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DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1966/70

TERRELLA MODEL EXPERIMENT, PRELIMINARY RESULTS

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ILLUSTRATIONS

SUMMARY

A spherical model of the Earth has been made to assist in determining the effect on the geomagnetic variations of eddy currents induced in the oceans. It includes a conducting core and uses a realistic primary field. Measurements indicate that induced currents do not completely explain the observed directions of magnetic variations, although their effect in the southern hemisphere is considerable. In the northern hemisphere they have only a minor effect at coastal locations. The vertical component is almost completely inhibited over the oceans themselves.

The coastal effect found in reality in both northern and southern hemispheres probably indicates a non-uniform conductivity in the deep crust or mantle.

1. INTRODUCTION

Since the beginning of 1962, work has progressed slowly on a model of the Earth designed to indicate the influence of the conductivity of the oceans on geomagnetic variations with periods of the order of tens of minutes. The model has been called a 'terrella'.

The design of the terrella and the physical principles involved have been described in a progress report (Parkinson, 1963). Some of the earlier measurements (made by J. R. Wilkie) were presented at the Berkeley meeting of the IUGG (Parkinson, 1964).

2. THE TERRELA

The terrella consists of a perspex sphere 45 inches in diameter on which is fixed a copper sheet 0.017 inch thick cut and shaped to represent the deep oceans. The length scaling used makes this thickness equivalent to about 5 kilometres. An aluminium core consisting of a spherical shell 41 inches in diameter and half an inch thick was placed concentrically in the terrella. Later, a more elaborate mounting was constructed so that the centre of the core could be moved relative to the perspex crust. The conducting core is necessary to simulate the highly conducting part of the mantle that is thought to exist beyond a depth of about 600 kilometres. Recently, Kertz (1965) has proposed the name 'conductosphere' for this region.

The primary coil described in the progress report is that appropriate to the northern hemisphere. Because it is not symmetrical about a meridian, a slightly different primary coil (its mirror image) had to be made for the southern hemisphere. Generally, one or the other of these primary coils was used to supply the external part of the geomagnetic variation field.

The search coil described in the progress report was used for some time. However, as well as being slow to use, it has the disadvantage that it must be at a height of about 5 millimetres (equivalent to about 50 kilometres) above ground level. This may lead to errors at locations close to coastlines.

It was found easier to use a pair of search coils, each consisting of about 200 turns of 38 gauge wire wound round a match. This forms a coil about 3 millimetres long and 3 millimetres in diameter. One of these is set 'vertically' at the location being measured and the other, fixed perpendicularly to the end of a probe, is rotatedin a 'horizontal' plane as close as possible to the vertical coil. After amplification, the outputs of the coils feed the X and Y displays of a CRO. Amplification is adjusted so that when the coils are held together and parallel a line at 45° is obtained on the CRO. Not only is this system very convenient for reading but also any phase difference between the vertical and horizontal components can be immediately detected.

Various horizontal directions of the oscillating field were obtained by rotating the primary coil about the geomagnetic pole and reading the direction of the resulting field for each 12 degrees of rotation. The series of directions obtained represents the different directions of the variation field at one observatory as bays occur at different local times.

For most of their area, the oceans have a depththat is either close to 5 kilometres (deep oceans) or less than 200 metres (continental shelves). Originally, only the deep oceans were represented on the terrella; it was argued that the conductivity of the continental shelves is so much less than that of the deep oceans that it could be neglected. Later, the shallow water between Australia and Indonesia and that between Japan and Asia was simulated by bronze wire mesh of integrated conductivity corresponding to 150 metres of sea water.

3. RESULTS OF MEASUREMENTS

Measurements of the directions of the resulting field were made at 22 locations on the terrella, corresponding to the observatories shown in Plate 1. The resulting directions of downward tilt of the preferred planes are shown in Table 1 and in Plates 2 to 5. Each circle in Plates 2 to 5 contains points representing the various directions taken up by the field as the primary coil is turned through 360°. Because the field is sinusoidal, only the downward direction needs to be shown. These diagrams are similar to the lower parts of those published previously (Parkinson, 1959). The dashed line represents the plane on which the directions of the field measured from magnetograms tend to lie. This has been called the 'preferred plane'.

Measurements were made at several locations on the terrella with various depths to the conductosphere between 300 and 800 kilometres. In almost all cases, the direction of the field is almost independent of the depth to the conductosphere. At Alice Springs the vertical field is relatively smaller for shallow depths of the conductosphere. The effect is so slight, however, that no definite information about the depth to the conductosphere can be gained from these measurements. The results plotted inPlates 2 to 5 were determined with a conductosphere depth of 600 kilometres.

The directions plotted in Plate 2 were determined after wire mesh had been installed to simulate the shallow water north of Australia. Diagrams A to D in Plate 3 show some of the directions determined without a conducting path north of Australia. As might be expected, there is a great difference in the directions at nearby locations such as Thursday Island (compare Plate 2, diagram B withPlate 3, diagram B). But it is surprising to find that the directions at locations as far south as Carnarvon and Brisbane (diagrams F and G in Plate 2 and diagrams C and D in Plate 3) are greatly influenced by the presence of even a poorly conducting path north of Australia. Without this northern conducting path, the preferred plane tilts downwards to the NNE and NNW at Carnarvon and Brisbane respectively. The position of the preferred plane can be made still more realistic by replacing the bronze wire mesh by solid copper, which simulates a deep ocean between Australia and Indonesia (see diagrams E and F in Plate 3). This is discussed below.

At several locations close to the wire mesh, a phase difference of up to 60° is often observed between vertical and horizontal components. On a magnetogram, such a phase difference would not be obvious, but the usual coincidence of peaks in the three components indicates that generally there is no such phase difference. However, a search for a systematic phase difference should be made in magnetograms from observatories near shallow water.

4. DISCUSSION OF RESULTS

It is reasonable to suppose that the directions measured at locations far inland are approximately those of the primary field (including induction in the uniform conductosphere). Tashkent and Alice Springs are sufficiently far inland that oceanic effects are probably small. Therefore the effect of the oceans can be judged by comparing the directions of the field at other locations in the same hemisphere with one of these two. By varying the position of the pole of the primary coil it can be established that the vertical component tends to become relatively greater the higher the latitude. This probably accounts for the difference between Tashkent and Alice Springs.

A comparison of diagram E in Plate 2 with the rest of Plate 2 indicates that the oceans in the southern hemisphere have a great effect on the directions of the resultant field. When a conducting path is provided north of Australia, fairly realistic directions are obtained at Port Moresby, Wyndham, Carnarvon, Brisbane, Gnangara, Esperance, and Albany. At Toolangi and Thursday Island, the tilt of the preferred plane is much less steep than at the corresponding locations on the terrella.

The tilt and direction of the preferred plane at Hermanus (diagram F in Plate 4) is duplicated quite well on the terrella, but that at Luanda (diagram E in Plate 4) is not. The discrepancy is similar to, although not as great as, that at Carnarvon when there is no conducting path north of Australia (diagram C in Plate 3).

Plate 5 shows terrella measurements from both coasts and the centre of the north Pacific Ocean as well as at a nearby inland location. The complete absence of a vertical component at Honolulu is typical of all measurements made over the deep oceans and does not agree with reality at all (Parkinson, 1962). The actual preferred plane on the coast of California was not determined, but Schmucker (1960) has indicated that the usual coastal effect is found there.

Essentially the same results are found whether the shallow water connection via Bering Strait to the Atlantic is simulated or not.

The most significant discrepancy in the north Pacific is at Kakioka (diagram B in Plate 5). Extensive work has been done on the results of this observatory by Rikitake and his co-workers (Rikitake, 1959). They found that the preferred plane tilts downwards to the north by about 30° to 40°. The terrella results define a preferred plane that tilts downwards to the south. Exactly the same results were obtained at Kakioka whether the water between Japan and Asia was included in the model or not. Measurements were made at Kakioka when primary coils were used over both hemispheres at the same time, but the results were still similar to those shown in diagram B in Plate 5.

We can conclude that conductivity in the water of the north Pacific Ocean has only a minor effect on the direction of the variation field in that region. This is contrary to the findings of Roden (1964). However, Roden's conclusion was based on measurements of the magnitude of the vertical component rather than the direction of the total field.

A significant discrepancy also appears at Valentia (diagram A in Plate 4). The preferred plane actually found at Valentia tilts downwards to the east in conformity with the usual coastal effect, but the terrella field dips downwards to the south, as at Tashkent and other northern hemisphere locations. The locations shown in Plate 4 are all on the coasts of the Atlantic Ocean. Agreement between terrella results and reality is better for the more southerly locations. In fact, a continuous change from the pattern at M'Bour to that at Valentia is found as the observing point moves northwards along the east coast of the Atlantic.

The preferred plane shown for San Juan (diagram B in Plate 4) is that found by Elvers and Perkins (1964). They found quite different planes at various parts of the island of Puerto Rico. Such fine detail cannot be duplicated on the terrella. However, this fact argues against the deep ocean being the controlling factor.

Conduction around Australia

Quite realistic directions of the variation field at coastal locations in Australia can be obtained on the terrella if a path of sufficiently high conductivity is provided north of the continent. This fact makes it tempting to ascribe the coastal effect to conduction in the deep ocean and shallow water surrounding the continent. However, four facts indicate that this conclusion must be treated with caution:-

(a) To achieve truly realistic directions of the variation field at Carnarvon and Brisbane it is necessary to provide a more highly conducting path between the Indian and Pacific Oceans than could be furnished by the existing shallow water.

(b) The phase difference between vertical and horizontal components apparent near the mesh on the terrella do not appear on corresponding magnetograms.

(c) If a heavy current flowed through the shallow water north of Australia, it would be concentrated into a very high density jet by the Torres Strait. This happens on the terrella, as is shown by the large vertical component at the location of Thursday Island. In reality, however, the vertical component at Thursday Island is quite small, indicating that there is no strong jet of current in Torres Strait.

(d) The discrepancy between the actual field and the terrella field at Luanda is of the same type as that at Carnarvon when there is no conducting path north of Australia. In the case of Luanda the direction actually observed cannot be explained by a conducting path north of the observatory.

5. CONCLUSIONS

The results can be summarised by classifying locations into five types:-

(a) Those bordering the Southern Ocean - the vertical component is large, both in reality and on the terrella, and correlates positively with a northern horizontal variation. This is almost certainly due to a great zonal circuit of current flowing in the Southern Ocean. Esperance, Albany, and Hermanus are examples.

(b) Southern hemisphere observatories on east or west coasts - the directions of the variation field at these are only moderately well duplicated on the terrella. There is a tendency for the preferred plane totilt downwards towards the north rather than inland, as it does in reality. Carnarvon, Brisbane, and Luanda are examples.

(c) Northern hemisphere coastal observatories - the coastal effect at most northern hemisphere observatories is not duplicated at all well on the terrella. Kakioka and Valentia are examples.

(d) Mid-ocean observatories - the terrella results indicate almost no vertical field at locations over deep oceans. Honolulu is an example.

(e) Inland observatories - the vertical field tends to be small both in reality and on the terrella. Tashkent and Alice Springs are examples.

The effect of eddy currents induced in the ocean water can apparently be considerable in some places, particularly in the southern hemisphere. However, it does not explain the direction of the variation field at all places. In particular, the directions at northern temperate observatories are not at all well duplicated on the terrella. This suggests that at least part of the coastal effect must be ascribed to differences in mantle conductivity, possibly connected with continents and oceans.

The field directions observed in most parts of Australia can be explained by the oceanic conduction plus a conducting path north of Australia, which is probably not provided by the shallow water between Australia and Indonesia. The situation in northern Australia, and particularly at Darwin, warrants further field investigations.

6. RECOMMENDATIONS

These results should be checked. Several aspects should be more carefully investigated. The effect of shallow water north of Australia indicates that the water over continental shelves, as well as deep oceans, must be simulated before the full effect of the sea water is taken into account. This is particularly so when shallow water joins two deep oceans.

On the terrella no account has been taken so far of conductivity in the crust. The comparatively poor conductivity below the ocean water and between oceans, across continents, may have a considerable influence on the overall pattern of current flow. Some special model experiments should be designed to investigate this.

The shape of the primary coils may be more critical than was at first thought. Particularly the practice of using a coil over only one hemisphere at a time is open to criticism because of the edge effect at the equatorial limit of the coil. This can exaggerate the vertical field greatly. A new primary coil covering both hemispheres and with more uniform wire spacing should be used.

Further work should be done on the phase relation between the components of the variation field. This would involve spectral analysis of magnetograms from selected observatories.

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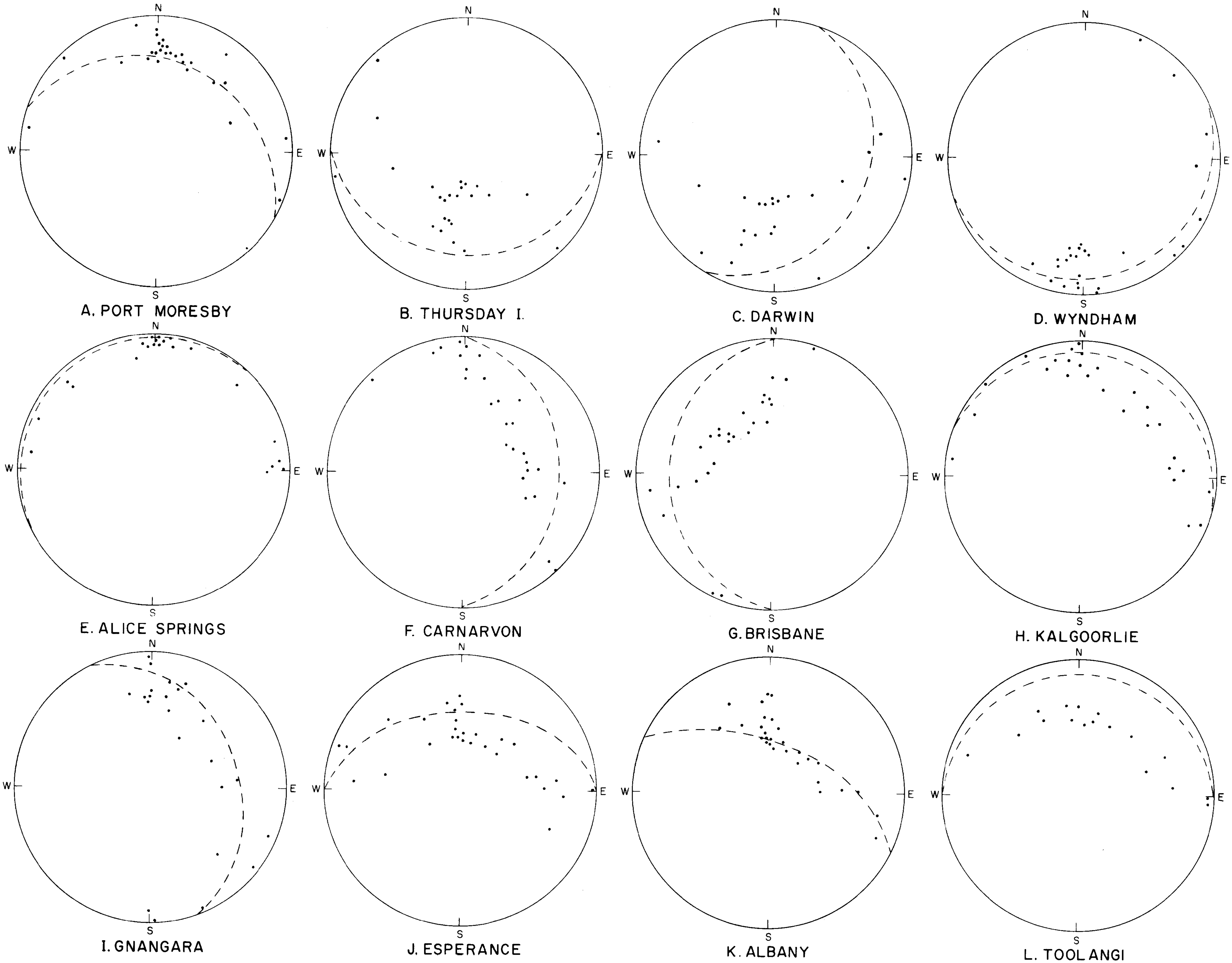
TABLE 1

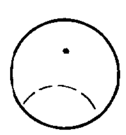
Comparison of preferred planes as derived from magnetograms and terrella readings

Observatory	Latitude	Longitude	Preferred plane: Magnetograms		Preferred plane: Terrella	
			Direction	Tilt	Direction	Tilt
Valentia	52°N	10°W	E	40°	SSE	25°
Tashkent	41°N	69°E			SSE	30°
Kakioka	36°N	140°E	N	30°	S	35°
California					SSE	45°
Honolulu	21°N	159°W	E	30°	-	0
San Juan	19°N	60°W	SE	15°	S	15°
M'Bour	14°N	17°W	ESE	20°	ESE	35°
Paramaribo	6°N	55°W	SSW	40°	S	40°
Luanda	9°S	13°E	E	25°	NE	25°
Port Moresby	9°S	147°E	NNE	35°	NNE	30°
Thursday Island	11°S	142°E	S	25°	SSW	50°
Darwin	12°S	131°E	ESE	30°	S	50°
Wyndham	15°S	128°E	SSE	10°	S	20°
Alice Springs	24°S	134°E	NW	55°	N	10°
Carnarvon	25°S	114°E	E	30°	ENE	50°
Brisbane	27°S	153°E	W	25°	WNW	45°
Kalgoorlie	30°S	122°E	NNE	10°	NNE	30°
Gnangara	32°S	116°E	ENE	35°	NE	50°
Hermanus	34°S	19°E	NNE	45°	N	50°
Esperance	34°S	122°E	N	40°	NNE	50°
Albany	35°S	118°E	NNE	60°	NNE	60°
Toolangi	38°S	145°E	N	10°	N	50°

PLATE I

LOCATIONS OF MEASUREMENTS



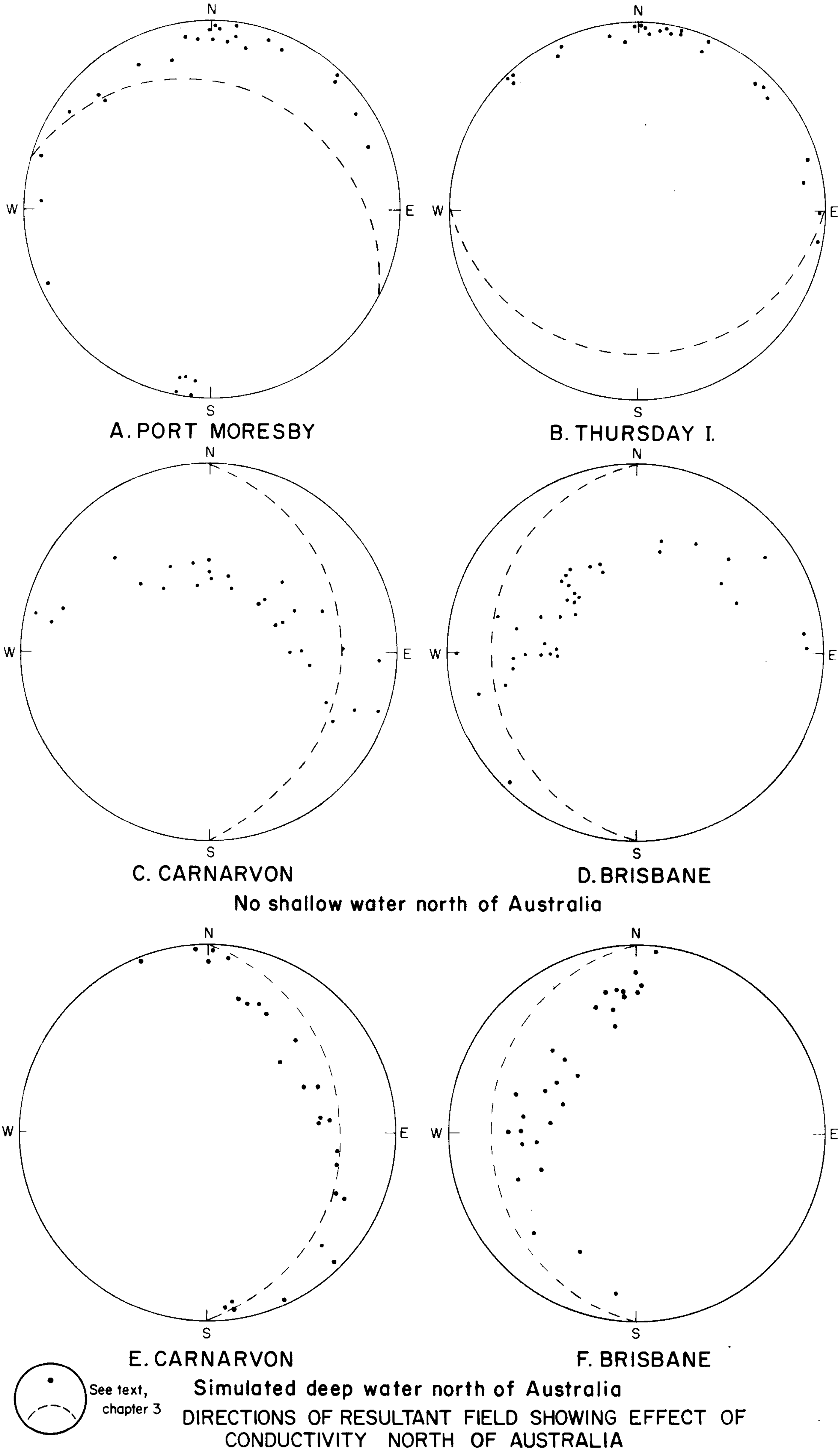

See text, chapter 3

DIRECTIONS OF RESULTANT FIELD AT AUSTRALIAN LOCATIONS

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS G82/1-26

To Accompany Record No. 1966/70

PLATE 3

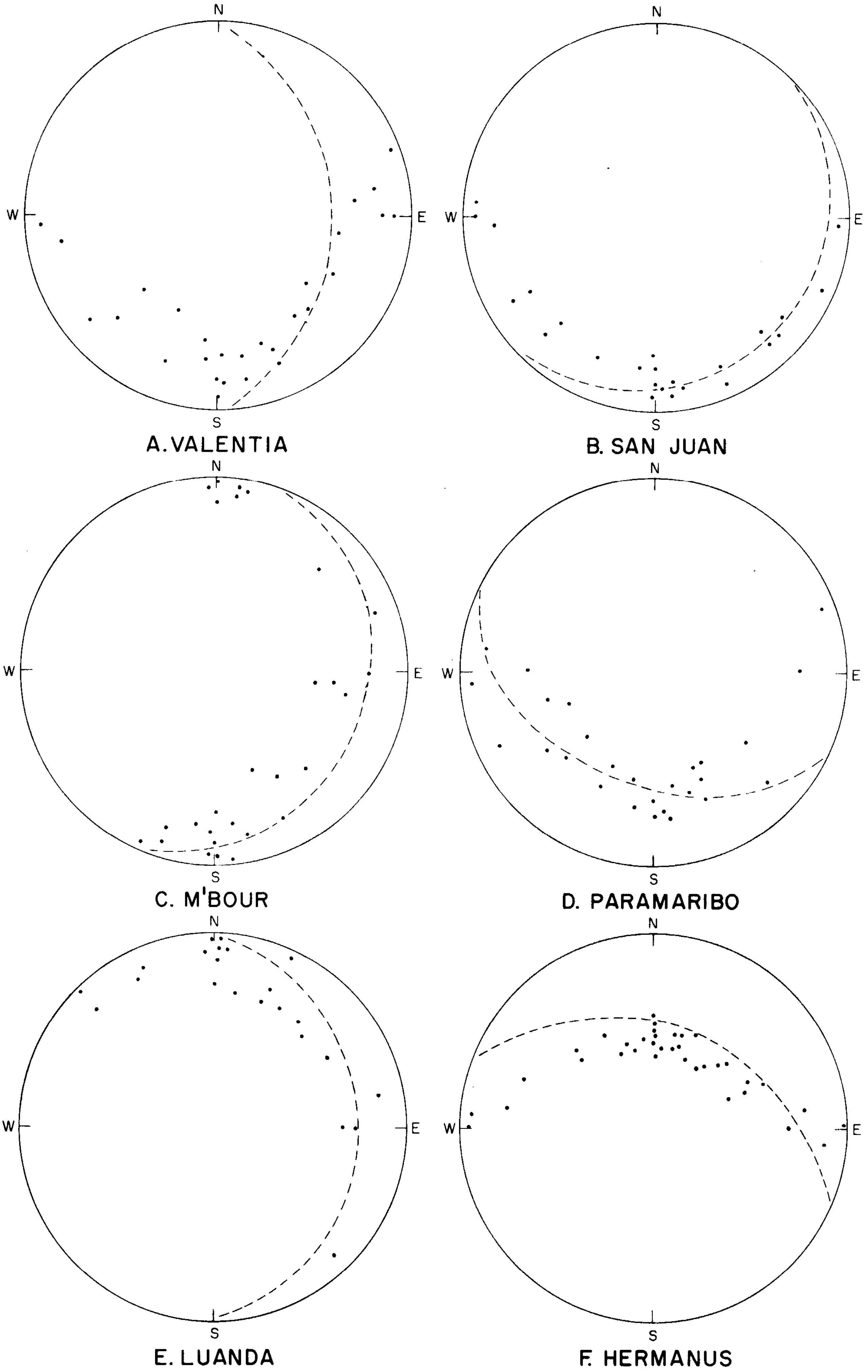


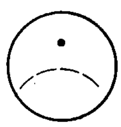
DIRECTIONS OF RESULTANT FIELD SHOWING EFFECT OF CONDUCTIVITY NORTH OF AUSTRALIA

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS G82/1-27

To Accompany Record No. 1966/70

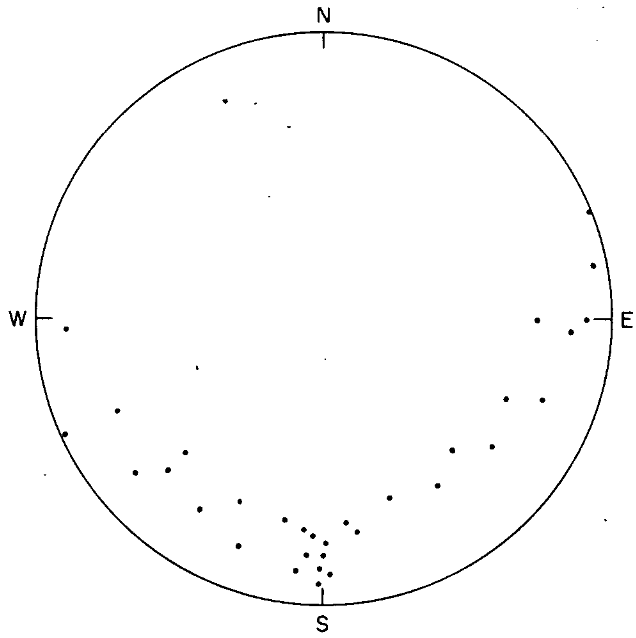
PLATE 4



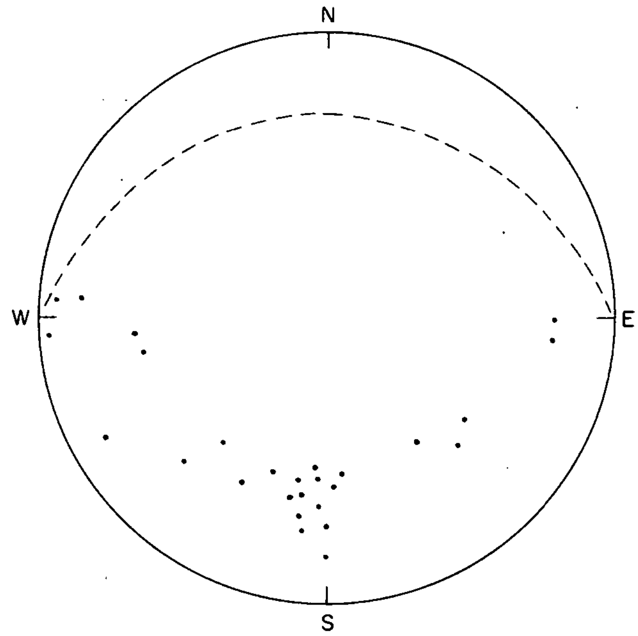


DIRECTIONS OF RESULTANT FIELD AT ATLANTIC LOCATIONS

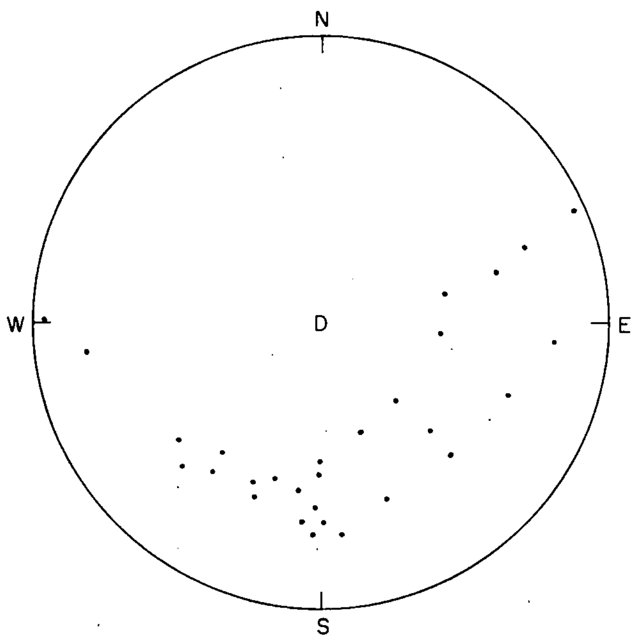
PLATE 5



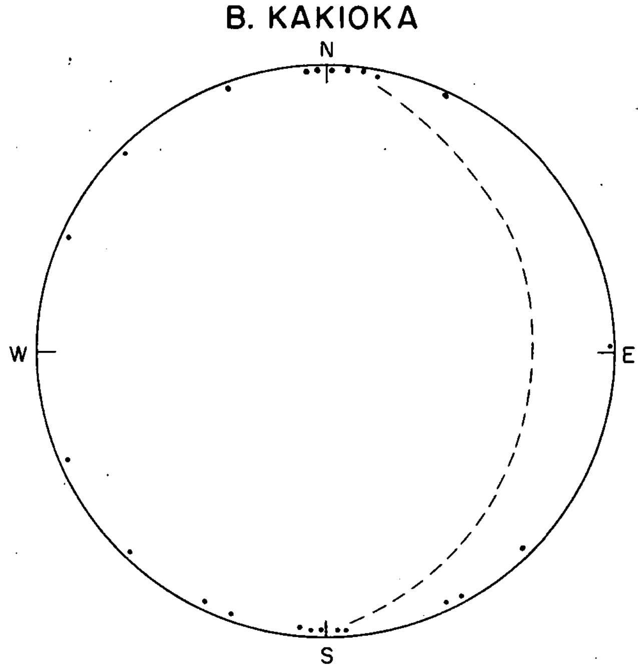
A. TASHKENT



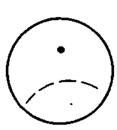
B. KAKIOKA



C. CALIFORNIA



D. HONOLULU



See text, chapter 3

Directions of Resultant fields at
an inland location (A)
coastal location (B & C)
mid ocean location (C)