Explanations of the arrows in Fig. 2. *POP′* is the preferred plane at Valentia looking magnetic north. *ON* is the downward normal. Its horizontal projection *OM* is the arrow in Fig. 2, in this case pointing magnetic west. The angle of tilt (θ) is 40°.

Kuyper (Ky) is on the northern coast of the island of Java, but the sea to the north is shallow. The nearest deep ocean is the Indian Ocean about 200 km to the south. Consequently the arrow points southward rather than northward. Port Moresby, however, does not seem to be affected by the deep ocean north of New Guinea.

At Darwin (Dw) the preferred plane has a high tilt to the WNW. This is surprising because the nearest deep ocean is more than 350 km away and is to the NNW.

Recordings were made at Toodyay (Td) to determine the effect of geology. Watheroo and Toodyay are the same distance from the coast line but the former is on a deep sedimentary basin, the latter on the Precambrian shield. The similarity of orientation of the preferred plane indicates that crustal geology has only a small effect on all but very rapid magnetic variations.

At the only observatory far inland, Alice Springs (AS), the preferred plane is almost horizontal, and at observatories a few hundred kilometres inland from the edge of the continental shelf, such as Toolangi (To) and Kalgoorlie (Kl), the tilt of the preferred plane is only slight.

At the only two observatories far from continents, results differ. The preferred plane is almost horizontal at S. Miguel (SM) but decidedly inclined at Honolulu (Ho).

This is summarized in Table 2.

Table 2

Relation between tilt and position of observatory

Tilt degrees	Continental Observatories distance within continental shelf			Oceanic Islands
	>300 km	300–100 km	<100 km	
>45°			Ay	
45°–36°		Wa, Td, Vl	Pa, Hr, Ep	
35°–26°	Dw	Ca, Gn, Ka	Mu, Hn, PM	Ho
25°–16°		Ib	MB, Am, Br	
15°–10°	Kl, To	Mb, Ky, Tn		
<10°	AS	Hu		SM

As can be seen, there is a tendency for the tilt to be smaller the farther inland the observatory is from the edge of the continental shelf. The outstanding exception is Darwin.

Table 2 also gives an idea of the frequency distribution of tilt. For instance a tilt of 35 degrees is normal for a coastal observatory. This means that the change in vertical intensity is equal to about 70 per cent of the horizontal component of the change when the latter is directed most favourably.

4. Mechanism of coastal effect

Most of the change vectors occur during bays and similar variations, whose current systems are similar. It is not surprising, therefore, that a preferred plane exists. In fact if we assume a system of primary currents and a conductivity distribution depending only on depth, the directions of magnetic vectors can be calculated. They are found to lie close to a plane.

The preferred planes actually found differ from these calculated planes in two important respects. One is that, at many observatories, the direction of tilt is east or west. With uniform conductivity this requires an asymmetry in the primary field which is most unlikely. The second feature which cannot be explained by uniform conductivity is the difference in the orientation of the preferred planes at nearby observatories; for instance Watheroo and Esperance, or Port Moresby and Hollandia.

The connexion between the direction of magnetic variations and the edge of the nearest continental shelf is too definite to be accidental. One possibility, which cannot be immediately dismissed, is that the effect can be explained by electromagnetic induction in the water of the oceans. Several authors have discussed this possibility; e.g. Chapman & Whitehead (1922), Rikitake & Yokoyama (1955), Rikitake (1959, 1960).

The average depth and conductivity of the oceans are sufficient for them to have a considerable influence, but their irregular shape makes the effect almost impossible to calculate. Rikitake (1960) has calculated the influence of a hemispherical ocean on the *Sq* field. He used a harmonic expansion up to terms of order 6, and found that the ocean should have a great effect on *Sq*. However, he believes that electric currents in the ocean do not control the direction of rapid variations in Japan (Rikitake 1959).

It is easy to see qualitatively how electromagnetic induction in the oceans could have the effect found at coastal observatories. The effect of a horizontal conducting lamina in a varying magnetic field of external origin is to oppose the vertical component of the ambient field and augment the horizontal component on the upper side of the lamina. If at one edge of the lamina the horizontal component of the field is increasing towards the lamina, then the induced currents must cause a vertically upward field just past the edge of the lamina, i.e. inland from the edge of the ocean. This is exactly the effect shown in Figure 2.

It is likely that along certain coastlines there would be a concentration of induced current owing to the shape of the continent. This could well be the explanation of the particularly large variation in vertical component around southern Africa and south-western Australia.

There is also the possibility that the conductivity in the mantle may be systematically higher below the oceans than below the continents, quite apart from the sea water itself. This also would give rise to the effect shown in Figure 2. Jacobs (1960) pointed out that the mantle below the oceans is probably different from that below the continents, to a considerable depth. It is most likely hotter and so may have a higher conductivity.

Before the magnetic results can be applied to problems of the mantle the effect of sea water must be evaluated and allowance made for it. Particular attention should be paid to anomalous locations such as Darwin and Honolulu.

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