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STRUCTURE OF THE BISMARCK SEA

by

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SUMMARY

A geophysical survey of the Gulf of Papua and Bismarck Sea was carried out by Compagnie Generale de Geophysique (CGG) under contract to the Bureau of Mineral Resources (BMR) during 1970. Gravity, magnetic, and reflection seismic profiles were recorded along traverses spaced 20 n miles apart over most of the region, but 10 n miles apart along the continental shelves of New Guniea and New Britain.

Water depths in the Bismarck Sea range mainly between 1000 and 2500 m and average about 2000 m. The sea is bounded in the north by the West Melanesian Arc, a topographic rise above the 1500-m isobath, and in the south by New Guinea and New Britain. It is divided into an eastern and a western basin by the 1000 to 1500-m deep Willaumez-Manus Rise, a bathymetric high extending northwest from the Willaumez Peninsula in New Britain to Manus Island in the West Melanesian Arc. The continental shelves of New Guinea, New Britain, and New Ireland range in width from a few kilometres to 30 km.

The gravity and seismic data show that the sedimentary section is at least 1000 m thick northwest of Wewak and off the Sepik River delta. Sedimentary troughs, at least 2000 m deep, lie between the Huon Peninsula and the South Bismarck Volcanic Arc and between the Arc and a basement ridge farther north. About 1500 m of sediment occurs off the northern New Britain coast. The West Melanesian Arc is a continuation of the New Ireland structure and is formed by at least 2000 m of sediment draped over a basement ridge. The western basin of the Bismarck Sea contains 100 to 200 m of sediment over smooth basement and is traversed by a single seamount chain which is probably an extension of the Bewani-Torricelli Ranges. Little sediment is found in the eastern basin which is floored by lavas and intrusive bodies and traversed by easterly-trending seamount chains and grabens.

(b)

Finlayson & Cull have presented structural profiles between the Witu Islands and the Gazelle Peninsula, based on seismic refraction data and gravity modelling, which show a crustal thickness of about 20km. Estimates of crustal thickness under the remainder of the Bismarck Sea are presented herein, and were computed from spatially filtered gravity, water depth, and sediment thickness values, with reference to a standard crust based on seismic refraction data in the New Britain/New Ireland region. Depths were found to average about 20km which is 5 to 10 km greater than is typical for marginal basins.

Previous work has shown that a band of shallow earthquake epicentres, the Bismarck Sea seismicity lineation, extends across the area at about $3^{o}30'$S. Focal mechanism solutions computed by Johnson & Molnar suggest that the lineation is a zone of left-lateral shearing but magnetic models computed by Conelly suggest that a limited form of north-south spreading has taken place about the lineation in the eastern Basin. Magnetic anomaly ridges trend eastwards across the Bismarck Sea, parallel to and on either side of the seismicity lineation, and both features show corresponding right-lateral offsets in the eastern basin. Further examination of the locations of earthquake epicentres for which focal mechanism solutions have been obtained reveals that some of them lie on these right-lateral offsets. If the alternative focal planes are selected for the focal mechanism solutions, the shearing indicated has a right-lateral sense and lies within a plane which trends north-northwest. This is more in keeping with the observed offsets of the seismicity lineation and magnetic anomalies. Thus in the eastern basin, at least, a limited form of north-south spreading appears to be taking place about the seismicity lineation, which is offset in a right-lateral sense by trancurrent faults.

INTRODUCTION

The Bismarck Sea is a marginal basin partly enclosed by the islands of New Guinea and New Britain, and the West Melanesian Arc which is composed primarily of New Ireland, New Hanover, and Manus Island (Pl. 1). Its maximum east-west and north-south dimensions are about 1200 and 400 km, respectively.

A geophysical survey of the Gulf of Papua and Bismarck Sea was carried out by Compagnie Generale de Geophysique, under contract to the Bureau of Mineral Resources , between September and December 1970. Water depth, gravity, magnetic, and seismic profiles were recorded along 7000 n. miles of track in the Bismarck Sea region. The survey lines were oriented north-south and were generally spaced 20 n miles except along the northern coasts of New Guinea and New Britain where the spacing was 10 n miles. (Pl. 2). Details of the operations, a discussion of data quality, and a preliminary interpretation of the data are given by Tilbury (1975).

A description and interpretation of seismic profiles, obtained as on-line monitor records, and gravity and magnetic data are presented. Contour maps of water depths and free-air and Bouguer anomalies are based on hourly data which form a grid of about 10 x 20 n miles over most of the area. The magnetic anomaly map is based on half-hourly values, forming a grid of 5 x 20 n miles. Contouring of these maps (Pls. 3, 5, 6, & 10) was carried out by computer using a program which fitted a surface of minimum curvature to the data points (Briggs, 1974); the other contour maps presented (Pls. 7, 8, & 9) were manually contoured using linear interpolation.

STRUCTURAL SETTING

The Bismarck Sea is a partly enclosed marginal basin flanked by island arc structures which have been active from Mid-Cretaceous to Recent time. The geology of the surrounding islands has been discussed by Thompson (1952); French (1966); Johnson (1970); Macnab (1970); Ryburn (1971); Johnson, Taylor, & Davies (1972); Johnson & Smith (1974); and Hutchinson (in prep.), and a geological map of the New Guinea region has been prepared by BMR. Some of the geological information available in 1970 has been summarized by Brooks (1971) and Willcox (1973).

The Bismarck Sea is bounded in the north by the West Melanesian Arc (Pl. 1), an arcuate ridge delineated roughly by the 1500-m isobath and incorporating Manus Island, New Hanover, and New Ireland. These islands and presumably the submarine portion of the arc are composed of a complex suite of volcanics and limestones of Late Tertiary and Quarternary age, draped over acidic basement rocks. A shallow but well-defined trench lies about 200 km north of the arc and appears to be associated with a band of scattered earthquake epicentres (Denham, 1969, and Pl. 1).

In northern New Guinea, the Bewani-Torricelli Orogenic Belt (Pl. 1) comprises island-arc volcanics and sediment ranging in age from Late Cretaceous to earliest Miocene. An extensive area of Miocene-Pliocene sediment, the Northern New Guinea Basin, lies between the New Guinea Highlands and the continental slope.

New Britain is an active island arc with a history of tectonism spanning most of the Cainozoic. The island is essentially a geanticline composed of Eocene and Oligocene volcanics and sediment intruded by diorite and partly mantled by Upper Tertiary limestone, volcanics, and sediment. Quaternary volcanoes, several of which are active, lie along the northern side of the island and extend westwards as an island chain. The volcanoes form the South Bismarck Volcanic Arc. The deep New Britain Trench parallels the southern coast and an associated Benioff Zone dips steeply northwards beneath the island (Denham, 1969).

The Bismarck Sea is divided into two oceanic basins by a broad northwesterly-trending rise between the Willaumez Peninsula of New Britain and Manus Island. Several easterly-trending chains of seamounts occur in the basins. The most prominent is a volcanic ridge of up to 1500 m relief which extends along latitude $3^{o}30'$S and appears to merge with the Bewani-Torricelli Ranges in the west. The presence of a major graben between New Britain and New Ireland (Brooks, Connelly, Finlayson, & Wiebenga, 1971) suggests that the eastern part of the Bismarck Sea has been subjected to tension in recent time. The basement underlying the eastern basin is very rugged and probably of volcanic origin, whereas basement west of the 'Willaumez-Manus Rise' is relatively smooth. The sediment cover is generally thin in the central part of the Bismarck Sea, but around the margins 2000 m or more of sediment has accumulated. In many places this sediment has been dammed behind basement ridges.

Magnetic anomaly ridges which in a regional sense extend approximately along latitudes 3^o and 4^oS exhibit localized east-northeast trends in the eastern Bismarck Sea and in several places appear to be offset in a right-lateral sense. They correlate closely with a band of shallow earthquake epicentres which is similarly offset (Denham, 1969; Willcox, 1971). Fault-plane solutions of events within this band indicate that left-lateral shearing along an east-west axis is taking place in the area (Jonhson & Molnar, 1972) and this suggests that the magnetic anomalies, and probably the seamount chains, are related to volcanic activity along a series of transcurrent or transform faults.

Several authors have suggested that the structural complexity of the Bismarck Sea region arises from successive formation and collision of island arc/trench systems which have formed on the flank of the northward-drifting Australian continent (for example, see Curtis, 1973). The region lies essentially between the Australian and Pacific Plates although several sub-plates have been defined (Johnson & Molnar, 1972; Curtis, 1973) based on the distribution of earthquake epicentres (Pl. 11). The dips of Benioff Zones north of the West Melanesian Arc and south of New Britain, and the depths and focal mechanism solutions of earthquakes in the Bismarck Sea suggest that the Bismarck Sea consists of North and South Bismarck Plates separated by a complex left-lateral shear zone and possibly short spreading ridges (Connelly, 1976; Taylor, 1976). The Pacific Plate is possibly underthrusting the North Bismarck Plate to the north of the West Melanesian Arc. The Solomon Sea plate is underthrusting the South Bismarck Plate beneath New Britain and gives rise to the present volcanic activity. The relation between the South Bismarck and Australian Plates is unclear, but there is a vague indication of a southerly-dipping Benioff Zone beneath the north New Guinea coast.

The Bismarck Sea has many of the characteristics of other marginal basins (Karig, 1971; Packham & Falvey, 1971). It is partly bounded by andesitic volcanic arcs and trenches, and regional free-air anomalies over it average about +50 mGal. Magnetic lineations appear to be present, although they are poorly developed. In the eastern basin at least, a tensional regime probably associated with spreading is indicated by grabens which lie between New Britain and New Ireland (Brooks et al, 1971). Only two heat flow measurements have been made (Halunen & von Herzen, 1973) and these indicate normal heat flow on the rise between Manus Island and the Willaumez Peninsula, and high heat flow southwest of it near the South Bismarck Volcanic Arc.

PREVIOUS GEOPHYSICAL SURVEYS

The following summary of regional geophysical surveys in the Bismarck Sea region is taken from Willcox (1973).

Aeromagnetic surveys

Young (1963) records the results of some widely spaced groups of reconnaissance traverses across the Northern New Guinea Basin. North-south traverses across the Bewani Geosyncline and northeast-southwest traverses across the Finisterre Ranges terminate at the coast, but those across the Prince Alexander Mountains extend to Kairiru Island, about 16 km offshore. Near the coast, the Finisterre traverses are interpreted to show basement dipping seaward at about 250 m/km. Lines across the other areas were flown in a more recent survey (Australia Aquitaine, 1967) and are discussed below.

The Sepik Aeromagnetic Survey was carried out by Geophysical Associates for Australian Aquitaine in 1967, within Permit P45. It covers an area north of the Sepik River. In the Wewak and Aitape districts traverses extend by up to 60 km beyond the coast. Line spacing is approximately 20 km.

Between Vanimo and Aitape a possible basinal structure is delineated by magnetic basement contours (Willcox, 1973, fig. 6). Basement dips north-northeasterly at about 150 m/km, reaching a depth of about 3000 m at the coast. Around Wewak, depth to basement varies from +8 m on Kairiru Island, to -350 m (i.e. above sea-level), 8 km to the east. Both basinal structures form part of a broader seaward dip along this portion of the New Guinea coast. Geophysical Associates drew the conclusion that the sedimentary sections indicated between Vanimo and Aitape, and east of Kairiru and Mushu Islands form prospective basins both on and offshore. It must, be pointed out however, that along the coastal strip this conclusion relies largely on inferences drawn from data recorded inland.

Various magnetic trends reflect the structures of the area. Anticlinal and synclinal trends lie sub-parallel to the coastline. Near Vanimo, an anticlinal feature in the Bewani-Torricelli-Prince Alexander Ranges is offset across a north-south line, indicating the presence of a major transcurrent fault.

The Madang Aeromagnetic Survey was carried out in 1968 by Compagnie Generale de Geophysique for Continental Oil (1968), in Permit P41. The Ramu River area was flown using a 2-km line spacing with 8-km spacing between tie-lines. Little coverage was obtained offshore but data from the Sepik/Ramu delta may assist interpretation of the structure of the offshore area.

The four magnetic markers indicated were considered to be due to (i) basic plutonic rocks of the basement, (ii) volcanics in the sedimentary section, (iii) metamorphic rocks within basement, and (iv) basic Cretaceous dykes.

The magnetic basement contour map indicates a major change in character of the basement across a north-south line along the lower reaches of the Ramu River. East of this line, the basement contours indicate a northwest-trending basin, with depths of up to 4000 m, transected by predominantly north-south faulting. The magnetic basement depression is parallel to the Ramu Gravity Low, but slightly offset to the southwest. West of the line, the magnetic basement contours indicate depths varying from 500 to about 4000 m, and a number of sub-parallel northwest-trending structural features. If this structural contrast is due to faulting, such as an extension or offshoot of the Ramu-Markham fault towards the coast, it may be evident in magnetic profiles on the continental shelf.

Gravity surveys

Between 1963 and 1967, scattered gravity observations were made throughout Papua/New Guinea by Shirley (1964) and St John (1967). A base network was also set up, extending into New Britain and Bougainville and superseding the base stations of lower accuracy at airports established by the University of Wisconsin in 1961. The base station values are in close agreement with those of the BMR Isogal Network. From regional gravity observations St John computed crustal models to fit some of the major anomalies. He concluded that it was not possible to differentiate from the gravity profiles between continental basement in Papua and oceanic basement north of the Highlands. He further concluded that 'Gravity gradients on the north coast indicate that the crust thins rapidly towards the true oceanic crust. Preliminary results from Rayleigh wave dispersion studies by J.A. Brooks .... indicate a crust of continental thickness throughout the inland areas of northern New Guinea'.

The Sepik River Helicopter Gravity Survey (Watts, 1969) established 1300 stations on a 6.3-km grid in an area bounded by the coast between Aitape and Madang, and the main cordillera. An offshore basin northwest of Wewak, inferred from aeromagnetic interpretation, was shown to coincide with a gravity low. Coastal basins were indicated by gravity lows west of Dagua, and a gravity low of 20-30 mGal closure offshore from Madang, was attributed to an area of thick sediment.

Laudon (1968) carried out land gravity surveys of the Solomon Islands, Manus Island, and the Gazelle Peninsula of New Britain. He concluded that, in general, the islands are characterized by very high free-air and Bouguer anomaly values and steep local gravity gradients. The Bouguer anomaly variations are related to the near-surface geological features; the highs being the expressions of basement ridges and Quaternary volcanics, and the lows the expressions of Tertiary sedimentary basins. The large magnitudes of the gradients, which are among the steepest in the world, probably result from large density contrasts between ultrabasic basement complexes in the uplifted cores of the islands and Upper Tertiary sediments on their flanks. In the Rabaul area of New Britain the apex of a steep-sided, V-shaped anomaly lies close to the volcanic craters, and Laudon surmised that '.....present volcanic activity may be associated with intersecting fracture zones that are

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filled with crystalline material or perhaps, at depth, with molten material within the lighter predominantly pyroclastic sequence of which the terrain around Rabaul is composed.' Marine and land gravity data in the region were interpreted to indicate that the Solomon Islands Chain is isostatically compensated, but that individual islands and their Quaternary volcanic piles are supported by the crust.

The Helicopter Gravity Survey, New Britain and New Ireland was carried out by BMR in 1969.

Marine gravity data in the Bismarck Sea region were obtained during 1963-64 by the vessel USS Shoup. Surface gravity meter readings were reduced to free-air anomalies, but positioning was of low accuracy as only dead-reckoned navigation data were available.

Several marine gravity and magnetic observations have been made aboard British and U.S. hydrographic vessels. Most of these were made by Rose et al. (1965) aboard HMS Dampier, as part of a survey around the Solomon Islands group.

A Bouguer anomaly map compiled by Rose, Woollard and Malahoff of the Hawaii Institute of Geophysics, from data gathered on board the ships Dampier and Baird, covers the areas southeast of New Britain and east of New Ireland.

The Japanese vessel Umitaka-maru took scattered gravity and magnetic readings along its track through St George's Channel and the Solomon Sea during 1964.

Bathymetric surveys

A bathymetric study by Krause (1965) deserves mention, as it was used in an attempt to correlate bathymetric data along the northern New Guinea coast with the known on-shore geology of New Guinea. Sources of information included the RECORDER expedition, soundings by HMS Cook, the Netherlands Hydrographic Office, and the U.S. Naval Oceanographic Office. Soundings were also available from the SNELLIUS Expedition and the ES Vityaz.

The principal features outlined by Krause were:

(i) a southern group of actively volcanic seamounts and islands (Bam-Umboi) trending into New Britain, and a northern inactive group (Wuvulu) which are largely sub-marine, considered to trend into the Admiralty Islands.

(ii) A dormant volcano in the middle of Vitiaz Strait.

(iii) A scarp of more than 300 m relief and 38^{o} slope east of Madang.

(iv) A trough at the foot of the continental slope west of Bam and Blupblup. The Sepik River appears to have built its delta to the edge of the shelf and may have filled the eastern end of this trough.

(v) A northeasterly structural trend off the north coast near the Irian Jaya/Papua New Guinea border which may be an extension of the Wuvulu volcanoes.

(vi) A structural trend indicating extension of the Bewani-Torricelli Mountains eastwards on the sea-floor.

BATHYMETRY (Pls. 3 & 4)

The description of bathymetry presented here is based largely on that of Tilbury (1975) and on unpublished notes by the author.

The Bismarck Sea is partly enclosed marginal basin with an average water depth of about 2000 m (Pl. 3). It is divided into two sub-basins by a northwest-trending rise extending from the Willaumez Peninsula in New Britain to Manus Island in the West Melanesian Arc. To the south it is bounded by the islands of New Guinea and New Britain which have 'continental shelves' only few kilometres wide. It connects with the 6000-m deep New Britain Trench via the Vitiaz Strait and St George's Channel, to the west and east of New Britain respectively. The northern margin of the Bismarck Sea is generally considered to lie along the West Melanesian Arc, a ridge delineated roughly by the 1500-m isobath and incorporating Manus Island, New Hanover, and New Ireland. The northern flank of this ridge dips steadily towards the West Melanesian Trench which has its axis about 200 km north of Manus Island.

The New Guinea continental margin consists of a very narrow shelf, generally less than 15 km wide, and a slope which drops abruptly from the 200 to 2000-m isobath into the western basin of the Bismarck Sea. The slope dips sharply at some 6^{o} in the west and gradually lessens to about 1 to 2^{o} east of Madang. Between New Britain and Wewak the slope has been modified by the volcanic island chain of the South Bismarck Volcanic Arc.

1b

The western basin of the Bismarck Sea is an elongate feature about 600 km from east to west and 100 km from north to south, with depths of 1800 to 2200 m. It extends parallel to the New Guinea coast between longitudes 143° and 147°E. Offshore from northwest New Guinea it deepens sharply westwards to 3600 m, connecting with the eastern end of the New Guinea Trench. Seismic and echo-sounding profiles show that the floor of the basin has little relief except for a major seamount chain which extends eastwards from the vicinity of Wewak (Pl. 4). The northern margin is formed by a gentle rise with gradients of only 1° - small compared with the steep gradients of the southern margin adjacent to New Guinea. A smooth-floored region lying at 1800 m in the eastern portion of the basin has been defined as the Bismarck Platform by Crook (1969).

The Willaumez-Manus Rise, which divides the Bismarck Sea into two basins, lies chiefly between the 1000 and 1800-m isobaths and is up to 100 km wide. It has gently sloping flanks which dip at less than 1° into both the eastern and western basins except near several islands and reefs where slopes are locally steeper.

The eastern basin of the Bismarck Sea is a triangular feature, slightly deeper than its western counterpart. It is about 200 km across in the southeast and narrows towards its apex near Manus Island, about 400 km to the northwest. The depth of the basin ranges from 2000 m along the edge of the Willaumez-Manus Rise to about 2600 m along the New Ireland margin, the sea-floor dipping towards the northeast. Gradients of the basin margin along the north coast of New Britain and south of the West Melanesian Arc average 3°, much steeper than the gentle 1° slopes of the southwestern boundary formed by the

Willaumez-Manus Rise. Several east-trending seamount ridges and grabens occur over the Willaumez-Manus Rise and in the eastern basin (Pl. 4). Between the Gazelle Peninsula and New Ireland the basin is restricted to a steep-sided trough which connects with the rifted St George's Channel/Bismarck Sea Trough (Brooks et al., 1971). The Weitin and Sapon Faults of southern New Ireland are parallel to and probably co-extensive with the steep northeastern margin of the basin. Rugged sea-floor topography characterizes the eastern basin and contrasts with the smooth sea-floor of the western basin and much of the Willaumez-Manus Rise.

The West Melanesian Arc is elevated about 1000 to 1500 m above the adjacent basins. Seafloor relief is mainly undulating and only in a few places can be described as rugged. Bathymetric highs along the ridge are clearly subsea extensions of islands such as, New Hanover. Dips are much shallower and relief more subdued in the area north of Manus Island (Pl. 4).

GRAVITY INTERPRETATION

Free-air anomalies (Pl. 5)

The Bismarck Sea, where free-air anomaly values average about +50 mGal (Pl. 7), appears to lie within a regional gravity high indicated by satellite observations (Gaposchkin & Lambeck, 1971), which covers offshore southeast Asia and the western Pacific. This feature must result either from a mass excess in the mantle or from a mass excess supported by the crust.

The shorter wavelength anomalies, generally less than 100 km across, variously reflect seafloor topography, igneous bodies, and variations in sediment thickness. Broad correlation of the free-air anomalies with bathymetry is quite apparent in the combined profiles (Pls. 13, 14, and 15). If the long-wavelength component is removed by filtering, as discussed in Appendix II, the residual free-air anomalies (Pl. 8) should correlate with seafloor topography and structure on a more local scale. Over most of the region this appears to be the case: west-northwest contour trends are parallel to the New Guinea coast; easterly-trending features north of New Britain coincide with the seamount chains and grabens in the eastern basin; and arcuate gravity contour trends follow the structure of the West Melanesian Arc.

Bouguer anomalies (Pl. 6)

The definition of the 'marine Bouguer anomaly' is given in Appendix I. Ideally, the Bouguer correction removes the gravity effect of seafloor topography by replacing the gravity effect of the water layer with that of a slab of the same thickness which has the assumed density of the sea floor sediments. The Bouguer anomalies presented in Plate 6 are based on an assumed sediment density of 2.2 tm^{-3}. This value is obviously inappropriate in some areas, particularly in the eastern basin for instance, where igneous bodies of greater density crop out on the sea-floor. The combined profiles (Pls. 13, 14, and 15) show computed hourly Bouguer anomaly values using densities of 2.2 and 2.8 tm^{-3}. On the portions of Lines 53 and 118 (Pl. 15) where igneous or metamorphic basement appears to form the sea-floor, the Bouguer anomaly profiles based on a density of 2.8 tm^{-3} show less correlation with seafloor topography than do the profiles based on 2.2 tm^{-3}. This further supports the interpretation that igneous or metamorphic basement forms the sea-floor.

Bouguer anomaly contours (Pl. 6) show a close correlation with the bathymetric contours (Pl. 3) over most of the area, and on a regional scale reflect variations in depth of the crust/mantle interface.

Two regional Bouguer anomaly highs overlie the eastern and western basins of the Bismarck Sea and are separated by a regional gravity trough over the Willaumez-Manus Rise. Along the New Guinea coast an intense regional gradient indicates that the crust thickens abruptly beneath the landmass. Small gravity lows to the east and northwest of Wewak correlate with sub-basins of the Northern New Guinea Basin (Tilbury, 1975). Near Madang, a gravity low of magnitude -140 mGal, partly delineated by Watts (1969), is attributed to a basin which probably contains several kilometres of Late Tertiary to Recent sediment.

A Bouguer anomaly trough corresponds to the West Melanesian Arc, supporting the concept that a basin with 2-3 km of sediment in New Ireland and relatively thick crust extends westwards beneath the sea. The presence of relatively thick sediment is confirmed by seismic profiles across the arc. The straightness of the Bouguer anomaly contours along the southern margin of the gravity trough indicates that the West Melanesian Arc is probably bounded on its concave side by a major fault, parallel to the coast of New Ireland and extending almost to Manus Island. This could be an extension of the Weitin or Sapon Faults which trend northwesterly across the southern part of New Ireland.

Along the northern coast of New Britain the Bouguer anomaly gradients are less steep and more variable in trend than those along the New Guinea coast and West Melanesian Arc. In the vicinity of Willaumez Peninsula and the isthmus between the Gazelle Peninsula and the rest of New Britain the contours change trend from predominantly easterly to southeasterly. In the latter case this is probably related to southeasterly-trending faults bounding the Wide Bay/Open Bay Graben and indicates that the graben may extend into the Bismarck Sea for up to 50 km.

An intense north-northwest-trending Bouguer anomaly ridge occurs on a submarine extension of the axis of Bougainville island and indicates a possible continuation of the Bougainville structure through the volcanic islands lying northeast of New Ireland.

Crustal thickness (Pl. 9)

The crustal thicknesses (strictly depths to 'Moho') were computed from spatially filtered gravity, water depth, and sediment thickness values, with reference to a standard crust computed from seismic refraction data in the New Britain/New Ireland region. (Appendix II).

The crustal thicknesses have values of about 20 km under the central portion of the Bismarck Sea. Beneath the West Melanesian Arc, the New Guinea coast, and St George's Channel they range from 24 to 28 km. From the South Bismarck Volcanic Arc to the Huon Peninsula the crust shows a progressive thickening from 25 to 35 km. In general, the crustal thickness shows an inverse relation with the bathymetry and Bouguer anomalies; the 20-km thickness contour corresponds roughly with the 2000-m isobath and the 160-mGal Bouguer anomaly contour. Although lateral variations in density have probably led to errors in the computed crustal thickness values, the results are a useful first approximation. To some extent their reliability can be assessed from crustal thicknesses determined by a seismic refraction survey along a line between the Witu Islands and the Gazelle Peninsula (Finlayson & Cull, 1973), which are within 3 km of those deduced from the gravity data.

The relatively thick crust under the West Melanesian Arc more than compensates for the high topography in the area and the mass deficiency caused by thick sediment, and may be partly related to interaction between the North Bismarck and Pacific Plates (Pl. 1). A similar downwarp of the base of the crust underlies the Willaumez-Manus Rise; however, the origin of this feature is not understood. The rise cannot be readily explained as a remnant arc of the type described by Karig (1972), since it lacks the characteristic scarps at its edges. It appears to antedate the volcanism and the commencement of seismic activity along the Bismarck Sea seismicity lineation (Denham, 1969).

The crustal thickening between the South Bismarck Volcanic Arc and the New Guinea coast probably compensates for both the thick sediments occurring just offshore and the coastal ranges. The two alternative causes of crustal thickening towards the New Guinea coast are:

(i) Subduction of an oceanic plate beneath the Australian Plate as evidenced by the existance of a poorly-defined Benioff Zone (Denham, 1969; Johnson & Molnar, 1972).

(ii) Subsidence of a topographically high area (i.e. New Guinea) to achieve or approach a state of isostatic equilibrium. Subduction would be the more basic cause as the New Guinea Landmass appears to have formed as a result of subduction and associated volcanism.

MAGNETIC INTERPRETATION (Pl. 10)

The definition of the magnetic anomaly as referred to in the text and in Plate 10, is given in Appendix I.

The Bismarck Sea is generally a region of high-amplitude, short-wavelength magnetic anomalies. Total field profiles show that amplitudes range between about +1500 and -1500 nT, although a range of only +800 to -1200 nT is apparent on the contour map owing to aliasing of the most intense anomalies by the half-hourly (approximately 8 km along traverses) sampling interval. The magnetic anomaly map (Pl. 10) shows that the anomalies over the eastern basin and southeast of Manus Island are more intense than those over the Willaumez-Manus Rise and the western basin. The West Melanesian Arc is associated with a relatively quiet anomaly pattern. Well-defined easterly trends are apparent over the eastern basin and to a lesser extent across the Willaumez-Manus Rise. Offshore from New Guinea the predominant trends are roughly parallel to the coast.

West of Wewak, a positive magnetic anomaly ridge over the 'continental slope' and adjacent New Guinea Trench (Composite profiles, Line 59, Pl. 15) is probably caused by relatively shallow basement which probably crops out on the slope. A northerly downthrow of basement, of possible 2-3 km, occurs along a fault which gives rise to the slope. The magnetic basement becomes shallower northwards from the coast to the edge of the continental shelf, and crops out on Kairiru Island off Wewak. Between Wewak and Karkar Island off Madang, a broad band of positive anomalies extends along the shelf and slope, and is probably caused by lava flows from the active South Bismarck Volcanic Arc. Intense magnetic anomalies at the southern end of Line 38 (Pl. 13), are associated with Karkar Volcano, which lies within the arc. Other magnetic features parallel to the New Guinea coast seem to broadly correspond with basement ridges and troughs. Magnetic anomaly lows east of Madang coincide with a -190 mGal gravity low and probably result from a thick sedimentary sequence.

An arcuate but diffuse magnetic anomaly occurs to the north of the South Bismarck Volcanic Arc and New Britain. About 20 km north of Willaumez Peninsula it is surmounted by an intense positive anomaly which could be caused by a submarine volcano. This would lie along the trend of the Quarternary-Recent volcanoes on the Peninsula. The volcanic Witu Islands give rise to intense anomalies which appear to be negative in Plate 10, but are probably only parts of intense dipolar fields which have not been completely resolved by the half-hourly data points.

The submarine portion of the West Melanesian Arc has a mainly quiet magnetic anomaly pattern, and this is consistent with other evidence for the presence of 2-3 km of sedimentary section in the area (see northend end of Line 106, Pl. 14). However, the volcanic islands southeast of Manus give rise to intense anomalies of up to 3000 nT amplitude.

Two well-defined anomaly ridges extend westward across the eastern basin, approximately along latitudes 3° and 4°S. In the Willaumez-Manus Rise they become diffuse, but farther west converge to form a single ridge which merges with the New Guinea coast near Wewak. This single ridge corresponds approximately with a chain of seamounts which appears to be an offshore extension of the Bewani-Torricelli Orogenic Belt. In the eastern basin the anomaly ridges show a broad correlation with basement ridges and in some places the intervening anomaly trough coincides with a graben (Line 106, Pl. 14; Line 118, Pl. 15) which forms a channel up to 2000 m deep between the Gazelle Peninsula and New Ireland (Brooks et al., 1971). It seems probable that these extensive linear anomalies are caused by lavas extruded from the central rift.

Three other features are associated with the linear magnetic anomalies:

(i) several right-lateral offsets are apparent, the most prominent occurring along the eastern edge of the Willaumez-Manus Rise (most noticeable at 148°E, southeast of Manus Island), and along a line joining the west coast of the Gazelle Peninsula to New Hanover (Pl. 10).

(ii) over most of the eastern basin the effect of seafloor topography on the magnetic anomalies suggests the presence of reversely magnetized material. This is apparent, for example, on Line 118 (Pl. 15) and on Line 106 at about 3°50' and 4°15'S (Pl. 14) where seamounts or basement ridges exhibit dipoles in which the positive lobe lies south of the negative lobe.

(iii) there are indications of symmetry in the magnetic profiles: on Line 118 (Pl. 15) this occurs about a point at 3°30'S and on Line 106 (Pl. 14) about a point at 3°40'S. On Line 38 (Pl. 13), which passes just to the west of Manus Island, there also appears to be poorly-defined symmetry about a point at 2°25'S, which is about 25 km south of the axis of the West Melanesian Arc. This symmetry is most clearly evident in the anomaly profile between 2° and 2°50'S.

Relation of magnetic anomalies to earthquake epicentres

The central magnetic anomaly trough and the right-lateral offsets correspond almost exactly with the band of shallow earthquake epicentres which make up the Bismarck Sea Seismicity Lineation (Denham, 1969; Pls. 1 and 11). Johnson & Molnar (1972) consider that the earthquake lineation defines the boundary between North Bismarck and South Bismarck lithospheric plates which are two of the five plates they postulate in the region. Focal mechanism solutions for a few widely spread earthquakes within the lineation, which are numbered in Plate 11, have all indicated left-lateral shearing along the lineation (Jonhson & Molnar, op. cit.). These solutions, especially numbers 9 and 10 in the western Bismarck Sea, are difficult to reconcile with the extensional regime indicated by the magnetic symmetry. Epicentres numbers 11 and 12 are near the right-lateral offset in the magnetic lineations, which if spreading is taking place may be a NNW-trending transcurrent fault. The choice of a NNW-trending rather than ENE-trending modal plane for those focal mechanism solutions would indicate shearing in a right-lateral sense along a NNW-trending fault, and would be compatible with the magnetic data.

Magnetic models

Connelly (1974) has derived magnetic models for three lines across the Bismarck Sea, including Line 106 (Connelly, Traverse A). As no bottom samples were available he assumed values of susceptibility and remanent intensity. These values and the ratio of remanent to induced components, of about 10:1, are realistic for oceanic basement (Irving, et al., 1976).

Reversely magnetized material was found to occupy most of the eastern basin, but a body about 50 km wide straddling the seismicity lineation is normally magnetized and was presumed to have formed during the present polarity epoch (the last 0.7 m.y.). Although these magnetic bodies may have originated by authodox seafloor spreading from a ridge coincident with the earthquake lineation, Connelly considered that this was not consistent with the following observations:

(i) the focal mechanism solutions showed left-lateral movement along the possible spreading-ridge,

(ii) reversely magnetized material extends under New Ireland and is hence probably older than New Ireland,

(iii) the theoretical anomaly profile over a simple seafloor spreading model was not a satisfactory fit to the observed anomaly profile.

As an alternative hypothesis involving a restricted form of spreading he proposed that, 'all the reversely magnetized material was formed first, presumably by very rapid extension, and as it underlies New Ireland it must have been formed at the same time as, or earlier than, New Ireland. The block was then further extended, probably in a north-south direction, producing the normally magnetized intrusions ...... Left lateral movement along the earthquake lineament ..... may not be directly related to the formation of the normally magnetized zone......'.

SEISMIC INTERPRETATION (Pl. 12)

The preliminary seismic interpretation presented in this text is based on a brief study of on-line monitor records made by the author in 1971, immediately after the survey, and on additional work carried out by Tilbury (1976). Record quality is generally only fair to poor, with a seismic penetration of 1 - 2s below sea-floor. A significant improvement in quality of the profiles would probably be achieved by six-fold common-depth-point (CDP) stacking; however, it is not anticipated that this will be carried out in the foreseeable future owing to the expense of processing and the apparent low petroleum potential of the Bismarck Sea region. It has not been possible to resolve much structural detail and the lines are too widely spaced to make reliable correlations from line to line.

The structural map (Pl. 12) combines Tilbury's interpretation with that of the author. The estimates of sediment thickness shown on the structural map are based on a seismic reflection velocity of 2000 m/s, equivalent to 1 m of sediment thickness for 1 ms of reflection time. However, in areas where the sediments are thick or consolidated, velocities are probably as high as 4000 m/s. Limestones and basalts, which may occur over large areas of the Bismarck Sea, can have velocities in the range 3500-6500 m/s.

Sediment thickness values in the Bismarck Sea vary between three easterly-elongated zones: on the West Melanesian Arc they range from 600 to possibly 3000 m; in the central zone, they are 100 to 300 m and the sediments overlie rugged basement; and along the New Guinea coast and north coast of New Britain they range from 300 to at least 2000 m.

New Guinea margin and western basin

The band of thick sediment offshore from New Guinea varies in width from about 80 km west of Manam to about 160 km north of Huon Peninsula. Sediment becomes progressively thinner away from the coast and is only 100-200 m thick on the basement rises which form the foundations of the West Melanesian Arc and Willaumez-Manus Rise.

Sediments are thick on the continental shelf between the New Guinea/Irian Jaya border and the mouth of the Sepik River, in a band 15 km wide, extending to the 1000-m isobath. West of Wewak, the sedimentary section is flat-lying and 500-1000 m thick. A smooth (?)basement rise and several intrusive bodies along the edge of the continental shelf, appear to have dammed the sediment derived from land. In its steepest parts the continental slope has a 10° gradient and is formed of exposed basement. The slope may be fault-controlled. At the foot of the slope, the sedimentary section is 300-700 m thick and is composed a thinly bedded sequence, possibly of carbonates, in some areas, and an accoustically semi-transparent section, possibly of pelagic and volcaniclastic origin in other areas. The (?)basement surface is very smooth throughout.

The Wewak Sub-basin of the Northern New Guinea Basin extends onto the continental shelf where it comprises over 1000 m of flat-lying well-stratified sediment (Tilbury, 1976). The sub-basin is bounded in the southeast by a major fault which separates it from an area of from shallow basement, and in the northwest by a series of northeast-trending basement ridges, one of which is exposed on Kairiru Island.

Northwest of the Sepik River delta a trough, about 1000 m deep, lies between the continental slope and a ridge 30 km to the north (Line 59, Pl. 15). Its eastern end appears to have been filled by sediment dumped by the Sepik River, but the sediment is thin farther west. The trough may be related to subduction of the South Bismarck Plate beneath the Australian Plate along the New Guinea coast (Pl. 1), although subduction is not clearly indicated by a Benioff Zone in this area (Denham, 1969).

A chain of seamounts which trends east-northeast converges with the shelf edge 18 km from the mouth of the Sepik River. The chain appears to have acted as a partial barrier to land-derived sediment. The prolongation of its trend intersects the coast near Wewak which suggests that it may be an offshore extension of the Bewani-Torricelli Ranges. However, the chain could possibly merge with the South Bismarck Volcanic Arc and follow a west-northwest trend parallel to the coast.

Between Karkar and Umboi Islands, north of Huon Peninsula, two deep sedimentary troughs have formed on the southern sides of basement ridges. Line 38 (Pl. 13) which passes just west of Karkar, crosses a small basin between basement ridges at 4^{o}S and $3^{o}20$S.

The southernmost trough lies between the coast and a basement ridge which is part of the South Bismarck Volcanic Arc. The sedimentary section in the southern half of the trough is at least 2000 m thick and could be more than twice this thickness. It is divided by two unconformities into an upper unit comprising a few hundred metres of well-stratified sediments, a middle unit about 500-1000 m thick which is accoustically transparent, and a lower unit of well-stratified sediments (Pl. 13). This trough is the source of the large gravity low to the east of Madang.

The northern trough lies between the South Bismarck Volcanic Arc and a basement ridge about 40 km (Line 38) to 70 km (Line 20) farther north. It contains up to 2000 m of well-stratified sediments which have similar characteristics to those in the upper unit of the southern trough. Only one unconformity is apparent, about 100-200 m below the seafloor. Evident on Line 38 (Pl. 13) is a smooth reflector at about 500 m below the seafloor, which may be basement.

The sediment above the upper unconformity in these troughs probably consists of volcaniclastics and clastic carbonates. Extensive sampling off Madang and some isolated sampling farther east and north by Krause (1965) showed dark or olive silt mixed with volcanic sand and shells. The lithologies of the deeper units are unknown but are probably related to those of the Finnisterre Ranges of the Huon Peninsula. The unconformities may correspond in age to the uplift of the Finnisterre Ranges in the late Miocene and initiation of the South Bismarck Volcanic Arc in the Quaternary.

The western basin of the Bismarck Sea is underlain by 100-200 m of acoustically-transparent sediments which extend over the western part of the West Melanesian Arc. The uniform thickness and lack of stratification is believed to indicate a predominantly pelagic source. The (?)basement reflector beneath the western basin is strikingly smooth and contrasts with the rugged basement on the Willaumez-Manus Rise and in the eastern basin.

New Britain margin and eastern basin

The relatively thick sediment in the troughs north of Huon Peninsula extends eastward along the shelf north of New Britain, as far as the Gazelle Peninsula. Igneous bodies are common, particularly near the volcanic Witu Islands and Willaumez Peninsula. To the east and west of the Willaumez Peninsula the sea-floor is in the form of three terraces deepening northwards and separated from each other by volcanoes or igneous intrusions (Line 106, Pl. 14). Thick sediments underlie each of the terraces.

To the west of the peninsula the section is at least 1300 m thick. An unconformity is indicated on some lines at about 500 m below the seafloor. It may lie between Pleistocene-Recent volcanic detritus and middle Miocene-Pliocene calcareous beds, or between the latter and Oligocene-Miocene volcanic sediments; both of these unconformities have been identified onshore.

East of Willaumez Peninsula, in Kimbe Bay, a smooth basement surface is overlain by a sedimentary section about 1500 m intruded by minor igneous bodies. The sediment is largely horizontally bedded but is gently folded in some areas.

The Wide Bay-Open Bay graben which forms the isthmus between the Gazelle Peninsula and the rest of New Britain probably extends into the Bismarck Sea for up to 80 km. Its bounding faults diverge seawards and appear to be associated with bands of intrusives on the shelf. It has been suggested that the northeastern fault may follow the west coast of the Gazelle Peninsula, but no evidence was found to support this.

The eastern basin of the Bismarck Sea is largely devoid of sediment except along its southern margin and in the northwest in the Manus Basin (Connelly, 1974). Basement is rugged and appears to be the product of recent volcanism. Several easterly-trending grabens, almost coincident with the magnetic anomaly trough and seismicity lineation (Pl. 11), indicate extensional tectonics. Seamounts of up to 2000 m relief are undoubtedly volcanoes. In profile they have twin peaks, which are probably the edges of volcanic craters. The highest seamounts form vaguely-defined chains which extend east-west following the structural grain.

At about 150°E the structural trend swings east-southeast and near St George's Channel swings southeast, roughly parallel to the fault-trends of southern New Ireland and the Gazelle Peninsula.

The St George's Channel-Bismarck Sea Trough, previously mapped east of 152°E (Brooks et al., 1971), extends westwards for a further 100 km. On Line 118 (Pl. 15) it appears as a 1500-m deep trough (probably a graben) between seamounts, but cannot be identified farther west. The trough is floored by horizontal or shallow-dipping sediments or undetermined thickness. Near the Duke of York Islands east of Rabaul, its northeastern edge corresponds to the shelf-break of New Ireland, which may be structurally controlled by an offshore extension of the Weitin Fault.

The New Ireland shelf becomes broader to the northwest and is about 30 km wide near Dyual Island. Any continuation of the Weitin Fault beyond this area is obscure. It may extend west-northwest roughly following the southern edge of the West Melanesian Arc, or it may follow a more westerly trend along the northern edge of the St George's Channel/Bismarck Sea Trough.

West Melanesian Arc

The submarine portion of the West Melanesian Arc, between New Hanover and Manus Island, consists of a considerable thickness of sediment draped over a basement-rise (northern end of Line 106, Pl. 14). The structure is asymmetrical with its crest displaced southward. The section is at least 1400 m thick and may be considerably thicker areas where basement cannot be identified. Towards the flanks of the structure, the broad folds within the section give way to tight folds and crumpling, which may have resulted from gravity sliding in response to basement uplift.

Sediments on the rise are of similar thickness to those on New Ireland, where 2300 m of lower Oligocene-Pliocene limestones and volcanics are draped over a basement rise (French, 1966).

The southern margin of the rise east of 148^{O}E is marked by an abrupt change in slope and a well-formed magnetic anomaly dipole (e.g. Pl. 14), which suggests that it coincides with a major fault zone. The sinuous shape of this margin can be attributed to right-lateral displacement of the fault zone along several orthogonal Faults. This interpretation is consistent with the observation of right-lateral offsets in the magnetic anomaly pattern and seismicity lineations.

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Beneath Manus Island the rise is broader and coalesces with the Willaumez-Manus Rise. Seismic penetration was poor on lines to the north and northwest of Manus Island, but the profiles show a sedimentary section at least 1100 m thick. The topography is hummocky, probably owing to reefs and small intrusions. The regional dip of the beds is to the north.

The crest of the West Melanesian Arc can be traced due west of Manus Island to about 145^{o}E, where it appears to be offset northwards by about 30 km. South of the crest, the sediment is 100-200 m thick and overlies a smooth basement reflector. North of the crest, the sediment is thicker (1100 m) and the smooth basement surface is affected by down-to-the-north faulting. The thick section terminates against igneous bodies along the northern margin of the Arc which is also the southern margin of the 5000-m deep West Melanesian Trench (Lines 51 & 53, Plate 4; Line 53, Pl. 15). Moderately folded sediments are evident in the Trench.

A north-facing escarpment is located on Lines 51 and 53 at about $1^{o}30'$S. It has an elevation of 900 m and a gradient of 20^{o}. On line 51, igneous basement is exposed on the scarp, but on Line 53 a stratified section at least 1200 m thick which dips southward at $6-10^{o}$ is exposed. South of the escarpment this south-dipping section is unconformably overlain by 200-300 m of horizontally bedded sediment. The dipping strata probably extend beneath the Hermit Islands and the Ninigo Group. A sedimentary seamount at the northern end of Line 59 and the igneous seamount at the northern end of Line 61 lie along the trend of the escarpment.

CONCLUSIONS

The Bismarck Sea is a partly enclosed marginal basin flanked by island arc structures which have been active from Mid-Cretaceous to Recent time. To the north lies the West Melanesian Arc and Trench, and to the south the islands of New Guinea and New Britain and the South Bismarck Volcanic arc.

The water depths range mainly from 1000 to 2500 m and average about 2000 m. The region is divided into a western and an eastern sub-basin by the Willaumez-Manus Rise which lies in water depths of 1000-1500 m. The eastern basin is characterized by rugged seafloor and basement topography and features, easterly-trending grabens and seamount chains, whereas the western basin is relatively smoothly floored. The continental shelves of New Guinea, New Britain, and New Ireland range from a few kilometres to about 30 km in width.

The positive free-air anomaly field over the Bismarck Sea is part of a regional gravity high which extends over most of offshore southeast Asia. Relative Bouguer anomaly highs over the eastern and western basins, and Bouguer anomaly troughs over the Willaumez-Manus Rise and West Melanesian Arc appear to reflect variations in crustal thickness. Bouguer anomaly lows west and northeast of Wewak, and east of Madang are attributed to sub-basins of the Northern New Guinea Basin.

The calculated crustal thickness in the region averages about 20 km. It is a few kilometres thicker beneath the West Melanesian Arc and Willaumez-Manus Rise, and thickens progressively from 25 to 35 km between the South Bismarck Volcanic Arc and Huon Peninsula. Crustal thicknesses in excess of 40 km probably occur beneath the coastal ranges.

The crust is about 5-10 km thicker than it is in other marginal basins (Packham & Falvey, 1971). This may be a result of the complex tectonic history which has probably involved several episodes of subduction, overthrusting and arc reversals (Thompson, 1967; Davies, 1971; Johnson & Molnar, 1972). Furthermore, if spreading was retarded owing to such causes as the encroachment of the Australian and Pacific Plates, thicker-than-normal oceanic crust may have been generated at the spreading centre. The situation may be similar to that on the Ontong-Java Plateau (Kroenke, 1972) where voluminous flood basalt appears to have formed a crustal column as thick as 40 km.

Magnetic anomalies are relatively small over the New Guinea and New Britain shelves and most of the West Melanesian Arc, where basement depths generally range from 1 to 3 km. In contrast, the anomalies are intense over volcanic islands and up to 3000 nT in amplitude in the eastern basin, where volcanic rocks make up most of the sea-floor. Two well-defined anomaly ridges extend westwards across the eastern basin, parallel with and to either side of the Bismarck Sea Seismicity Lineation (Denham, 1969). Each ridge has two right-lateral offsets which are also present in the seismicity lineation. In the western basin the ridges coalesce and follow the trend of a seamount chain, which is a possible offshore extension of the Bewani-Torricelli Ranges.

Magnetic models across the eastern basin (Connelly, 1974) indicate that most of the area is reversely magnetized, but that a normally magnetized block is centred on the seismicity lineation. This normally magnetized block contains a central graben in many places, and is presumed to be composed of volcanics which have been extruded during the present polarity epoch (last 0.7 m.y.). It thus seems reasonable to postulate that some form of north-south extension or seafloor spreading is taking place in the basin (Connelly, op. cit.).

The postulation of spreading seems to be at variance with focal mechanism solutions for the earthquakes, all of which have shown the lineation to be associated with left-lateral shearing (Johnson & Molnar, 1972). However, the two earthquakes in the eastern basin for which solutions have been obtained, lie close to a right-lateral offset observed in the seismicity lineation and magnetic anomaly ridges. If the alternative focal plane were chosen for these solutions they would indicate right-lateral shearing along a transcurrent fault which trends north-northwest. Thus, in the eastern basin, the seismicity lineation may be related to an east-west oriented spreading ridge with right-lateral offsets. However, the presence of epicentres along the ridge crest, rather than along the transforms only, is atypical of most mid-ocean spreading ridges.

In the western part of the Bismarck Sea, the focal mechanism solutions for two earthquakes which are located near the axis of the seismicity lineation also indicate left-lateral shearing.

Areas of thick sediment occur along the coasts of New Guinea and New Britain, and on the West Melanesian Arc between New Hanover and Manus Island. Northwest of Wewak, and off the Sepik River delta, at least 1000 m of sediment has accumulated south of a basement ridge and south of the chain of seamounts extending offshore from the Bewani-Torricelli Ranges. A deep trough with more than 2000 m of sediments lies between Huon Peninsula and the South Bismarck Volcanic

Arc; another lies between the Arc and a basement ridge 40-70 km farther north. A section at least 1300 m thick lies between New Britain and the Witu Islands, and a section at least 1500 m underlies Kimbe Bay.

The West Melanesian Arc appears to be an extension of the New Ireland structure. It is composed of about 2000 m of sediment draped over a basement ridge. The section is broadly folded over most of the structure, except near the margins where tight folds and slumps are apparent. The Arc extends westwards to about 145^{o}E. Between Manus Island and New Hanover the southern margin of the Arc is probably formed by a series of en echelon faults.

The western basin is underlain by 100-120 m of sediment overlying a smooth basement reflector. In contrast, the eastern basin is floored by lavas and intrusive bodies and sediment is very thin or absent. The St George's Channel/Bismarck Sea Trough (Brooks et al., 1971), a deep graben between New Ireland and the Gazelle Peninsula, extends as far west as 151^{o}E. Its northern edge may be structurally controlled by an offshore extension of the Weitin Fault from southern New Ireland.

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APPENDIX I - Definition of gravity and magnetic anomalies

The absolute gravity values were determined by ties into the Australian Isogal Network at each port call. These ties also provided a check on the drift characteristics of the La Coste and Romberg meter.

Free-air gravity anomalies were obtained by applying latitude corrections and Eotvos corrections to the observed gravity values. The latitude effect was derived from the gravity field of the International Reference Spheroid:-

$$978.049\ (1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 2\phi),$$

where ϕ is the latitude.

The Eötvös effect, due to the motion of the ship over the spheroid, is given to a first approximation by:

$$7.5\ \phi\ Ve,$$ (Glicken, 1962)

where ϕ is the latitude,

and Ve is the eastward component of velocity in knots,

given by the gyro-heading and the sonar doppler velocity

averaged over ten minutes.

Corrections for ocean tidal variations have not been included.

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Bouguer Anomalies were computed by applying a correction at each station, given by the formula $2\pi G\Delta\rho d$,

where G is the Universal Gravitational Constant,

$\Delta\rho$ is the difference in density between water and

sediment, assumed to be 1.2 tm^{-3},

and d is the depth of water.

Magnetic anomalies are defined by the relationship:

(magnetic anomaly) = (total intensity) -(diurnal) - (IGRF)

where IGRF is the International Geomagnetic Reference

Field (Cain, Langal, & Hendricks, 1966).

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APPENDIX II - Computation of crustal thickness

An approximation of the crustal thickness in the Bismarck Sea region has been derived by spatial filtering of the free-air anomaly, water depth, and sediment thickness values, and comparing the gravity effect of the filtered values at each station with that of a 'standard crust' derived for the New Britain/New Ireland region from seismic refraction studies (Finlayson & Cull, 1973).

Choice of a filter

It has been awsumed that local physiographic and geological features of less than one degree width (112 km) are generally supported by the crust and are probably not in isostatic equilibrium. Hence a filter should ideally remove gravity, bathymetric and sedimentary features with widths of less than 112 km. Of the numerous filters which partially satisfy this requirement three warrant special consideration.

A band-pass filter with a frequency cut-off of 1/112 cycles per km theoretically suits the purpose but is impracticable to apply by computer. In the space domain, the filter operator is a sinc function which extends for an infinite distance. If serious distortion is to be eliminated the operator cannot be truncated at less than 168 km from its mid-point - that is at its third oscillation through zero (Holloway, 1959). The convolution of such a lengthy operator with the data points is not only costly in terms of computer time but is mathematically unsound (Holloway, op. cit.).

The widely used one-degree running mean (cf. St John, 1967, p. 56), which is a rectangular operator with a half-width of 56 km and height 1/112, also has undesirable properties. Its frequency response curve is a sinc function which has a negative response (that is, causes phase reversals) of 0.21 for wavelengths in the range 56-112 km.

In order to minimise distortion and phase reversals and yet obtain a reasonably short filter operator, the data were filtered with a normal probability function filter. Its frequency response R(f) is given by,

$$R(f) = \exp\ (-2\pi^2 \sigma^2\ f^2)$$

where, σ is the standard deviation.

Its operator or weight function W(x) has the form,

$$W(x) = (2\pi\sigma^2)^{-\frac{1}{2}}\ \exp\ (-x^2/2^2)$$

where, x is distance.

The main disadvantage of this function is that it lacks a sharp frequency cut-off. The parameters chosen gave a response of 0.5 at 1/112 cycles per km and the operator was truncated at three standard deviations (3σ) or 62 km from its midpoint, where the weight was insignificant (0.004).

In the technique used, each hourly data point was selected in turn and all points within 62 km of it were located and multiplied by weights associated with their offsets. The resulting values were summed and normalized by dividing by the sum of the weights.

A regional free-air anomaly map was produced in this way (Plate 7). The filtered data on the map has two limitations: firstly, the number of data points used in determining each filtered value was variable and as only marine data were used, the filtering is incomplete near the coast; secondly, the frequency response along any azimuth is to some extent dependent on the number and distribution of data points along it. Similar limitations are associated with the filtered values of water depth and sediment thickness used in the computation of crustal thickness. The residual free air anomalies are shown in Plate 8.

Standard crust

Finlayson & Cull (1973) have shown from seismic refraction evidence that crustal thicknesses are about 32 km where free-air anomalies are zero along the coasts of New Britain and New Ireland. They plotted Bouguer anomalies against crustal thicknesses for the area, and obtained a gradient of -20 mGal km^{-1}. When this value is equated to the derivative of the expression for the gravity effect of a parallel-sided slab (Bouguer slab):

$$d\,(BA)/dD = -20 = 41.85\,\Delta\rho$$

where, BA is the Bouguer anomaly,

D is the thickness, and

$\Delta\rho$ is the density contrast of the slab,

the density contrast is found to be 0.478 gcm^{-3}. If this is assumed to be the density contrast between the crust and the mantle, and a density of 3.33 gcm^{-3} is assumed for the mantle

(Rose, Woollard & Malahoff, 1968), a density of 2.85 gcm^{-3} is calculated for the crust. Hence, in computing the crustal thicknesses the 'standard crust', which gives zero free air anomaly at sea-level, is taken to be 32 km thick and of density 2.85 gcm^{-3}, overlying mantle of density 3.33 gcm^{-3} (Pl. 9).

Crustal Thickness

The crustal thickness at each position was computed making the following assumptions:-

(i) The column consists of four layers: water, sediment, crust and mantle with respective densities of 1.00, 2.20, 2.85 and 3.33 gcm^{-3}.

(ii) Lateral variations in density are not significant.

(iii) The standard crust is 32 km thick.

(iv) The Bouguer slab formula is a sufficient approximation to the gravity effects of the four layers.

Since it is unlikely that the densities are appropriate over the entire Bismarck Sea area, the map of crustal thickness (Plate 9), must be regarded as a first approximation only.

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FINLAYSON, D.M., & CULL, J.P., 1973 - Structural profiles in the New Britain/New Ireland region. J. Geol. Soc. Aust., 20(1), 37-48.

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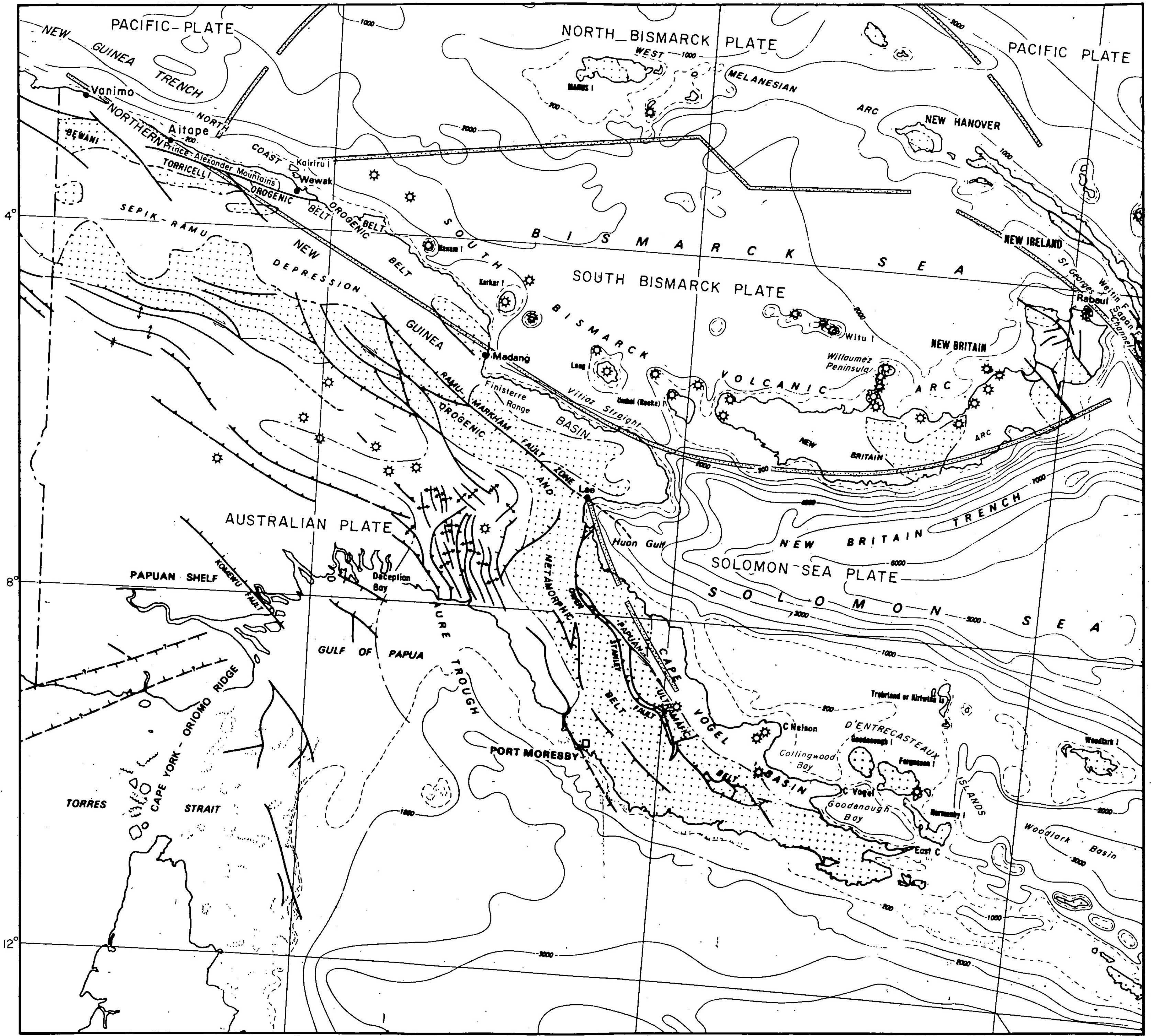
ROSE, J.C., WOOLLARD, G.P. & MALAHOFF, A., 1968 - Marine gravity and magnetic studies of the Solomon Islands. American Geophysical Union Geophysical Monograph, 12.

ST JOHN, V.P., 1967 - The gravity field of New Guinea. Ph.D. thesis, Univ. Tasmania (unpubl.).



STRUCTURAL MAP OF PAPUA NEW GUINEA

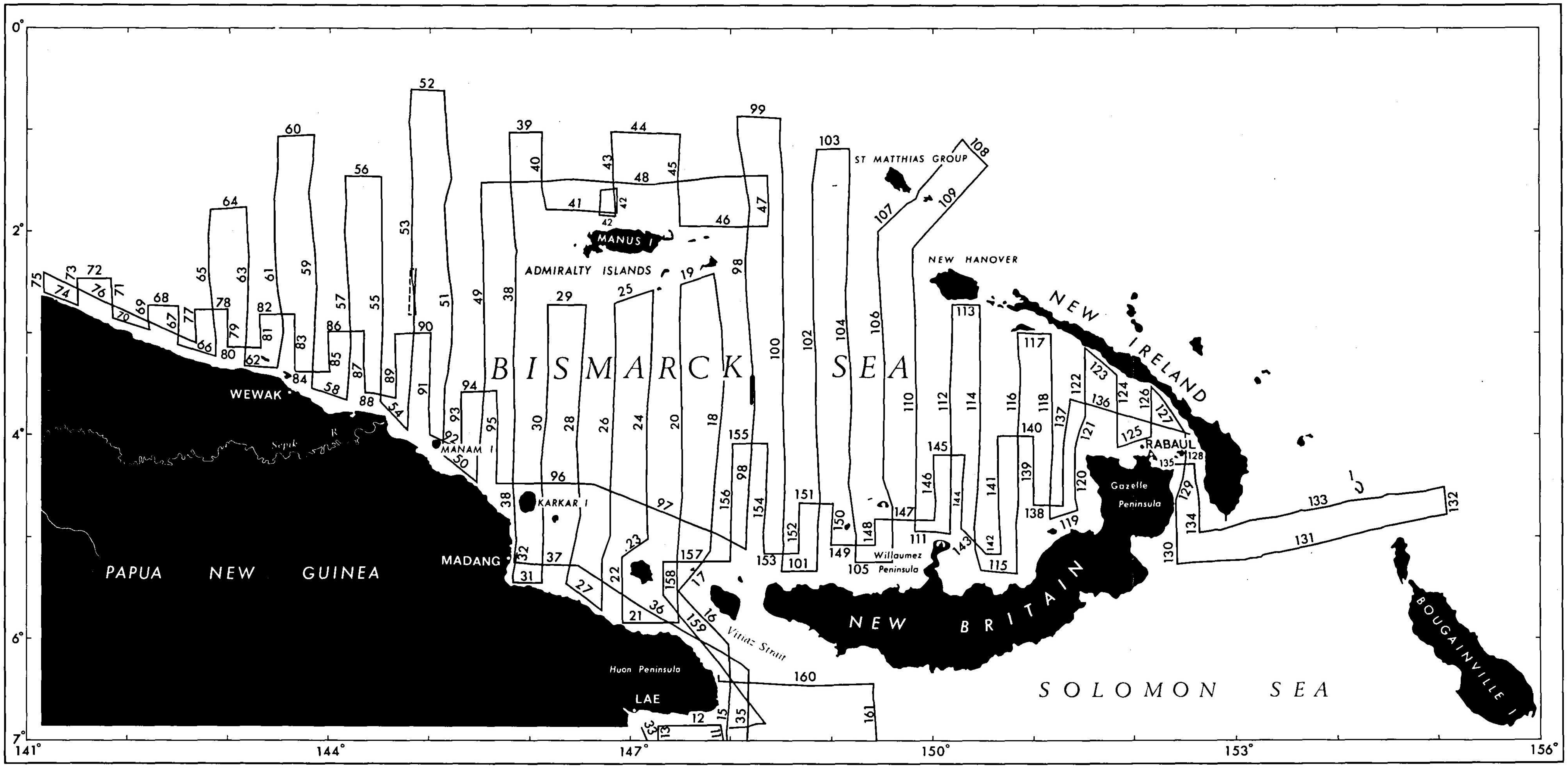
(after Tilbury, 1973)

100 0 100 200 km

(Compiled from the Tectonic Map of Australia and New Guinea, Geological Society of Australia, 1971)

LEGEND

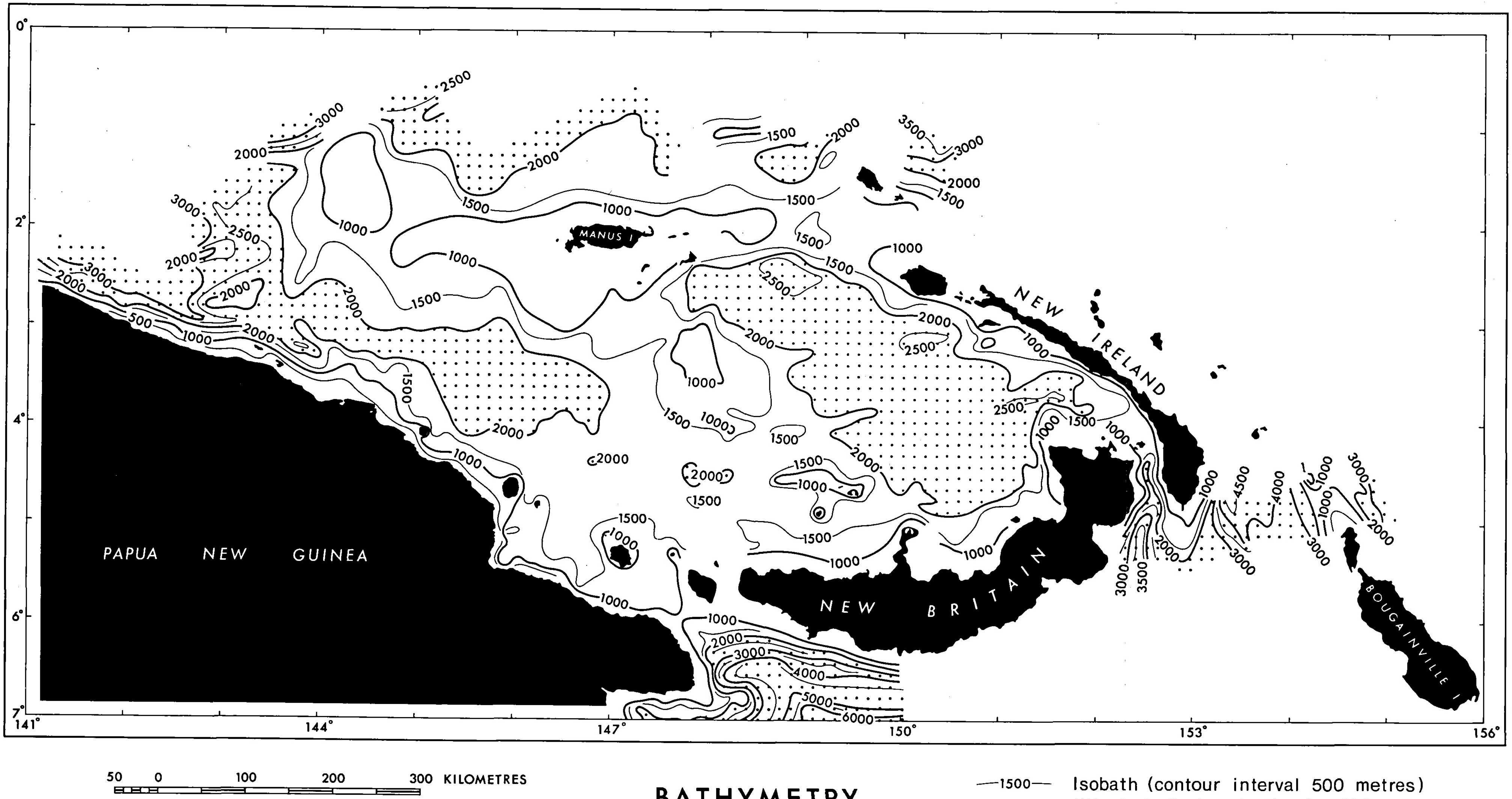
- Geological and tectonic boundary
- Anticline
- Syncline
- Fault, type unknown
- High-angle fault, normal or reverse, ticks denote downthrown block
- Thrust-fault, teeth point to upper plate
- Strike slip fault
- Active and recently active volcanoes
- Bathymetric contours in metres (200, 1000)
- Mainly volcanic and metamorphic rocks
- Hypothetical plate boundaries



50 0 100 200 300 KILOMETRES

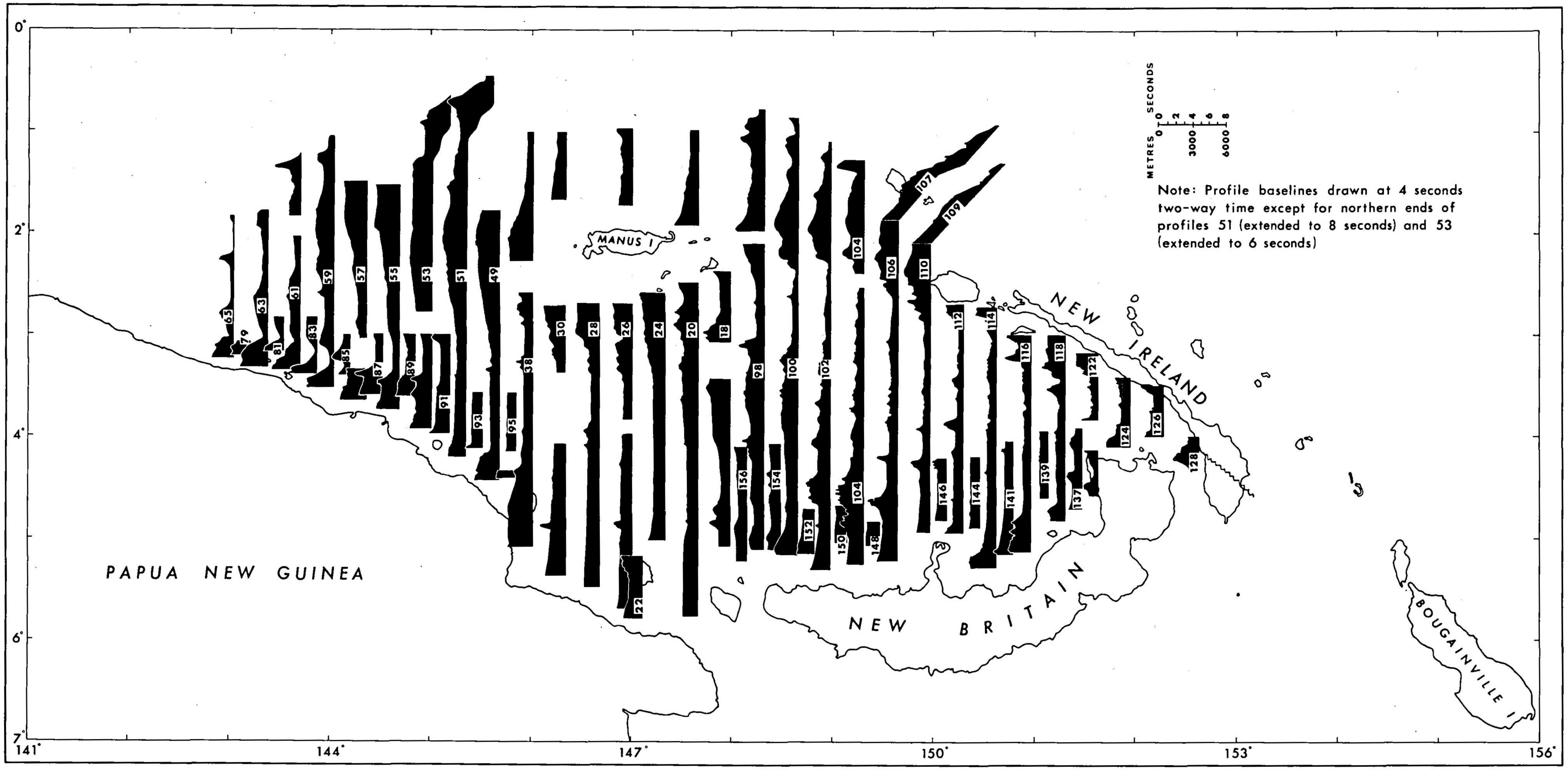
TRACK MAP

96 Numbered traverse, survey 05



BATHYMETRY

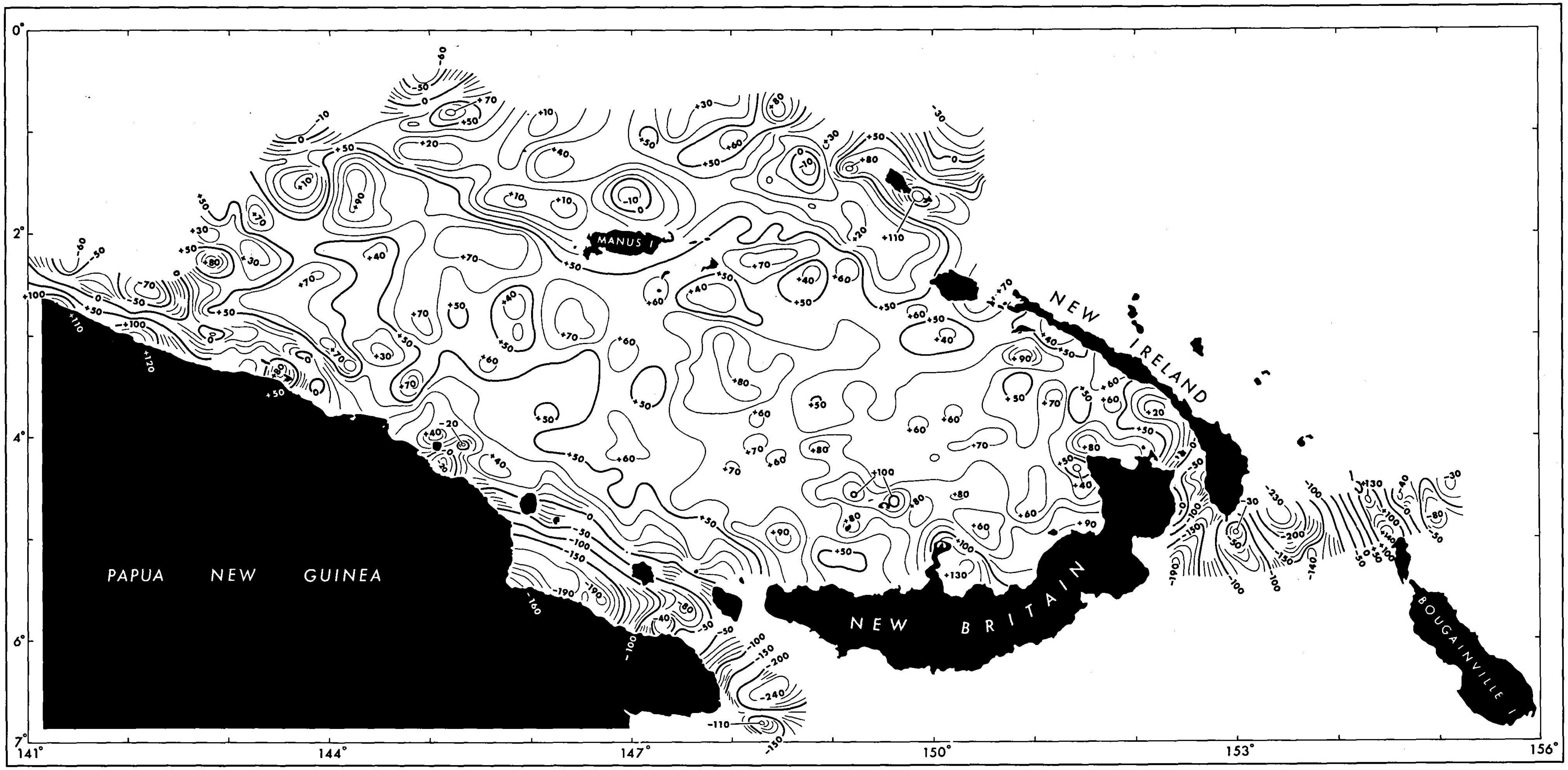
—1500— Isobath (contour interval 500 metres)
Stipple indicates depth of >2000 metres



50 0 100 200 300 KILOMETRES

BATHYMETRIC PROFILES

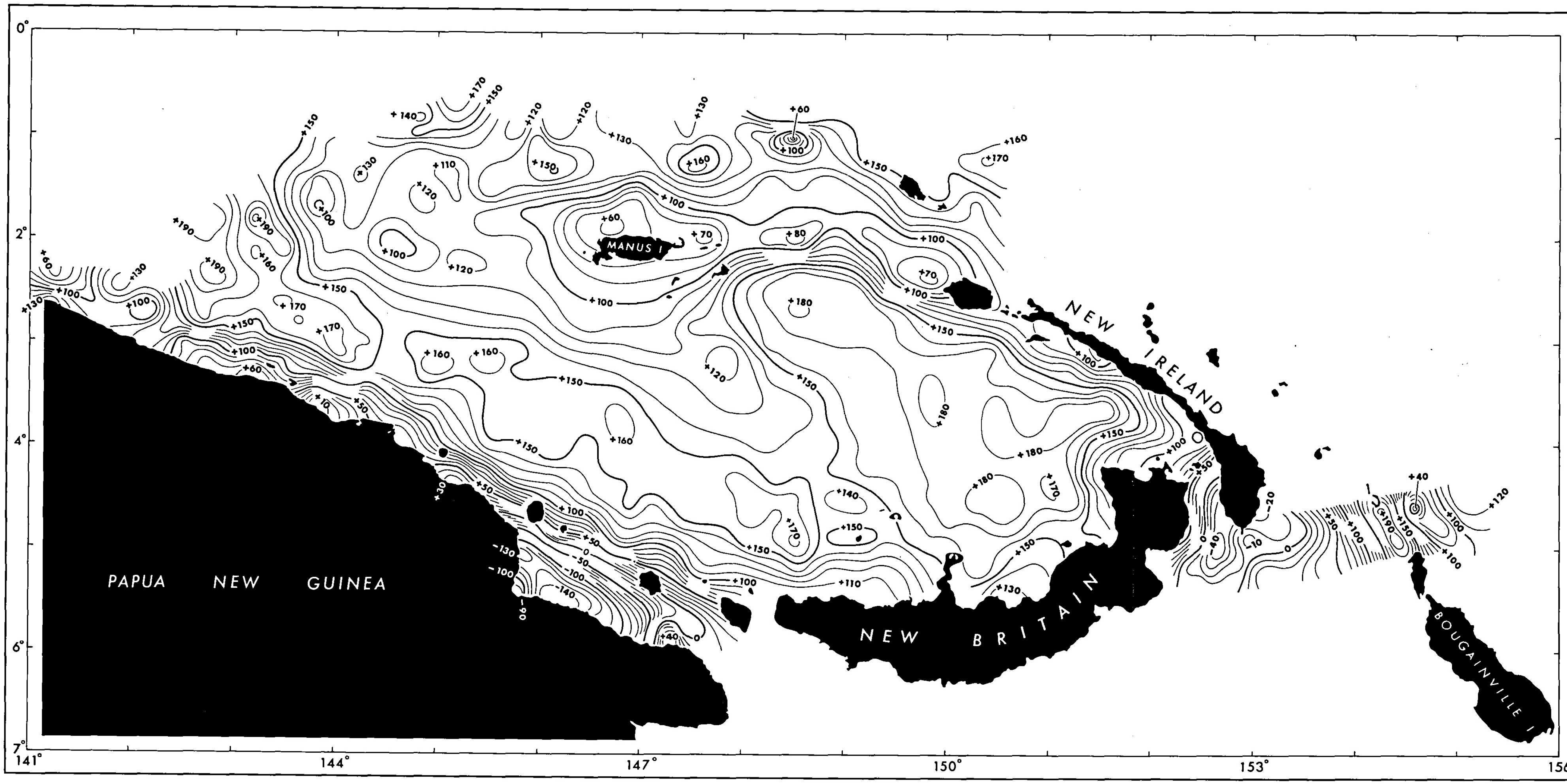
Numbered bathymetric profile



50 0 100 200 300 KILOMETRES

FREE AIR ANOMALIES

+50 Isogal (milligals)

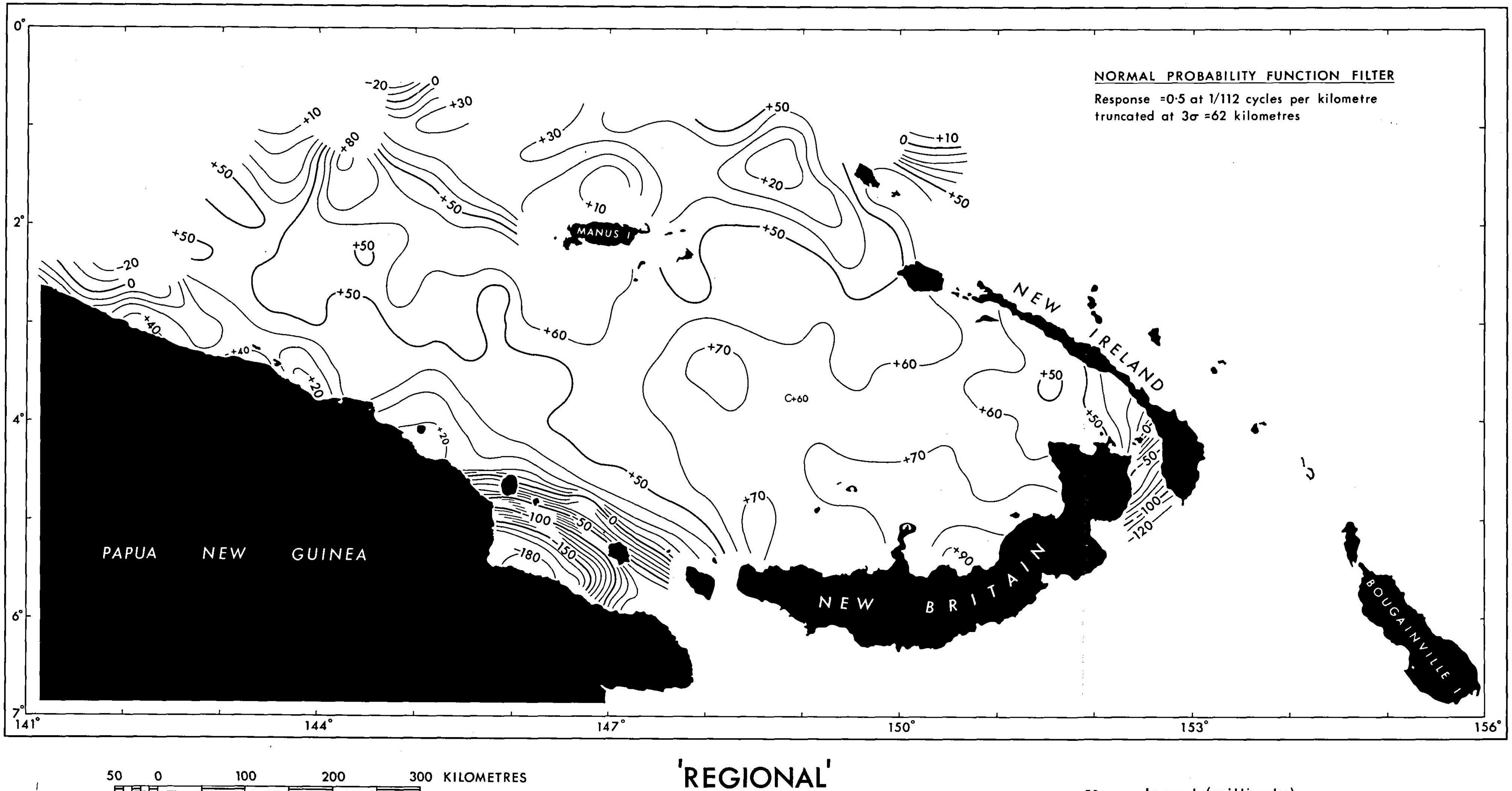


50 0 100 200 300 KILOMETRES

BOUGUER ANOMALIES

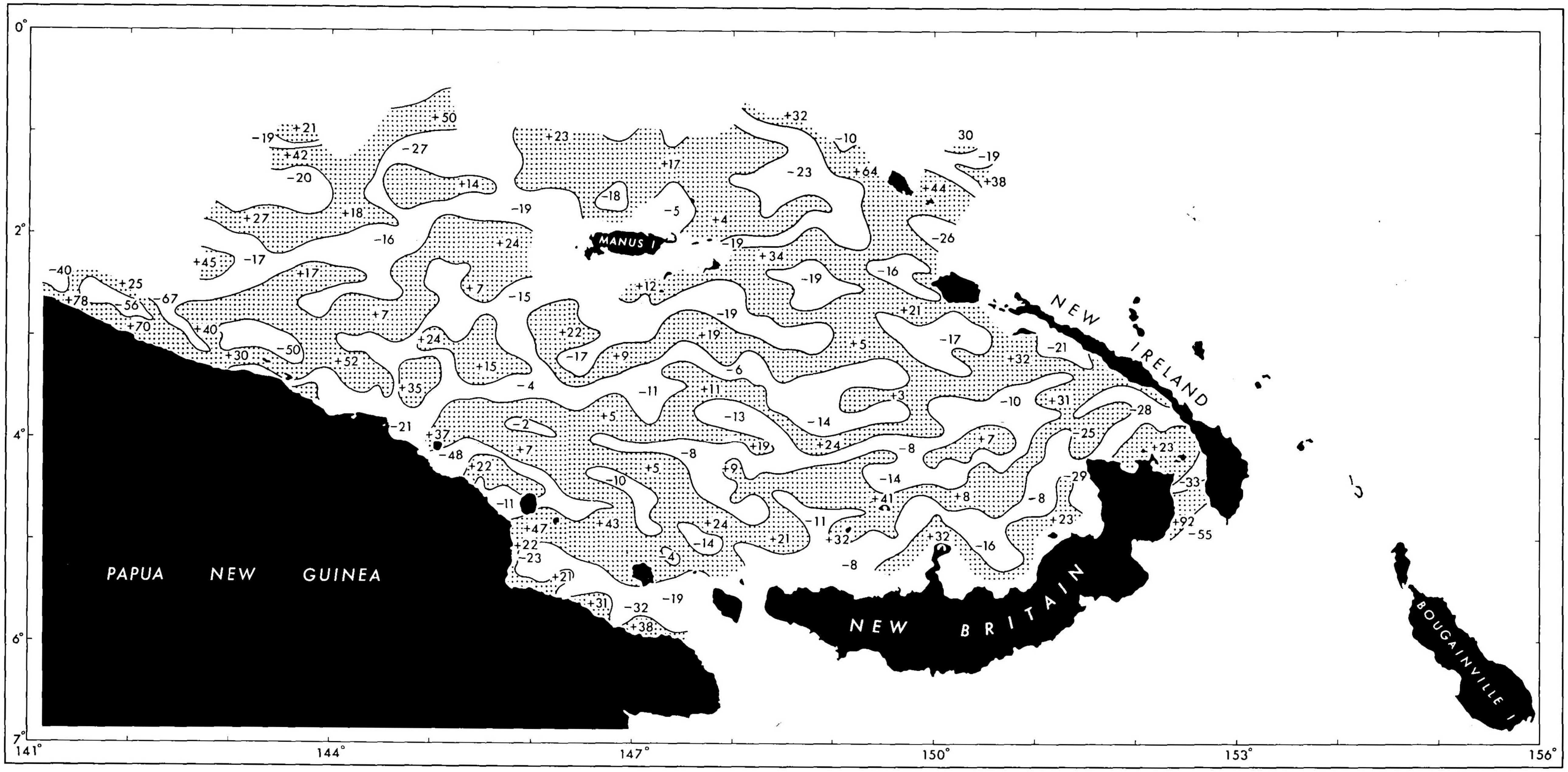
—+100— Isogal (milligals)

For the calculation of Bouguer anomalies 2·2 g/cm³ has been adopted as an average rock density



'REGIONAL' FREE AIR ANOMALIES

—-50— Isogal (milligals)

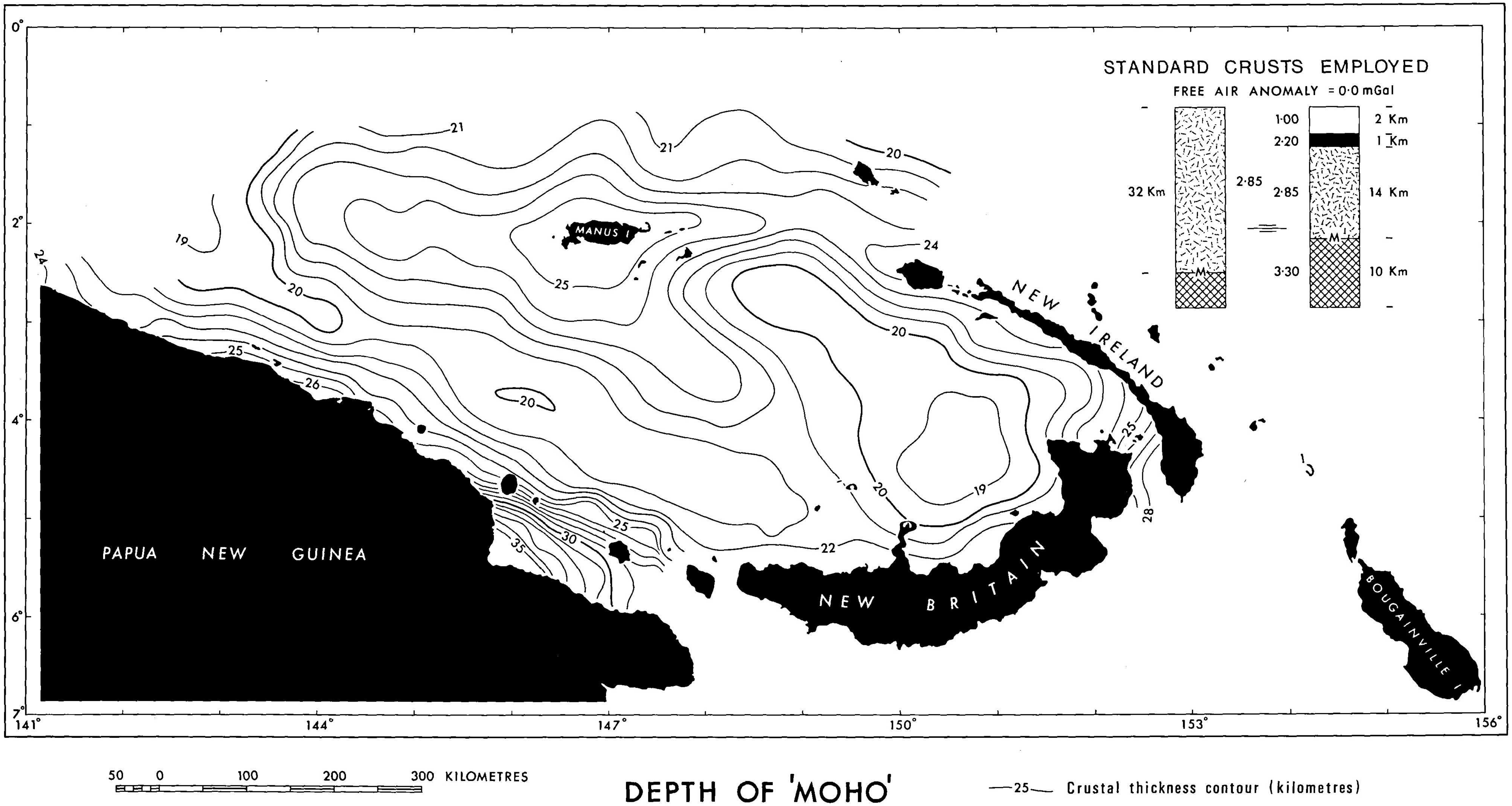


50 0 100 200 300 KILOMETRES

'RESIDUAL' FREE AIR ANOMALIES

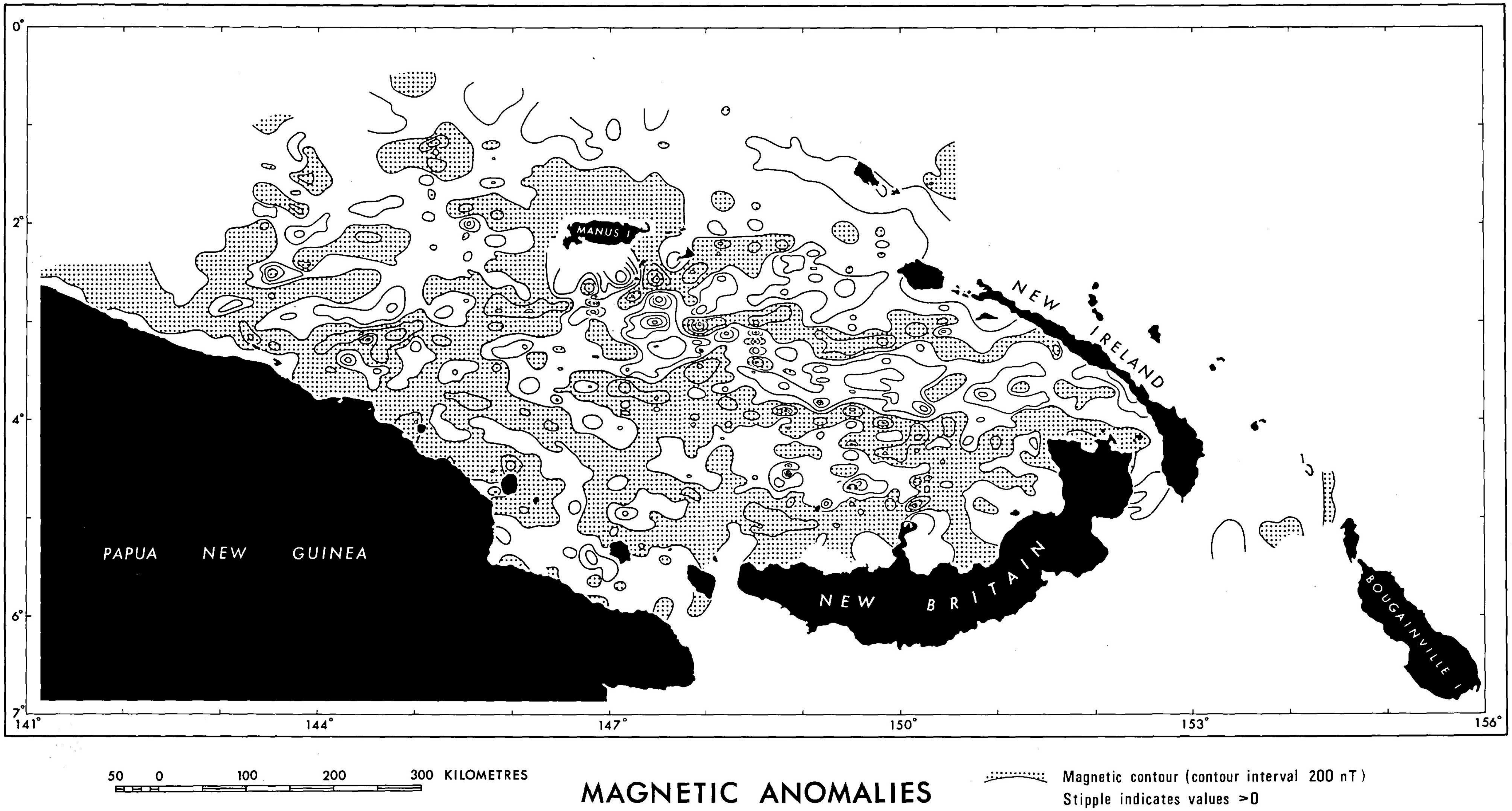
Isogal (value 0 milligals)
Stipple indicates values >0

-38 Spot value (milligals)

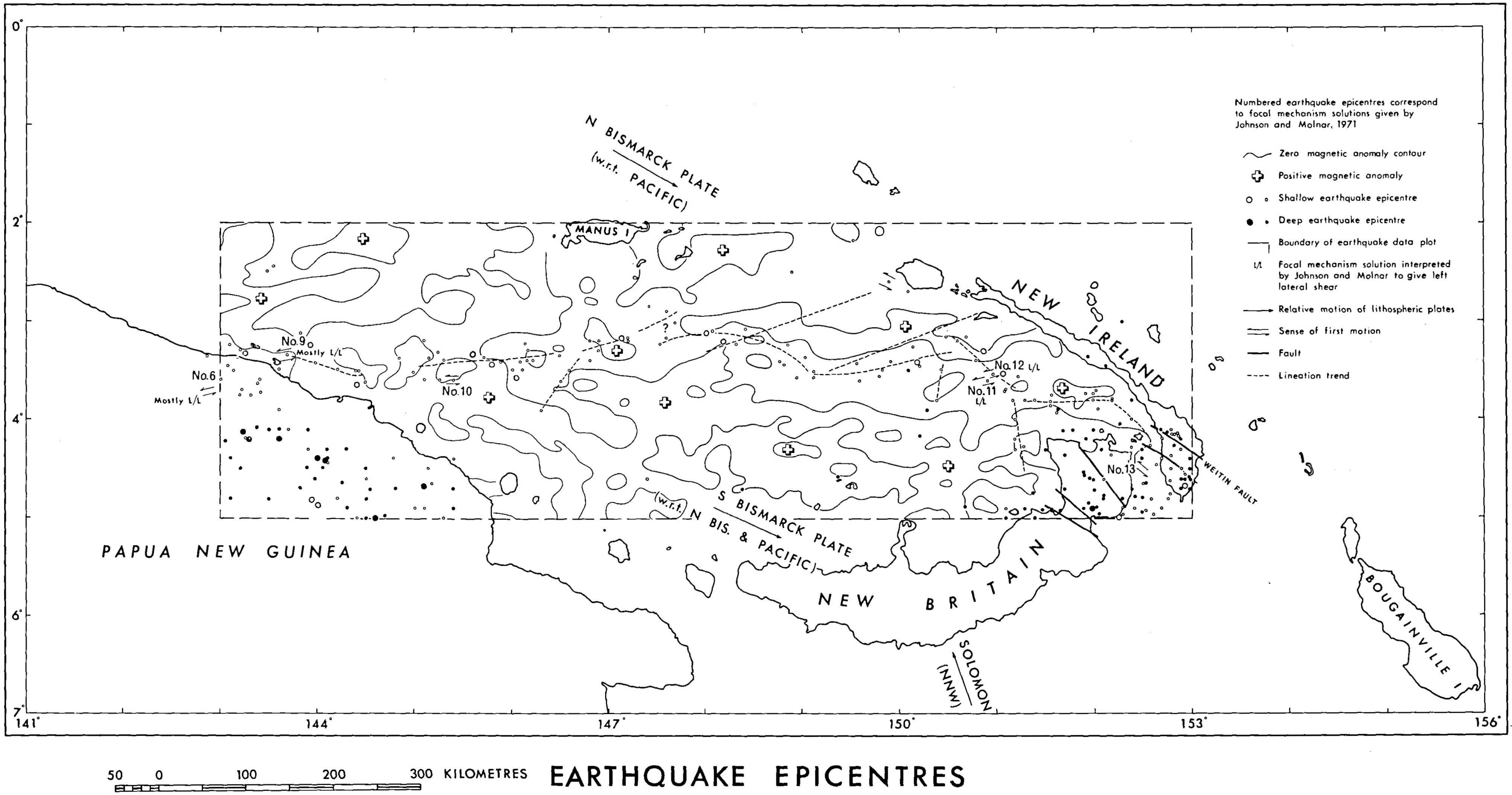


DEPTH OF 'MOHO'

—25— Crustal thickness contour (kilometres)

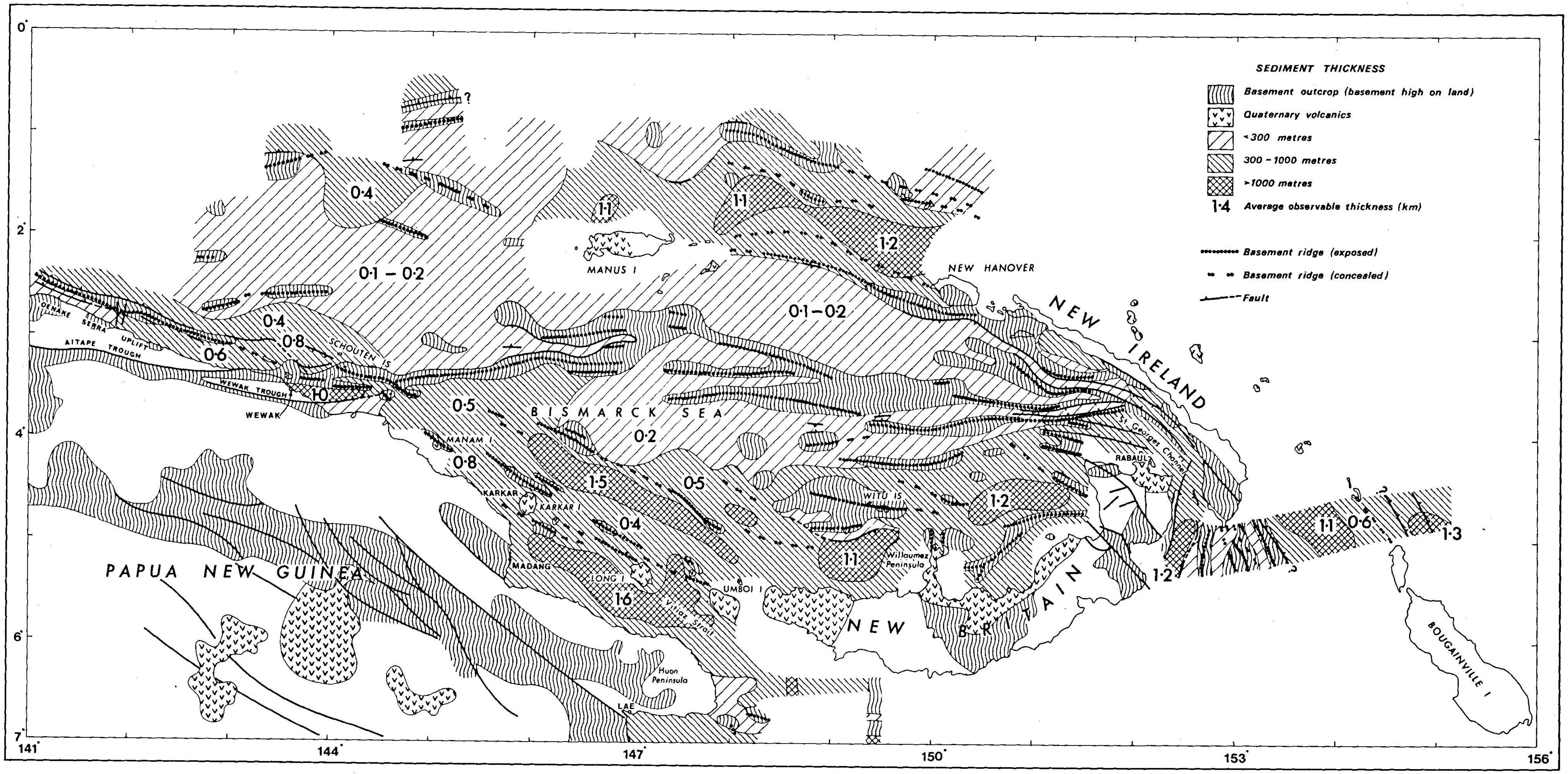


MAGNETIC ANOMALIES



EARTHQUAKE EPICENTRES

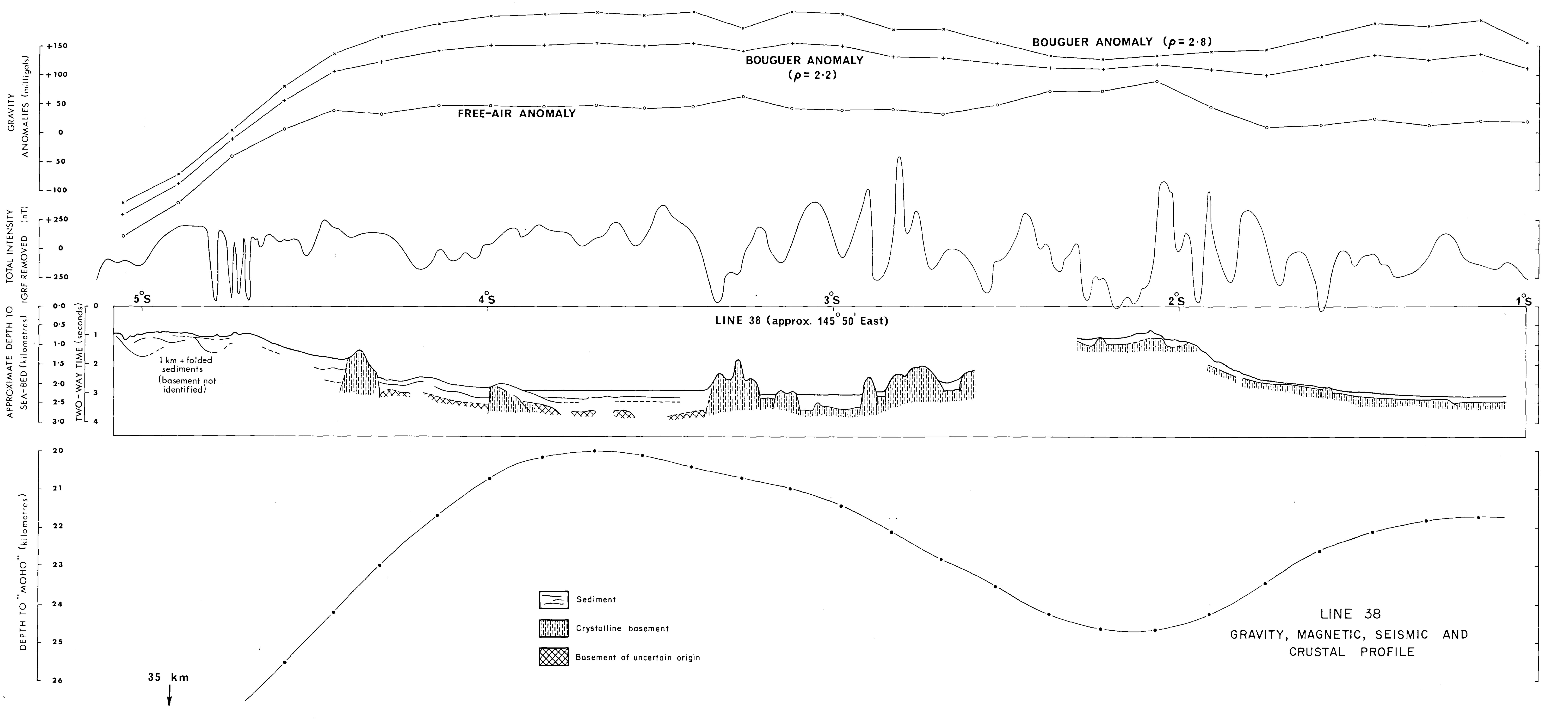
RELATED TO MAGNETIC ANOMALY CONTOURS



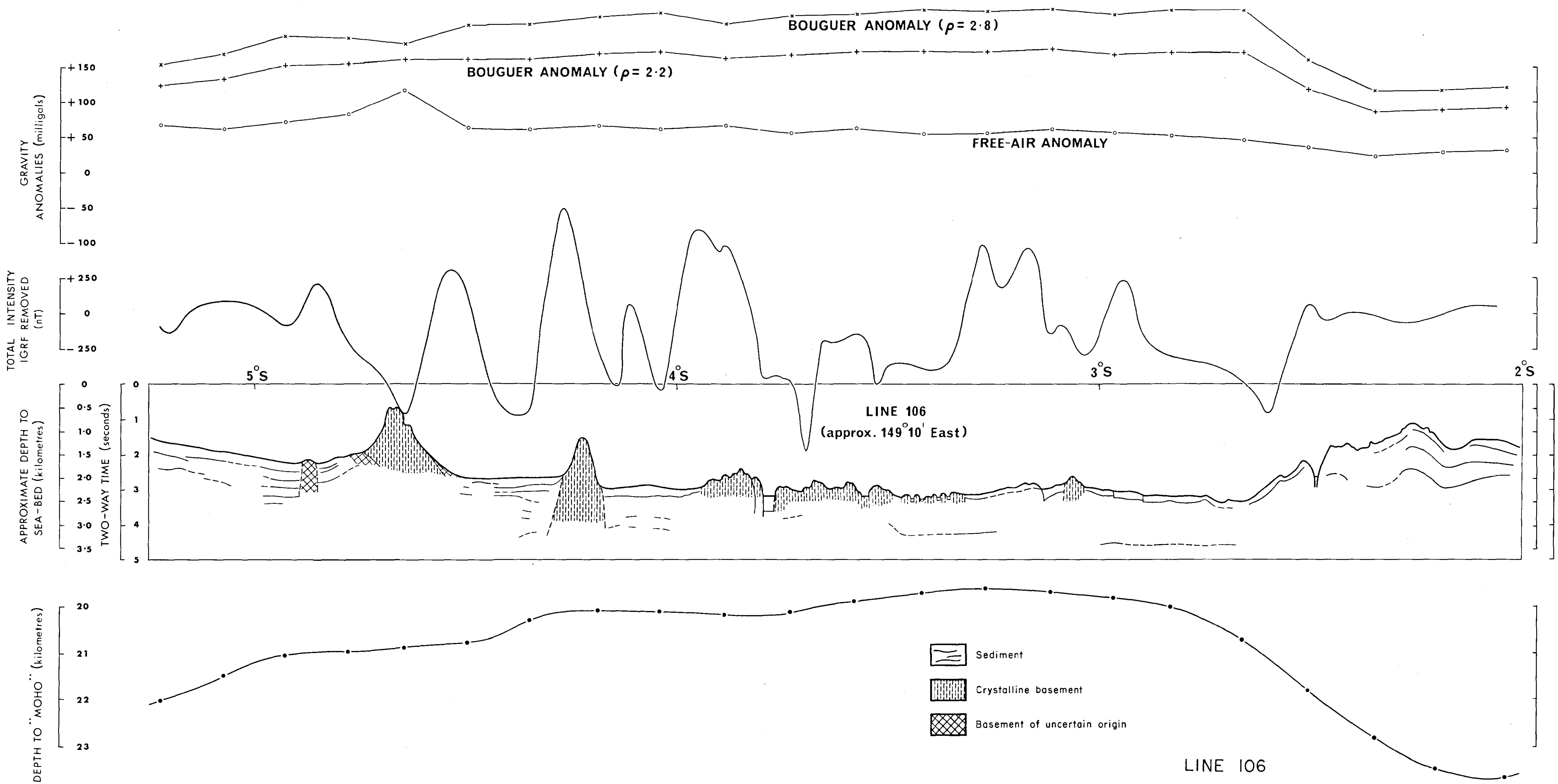
50 0 100 200 300 KILOMETRES

STRUCTURE

(After Tilbury, 1976)

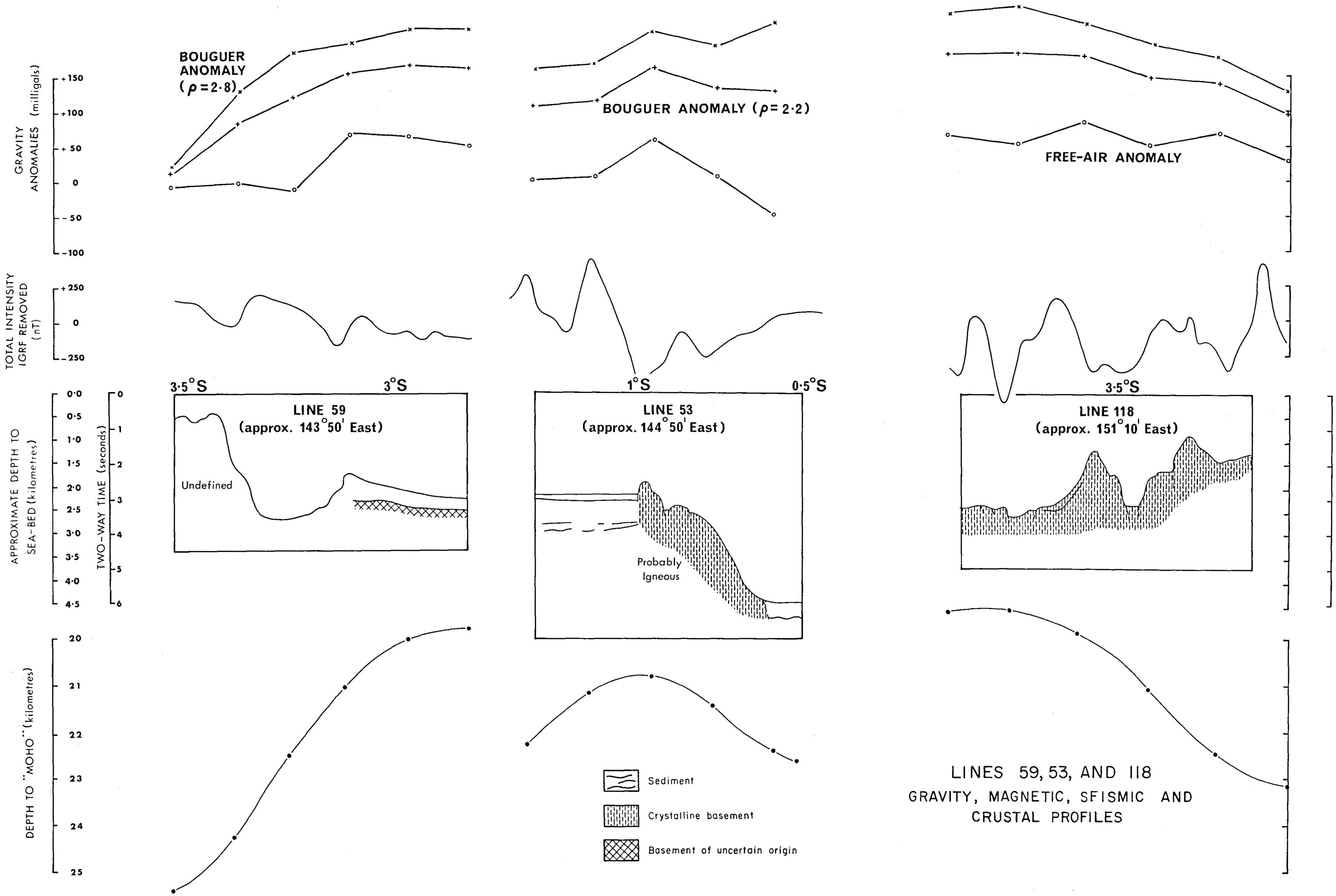


GRAVITY ANOMALIES (milligals)
+150
+100
+ 50
0
– 50
–100
BOUGUER ANOMALY (ρ = 2·8)
BOUGUER ANOMALY (ρ = 2·2)
FREE-AIR ANOMALY
TOTAL INTENSITY IGRF REMOVED (nT)
+250
0
–250
5°S
4°S
3°S
2°S
1°S
APPROXIMATE DEPTH TO SEA-BED (kilometres)
0·0
0·5
1·0
1·5
2·0
2·5
3·0
TWO-WAY TIME (seconds)
0
1
2
3
4
LINE 38 (approx. 145° 50' East)
1 km + folded sediments (basement not identified)
DEPTH TO "MOHO" (kilometres)
20
21
22
23
24
25
26
Sediment
Crystalline basement
Basement of uncertain origin
35 km
LINE 38
GRAVITY, MAGNETIC, SEISMIC AND CRUSTAL PROFILE



LINE 106

GRAVITY, MAGNETIC, SEISMIC AND CRUSTAL PROFILE



LINES 59, 53, AND 118
GRAVITY, MAGNETIC, SEISMIC AND CRUSTAL PROFILES