GEOLOGY AND GEOPHYSICS OF THE LYRA BASIN

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ABSTRACT

Geological and geophysical data acquired by the Hawaii Institute of Geophysics in 1970 and 1971 are used to interpret the tectonic setting and history of the Lyra Basin, situated in the western equatorial Pacific north of New Guinea. Interpretations were made from a bathymetric chart, newly constructed from HIG and other available data, a chart of depth to acoustic basement, which shows approximate thickness of sediment, a free-air gravity map, magnetic profiles, and an examination of seismic reflection profiles.

The Lyra Basin has been referred to as a marginal basin, but its origin and tectonic setting are seen to have several differences from other marginal basins in the western Pacific. The sea floor west of the Ontong Java Plateau was created by a spreading center on the Euripik Ridge. Subduction created the Mussau Trough and Ridge which separated the topography of the Lyra Basin from the East Caroline Basin, and the separation is maintained even though subduction has ceased. Free-air gravity anomalies over the Mussau Trough and Ridge show a remarkable similarity to published gravity data over trenches of active subduction zones, with a 10-km displacement of values of - and + 140 mgal eastward, toward the ridge. Faults seen on seismic reflection records suggest two periods of deformation throughout the area of study. An older period is associated with the initiation of

subduction in the Mussau Trough and is seen as the graben-bounding faults of the Lyra Trough and as other tensional faults. After the end of spreading in the Caroline Basin and subduction in the Mussau Trough, a younger period of faulting disturbed the entire sequence of sediments. This later deformation was caused by intraplate adjustments due to the convergence of the Pacific and Australian plates. Subduction into the Manus Trough, a trench, is another result of the convergence between the Pacific and Australian plates. The presence of a clearly identified trench, sediment-filled forearc basin, and volcanic arc of the northern Bismarck Archipelago suggests there has been a substantial amount of subduction. Today, however, seismic activity is weak and subduction may be diminishing in the Manus Trough.

Magnetic and seismic refraction data are less conclusive, but nevertheless support this history for the Lyra Basin.

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INTRODUCTION

The Lyra Basin is a structurally complex basin situated in the western equatorial Pacific, north of the Bismarck Archipelago (Figure 1). The basin, of 500,000 km^2 in area, is enclosed by the somewhat discontinuous Caroline Island Ridge to the north, the Ontong Java Plateau to the east, the Bismarck Archipelago to the south and the Mussau Trough and Ridge to the west. The structural complexity is illustrated by the presence of three troughs, each exceeding 5600 meters in depth, within or adjacent to the basin (Figure 2).

Pacific exploration may have begun as early as 2000 years ago with the nomadic migrations of the Polynesians. The Polynesians were the major Pacific explorers until 1519, when Magellan's voyage opened the Pacific to European exploration. Thereafter, European powers continued their exploration, exploitation, and cartographic expeditions. Noteworthy was the voyage of HMS Challenger from 1872 to 1876, and which was "the real foundation of Oceanography as a science" (Fairbridge, 1966). In 1875, HMS Challenger made the first scientific survey in the Bismarck Sea and in the area of this study. Two cruises by the Hawaii Institute of Geophysics (HIG), by the R/V Mahi in 1970 and the R/V Kana Keoki in 1971, are among the latest scientific surveys in this area and supply the bulk of the data used in this study.

Figure 1. Western Equatorial Pacific, and area of study (shaded), which includes the Lyra Basin.

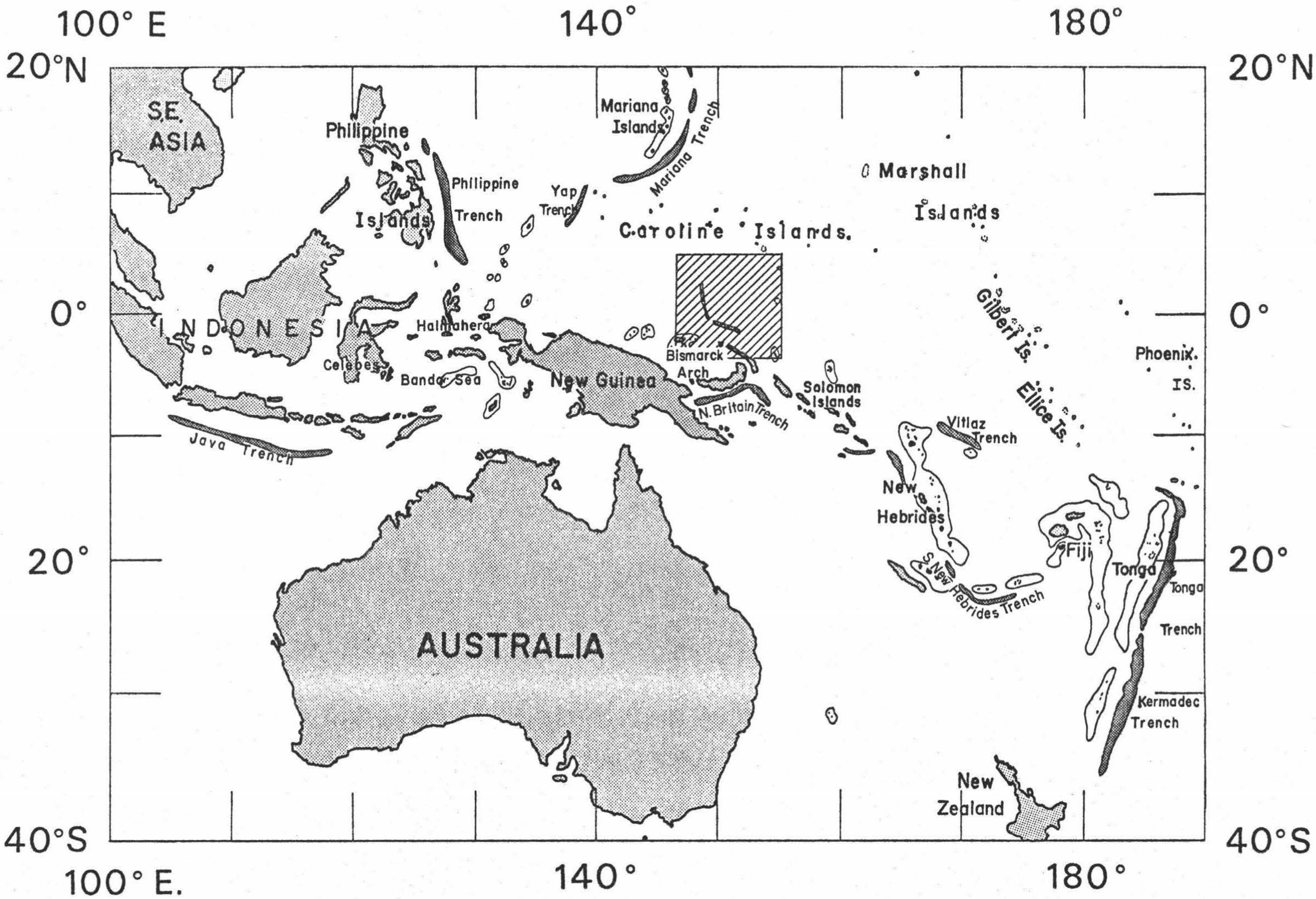
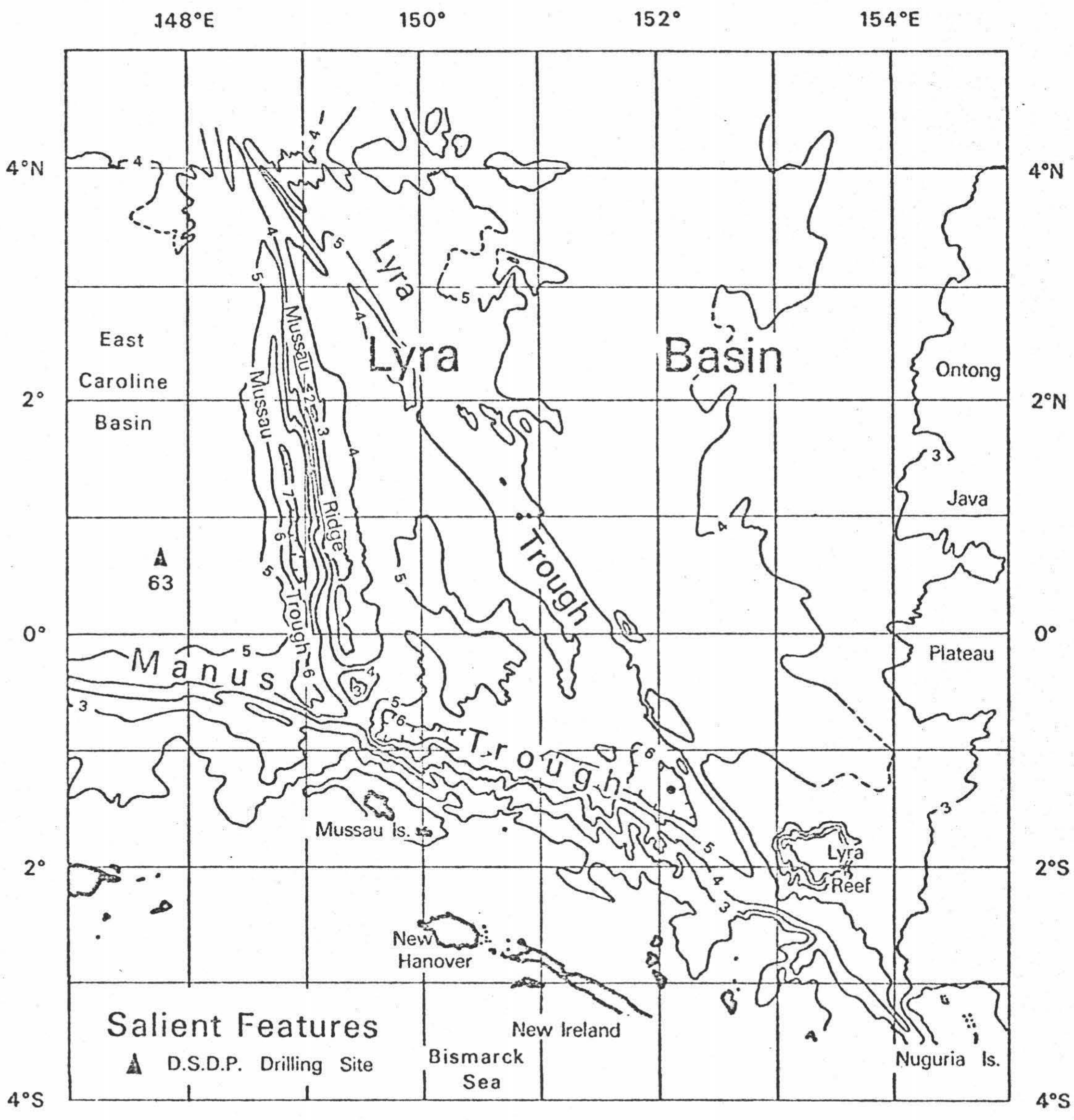

100° E
140°
180°
20°N
0°
20°
40°S
100° E.
S.E. ASIA
Philippine Islands
Philippine Trench
Mariana Islands
Mariana Trench
Yap Trench
Caroline Islands.
Marshall Islands
INDONESIA
Halmahera
Celebes
Banda Sea
New Guinea
Bismarck Arch
N. Britain Trench
Solomon Islands
Gilbert Is.
Ellice Is.
Phoenix. IS.
Vitiaz Trench
New Hebrides
S. New Hebrides Trench
Fiji
Tonga
Tonga Trench
Kermadec Trench
Java Trench
AUSTRALIA
New Zealand

Figure 2. Salient Features of the Lyra Basin.


148°E
150°
152°
154°E
4°N
2°
0°
2°
4°S
2°N
2°S
Lyra
Lyra
Basin
East
Caroline
Basin
Mussau
Mussau
Ridge
Trough
Trough
Manus
Trough
Ontong
Java
Plateau
63
Mussau Is.
Lyra
Reef
New
Hanover
New Ireland
Bismarck
Sea
Nuguria Is.
Salient Features
D.S.D.P. Drilling Site

A regional bathymetric analysis was not published until Hess (1948) analyzed the data in this area. Hess did not distinguish the Lyra Basin as a separate physiographic region, but rather he included it within the East Caroline Basin. Hess referred to the Mussau Trough and Ridge as a probable transcurrent fault. Subsequent analysis included the shipboard observations of the scientific staff of the Deep Sea Drilling Project (DSDP) on the D/V Glomar Challenger, Leg 7, who distinguished the Lyra Basin as a distinct physiographic province, assuming it to be a foundered segment of the Ontong Java Plateau (Kroenke and others, 1971). From a bathymetric study, Orwig and others (1972) attested to the block-faulted nature of the Lyra Basin but they were uncertain as to its origin. Erlandson and others (1975) have subsequently referred to the Lyra Basin as a marginal basin which formed behind a subduction zone in the Mussau Trough.

The staff of the D/V Glomar Challenger show the Lyra Basin extending as far north as 6.5° N, into the Caroline Islands. In this study, because of insufficient data, the Lyra Basin refers only to the area south of 4° N, in the southeastern part of what was previously referred to as the East Caroline Basin.

The purpose of this study is to present the geological and geophysical information about the Lyra Basin, and in particular, to determine whether or not the data support the proposed history of sea-floor spreading on the Euripik Ridge (Erlandson and others, 1975), and can define the tectonic boundary between the Lyra Basin and the Ontong Java Plateau.

GEOLOGIC SETTING

The Lyra Basin, itself structurally complex, is situated in one of the more complex areas of the Pacific. Indeed, this area of the Pacific may be a mosaic of small crustal plates whose interactions have been episodic through time, depending upon spreading rates and directions of the major lithospheric plates.

The setting of this study is within the realm of interaction and response between four lithospheric plates in close proximity to one another. The recent literature does not dispute the existence of complex interrelationships between the four plates (Pacific, Indian-Australian, Philippine, and Asian), but differs in interpreting how the interrelationships are responsible for the abundance of island arcs and marginal basins that are found in the west and southwest Pacific.

The location of the Lyra Basin in relation to the major plate boundaries is uncertain. This uncertainty is not because of vague boundaries of the Lyra Basin, but because of the difficulty in defining the actual present and past boundaries of the major plates. Katili (1971) has placed the westernmost edge of the Pacific plate at the island of Halmahera, whereas Fitch (1970) has it placed farther west at Celebes. Bracey and Andrews (1974) have put the western edge of the Pacific at the Philippine Trench and postulated that the boundary is in the initial stages of shifting to the East, between the Mariana and Mussau Troughs.

To the east of the Lyra Basin the boundaries are also complicated, but only the Pacific and Australian lithospheric plates are involved. The Ontong Java Plateau is part of the Pacific plate (Kroenke, 1972), with the Solomon Islands trench forming the boundary with the Australian plate.

Movements between the Lyra Basin on the Pacific plate and the Bismarck Archipelago on the Australian plate may be indications that a complex border region exists in this area also. These movements are seen south of the Lyra Basin by earthquake focal mechanisms as left-lateral slippage parallel to Pacific Plate motions (Johnson and Molnar, 1972). There are also strong east-west left-lateral movements some 200 km south of New Ireland in the Bismarck Sea.

A probable explanation for the confusion in plate boundary determinations may be due to the presence of small crustal plates at the borders of the major plates. Johnson and Molnar (1972) have identified, by seismicity, at least three small crustal plates south of the Manus Trough and east of New Guinea, explaining the focal mechanisms mentioned above. Fitch (1972), also by seismicity, has postulated a number of small plates in western New Guinea, the Banda Sea, and in the Philippine Islands to explain the complex plate boundaries found in these regions.

The existence of a small plate is also indicated north of New Guinea, in the East Caroline Basin, by age and seismic anomalies. Andrews (1971) points out that there is a great age difference between the sea floor of both the Caroline Islands and Caroline Basin compared to the Pacific crust in the Mariana Basin (Oligocene and Cretaceous respectively). Seismicity shows that the only area in the southwest Pacific in which slip vectors are not parallel to the predicted direction of motion of the major lithospheric plates is also in the area north of New Guinea. To explain the anomalous age, Winterer and others (1971) proposed that there had been a local center of sea-floor spreading within the Caroline Basin. Subsequent work has considered the spreading hypothesis in more detail, although there still exists disagreement as to the location and direction of spreading. Whether or not spreading occurred on the Euripik ridge in a northeast direction (Erlandson and others, 1975), or in a southern direction from a ridge which has been lost by subduction beneath the Caroline Island Ridge (Bracey, 1975), there is convincing evidence that the area of the Caroline Basin was not formed as part of the Pacific Plate.

DATA ACQUISITION AND PROCESSING

Continuous underway geophysical data used in this thesis include 3.5 KHz echo soundings, variable frequency seismic reflection, gravity, and magnetics. Where the bottom topography permitted, refraction data were also taken by the ASPER technique. Hawaii Institute of Geophysics collected data on two different cruises in this area, the 70-04-22 R/V Mahi, and 71-04-26 R/V Kana Keoki (Woodlard, 1970, 1971). All data from these two cruises are controlled by satellite navigation, except for a 24 hour section in 1970 (central portion of the north-south track segment at 150.6^{o}E, Figure 3). This short section had celestial and dead reckoning fixes because the satellite navigator was not operating.

Bathymetry

All bathymetric data were corrected for the variations in sound velocity in sea water (Matthews, 1939).

Bathymetric data were picked assuming the first reflection return (closest to the ship) to be true water depth. Since the descending sound signal spreads in a cone of approximately 18^{o}, at 5km water depth the returning signal could be from anywhere within a 1.6km diameter area of the sea floor. Any bathymetric highs within the reflection cone can yield the first return, unavoidably giving the data a shallow bias. The convention of using the highest reflection is used to standardize picking. The actual depth along a track does not, in many cases, become apparent until the data are plotted on a chart and the regional trends examined. Many of these difficulties can be alleviated if a narrow-beam echo sounder is used (Belderson and others, 1972).

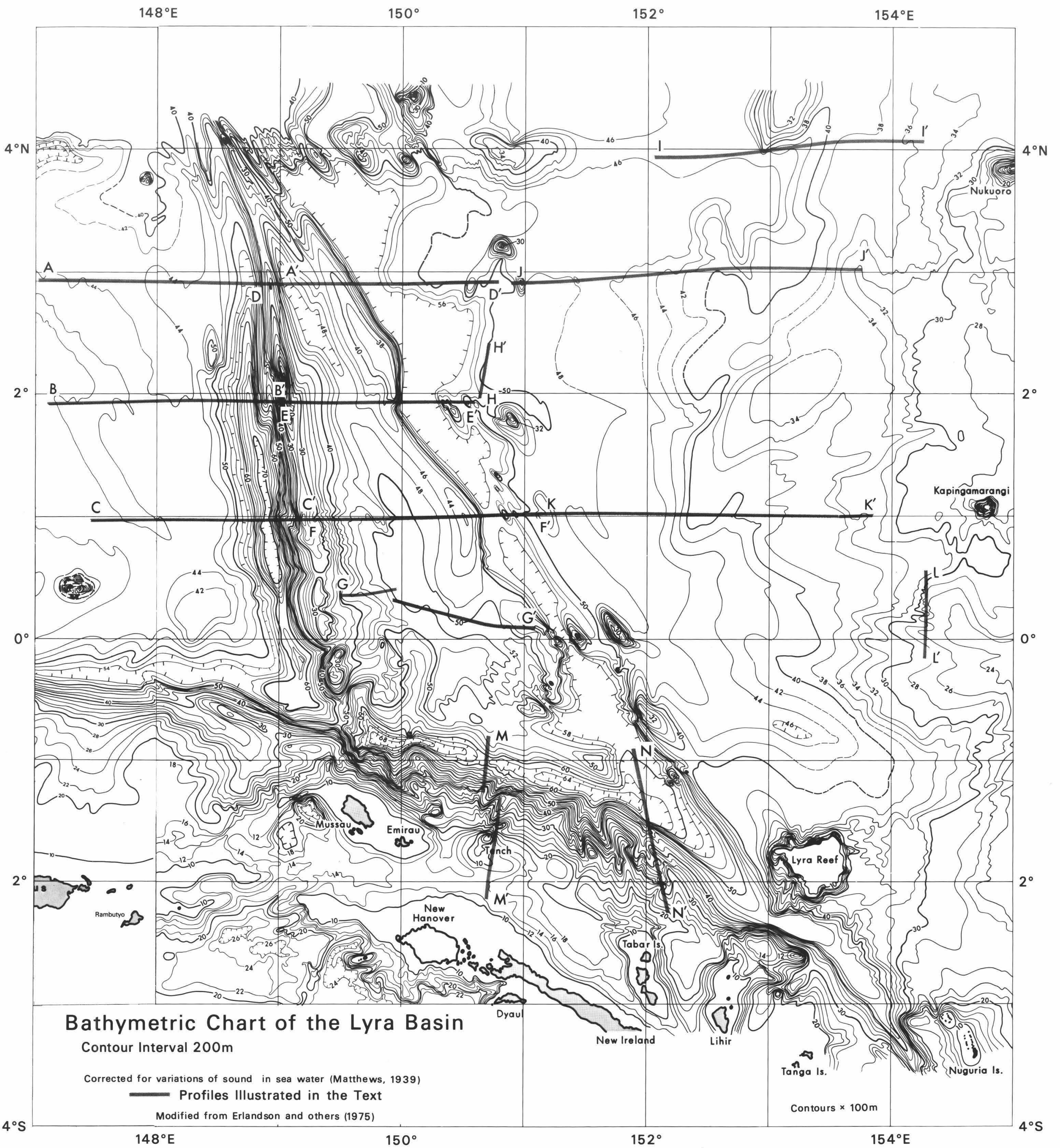
The Netherlands and Australian hydrographic offices were kind enough to supply "General Bathymetric Charts of the Oceans" (GEBCO) charts in the area of this thesis. They form the basis for the contours in areas where HIG data did not exist (Figure 3). Bathymetry from DSDP Leg 7 of the D/V Glomar Challenger was obtained by digitizing the original tracings that L. W. Kroenke made of the reflection profiles (Kroenke and others, 1971).

Seismic Reflection

An account of the development of HIG's profiling and seismic reflection systems, and the shipboard procedures, is covered thoroughly by Kroenke (1972), and therefore it will not be necessary to repeat it in this paper.

Reflection records were traced to determine the subsurface structure and sediment thickness. Because the mixed-frequency records (about 50 to 100 Hz combined with 150 to 300 Hz) give the best representations of the bottom, these were the most commonly traced records, with frequent

Figure 3. Bathymetry of the Lyra Basin, modified from the chart of Erlandson and others (1975) which shows all track lines and spot soundings. Data sources include DSDP, Leg 7, Hawaii Institute of Geophysics (HIG), and data from General Bathymetric Charts of the Oceans (GEBCO). Profiles indicated are from HIG data. Contours are broken where data control is absent.



148°E
150°
152°
154°E
4°N
2°
0°
2°
4°S
Nukuoro
Kapingamarangi
Mussau
Emirau
Tench
Lyra Reef
New Hanover
Rambutyo
Tabar Is.
Dyaul
New Ireland
Lihir
Tanga Is.
Nuguria Is.
Bathymetric Chart of the Lyra Basin
Contour Interval 200m
Corrected for variations of sound in sea water (Matthews, 1939)
Profiles Illustrated in the Text
Modified from Erlandson and others (1975)
Contours × 100m

reference to the low and high frequency records where available. Tracing is the only way to keep track of the basement and correlate it across the record where the actual acoustic basement is masked beneath a layer above it in the sedimentary column, or is faded and intermittant on the records. The tracing, then, provides a clear and uncomplicated interpretation of the sediment thickness that can be easily and confidently digitized and put onto the computer.

The sediment-thickness data put into the computer are available in many forms. The form that was plotted and contoured in this thesis is travel time in seconds, from sediment surface to acoustic basement. There are many advantages to supplying a velocity structure to the sediment so that "real" thickness can be determined (Kroenke, 1972), but this was not done here for two reasons. First, there are no DSDP holes or any wide angle reflection data in the Lyra Basin which might have been used to determine the velocity of the sediments. Second, it seemed inappropriate to correlate the sediment velocity structure of the Lyra Basin to the neighboring Ontong Java Plateau or East Caroline Basin where DSDP drilling sites exist, because in the Lyra Basin sedimentary characteristics change, as a result of considerable erosion, redeposition, and deformation.

The contour charts of sediment thickness and gravity were made using the bathymetric chart to suggest sediment and gravity trends. This was done because the volume of data controlling the bathymetry far exceeds that controlling the sediment or gravity.

Magnetics, Gravity, and Seismic Refraction

The reduction of magnetics, gravity, and seismic refraction data was conducted by other HIG investigators and will only briefly be covered here.

The magnetic data (Hanschumacher and others, 1975) were obtained by a Varian 4360 Proton Precession Magnetometer which recorded the total geomagnetic field strength onto an analog strip-chart recorder. These records were picked at 50 gamma intervals and at all high and low inflection points. These data were merged with the navigation data in the computer and the International Geomagnetic Regional Field was removed to leave the residual values. The data were plotted for analysis in profiles at 400 gammas per inch.

The gravity data were reduced as free air anomalies with no corrections for terrain or assumed crustal density.

In addition to those data acquired by HIG, gravity data from other institutions were also used. The free air anomalies were contoured at 20 mgal intervals.

Existing crustal velocity data (Hussong, 1972; Den and others, 1971; Finlayson and others, 1972; Furumoto and others, 1973) were supplemented by unpublished HIG ASPER sonobuoy stations.

ANALYSIS AND OBSERVATIONS

Erlandson and others (1975) have described the tectonic history for this area. They hypothesize that a north-northwest trending spreading center was located on the Euripik Ridge. In this reconstruction, the Mussau Trough, Mussau Ridge, and Lyra Trough respectively represent the trench, volcanic arc, and marginal basin of a subduction zone. Spreading ceased in the late Oligocene, but deformation has continued because of interactions between the Pacific and Australian lithospheric plates.

Physiography

The gross physiographic trends are evident on Figure 3, a bathymetric chart of the Lyra Basin updated and expanded after the chart of Erlandson and others (1975). The more prominent features include the Mussau Trough and Ridge, Lyra Trough, western flank of the Ontong Java Plateau, Manus Trough, and the islands of the Bismarck Archipelago.

The basis for dividing the Lyra Basin into different regions is physiographic, and these regions fit into history of subduction with its associated features which will be described separately. These regions are the western margin, central, eastern and southern parts of the Lyra Basin.

Western Margin

The area of the old subduction zone, that is to say, the eastern flank of the Caroline Basin and the Mussau Trough and Ridge, constitutes the western margin.

The western side of the Mussau Trough was described by Erlandson and others (1975) as descending "with increasing gradient into the Mussau Trough". Before it descends into the trough, the western side is characterized by a rim elevated above the average depth of the East Caroline Basin by about 200 meters, ranging in width from 100 km in the south to about 200 km in the north. The elevated bathymetry of the seaward side of the trenches in the Carribean have been referred to as 'outer ridges' (Heezen and others, 1959), and that term will be used to refer to this area of the Mussau Trough as well. The outer ridge of the Mussau Trough is very similar to the topographic phenomena associated with the 'outer gravity highs' on the seaward side of some of the Pacific's active deep ocean trenches (Watts and Talwani, 1974). The correlation between the outer ridge and the gravity in the Lyra Basin will be covered in the gravity section.

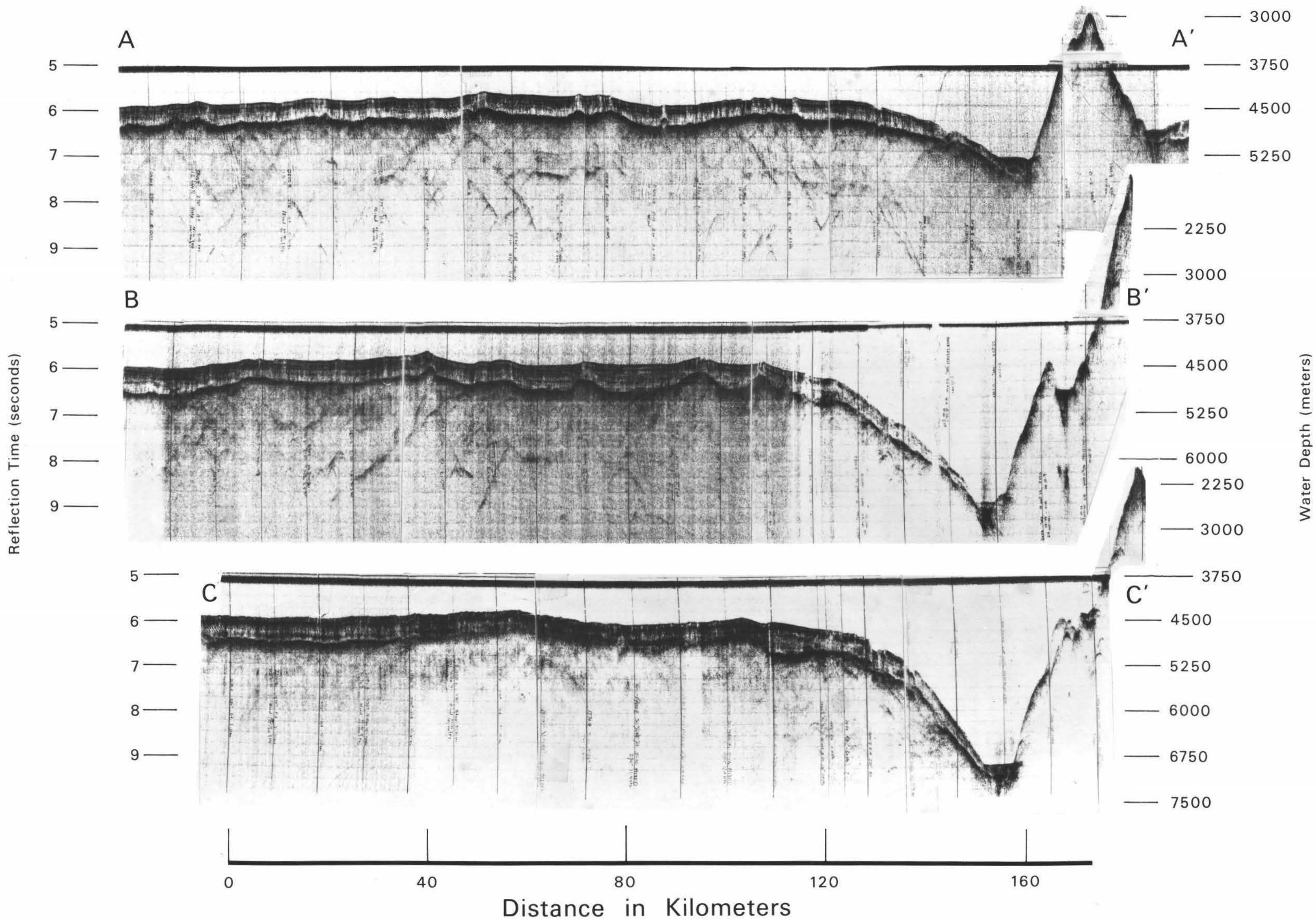
The outer ridge of the Mussau Trough is not characteristic of a simple flexing of a descending lithospheric plate. The crest of the outer ridge seems to be composed of one or more north-northwest trending undulations. The undulations are structurally controlled and are parallel to the extinct spreading center to the west. Although offset from one another along the length of the Mussau Trough the undulations are confined to the region of the outer ridge. The absence of north-south traverses prevents a thorough delineation of the undulation offsets.

The outer ridge and the undulations thereon are not merely sedimentary phenomenon as is seen in the reflection records (Figure 4). Structural control for these features appears as normal faults. The faulting indicates two periods of deformation. The first deformation uplifted basement with a draping of its overlying sediments, which must have occurred early in the historical sequence. The second is seen as younger faults cutting the entire sedimentary sequence.

The gradient of the eastern slope of the outer ridge decreases to the north with a corresponding shoaling of the adjacent Mussau Trough. Sediment cover also is thinner in the northern reaches of both the outer ridge and the trough (Figures 3 and 4).

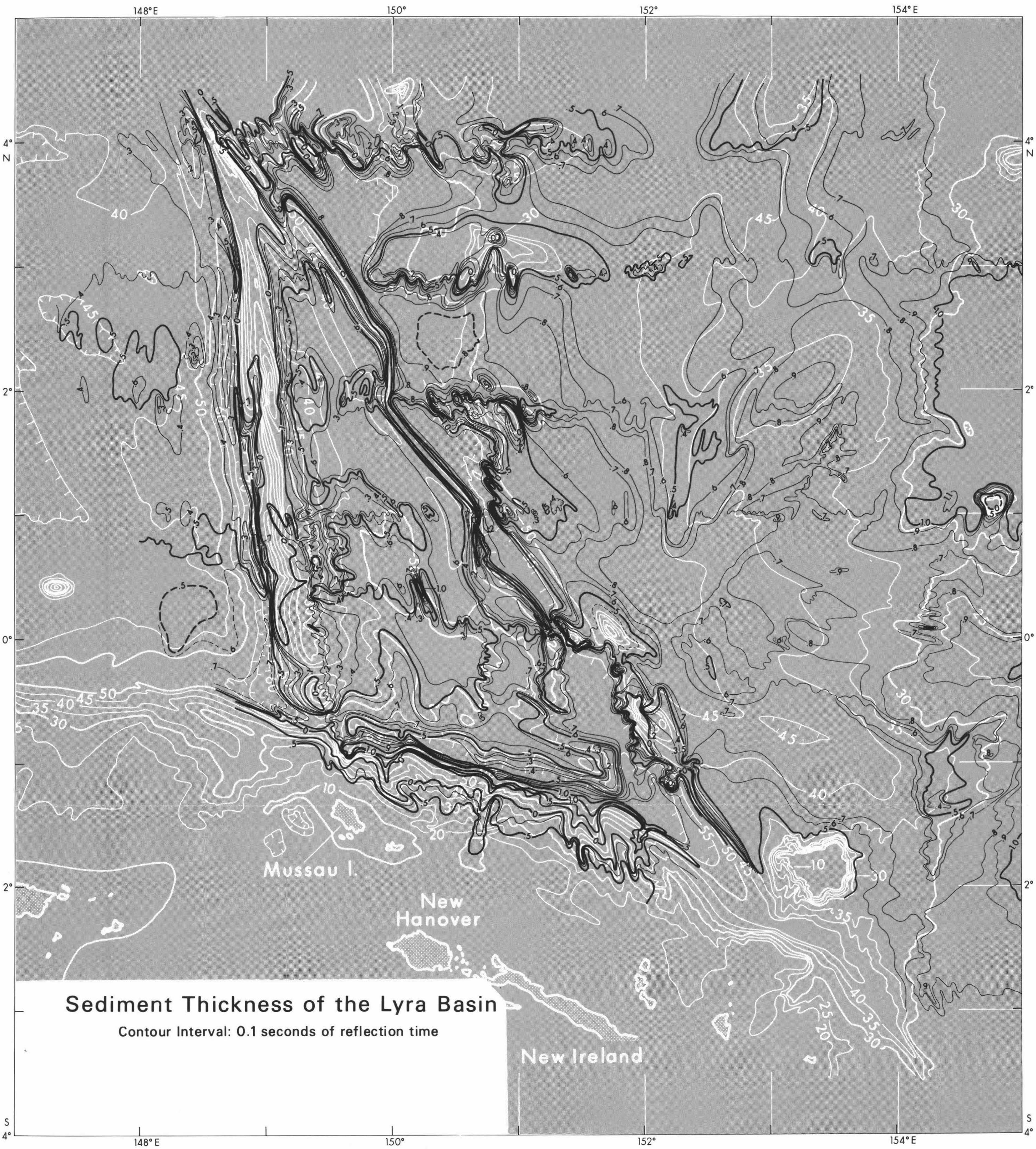
The structural framework of the Mussau Trough and Ridge is complex. Hess (1948) was first to note a 110 km-offset in the deepest and highest elevations. Erlandson and others (1975) later noted the block-faulted steep escarpment of the ridge, with valleys and varying amounts of sediment following the faults from the ridge crest to the trough below (Figures 3 and 5). The Mussau Ridge is

Figure 4. Profile composite across the western margin of the Lyra Basin. The structure of the undulations on the outer ridge is seen on the western side of all profiles. Note the increase in gradient of the western flank of the Mussau Trough from north (A-A') to south (C-C'). Vertical exaggeration: 12:1.



A
A′
B
B′
C
C′
Reflection Time (seconds)
5
6
7
8
9
Water Depth (meters)
3000
3750
4500
5250
2250
3000
3750
4500
5250
6000
2250
3000
3750
4500
5250
6000
6750
7500
0
40
80
120
160
Distance in Kilometers

Figure 5. Chart of intervals of reflection time in the Lyra Basin. Isopachs of sediment thickness may be interpreted from this map. Data are from HIG and from DSDP, Leg 7. Contour interval of the bathymetry, shown in white, is 500m.


148°E
150°
152°
154°E
4° N
2°
0°
2°
S 4°
Mussau I.
New Hanover
New Ireland
Sediment Thickness of the Lyra Basin
Contour Interval: 0.1 seconds of reflection time

intermittent and broken in character where it approaches the Manus Trough to the south.

The distinctive topographic character of the outer ridge and Mussau Trough and Ridge is lost to the north (Figure 3). The broad arch and topographic relief of the outer ridge becomes constricted and elevated as it encounters the northeast-striking Kiilsgaard Fracture Zone at 4° N (Erlandson and others, 1975). North of 3° N, the Mussau trough-ridge system loses its distinct subduction-zone appearance, which was so evident to the south. This change in appearance is caused by faulting associated with convergence of the trough-ridge with the northwest striking Lyra Trough.

Central Lyra Basin

The central portion of the Lyra Basin includes the eastern slope of the Mussau Ridge and the Lyra Trough with its eastern and western rims.

The gentle eastern slope, characteristic of the southern Mussau Ridge, changes to the north. Here, as the Lyra Trough converges with the Mussau Ridge, a steepening of the slope occurs, on the far left (west) of northernmost profile (Figure 6, profile D-D'), the Mussau Ridge appears as a volcanic peak.

Between the Mussau Ridge and the Lyra Trough is a triangular crustal segment outlined by the 5600m contour in

Figure 6. Profile composite across the western and central Lyra Basin. Note the severity of faulting in the western Lyra Basin and tilted fault blocks on the eastern rim of the Lyra Trough. Vertical exaggeration: 12:1.

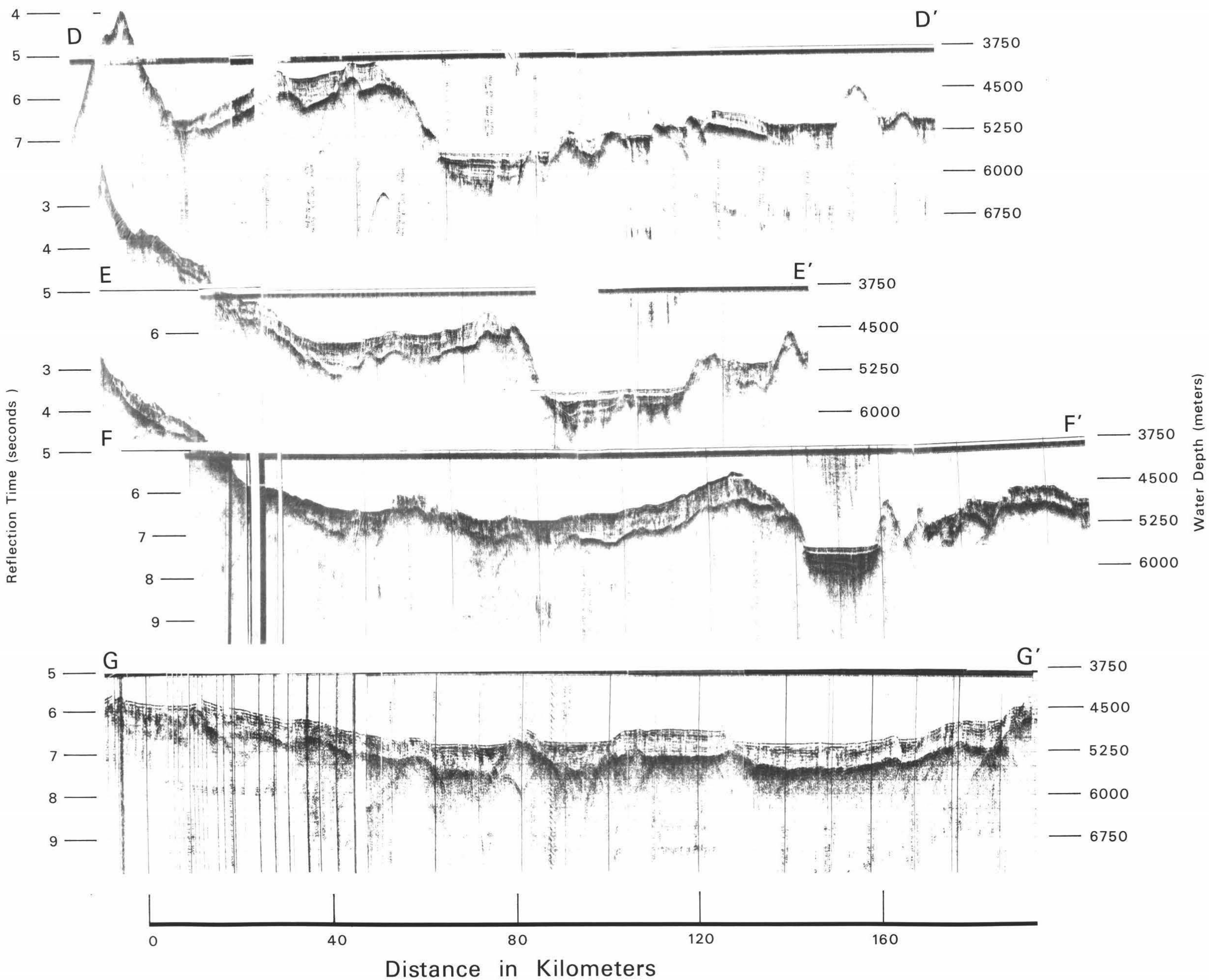

D
D′
E
E′
F
F′
G
G′
Reflection Time (seconds)
Water Depth (meters)
3750
4500
5250
6000
6750
0
40
80
120
160
Distance in Kilometers

Figure 3 which will be referred to informally as the southwestern Lyra Basin.

The most prominent structural trends within the southwestern Lyra Basin are faults striking north-northwest, parallel to trends of the outer ridge. These patterns are contoured as hills and basins on the bathymetric chart, and are controlled by basement faulting. Tilting of blocks in this segment of the Lyra Basin is common, but the direction of the tilting is not consistent (Figure 6). Profile D-D' shows the complex faulting as tilted blocks sloping toward the Mussau Ridge. Profile E-E', 110 km to the south, appears to be transitional with blocks tilting both toward the ridge and toward the Lyra trough. The southern profiles, F-F' and G-G', have components tilting mainly toward the trough, and horsts and grabens are common.

Within the triangular segment, patterns of thin sediment follow the crests of the horsts and tilted blocks (Figure 5), with ponds of sediment in the intervening basins. The ponded sediment originates from the tops of the horsts, and also from the eastern slope of the Mussau Ridge. The thinning of the sediments on the flank of the Mussau Ridge and their absence on the crest are evident on the various profiles of Figure 6.

Similar to the structure of the undulations on the outer ridge, two periods of deformation also are indicated in the southwestern Lyra Basin (Figure 6). The first period is represented by faulting and tilting of crustal blocks at a time after thick sediments had already been laid down. The originally horizontal sediments are tilted along with the blocks. After the initial deformation ponded sediments gathered in the newly formed topographic lows. Horsts, on which thick sediment is displaced above the surrounding topography, are interpreted as having formed during the second period of deformation. The second period is interpreted as being fairly recent because the fault scarps appear fresh, and erosion has not yet occurred.

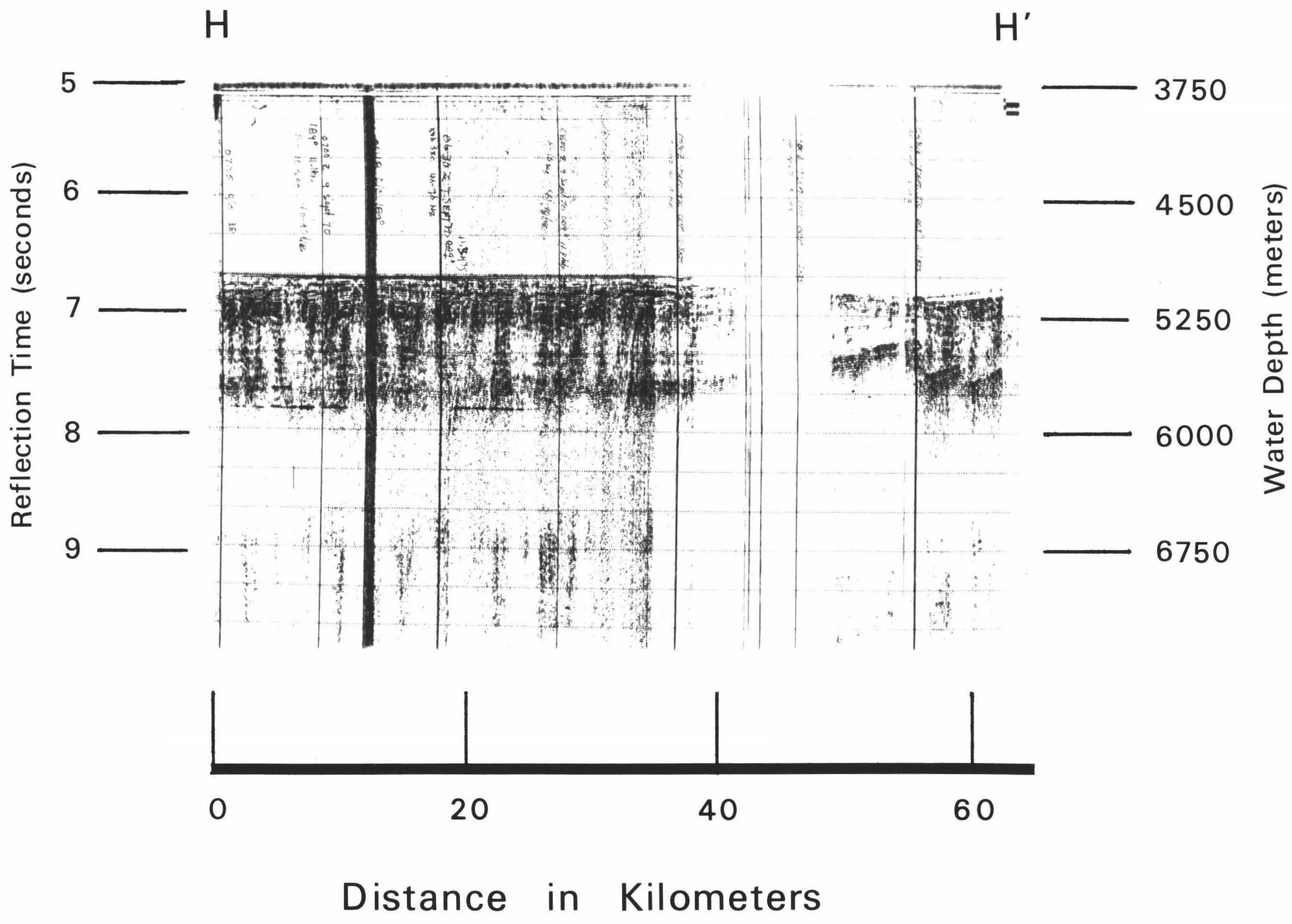
The southern reaches of the southwestern Lyra Basin 'step' down into the Manus Trough through a series of small normal faults (Figure 10, profile M-M'). Erosion is evident on the isopach chart (Figure 5) as thin sediment on the steeper slopes.

The Lyra Trough is a graben which averages 5600 meters in depth. The eastern rim of the Lyra Basin is structurally different from the western rim (Figures 3 and 6). On the west there is a steep escarpment more than 1 km high, and a rim composed of a series of three en echelon ridges striking north-northeast, parallel to the patterns of the southwestern Lyra Basin. Sediment thins markedly eastward up to the crest of the rim, and it is absent on the steep scarp leading into the Lyra Trough. The eastern rim is characterized by extensive block faulting and volcanic extrusives (Erlandson and others, 1975). The profiles of Figure 6, D-D' through F-F', show both rims. The most severe faulting of the eastern rim is in the north, where blocks tilted to the east drop down into the Lyra Trough. A profile across the eastern rim is somewhat blocky, but the sediment cover, although absent on the volcanic peaks, is continuous into the trough. Faulting severs the complete sedimentary column and alludes to a second tectonic episode similar to those previously mentioned.

The Lyra Trough is widest at the north and south and narrow in the middle. At its southern end it merges with the Manus Trough forming a broad floor gently sloping toward the south (Figure 3). The width of the northern end of the trough is attributed to the faulting down of blocks from the eastern rim, and their subsequent burial by sediments. Accumulation of sediment has been more extensive in the central portion of the Lyra Trough, and sediment thins toward the north and south. The lower two-thirds of the sedimentary column in the trough exhibits small-scale deformation which is overlain by horizontal layers. This is seen in profile H-H' (Figure 7) as 'transparent' zones where the continuity of the layers have been destroyed by deformation.

The basement in the Lyra Trough rises abruptly as it approaches the area of complex structure to the north. Sediments within the trough thin markedly toward the structure, confining any appreciable sediments to the

Figure 7. Sedimentary sequence in the Lyra Trough. Small-scale deformation is overlain by horizontal sediments. Vertical exaggeration: 12:1.



H
H′
5
6
7
8
9
Reflection Time (seconds)
3750
4500
5250
6000
6750
Water Depth (meters)
0
20
40
60
Distance in Kilometers

topographic lows. Whether or not the Lyra Trough passes through the structured area is not certain, but the steep graben (4°N, 149.5°E) is along the projected strike of the Lyra Trough and so is where it may pass through. Insufficient data prevent a reliable interpretation of the physiography of the northern limits of Figure 3 as well as the area farther to the north.

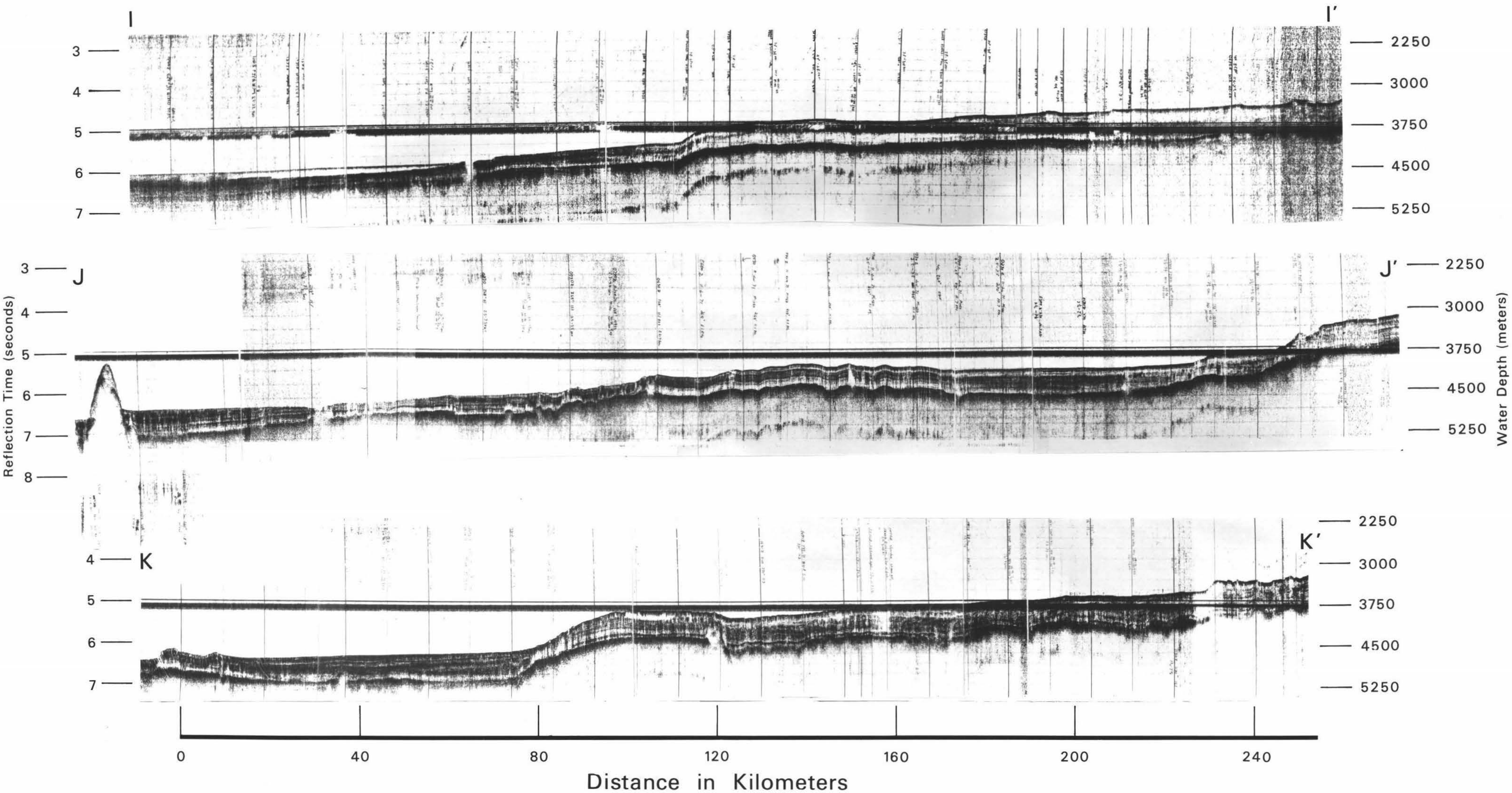
Eastern Lyra Basin

The eastern Lyra Basin is comprised of blocks faulted down from the Ontong Java Plateau (Kroenke and others, 1971; Orwig and others, 1972). Formation of these blocks has occurred in two belts, concentrated at 3 km and 4 km depths, creating an upper set of blocks and a lower one, both faulted down relative to the plateau. Although the stratigraphy and structure of the upper and lower blocks are different, their integrity is maintained as far as the Lyra Trough, where, in the northern half, they form large angular offsets in the eastern side of the trough (Figure 3).

Faulting and deformation is much more common on the upper block and has given the topography an irregular buckled appearance (Figure 8).

The basement and overlying sediment of the lower block appear different from the upper block. The acoustic basement becomes vague immediately west of the upper block, with

Figure 8. Reflection profile composite across the eastern Lyra Basin. Note, on the lower block (left side), sediment ponds; in the center, fracture between the two blocks; on the upper block, prevalent faulting and buckling; and the far right, sediments characteristic of the Ontong Java Plateau. Vertical exaggeration: 12:1.

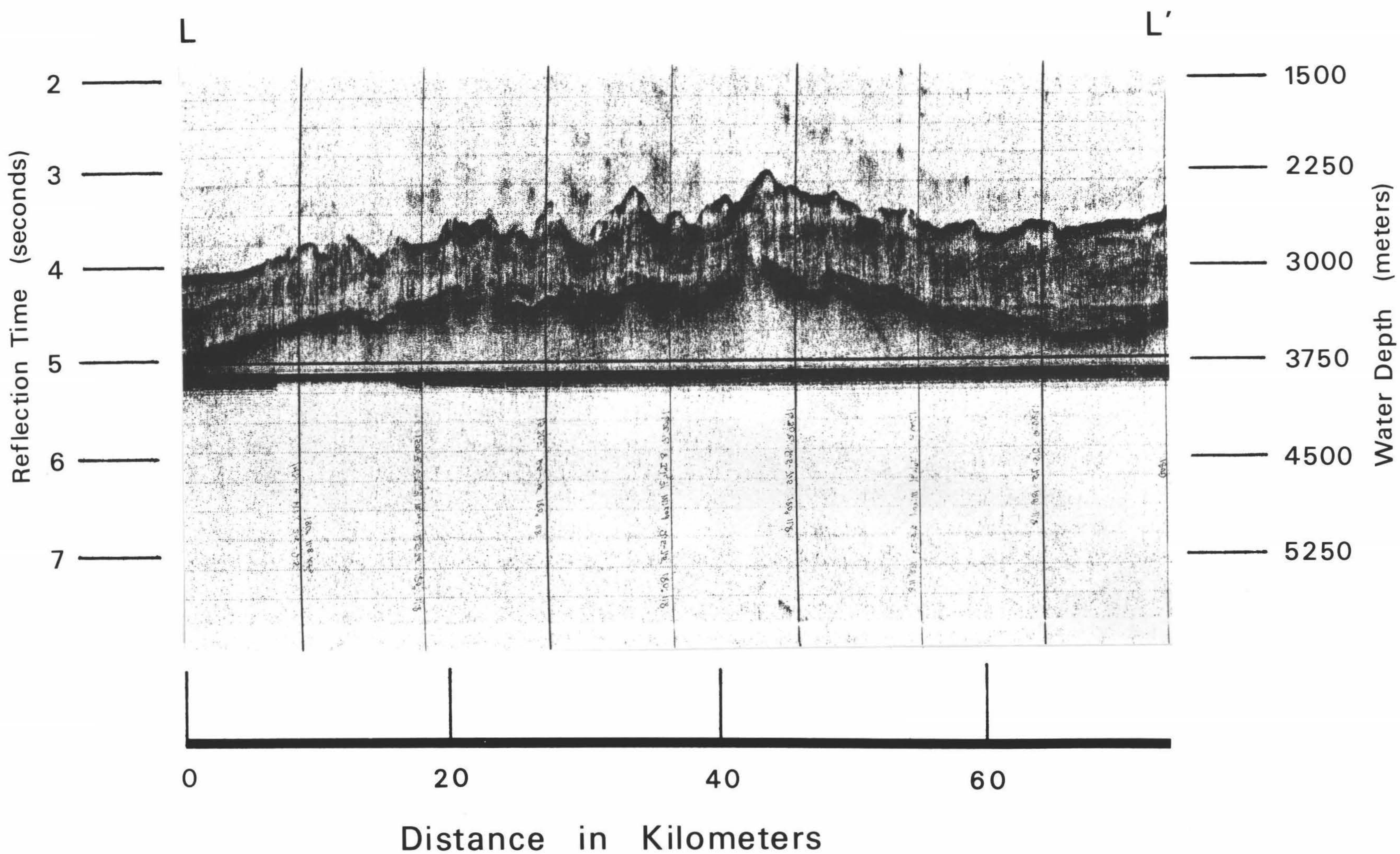

I
I′
J
J′
K
K′
Reflection Time (seconds)
3
4
5
6
7
8
Water Depth (meters)
2250
3000
3750
4500
5250
0
40
80
120
160
200
240
Distance in Kilometers

basement reflectors fading initially under deep sedimentary fans and then under accumulations of ponded sediment (Figure 8). The lower block has a characteristic tilt, with the eastern side being lower than the western. The tilt of the lower block, although more gentle, is in the same rotation as the intense faulting of the adjacent eastern rim of the Lyra Trough (Figure 6, profiles D-D' and F-F').

The sediment cover on the lower block can be used for determining the relative age of the faulting. A lower layer of old sediments, severed by the faulting, is unconformably overlain by sediment fans (Figure 8, profile K-K') originating from the upper block and the valleys edging the Ontong Java Plateau.

The stratigraphy changes from the east to the west. On the extreme eastern side of profile J-J' and to a lesser extent on profile K-K' (Figure 8), sequences of horizontal calcareous sediments greater than 1 second in thickness, typical of the Ontong Java Plateau, enter the region of the Lyra Basin (Figure 5). As they slope down onto the upper block in the Lyra Basin, erosion takes place (Figures 8, profile K-K', and 9). The upper block of the eastern Lyra Basin seems to maintain the characteristic plateau sediments and does not appear to be accumulating much transported sediment. On the lower block, however, large sedimentary fans (profile K-K') and extensive sedimentary ponds (profiles I-I' and J-J') are seen to lie unconformably over older

Figure 9. Erosion on the western margin of the Ontong Java Plateau. Irregular topography is erosional valleys. Vertical exaggeration: 12:1.


L
L′
2
3
4
5
6
7
Reflection Time (seconds)
1500
2250
3000
3750
4500
5250
Water Depth (meters)
0
20
40
60
Distance in Kilometers

sedimentary sequences and so the sediments no longer appear as typical of the plateau.

Southern Lyra Basin

Within and adjoining the southern part of the Lyra Basin are the Manus Trough and the Bismarck Archipelago to the south.

The Manus Trough, or Trench, is arcuate, concave southward, and extends eastward and westward beyond the borders of the southern Lyra Basin. The deepest part of the Manus Trough, at 6800 meters, is on the eastern side of a saddle formed by the trough's intersection with the Mussau Ridge.

South of the Manus-Massau Trough intersection the topography of the Bismarck Archipelago appears constricted, most clearly visible by the gap in the 1 km contour at 149°E (Figure 3). Possibly associated with the constriction are a couple of anomalously deep areas (2600 m) west of the Mussau Island. West of New Hanover the Bismarck Sea extends northward, accentuating the constriction in the Archipelago.

Erosion has occurred on both the arc and the Lyra Basin sides of the Manus Trough. A thinning of the sedimentary cover is seen over the block-faulted crust, described above as stepping down into the trough. The reflection records show no sediment on the inner wall of

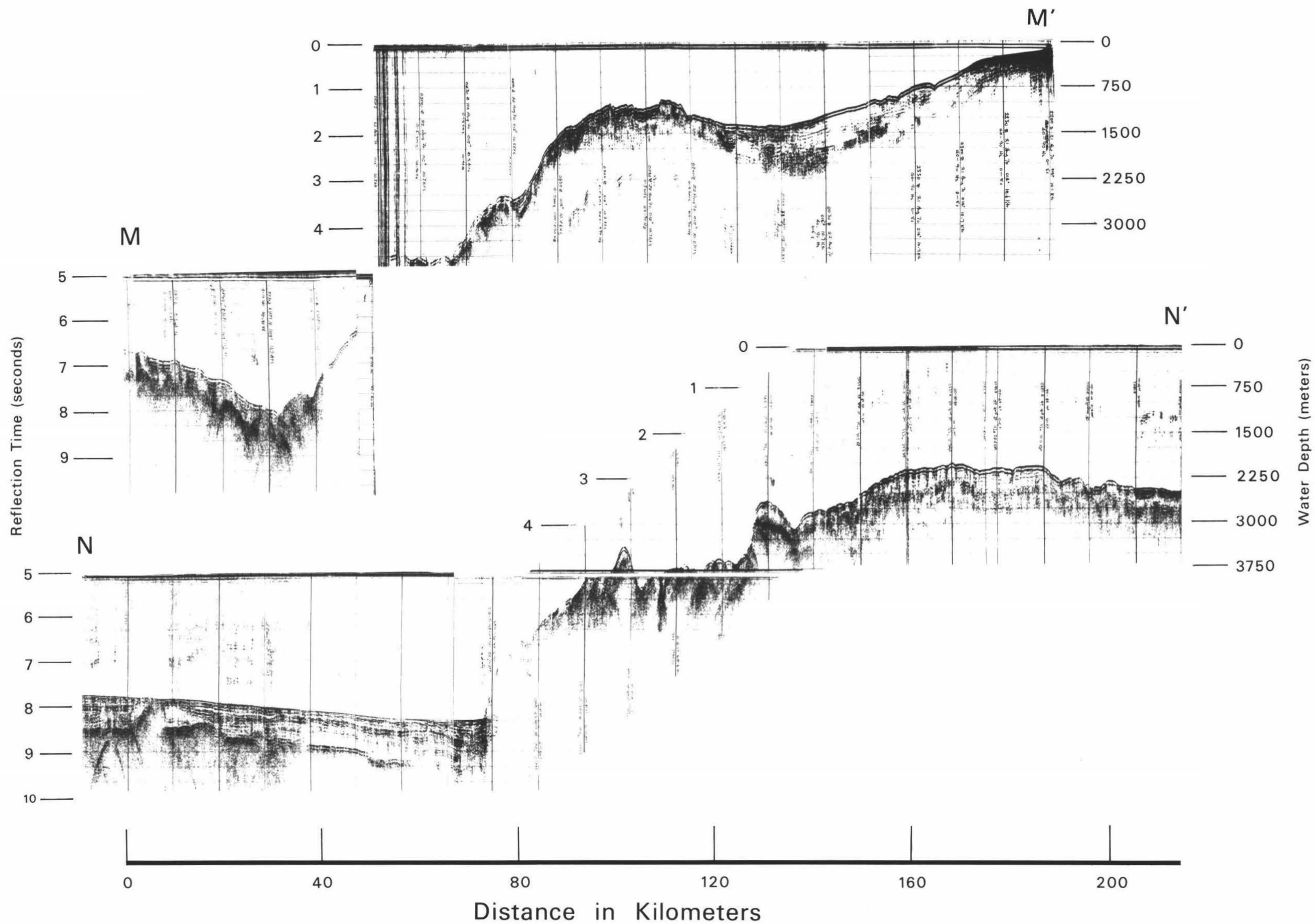
Manus Trough, between the trench axis and the forearc basin.

The inner wall of the Manus Trough is complex structurally with numerous deep valleys following structural trends (Figure 3). A break in the slope occurs at about 4000m, forming a small terrace. From the terrace the slope continues up to an anticlinal fold and on up to the south into a broad valley approximately 25 km wide. Accurate definition of these features is limited because only a few reflection traverses cross this area.

Thin sediment cover on the anticlinal fold overlies older and extremely deformed sediment. Profile N-N', Figure 10, crosses obliquely up the foreslope and over the anticlinal fold and shows the older sediments. Profile M-M' shows the basin and its thick sequences of sediments, but the limitations inherent in the reflection system prevent the depiction of the older sediments which are deeper in the sequence.

The general structural morphology of this region, as seen in the two profiles of Figure 10, resemble that of the landward side of subduction zones described as areas of active sedimentary accretion (Karig and Sharman, 1975; Coulbourn and Moberly, 1975).

Figure 10. Reflection profile composite across the Manus Trough and the northern edge of the Bismarck Archipelago. Profile M-M' does not extend into the forearc basin shown in N-N'. The double layer apparent at the water-sediment interface across these profiles is due to a problem in the acoustic system on the ship. Vertical exaggeration: 12:1.



M'
M
N'
N
Reflection Time (seconds)
Water Depth (meters)
0
1
2
3
4
5
6
7
8
9
10
0
750
1500
2250
3000
3750
0
40
80
120
160
200
Distance in Kilometers

Gravity

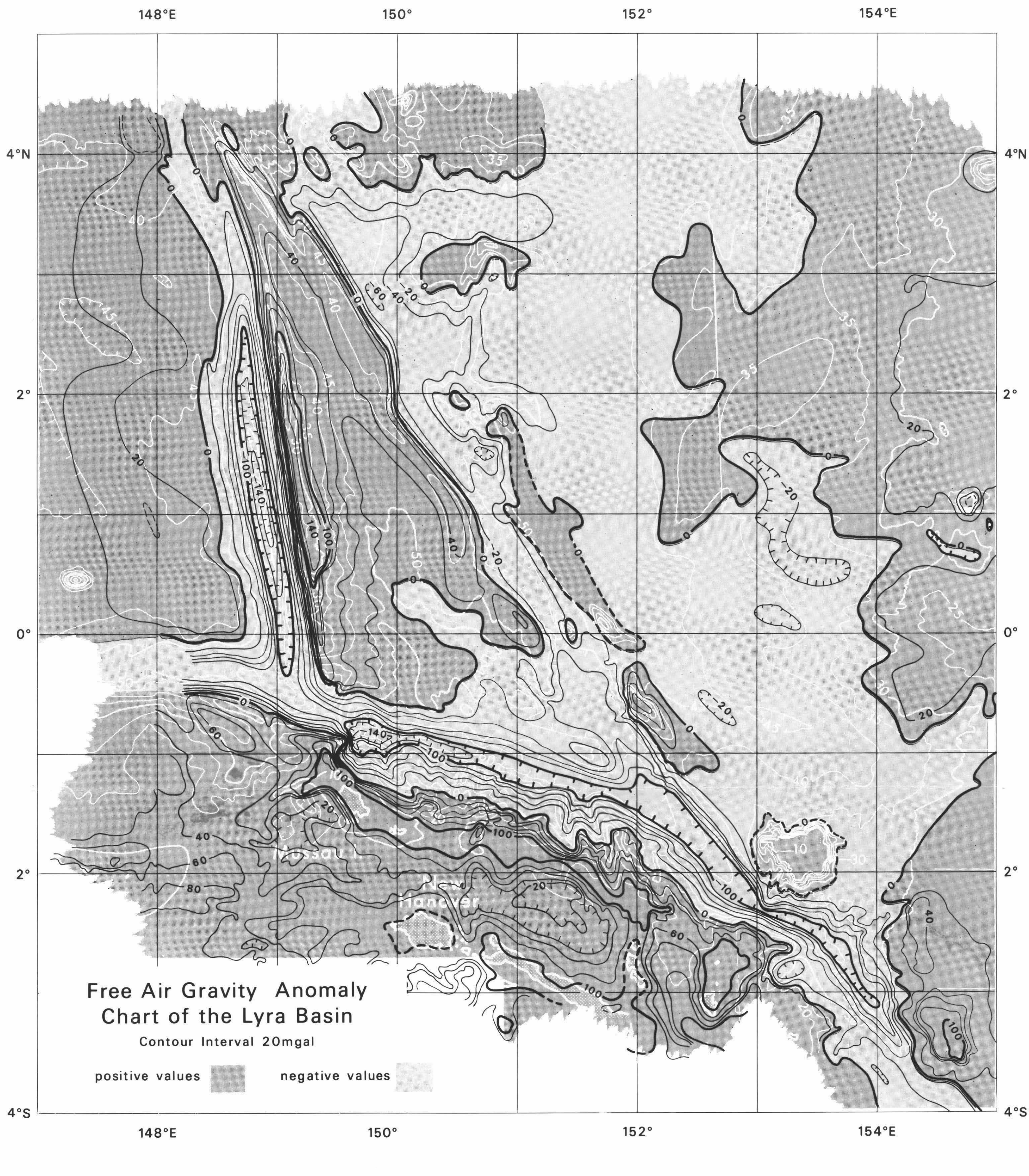
The free-air gravity map (Figure 11) was prepared from shipboard gravity traverses. Where the traverses were widely spread, the trend of the bathymetry was used to control the contouring. This gives the gravity contours an appearance similar to the bathymetry (Figure 11).

West of the Mussau Trough the trend of the outer gravity high is coincident with the outer ridge. North of the large offset in the bathymetric undulations of the outer ridge (2^{o}N in Figure 3), the gravity high follows the undulation closest to the Mussau Trough.

Table 1 shows how the gravity and bathymetric data over the Mussau Trough and Ridge compare with similar regions of active trench and arc systems (Watts and Talwani, 1974). A similarity is observed in Table 1, but the values of the Mussau system are subdued in comparison with the others.

The configuration of the gravity field over the Mussau Trough and Ridge closely resembles the bathymetry. The resemblance is complete except for a 10-km eastward displacement of the gravity extremes relative to the bathymetry (Figure 11). The resemblance is also maintained along the strike of the Mussau Trough and Ridge where the negative anomaly decreases as the depth of the trough shoals towards the north.

Figure 11. Contoured gravity (free air) chart of the Lyra Basin. The outer gravity high is seen to the west of the Mussau Trough. The gravity values over the Mussau Trough and Ridge are displaced to the east relative to the bathymetry (white bathymetric contours on the gray field, contour interval = 500m). The zero milligal contour on the eastern side of the basin arbitrarily defines the Lyra Basin-Ontong Java Plateau boundary. The forearc basin (+20 mgal) of the Bismarck Archipelago indicates low density material (sediments) is present in thick sequences.



148°E
150°
152°
154°E
4°N
2°
0°
2°
4°S
Mussau I.
New Hanover
Free Air Gravity Anomaly
Chart of the Lyra Basin
Contour Interval 20mgal
positive values
negative values

Table 1

Comparative Gravity Data Between Active Arc-Trench Systems and the Mussau Trough and Ridge

Trench	Arc Anomaly (mgal)	Trench Depth	Trench Anomaly (mgal)	Height of O.R.	O.G.H. Anomaly (mgal)	Width of O.G.H.
Aleutian	+184	7300m	-220	500-900m	+55	600km
Kuril	+247	9600m	-285	300-700m	+40	400km
Mariana, Japan	+200	9400m	-322	300-800m	+70	500km
Philippine	+90	8600m	-250	400-800m	+70	600km
Mussau Trough	+140	7100m	-140	200-300m	+25	250km

O.R. = Outer Ridge; O.G.H. = Outer Gravity High

Data, except for the Mussau Trough, from Watts and Talwani, 1974.

Gravity fields behind trench-arc systems have yet to be thoroughly investigated (Watts and Talwani, 1974), so a comparison of this region of the Mussau system and the active systems cannot be made at this time. The gravity, however, in the marginal basin (Lyra Basin proper) also appears to reflect the bathymetry.

The free air gravity field over the eastern rim of the Lyra Trough is characterized by a positive anomaly that is highest over the seamounts (Figure 11). Apparently, this pattern is caused by the area being heavily faulted and intruded by volcanic material, as mentioned earlier.

Immediately east of the positive anomaly along the rim is the broad area of the lower block of the eastern basin. Over its entire extent, the block exhibits a negative anomaly that averages -12 mgal. South of 1^{o}N (Figure 11) the zero gravity contour crosses onto the upper block of the Lyra Basin, deviating from its usual affiliation with the bathymetry. Here, the contours form a steep gravity gradient. The zero contour and the +20 mgal anomaly, common to the western Ontong Java Plateau, are in close proximity to one another.

The Manus Trough and Bismarck Archipelago present another extreme variation in the gravity. The continuity of the negative anomaly along the Manus Trough is maintained a great distance, but the area of greatest anomaly, -140 mgal, is confined to the deepest part of the trough, immediately east of its intersection with the Mussau Ridge.

On the foreslope of the Bismarck Archipelago and regions farther south, the gravity again reflects the topography, with the one exception being the sedimentary basin behind the anticlinal fold. There is a break in the gravity gradient coincident with the structural terrace of the foreslope mentioned earlier. The anticlinal fold, at the crest of the foreslope, has an anomaly averaging +100 mgal, less than that over Mussau Ridge. On the anticlinal fold in the vicinity of volcanic islands, however, the anomalies are larger. Farther south, the broad sedimentary basin has a positive anomaly much subdued in relation to its elevation. The islands on to the south, New Hanover and New Ireland, also have a relatively high gravity expression of +100 mgal.

Gravity ridges with a high positive anomaly trend north-south and connect the anticlinal fold and the islands of the Bismarck Archipelago. The gravity ridge farthest to the east, at 152.4°E, has one of the two active solfatara (fumarole) fields of this area, situated on Lihir Island (Fisher, 1957).

Magnetics

Magnetic anomalies at sea have been used to indicate, clarify, or define submarine structures, and recently the anomalies have been used to support the theory of sea-floor spreading. Magnetic anomalies are dependent upon several factors, among which are: the magnetic susceptibility of the basement rock; the quantity of rock intruded or extruded; its position relative to the geomagnetic equator; and the time required for the extrusion to be completed.

Even though some Pacific seamounts have magnetic anomalies of several thousand gammas (Bullard and Mason, 1963), their anomaly magnitudes vary according to the factors mentioned above. Many anomalies are small, for example, for a seamount formed at the geomagnetic equator where the magnetic field is weakest. Mafic rocks tend to contain more magnetic minerals than silicic rocks, but if the seamount is deficient in magnetic minerals, the magnetic anomaly associated with the seamount will also be small. If the seamount was formed over a period of time during which one or more magnetic reversals occurred, the reversals will tend to cancel one another and the overall anomaly may be negligible.

The strike of a linear magmatic feature will also affect the magnitude of the anomaly. A north-striking linear feature is parallel to the geomagnetic field and the contrast from positive to negative over its length is slight; consequently the anomaly will be small.

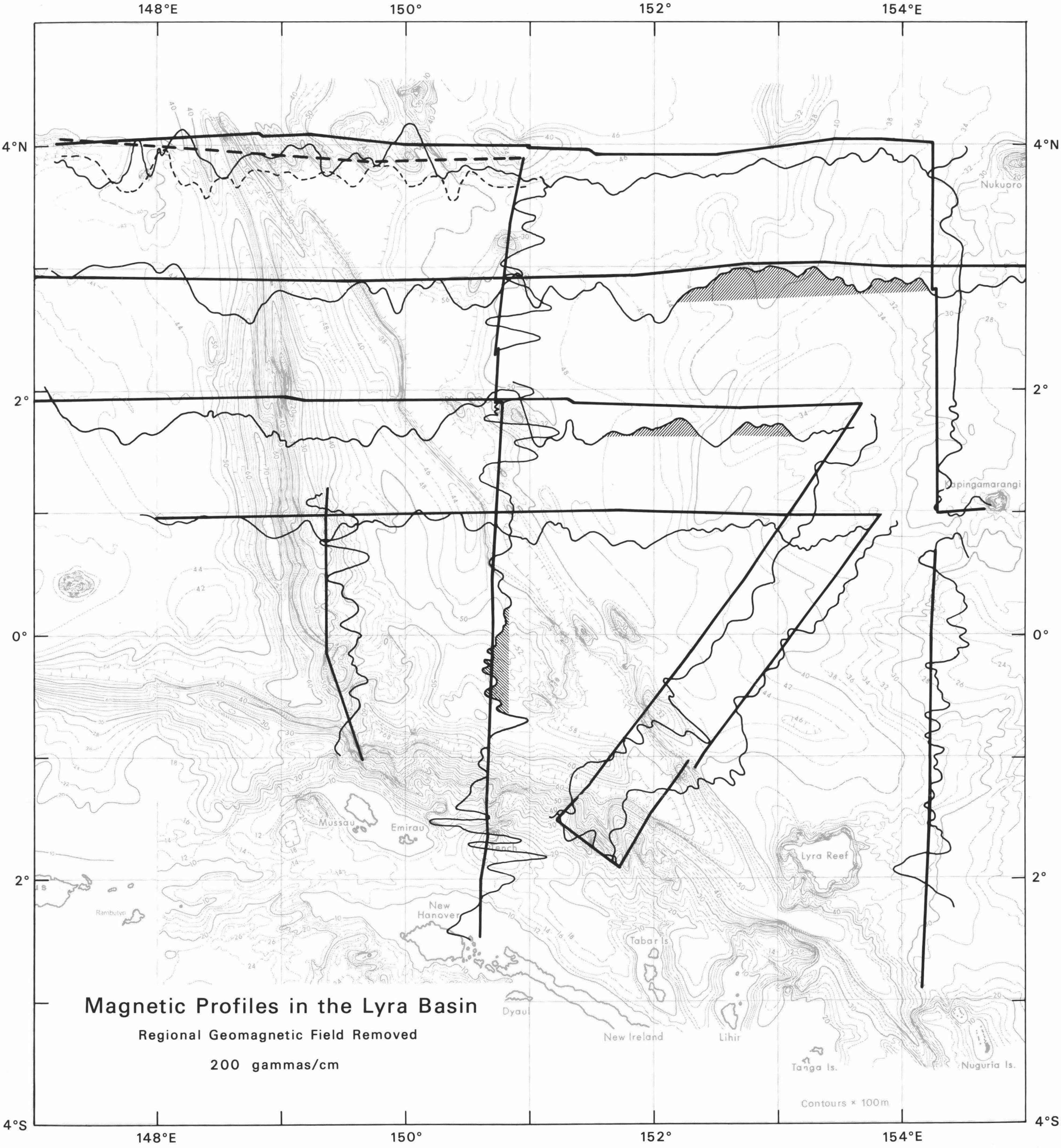
The magnetic anomalies in the Lyra Basin tend to be quite subdued, or even absent where they might have been expected. There are no significant anomalies over the Mussau Trough or its adjacent ridge, over the triangular and highly faulted western flank of the basin, or over the large block faults of the eastern flank of the basin (Figure 12).

The eastern rim of the Lyra Trough has some small scale anomalies, of about ± 150 gammas north of the equator and ± 225 gammas south of the equator. Other anomalies of the same general magnitude are apparent on the two adjacent tracks in the northwesternmost section of the map. The dissimilarity of the anomalies on these two tracks indicate that they are not linear, and, like the anomalies on the eastern rim of the Lyra Trough, they are probably the result of the numerous seamounts which are in the two areas.

In several areas the anomalies exhibit a broad rise at noon local time. These are interpreted as diurnal variations in the geomagnetic field and not due to structure as magnetic anomalies. They are marked by shaded profiles on Figure 12.

With the magnetic signature of the Lyra Basin in mind, the factors which give rise to magnetic anomalies

Figure 12. Magnetic profiles in the Lyra Basin. Magnetic anomalies are not significant over the Mussau Trough and Ridge, the western Lyra Basin, or the fault blocks of the eastern flank of the basin. Anomalies on the eastern rim of the Lyra Trough and the northwestern tracks are due to rough topography. Shaded parts of profiles show diurnal variations.



Magnetic Profiles in the Lyra Basin

Regional Geomagnetic Field Removed

200 gammas/cm

can be used to support a tectonic history. This is done not by the presence of certain anomalies but by their absence, and will be discussed in a later section.

Seismic Refraction

The seismic refraction data in the Lyra Basin are sparse, and the crustal thicknesses that are available are not conclusive. Hussong (1972) has presented all of the seismic refraction data of the area which has been reduced at HIG, namely, one line of ASPER stations (Figure 13). In these Lyra Basin stations, mantle was never reached, a result that was partially attributed to the complex structure in the area. Also, none of the ASPER stations shows any layers which are correlatable by velocity or thickness to layers underlying the neighboring Ontong Java Plateau (Hussong, 1972).

Even with only one line of reliable data, it is apparent that the crust in the Lyra Basin is not as thick as the crust of the neighboring Ontong Java Plateau, where crust attains a thickness of 30 to 40 km (Figure 13). Although there are good data to the east on the Ontong Java Plateau, and to the west in the East Caroline Basin, for the Lyra Basin itself, the seismic refraction data "are not sufficient to warrant any speculation on the geology and crustal configuration of this region at this time" (Hussong, 1972, p. 83).

Figure 13. Seismic refraction in the Lyra Basin, redrawn from Hussong (1972). In the Lyra Basin stations the Moho was not reached. The structure of the basin, however, is notably dissimilar with line W of the Ontong Java Plateau.

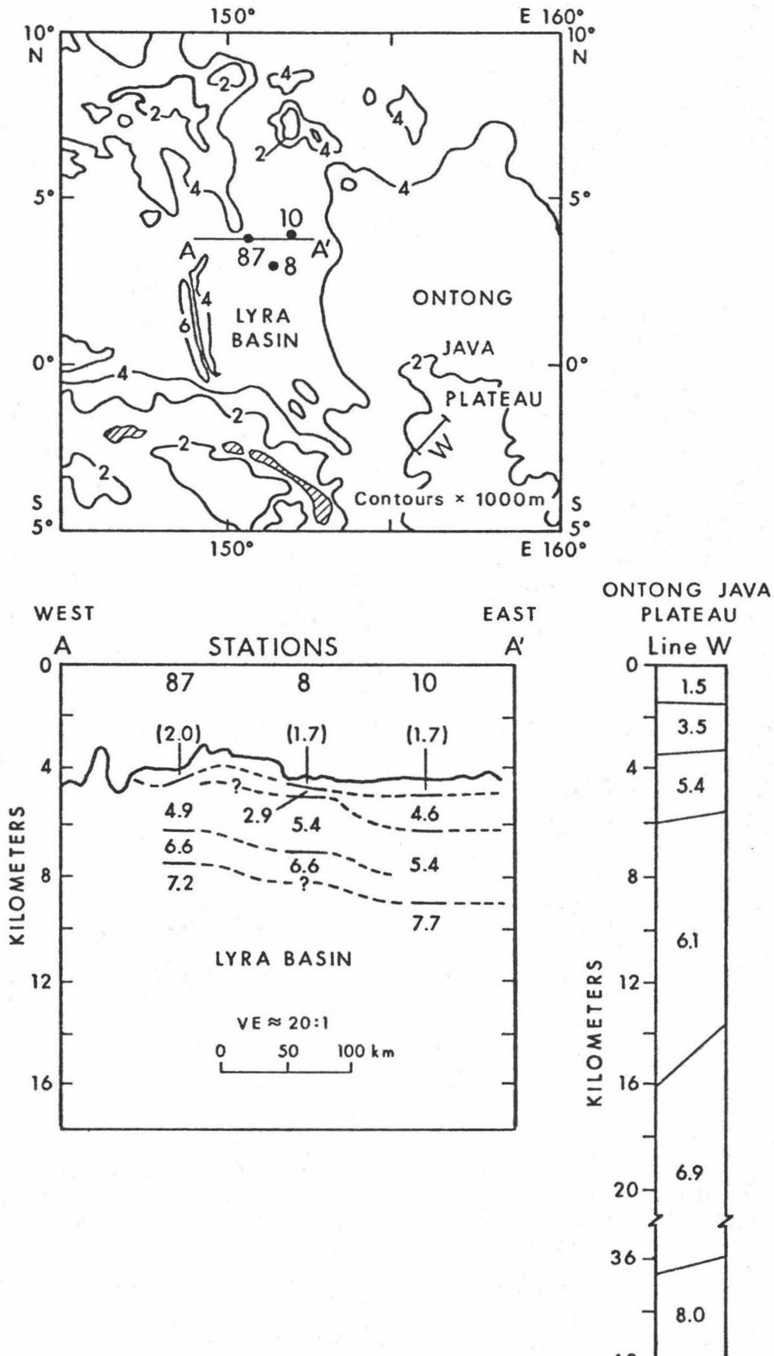

150°
E 160°
10° N
5°
0°
S 5°
LYRA BASIN
ONTONG
JAVA
PLATEAU
Contours × 1000m
A
A'
87
8
10
W
WEST
EAST
STATIONS
KILOMETERS
(2.0)
(1.7)
(1.7)
4.9
2.9
5.4
4.6
6.6
6.6
5.4
7.2
7.7
LYRA BASIN
VE ≈ 20:1
0 50 100 km
ONTONG JAVA PLATEAU
Line W
1.5
3.5
5.4
6.1
6.9
8.0

Figure 13

DISCUSSION OF TECTONIC ACTIVITY

The tectonic framework and history of events in the Lyra Basin are tied closely to the history of the adjacent Caroline Basin. Erlandson and others (1975) have proposed a history for the Caroline Basin that is outlined as follows:

1. The oldest event was the generation of the crust by sea-floor spreading, which was initiated along the western margin of the Ontong Java Plateau. The ridge crest thereby migrated westward from the plateau.

2. Spreading continued and compressional stresses accumulated within the newly formed crust, due to the interactions of the spreading system with the Ontong Java Plateau and the northward-moving Australian plate.

3. Compression was relieved by underthrusting (subduction) in the Mussau Trough allowing tensional features to form.

4. Spreading ceased in late Oligocene time, but a continued outpouring of basalts on the Euripik Ridge thickened the crust and preserved the topographic relief there.

5. The region subsided.

6. Continued northward movement of Australia initiated subduction on the Manus Trough.

7. Interactions between the Pacific and Australian

plates resulted in intraplate readjustments along pre-existing structure.

The discussion of tectonic activity in the Lyra Basin will emphasize these topics that could not have been studied in the Caroline Basin or the Ontong Java Plateau: evidence for subduction with the concurrent formation of the Mussau Trough and Ridge separating the Lyra Basin from the Caroline Basin; two periods of faulting which appear throughout the area; and the morphological and structural features of the Manus Trough and the Bismarck Archipelago. The problem of locating the crustal boundary between the Lyra Basin and the Ontong Java Plateau is also covered below under a separate heading, but it, unlike the other topics discussed, is not specifically affected by the overall history of spreading and later deformation in the Caroline and Lyra Basins. There would have to be a western limit to the plateau basalts regardless of what formed the sea-floor farther to the west.

Evidence for Subduction

Subduction in the Mussau Trough is fairly well substantiated by the data presented in this paper, and does not depend on whatever style of spreading might be proposed for the Caroline Basin. The similarity between the gravity data over the Mussau Trough along with 10km eastward displacement relative to the topography, and published gravity data that has been obtained from other trenches is remarkable (Table 1). The subdued nature of the gravity values in the Lyra Basin is as expected, because subduction probably ended in the late Oligocene. The absence of significant magnetic anomalies over the Mussau Trough is also consistent with published data over ocean trenches (Fisher and Hess, 1963). The absence of any area of sediment thickness intermediate between sediment thickness at the western and the eastern sides of the Mussau Trough, which have less than .5 sec. and more than .6 sec. of sediment respectively, may be explained by a loss of sea floor into the Mussau Trough.

The Mussau Trough looks more like a trench in the south than it does in the north. This is seen in the reflection profiles of Figures 4 and 6, and was described earlier in the section on physiography as a northward decrease in gradient of the outer slope of the Mussau Trough and a northward increase in gradient of the eastern slope of the Mussau Ridge. Gravity data show a progressive loss towards the north of both the amplitude of the free-air anomalies and their 10km-eastward displacement relative to the bathymetry. Perhaps there has been greater subduction in the south, as suggested by the eastward displacement of the southern portion of the spreading center (Euripik Ridge).

The persistence of the gravity anomaly and topographic relief long after the cessation of subduction suggests that a substantial portion of sea floor which was subducted may still be beneath the arc-trench system.

Additional evidence bearing on the question of subduction is seen in the seismic refraction and magnetic data. Seismic refraction data indicate a genetic relationship between the Lyra Basin and the East Caroline Basin because of a similarity in their crustal sections. The crustal sections of the Ontong Java Plateau, the Bismarck Archipelago, and Bismarck Sea, on the other hand, are all thicker than the Lyra Basin and do not indicate any obvious relationship (Finlayson and others, 1971; Furumoto and others, 1973).

Magnetic data suggest that the formation of the Lyra Basin was like the East Caroline Basin, post-Cretaceous. The absence of strong magnetic anomalies in the Lyra Basin suggests that it was formed closer to its present position near the geomagnetic equator and, therefore, more recently than the Cretaceous crust of the Ontong Java Plateau, which was formed approximately 33° S (Kroenke, 1972; Andrews and Packham, 1973; Hammond and others, 1974). The seismic refraction and magnetic data, however, are less valuable than the topographic and gravity data in showing the relationship of the Lyra Basin to the Caroline Basin.

Periods of Deformation

The two periods of deformation listed in the sections on physiography are based on interpretations of structure and stratigraphy shown on seismic reflection records. The older deformation, including undulations on the outer ridge, northwest-striking structure in the western Lyra Basin, and the upper and lower blocks on the eastern flank of the Lyra Basin, is restricted to the lower two-thirds of the sedimentary sequence. The cessation of spreading on the Euripik Ridge (late Oligocene) indicates a minimum age for this deformation. The lower two-thirds of the sediments in the northern Lyra Trough (Figure 6, profile D-D') are seen to be severed by the tilted fault blocks of the eastern rim of the trough and overlain by younger, flat-lying sediments. This relationship dates the formation of the Lyra Trough as having been simultaneous with the older period of deformation.

The cause for faulting to occur within a short interval over as large an area as the Lyra Basin is attributed to the initiation of subduction in the Mussau Trough. Subduction released compressional forces within the basin, precipitating the near-simultaneous faulting.

The younger period of deformation has deformed the entire sedimentary sequence and it has also been found throughout the area of this study. An enigma arises when trying to place a time and cause to this younger period of faulting and buckling. A recent age might be inferred because the faults have severed even the youngest sediments, but the absence of seismic activity in the area prevents the conclusion that many faults are active today.

Paleomagnetic studies do not aid in solving the enigma because they indicate that the younger period of deformation cannot be attributed to recent changes in spreading rates or in spreading poles; no changes for the Western Pacific seem to have occurred with the last 10 or 12 my (Hammond and others, 1974; Minster and others, 1973).

Though the enigma exists, the second, younger period of deformation is interpreted as readjustments within the crust of the Lyra Basin in response to interactions between the Pacific and Australian plates, and faulting along already existing structure.

Manus Trough and the Bismarck Archipelago

The Manus Trough forms the southern boundary of the Lyra Basin. Because the Bismarck Archipelago lies outside the main area of this study and because good profiles over the archipelago are scarce, only a cursory examination has been made of this area.

The reflection profiles of Figure 10 suggest that subduction has been occurring in the Manus Trough for a long time, although the time that subduction began has not been determined. The advanced stage of the Manus Trough is inferred from the close similarity between the northern side of the Bismarck Archipelago and the accretionary fronts on the landward side of some of the active trenches. The relatively low gravity anomaly behind the inner slope of the Manus Trough suggests that low density material, perhaps sediments, has indeed accumulated to large amounts.

Lyra Basin - Ontong Java Plateau Boundary

Identification of the structural boundary between the Ontong Java Plateau and the Lyra Basin was one of the problems I had hoped to resolve in this thesis. This cannot be done at this time, however, with any degree of certainty.

One problem in resolving the boundary is that flood basalts on the plateau would be expected to form a lenticular body, with a regional thinning of oceanic crust rather than a sharp discontinuity.

One of the more useful tools needed to determine the boundary would be north-south seismic refraction lines on the upper and lower blocks of the eastern Lyra Basin. The only refraction sites with data in the Lyra Basin are aligned east-west (Figure 13), and are confined to the lower block; none of the refractions had reached the Moho. The results show that the crustal structure on the lower block is different from the Ontong Java Plateau. The difference between the plateau and the lower block is further indicated by a change in the acoustic stratification in the sediments as they pass to the lower block. The loss of reflectors that might be correlateable, from the upper block to the lower block, along with the gradual thinning of the sediments from their maximum on the plateau, indicate that the upper block was probably always nearer to the plateau's elevation than the lower block was.

The path that the zero milligal gravity contour makes on the eastern flank of the basin (Figure 11) is perhaps the best arbitrary border between the plateau and the basin. This assigns the upper block to the region of the plateau and the lower block to the Lyra Basin. The edge of the Ontong Java Plateau strikes northwest, more or less parallel to the strike of the Lyra Trough, and so the alignment of the Lyra Trough when it was formed may have been determined by the plateau.

SUMMARY AND HISTORY OF TECTONIC EVENTS IN THE LYRA BASIN

The Lyra Basin has been referred to as a marginal basin, and as such, there are some aspects which are unique to it. The Lyra Basin lies north of the northernmost extension of the Australian plate and entirely within the Pacific plate, marginal to a flood-basalt plateau rather than a continent, and formed in response to subduction from a small independent spreading center rather than from the Pacific Rise system.

Sea-floor spreading from the Euripik Ridge formed the crust of the Caroline and Lyra Basins. The Lyra Basin did not attain its physiographic distinction, however, until subduction began in the Mussau Trough and the Mussau Ridge was up-thrusted. Compressional stress in the Lyra Basin, which had been accumulating because of convergence between the Euripik Ridge spreading center, the Ontong Java Plateau, and the northward moving Australian plate, was relieved by the subduction, resulting in an episode of tensional faulting. Associated with this episode and belonging to the older of two periods of deformation are the northwest-striking undulations on the outer ridge of the Mussau Trough. Other tensional features of the same period are northwest-striking faults in the western Lyra Basin and blocks of the eastern flank of the Lyra Basin which have faulted down from the Ontong Java Plateau and ended in the Lyra Trough, a graben. Subduction began in the Manus Trough after activity in the Mussau Trough terminated. The earliest history of tectonic activity in the Manus Trough is not known, but the presence of a clearly identified trench, sediment-filled forearc basin, and volcanic arc of the northern Bismarck Archipelago are evidence that a substantial amount of subduction has occurred. Present seismic activity in the Manus Trough is weak suggesting that its subductive history may be coming to a close. Interactions between the Pacific and Australian plates caused readjustments along preexisting structure that faulted and buckled the entire sedimentary sequence. This second period of deformation is also found throughout the Lyra Basin, and may be continuing up to the present day.

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