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MAGNETIC AND SEISMIC PROFILER RECORDS IN THE BISMARCK SEA, MELANESIAN ARCHIPELAGO

by

J.B. CONNELLY

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J.B. CONNELLY

Bureau of Mineral Resources, Geology and Geophysics,

Canberra, Australia

SUMMARY

A marine geophysical survey of the Bismarck Sea was carried out by the Australian Bureau of Mineral Resources in 1970, when magnetic, gravity, and seismic reflection recordings were made along north-south traverses with a spacing of 30 to 40 km. The magnetic data were interpreted first by visual inspection of magnetic and topographic trends and then by two-dimensional computer modelling along typical profiles. The interpretation indicates that the Bismarck Sea is divided into two main tectonic provinces and that the boundary between them roughly coincides with a line joining Manus Island and the Willaumez Peninsula of New Britain. An area of apparently non-magnetic basement about 10 km wide coincides with a well defined band of shallow earthquakes which runs east-west across the centre of the Sea. A major boundary is present at the eastern end of the Sea along the west coast of the Gazelle Peninsula of New Britain; it continues along an offset in the band of earthquakes to New Hanover.

INTRODUCTION

During September and November 1970 a marine geophysical survey of the Bismarck Sea (1) in western Melanesia was conducted by the Compagnie Generale de Geophysique ship R.V. Hamme under contract to the Australian Bureau of Mineral Resources, Geology & Geophysics (BMR). Magnetic, gravity, and seismic reflection recordings were made along predominantly north-south traverses (Fig. 1). Two additional marine surveys which made only magnetic and seismic reflection recordings were conducted during 1967 and 1969 by BMR in the St.Georges Channel area (2, 3). Seismic refraction studies of New Britain and the eastern Bismarck Sea (4, 5) and land gravity coverage (6, 7) of the whole of New Britain, New Ireland and parts of the north coast of mainland New Guinea provide comprehensive geophysical data in the area. Figure 2 shows localities and tectonic features mentioned in the text.

The Bismarck Sea is situated in one of the most complex tectonic areas of the world. According to Johnson & Molnar (8), it is composed of two small plates and has no less than four triple plate junctions in its immediate vicinity; alternatively the area could be considered a marginal basin as defined by Karig (9), although earthquake focal mechanisms (8) seem to rule out this possibility. Detailed geophysical information in this complex region will therefore help to resolve the area's tectonic relation to the general framework of the western Pacific.

GEOLOGY

A detailed account of the geology of the whole of the New Guinea region is in preparation (10), including the areas surrounding the Bismarck Sea.

New Ireland, New Britain, Manus Island, New Hanover, and the area of the north New Guinea coast bounded by the Ramu and Markham rivers are all geologically similar and appear to have originated as island arc structures - New Britain during the Eocene, and New Ireland, New Hanover, Manus Island, and the area on the New Guinea mainland during the Oligocene. A large part of this area subsided during Miocene times, and considerable thicknesses of reef limestone were deposited; these are now elevated in places to 2000 metres above sea level. This uplift, which commenced in late Pliocene times, continues still along the south coast of New Britain, along the south and west coasts of New Ireland, at the eastern end of Manus Island, and along the coast of mainland New Guinea. Quaternary faulting with a predominantly northwest direction has occurred in the Gazelle Peninsula and southern New Ireland.

That part of the New Guinea coast which lies west of the mouth of the Sepik river is geologically distinct from the island arc structures described above. It appears to have originated as a eugeosyncline in late Cretaceous or early Tertiary times. Deposition into the geosyncline continued until the upper Miocene; the area then started to emerge, although it was subjected to several further periods of marine transgression before finally emerging in the Pliocene.

GENERAL GEOPHYSICAL SETTING

The seismicity of the area has been well described by Denham (11), and epicentres of earthquakes that have been recorded by more than 10 stations are shown in Figure 3.

Two well defined Benioff zones are present: one which dips steeply to the north beneath New Britain, and one which is almost vertical beneath southern New Ireland and the Solomon Islands. Earthquakes in mainland New Guinea are scattered, however, and are not aligned in a Benioff zone. Across the centre of the Bismarck Sea there is a zone of shallow earthquakes in a band some 20 km wide which will be referred to as the earthquake lineament. The lineament is made up of four linear sections, one of which is about 500 km long and the other three 100-150 km long. The longest section is in the western half of the sea and the three shorter ones are in the east. All the linear sections strike approximately east-west except for the most easterly, which strikes northwest and is roughly in line with the west coast of the Gazelle Peninsula. The intensity of seismic activity is much the same along all the linear sections.

The gravity field over the Bismarck Sea (1) shows little relief superimposed on an average free-air anomaly value of about +50 mgal and a Bouguer anomaly value of +150 mgal. Over New Britain (6) the average Bouguer anomaly is +100 mgal with a substantial high of +190 mgal south of the Willaumez Peninsula. New Ireland and Manus Island (6) have an average Bouguer anomaly of +80 mgal and the north coast of New Guinea has in general a negative Bouguer anomaly with the main low of -200 mgal over the Ramu Valley (7).

Seismic refraction studies by Finlayson et al. (5) indicate a depth to the Moho of 15 to 20 km in the eastern Bismarck Sea and an absence of any substantial thickness of material with a velocity of 5.8 to 6.5 km/s. The 5.8 to 6.5 km/s layer is present south and west of the Bismarck Sea where it extends to depths of 10 to 15 km beneath New Britain and New Ireland, and to depths of 21 km along the northern margin of the Solomon Sea. The depth to the Moho increases beneath New Britain; this increase is very rapid along the western margin of the Gazelle Peninsula and Moho depths of 32 km are recorded under the Gazelle Peninsula; beneath the southern part of New Britain the depth gradually increases to 30 km or more along the northern margin of the Solomon Sea. The absence of a 5.8 to 6.5 km/s layer in the Bismarck Sea suggests a similarity to normal ocean basins but the Moho depth of 15 to 20 km is greater than would be expected for oceanic crust.

TOPOGRAPHY AND SEDIMENT DISTRIBUTION

Figure 1, a diagrammatic representation of the topography and sediment distribution as derived from seismic profiling records, shows that topographic relief over most of the area is moderate. The water depth is about 2000 m except for two rises (Fig. 2): the Willaumez-Manus Rise, which extends from 143°30'E eastwards through a point south of Manus Island to the vicinity of the Willaumez Peninsula; and the New Hanover-Manus Rise, which extends from Manus Island to New Hanover. The Willaumez-Manus Rise is a broad rise covered with a thin layer of sediment, but the New Hanover-Manus rise is much sharper, especially along its southern edge, and is covered by thick sediments. The New Hanover-Manus rise has a north-south offset at about 149°15' where the easterly portion is offset to the south by about 50 km, and this offset probably represents a cross-fault. The water depth over both the rises is about 1000 m.

Sediments occur over much of the Bismarck Sea, but a substantial sediment-free area strikes east across the centre from 143°30'E to 150°30'E; this is centred on the earthquake lineament. East of the Willaumez-Manus Rise this sediment-free area is some 50-60 km across at its widest point and has very little topographic relief. At the Willaumez-Manus Rise the sediment-free area narrows to a width of 20-30 km; at the same time the topography of the area becomes much more rugged, and the northern edge drops sharply to the Manus Basin, a small basin southwest of Manus Island. West of the rise the sediment-free area is much narrower and is more in the nature of a chain of small seamounts in a zone about 40 km wide.

Sediments are prevalent southwest of the Willaumez-Manus Rise; they reach a thickness of one kilometre immediately south of the chain of seamounts and thicken southwards to reach two kilometres near the coast of mainland New Guinea. Extensive sediment sampling off Madang and some isolated sampling farther east and north by Krause (13) showed dark or olive silt mixed with volcanic sand and shells.

East of the Willaumez-Manus Rise the sediments thicken gradually southwards from the sediment-free area and basement outcrops are far more numerous than in the west. There is evidence that recent intrusions have deformed the sediments, especially near the earthquake lineament and close to the Bismarck Volcanic Arc.

The profiles in the St Georges Channel area resemble those in the sediment-free area already described in the Bismarck Sea except for the greater amount of sediment; proximity to land probably accounts for the difference. This area is complex and has many localized features. More detailed seismic profiling (14) has revealed a prominent ridge, probably of volcanic origin, northeast of the Gazelle Peninsula; another smaller ridge is present (Fig. 1) farther west, off the south coast of New Ireland. Figure 1 also shows some evidence of normal faulting along the north coast of the Gazelle Peninsula, but this is only of local occurrence.

Two other features are worthy of special mention. Along the northern coast of New Guinea there is a shallow trench, which is probably a continuation of the larger trench along the north coast of West Irian. Where the trench occurs in the survey area (142°30'E - 143°30') it is only about 2000 metres deep, but its profile on seismic reflection records resembles deep ocean trenches. The second feature is the distinct topographic boundary between New Britain and New Ireland, where the 1900-m isobath can be traced right through St Georges Channel from the Bismarck Sea to the Solomon Sea. This feature has been well described by Brooks et al. (14).

MAGNETIC EXPRESSIONS

A total force magnetic contour map of the Bismarck Sea, taken from Willcox (1), is shown in Figure 4. The values plotted are residual values relative to the International Geomagnetic Reference Field (15). These are preliminary contours, calculated only from half-hourly values, so the map gives only a broad general picture; for detailed work the analogue profile records must be used. The magnitude, inclination, and declination of the Earth's magnetic field in this region are about 40,000 nT, -22 degrees, and 6 degrees E respectively.

The anomalies show a pronounced east-west trend which in the centre of the Sea roughly follows the earthquake lineament. Towards the edges of the area the trends parallel the land masses. This is especially noticeable along the northern coastlines of New Britain and mainland New Guinea, and aeromagnetic work on the mainland (16, 17, 18) shows that the magnetic trends there are also parallel to the coast. A prominent low is present along most of New Ireland. In the north it splits into two branches: one branch crosses New Hanover and parallels the earthquake lineament; the other continues through the St Matthias Group and bends round along the southern margin of the West Melanesian Trench (19), whose position is marked in Figure 2.

The dominent amplitude of the anomalies is about 1000 nT peak-to-peak, but there is a zone of more intense anomalies southeast of Manus Island with peak-to-peak amplitudes of about 2000 nT. The amplitude of the anomalies decreases in general towards land except where volcanics are present, as in the Bismarck Volcanic Arc (20). Lower-amplitude anomalies are present over the New Hanover-Manus Rise and over the area of thick sediments in the New Guinea Basin, where amplitudes are typically about 500 nT peak-to-peak.

Most of the anomalies have wavelengths in the range 10 to 15 km. The higher-amplitude anomalies (2000 nT) tend to have wavelengths of 10 km or less whereas the lower-amplitude anomalies may have wavelengths up to 40 km.

DETAILED MAGNETIC INTERPRETATION METHOD

An initial interpretation was made by a visual inspection of the magnetic contour map in conjunction with the magnetic profiles and seismic reflection profiles. Areas with uniform magnetic and topographic trends were selected and typical profiles across these areas were used for a detailed magnetic interpretation.

A computer program for matching observed and theoretical magnetic profiles was used for the detailed interpretation. It is based on a formula derived by Sharma (21), for magnetic bodies of infinite lengths along the strike. The computer displays the observed profile on a cathode ray tube. With a light pen the operator draws on the tube the cross-section of the proposed model; the computer calculates the anomaly due to this model and displays it for comparison with the observed profile.

The acoustic basement picked from the seismic reflection records was assumed to be the source of the magnetic anomalies and any overlying sediments were assumed to be non-magnetic. The basement was assumed to be continuous and to be remanently magnetized in either the normal or reversed direction: no other directions of remanent magnetization were considered. No bottom samples were available to give an indication of the values of susceptibility and remanent intensity to be expected, but values of 0.001 c.g.s. units and 0.004 c.g.s. units respectively were assumed for these quantities. These values and the ratio of remanent to induced components, which is about 10:1, are realistic for oceanic basement (22). In view of the arbitrary values adopted for susceptibility and remanent intensity the value adopted for the depth to the bottom of the magnetized layer is of very little consequence; it was assumed to be 4 km below sea level. As the interpretation proceeded and patterns became evident, the limitation of a continuous basement was removed.

Three profiles were interpreted, and initially the effects of normally magnetized and reversely magnetized basement along the whole length of the profile were computed. The interpretation of structure was started at those points where the initially computed curves suggested that the basement was either entirely normally or entirely reversely magnetized, and was extended along the profiles from these areas to give a final interpretation consisting of a series of reversed and normal blocks (Fig. 5).

That the interpretation arrived at by this method is by no means unique is well known from potential theory. Another possible source of ambiguity to which no reference could be found in the published literature is the uncertainty in the level chosen for the regional field. The regional field is known only to about plus or minus 50 nT at best and it is to be hoped that an incorrectly chosen regional field would show up as a simple displacement between the observed and calculated curves. However, it is possible that different regional fields would lead to different interpretations, and the problem certainly deserves further attention.

DISCUSSION

The Willaumez-Manus Rise divides the Bismarck Sea into two main tectonic provinces. The two provinces are very similar south of the earthquake lineament; each province contains a sedimentary basin with magnetic trends parallel to the adjacent land masses. North of the earthquake lineament, however, the eastern province's abrupt change of slope at the New Hanover-Manus Rise contrasts with the western province's very gradual slope of the Willaumez-Manus Rise.

The hypothesis of a reversely magnetized block intruded and faulted by very recent earth movements was adopted for the eastern province. This hypothesis explains the pattern of anomalies in the eastern half of the Sea and could be made to fit different traverses by slight modifications. Attempts were made to fit the standard time scale of polarity reversals to an area of symmetry across the earthquake lineament, but no satisfactory fit could be obtained. No hypothesis was adopted for the western area.

Eastern province

The magnetic interpretation (Fig. 5) of Traverse A, which lies in the eastern province (Fig. 2) suggests that a reversely magnetized block stretches from the Bismarck Volcanic Arc to the New Hanover-Manus Rise. Reversely magnetized material was first detected south of the earthquake lineament, where calculation of the terrain effects fitted only for reversely magnetized terrain. Reversely magnetized material was also found north of the earthquake lineament and the pronounced low all along New Ireland appears to be caused by the reversely magnetized body dipping under New Ireland. At the earthquake lineament, the sea-floor is normally magnetized material with little if any sediment cover (the sediment-free area described above), indicating that this part of the floor of the Bismarck Sea is the product of recent earth movements (the last 0.7 m.y.). Farther south from the earthquake lineament is another area of normally magnetized material relatively free from sediment.

The recent, normally magnetized intrusions suggest that the area is subject to tension, probably in a north-south direction. The boundary between reversely and normally magnetized material is very sharp near the south coast of New Hanover, suggesting that New Ireland broke away as a rigid block from the weaker floor of the Bismarck sea, which has itself split in several places producing the series of normally magnetized intrusions.

A major tectonic boundary, comprising the most easterly linear section of the earthquake lineament and the west coast of the Gazelle Penninsula, marks the eastern edge of the province. The magnetic trends terminate at this boundary and in an east-west seismic refraction line across it, Finlayson and others (4, 5) found a change in mantle depth from 20 km west of the Gazelle Peninsula to 32 km beneath the Gazelle Peninsula.

East of the boundary, the magnetic interpretation indicates no reversely magnetized material except possibly beneath New Ireland. The whole St Georges Channel area is probably very similar to the zone of normally magnetized intrusions in the eastern Bismarck Sea, except for its thicker cover of sediment due to the proximity of land.

Non-magnetic material at the earthquake lineament

A plug of non-magnetic material roughly 10 km wide was detected at the earthquake lineament in both the eastern and western provinces and in the St Georges Channel area (Fig. 5). Two possible explanations of this phenomena are put forward. Wiebenga (23) has suggested that the non-magnetic material is the final product of a fractionation of upper mantle material by partial melting which occurred as the Bismarck Sea split open under tension; this interpretation is supported by the series of recent, normally magnetized intrusions. An alternative explanation is that the non-magnetic plug is a highly fractured area with magnetic anomalies of such short wavelength that they are not detectable at sea level. Focal mechanism solutions on the earthquakes along the lineament (8) give sinistral strike-slip solutions and support this last idea.

Western province

Southwest of the Willaumez-Manus Rise both the topography and the magnetic anomaly pattern appear simple, and the area has apparently been not much deformed by recent earth movements. The area may be in an early stage of extension producing the chain of seamounts along the southern edge of the Willaumez-Manus Rise.

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Figures

Fig. 1. North-south ship traverses in the Bismarck Sea with diagrammatic representation of sediment distribution.

Fig. 2. Locality map of the Bismarck Sea and surrounding area showing the main tectonic features defined in this paper.

Fig. 3. Seismicity of the Bismarck Sea region to March 1972.

Fig. 4. Total force magnetic contour map of the Bismarck Sea.

Fig. 5. Detailed magnetic interpretations of three traverses.

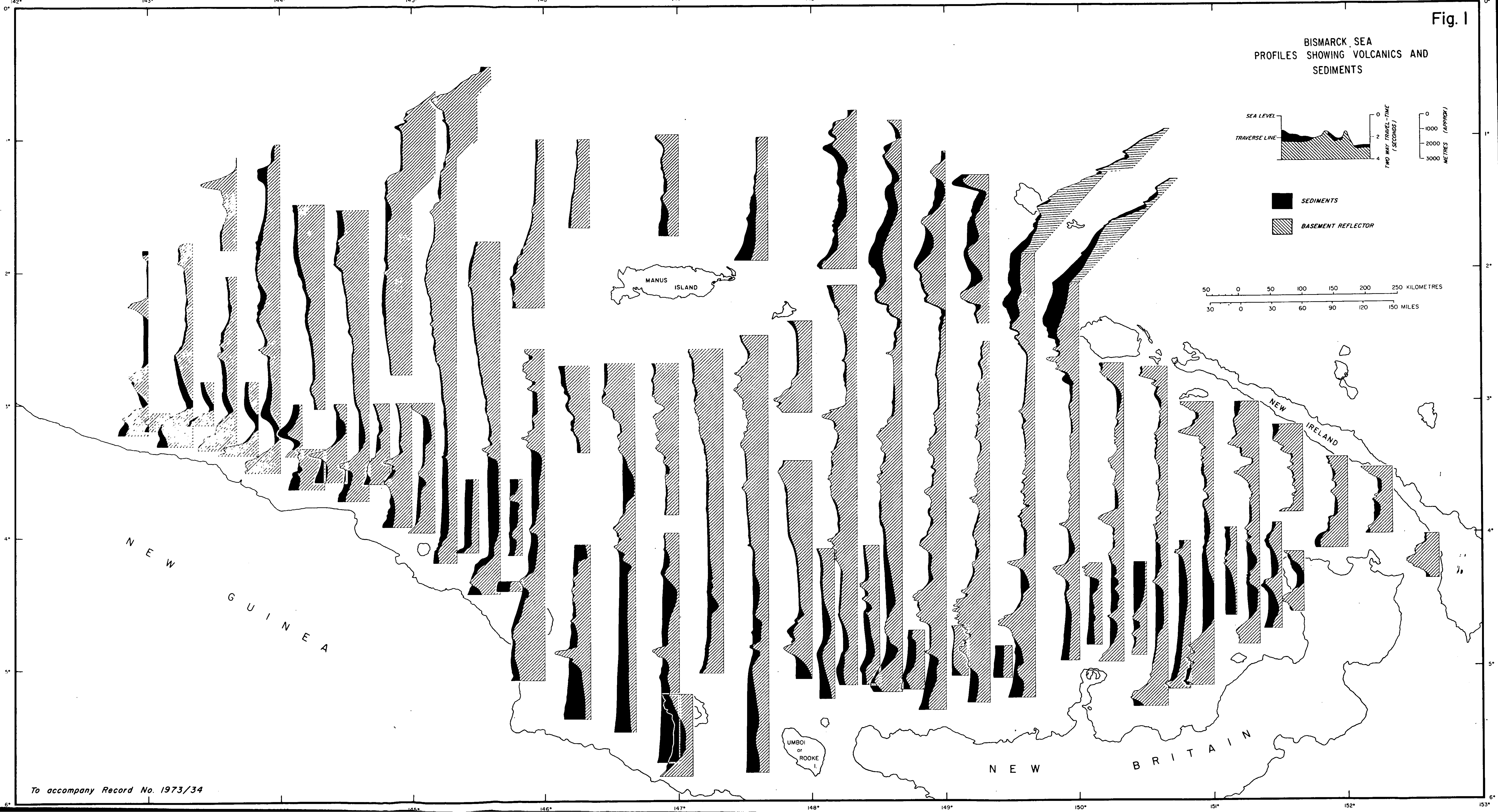

Fig. 1
BISMARCK SEA
PROFILES SHOWING VOLCANICS AND SEDIMENTS
SEA LEVEL
TRAVERSE LINE
TWO WAY TRAVEL-TIME (SECONDS)
0
2
4
METRES (APPROX)
0
1000
2000
3000
SEDIMENTS
BASEMENT REFLECTOR
50 0 50 100 150 200 250 KILOMETRES
30 0 30 60 90 120 150 MILES
MANUS ISLAND
NEW IRELAND
NEW GUINEA
NEW BRITAIN
UMBOI or ROOKE I.
142°
143°
144°
145°
146°
147°
148°
149°
150°
151°
152°
153°
0°
1°
2°
3°
4°
5°
6°
To accompany Record No. 1973/34

LOCALITY MAP OF THE BISMARK SEA AND SURROUNDING AREA SHOWING THE MAIN TECTONIC FEATURES DEFINED, IN THIS PAPER

To Accompany Record No 1973/34

PNG/BIO-194

(BASED ON PNG/BO-36)

SEISMICITY OF THE BISMARCK SEA REGION TO MARCH 1972.

(BASED ON PNG/BO-36)


FIGURE 4
POSITIVE
NEGATIVE
CONTOUR INTERVAL —200 GAMMAS
B Interpreted magnetic traverse
50 0 150 km
50 0 50 Miles
ST MATTHIAS GROUP
MANUS I
NEW IRELAND
NEW GUINEA
PAPUA
NEW BRITAIN
BOUGAINVILLE I
A
B
C
Plotted Values = Observed values minus International Geomagnetic Reference Field values
TOTAL FORCE MAGNETIC CONTOUR MAP OF THE BISMARCK SEA
0°
2°
4°
6°
7°
141°
144°
147°
150°
153°
156°
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DETAILED MAGNETIC INTERPRETATIONS OF TRAVERSES A, B, AND C

To Accompany Record No 1973/34

PNG/BIO-195