REFLECTION PROFILING

INVESTIGATIONS OF THE EAST CAROLINE BASIN

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We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Geology and Geophysics.

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ABSTRACT

Analysis of continuous seismic reflection profiles obtained from the East Caroline Basin in the western equatorial Pacific show that a predominately smooth basaltic basement is overlain by relatively undisturbed Oligocene to Recent pelagic sediments. Correlation of the profiles with the sedimentary column drilled at DSDP sites 62 and 63, together with the morphology of the basement, suggest that the basement was rapidly emplaced. A north-south developmental history best explains the observed sediment distribution in the basin. Major deformation (pre-Miocene) occurred mainly at the margins of the basin. Two sets of gentle troughs and basins, which were found to be oriented north-south and northeast-southwest within the basin, may also have been formed at the same time. Tectonic subsidence of the basin in Miocene time probably reactivated many of the faults. Widespread, more recent, faulting has also occurred, with largest displacements found in the southern portion of the basin.

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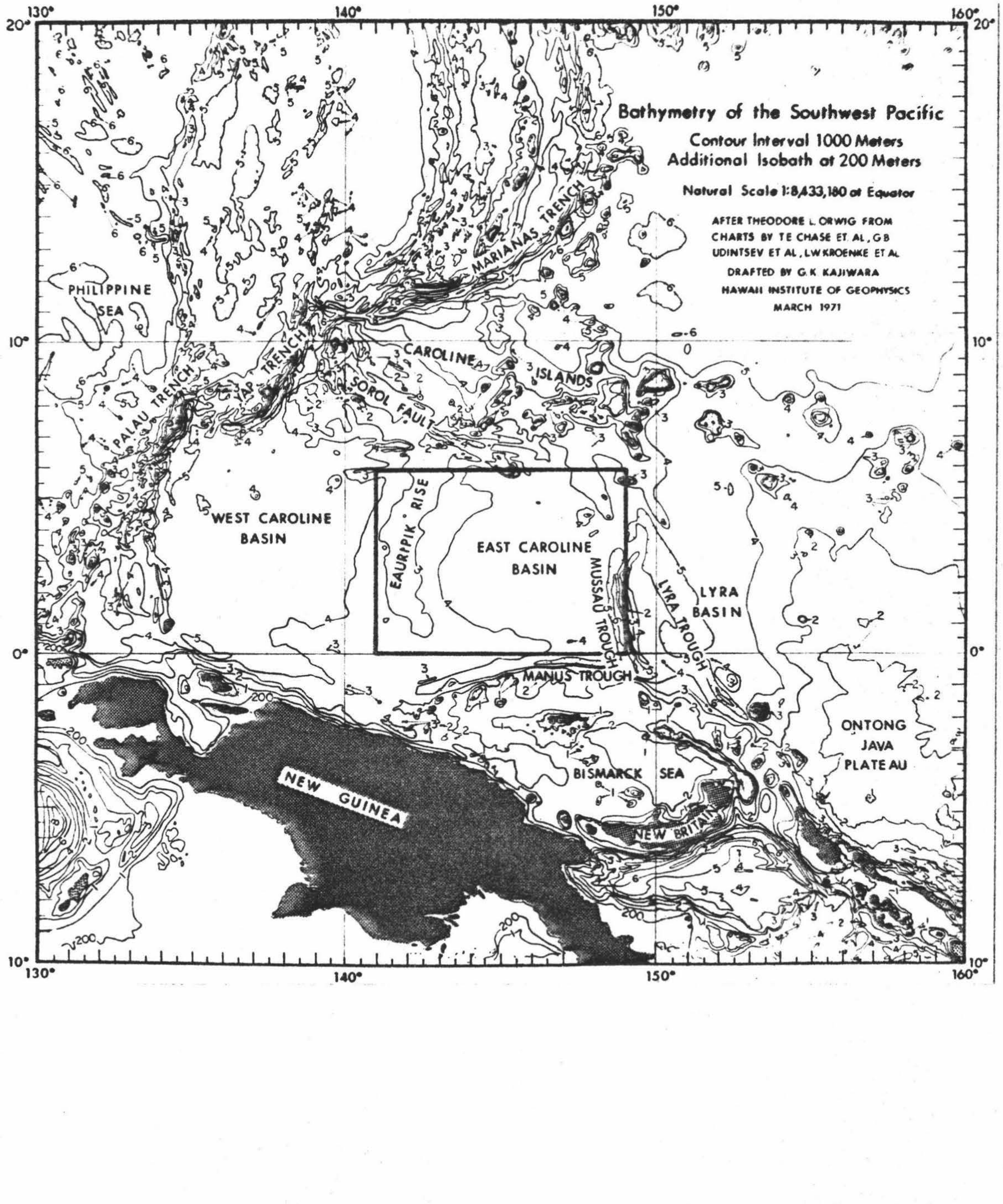
INTRODUCTION

The East Caroline Basin is situated north of New Guinea within the western equatorial Pacific. It is bounded to the north by the Caroline Ridge and intervening Sorol Fault (Hess, 1948) and to the east by the Mussau Trough. To the south lies the Manus Trough and New Guinea, and to the west the Eauripik Rise, which separates the East Caroline Basin from the West Caroline Basin. Situated farther to the west are the Yap and Palau trenches (Fig. 1).

The leg 7 scientific staff of the D/V GLOMAR CHALLENGER has shown that the basement within the East Caroline Basin and on the Eauripik Rise is of Oligocene age (Winterer, *et al*., 1971). Earlier work by the leg 6 scientific staff had shown that the Caroline Ridge to the north is also Oligocene in age. In view of the recent general acceptance of the New-Global-Tectonics and sea floor spreading theories (Le Pichon, 1968; Isacks, Oliver, and Sykes, 1968), it is surprising that such youthful crust is found to lie so far to the west of the East Pacific Rise and yet to the east of any active trenches. Two major questions have been posed regarding this region as a result of the work done on board the GLOMAR CHALLENGER: first what is the extent and nature of this young crust, and second, what was the mechanism of its emplacement? This present study attempts to describe the characteristics and history of the East Caroline Basin, and may help resolve the question regarding the genesis of the general region. The analysis of continuous reflection profiles gathered at sea by the Hawaii

Figure 1. Bathymetry of the southwestern Pacific (after Orwig). Chart 2 (the East Caroline Basin) covers the area shown as the inset.


Bathymetry of the Southwest Pacific
Contour Interval 1000 Meters
Additional Isobath at 200 Meters
Natural Scale 1:8,433,180 at Equator
AFTER THEODORE L. ORWIG FROM
CHARTS BY T.E. CHASE ET. AL., G.B.
UDINTSEV ET AL., L.W. KROENKE ET AL.
DRAFTED BY G.K. KAJIWARA
HAWAII INSTITUTE OF GEOPHYSICS
MARCH 1971
PHILIPPINE SEA
MARIANAS TRENCH
PALAU TRENCH
YAP TRENCH
CAROLINE ISLANDS
SOROL FAULT
WEST CAROLINE BASIN
EAURIPIK RISE
EAST CAROLINE BASIN
MUSSAU TROUGH
LYRA TROUGH
LYRA BASIN
MANUS TROUGH
ONTONG JAVA PLATEAU
BISMARCK SEA
NEW BRITAIN
NEW GUINEA
130°
140°
150°
160°
20°
10°
0°

Institute of Geophysics (HIG) during 1970 and 1971 forms the basis of this work.

Depths to the sea floor in the East Caroline Basin average near 4400 meters. Generally well-stratified pelagic sediments vary in thickness from about 0.6 seconds of reflection time near the equator to about 0.3 seconds at 4 degrees north latitude. Where drilled by the GLOMAR CHALLENGER, the sediments lie on basaltic basement. Remarkably smooth basement characterizes the central portion of the basin, whereas rougher basement topography, resulting largely from structural deformation, is found around the margins of the basin. Because the basin is so characterized, an excellent opportunity exists to correlate reflectors within the basin. Consequently, ages of tectonic events in the region can be determined. Deep Sea Drilling Project (DSDP) site 62 on the Eauripik Rise and site 63 on the eastern margin of the basin provide control for the correlation.

GEOLOGIC SETTING

Bathymetric and seismic trends delineate clear boundaries between regions surrounding the East Caroline Basin. Along the north coast of New Guinea, earthquakes of shallow and intermediate depth occur in abundance. Early studies implied that an ill-defined plane of seismicity, similar to those found associated with many trenches, dipped southwards (Gutenberg and Reichter, 1941). Recent work has shown the region to be more complex (Denham, 1969). Two clear belts of earthquakes are found for this region: one extends along the coast of New Guinea into the adjacent New Britain-New Ireland earthquake belt; the other one splits off from the coast of New Guinea and extends across the Bismarck Sea to the north of New Ireland (Denham, 1969).

These belts merge near New Ireland and continue eastward along the Solomon Island group as one earthquake belt. No easily discernible dipping plane of earthquakes is seen along the north coast of New Guinea. Hypocenters of shallow and intermediate depth are generally located within the same vertical section. To the west, near Borneo, the patterns of earthquakes become still more complicated (Barazangi and Dorman, 1969). The general area is characterized by several trenches and marginal ocean basins (Menard, 1967).

Left-lateral shear zones have been reported for northern New Guinea (Krause, 1965). Theoretical studies suggest that the rate of accumulative strike-slip displacement amounts to 9 to 11 centimeters per year along these faults (Le Pichon, 1968).

The earthquakes of northern New Guinea evidently result from the interaction of the Australian-New Guinea block with the Pacific plate. Apparently, the crust of the Pacific is moving westward relative to the Australian block, which is moving northward relative to the Pacific.

The Marianas-Yap-Palau trench system appears to mark the eastern margin of the Philippine plate (Katsumata and Sykes, 1969). Associated with these trenches, and closely paralleling them, are zones of earthquakes. Interestingly, only shallow focus earthquakes appear to have been recorded for both the Yap or the Palau trenches, whereas deeper focus earthquakes are common along the Marianas Trench (Katsumata and Sykes, 1969; Barazangi and Dorman, 1969).

West of the Yap-Palau trenches, structural trends strike largely in a north-south direction (Chase and Menard, 1969). These north-south trends appear to extend as far as New Guinea. Krause (1965) has pointed out that two distinct structural trends, striking north-south and east-west, are found to the north of New Guinea. The boundary between these two trends is Mapia Ridge, which is roughly the geographical extension of the Palau Trench. It appears probable that the Philippine plate west of Mapia Ridge and the Palau Trench is characterized by primarily north-south trends.

East of Mapia Ridge lies the West Caroline Basin. Unlike the Philippine plate, the West Caroline Basin is a generally flat region.

In the southern portion, near New Guinea, shallow basins are oriented in an east-west direction (Krause, 1965). On the equator, and adjoining the East Caroline Basin, is located the enigmatic Manus Trough, which also strikes in an east-west direction.

North of the Caroline basins and trending in a roughly parallel direction to the New Guinea seismic belt lies the Sorol Fault zone (Hess, 1948). The Caroline Ridge is situated just to the north and strikes in a similar direction. Large grabens and step faults that parallel the Sorol Fault are located within this region (Andrews, 1971). Reflection records reveal that the basement marginal to, and including, the Sorol Fault is highly deformed.

Associated with the Caroline Ridge area are earthquakes having hypocenters shallower than 35 kilometers (Katsumata and Sykes, 1969). However, their distribution is relatively widespread and no obvious pattern is observed for the ridge.

A natural designation for the eastern boundary of the East Caroline Basin is the north-south oriented Mussau Trough. Hess (1948) has pointed out that the Mussau Trough is "one of the very few places in the ocean, outside the trenches related to island arcs, where the depth exceeds 3500 fathoms". Analysis of reflection profiles has revealed that the structure to the east, where the northwest-southeast striking Lyra Trough is found, is complicated (Orwig, et al., 1972). The transition from the unusually thick sedimentary sequences of the much older (Cretaceous?) Ontong Java Plateau (Kroenke, 1972) to the thinner sediment within the younger (Oligocene) East Caroline Basin (Winterer, et al., 1971) must occur within the Lyra Basin or at the Mussau Trough. The exact location of this transitional zone has not yet been identified and therefore, the Mussau Trough may not represent a genetic boundary between the East Caroline Basin and the older region to the east.

Detailed contouring of the bathymetry of the Lyra Basin by Orwig, et al. (1972) has shown the Lyra Trough, which is located within the Lyra Basin, to be a remarkably straight feature extending hundreds of miles in a northwest-southeast direction. Depths within the trough exceed 5400 meters. To the east, large blocks of the western portion of the Ontong Java Plateau have been downfaulted into the Lyra Basin (Kroenke, 1972). A thick sedimentary column is found in the Lyra Basin east of the Lyra Trough which may have affinities with that found on the Ontong Java Plateau (Orwig, et al., 1972). It therefore appears likely that either the Lyra Trough or the Mussau Trough represents the genetic boundary between the East Caroline Basin and the older region to the east.

DATA PROCESSING

Initial Processing

This study is based primarily on the analysis of continuous seismic reflection profiles from portions of the Hawaii Institute of Geophysics 1970 cruise, legs 3 and 4 (R/V MAHI), and the 1971 cruise, leg 2 (R/V KANA KEOKI). In addition, tracings and photographs from D/V GLOMAR CHALLENGER reflection records were analyzed for the part of leg 7 between drill sites 62 and 63. Bathymetry recorded by the R/V BARTLETT is also incorporated in the bathymetric map, as are certain features shown in the bathymetry published by Chase and Menard (1969).

The shipboard techniques used in the recording of continuous reflection profiles on HIG cruises have been described by Kroenke (1972) and need not be reviewed here. Satellite navigation was used for all cruises. The ship tracks were determined by computer from navigation records.

Whereas bathymetry was determined from tracings of reflection profiles for the GLOMAR CHALLENGER track, 3.5 KHz or 12 KHz records were used for the R/V MAHI and R/V KANA KEOKI tracks. R/V BARTLETT bathymetry was received in computer print-out form. All of the bathymetric data were corrected for the changes in the speed of sound in sea water as a function of depth for this region (Matthews, 1939). All bathymetry was processed by computer.

Correlation of a Miocene Horizon

A prominent middle Miocene reflector that was reported for sites 62 (at 390 meters) and 63 (at 140 meters) has been traced throughout the East Caroline Basin. This is apparently the same reflector that was traced by Den *et al*. (1971) and by Winterer *et al*. (1971).

The reflector is interpreted here as being an isochronous surface. Correlation between the two drill holes supports this interpretation, at least for the southern part of the basin. The nature of deposition in this region would seem to exclude disturbing effects which might alter the smooth character of the stratigraphic record. As will be shown, there is evidence that, although occurring to some degree, bottom currents are not presently powerful enough to greatly disturb the column. Nor do they appear to have been much more powerful in the past. Also, the environment of deposition appears to have remained relatively uniform throughout the East Caroline Basin. All this points to deposition under rather uniform conditions, which certainly does not detract from the assumption of the isochronous nature of the reflector. Furthermore, agreement in depth to the reflecting horizon (middle Miocene) at ship-crossing points is good. Also the highly stratified appearance of the sediments, together with their conformable relationship, lends support to the presumed isochronous nature of the horizon.

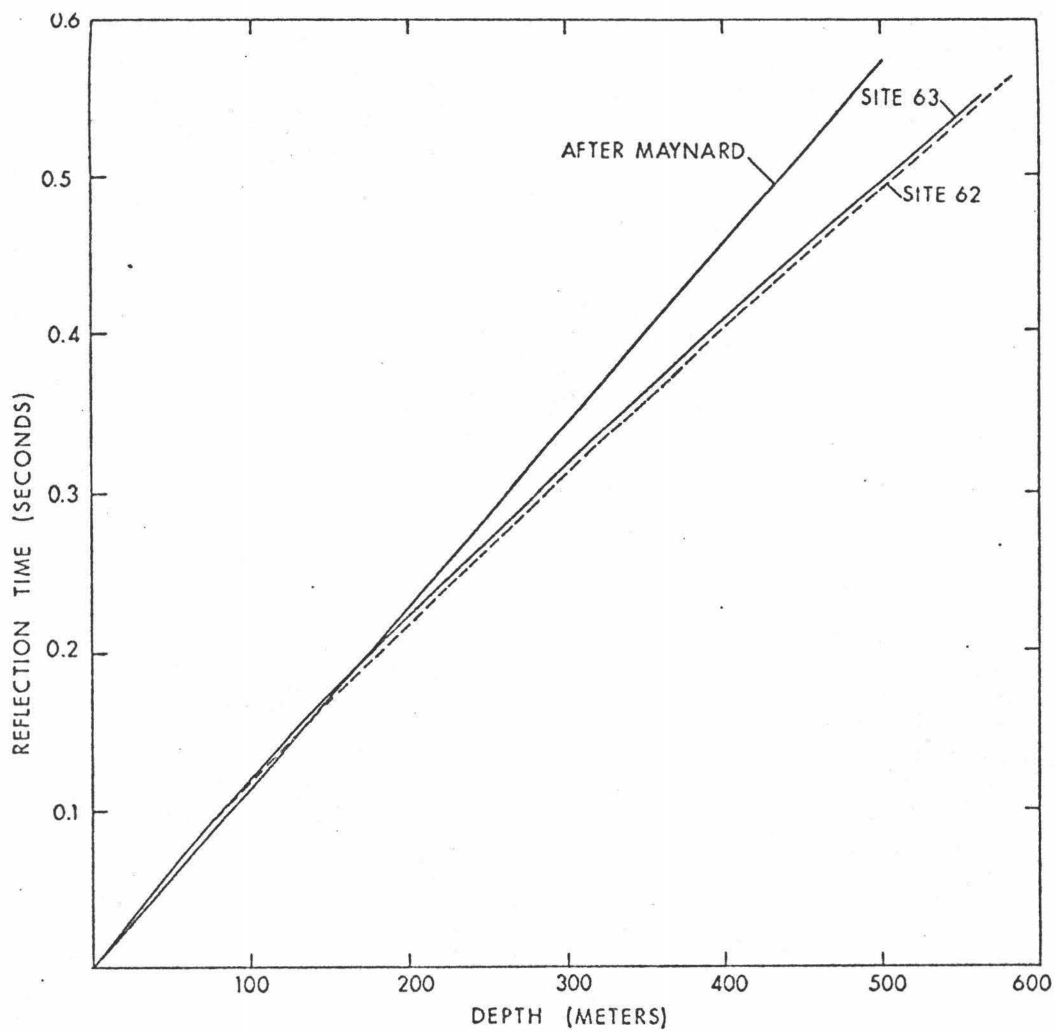
It should be pointed out, however, that the reflector corresponding to this horizon changes character from place to place. This can probably be attributed to slight lateral variation in the composition of the sediments. Careful tracing of phantom horizons appears to justify correlation. The middle Miocene horizon that has just been discussed is shown as a heavier line in the accompanying illustrations within the text.

Sediment Acoustic Velocities

The excellent core recovery for DSDP sites 62 and 63 provided a means for determining reflection time-depth curves for these sites, which in turn allowed a correction factor to be applied to the observed depths (in seconds) on the reflection profiles, thus yielding true sediment thicknesses. Depths and reflection times of lithologic boundaries within the cores have been reported (Winterer et al., 1971). A plot of these points on a graph (having depth as a function of reflection time) places constraints on the shapes of the reflection time-depth curves. If a continuously increasing velocity with depth is assumed (this assumption is supported by reported increased induration with depth), smooth curves can be fit to the data. This has been done and curves for both sites are shown in Fig. 2.

The general shape of the two curves appears to be relatively independent of the length of time that the sediment has resided on the ocean floor. This hypothesis is based on the fact that deposits of Miocene to Recent age are more than two times thicker at site 62 than at site 63 (390 m. vs. 140 m.). The sediments cored at the two sites show close similarity in composition, with

Figure 2. Reflection time versus depth curves for DSDP sites 62 and 63 and after Maynard (ms. in prep.). Maynard's curve was determined from an average of wide angle reflection and refraction measurements on the Ontong Java Plateau.


0.6
0.5
0.4
0.3
0.2
0.1
REFLECTION TIME (SECONDS)
AFTER MAYNARD
SITE 63
SITE 62
100
200
300
400
500
600
DEPTH (METERS)

one significant exception where a higher percentage of clay was cored in the upper 100 meters at site 63.

It therefore appears that the lack of variation in sediment type between the two sites, at least below 100 meters, contributes to the similarity in the velocity structure between the two sites. The considerable age difference for horizons of equal depth (below 100 meters), in conjunction with the remarkably similar curves, suggests that the major factor contributing to increased velocity with depth is compaction or induration of the deeper sediments.

Preliminary determination of velocity versus depth from the reflection time-depth curve (Fig. 2) for site 63 indicates that the velocity increases most rapidly near depths corresponding to the major reflectors (0.16 and 0.36 seconds). These depths correspond to decreases in the drilling rates. This fact, along with the similar appearance of the curves for the two sites previously discussed, indicates that the curves appear to be reliable. In addition, the general shape of these curves, when converted to a velocity-depth curve, is in agreement with empirically derived curves for deep sea sediments (e.g. Houtz, et al., 1968; Nafe and Drake, 1957).

Determination of Mean Sediment Thicknesses

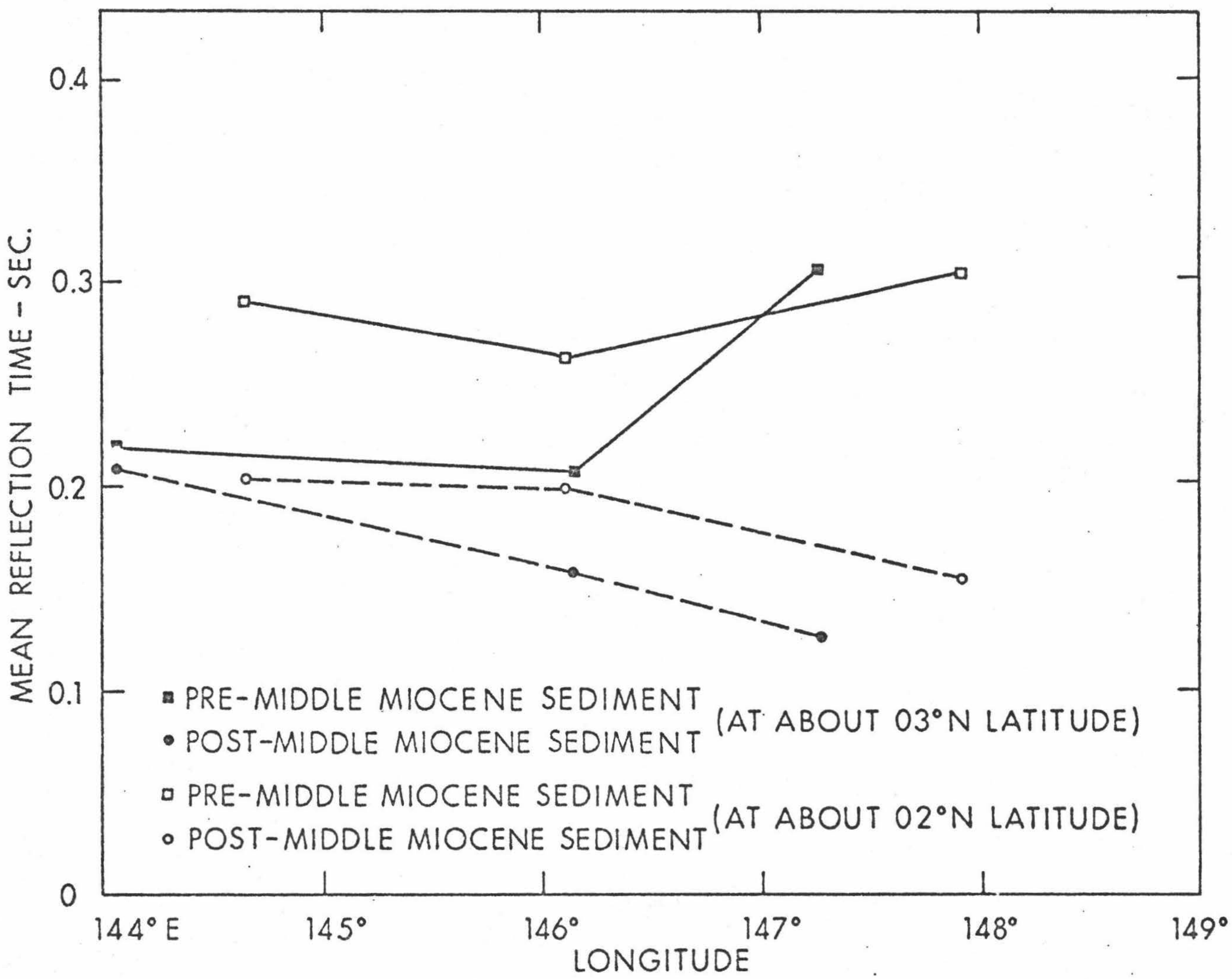
The mean reflection times for both pre-Miocene sediments and post-Miocene sediments have been determined for several reflection profiles. Plots of these determinations (in seconds) as a function of either latitude or longitude (the other parameter being held constant) are shown in Fig. 3 and Fig. 4.

Three factors governed the selection of the profiles used for these determinations. First, all represent approximately the same average depth range within the East Caroline Basin (about 4300 to 4500 meters). Secondly, all were chosen such that a plot of the positions would either be aligned north-south or east-west. Thirdly, all are relatively far from, and consequently uneffected by, major bathymetric features such as the Eauripik Rise and the Mussau Trough. All plots have been normalized to equal length and corrected for variations in ship speed. The location of each profile is shown on the track chart (chart 1).

The plots give an indication of mean sediment thicknesses versus position within the East Caroline Basin and can be used to compare the relative sediment thicknesses in regions of rough basement topography. Local variations due to basement topography, should average out to yield an estimate of the sediment present. Possible interpretations of the significance of these results will be discussed later.

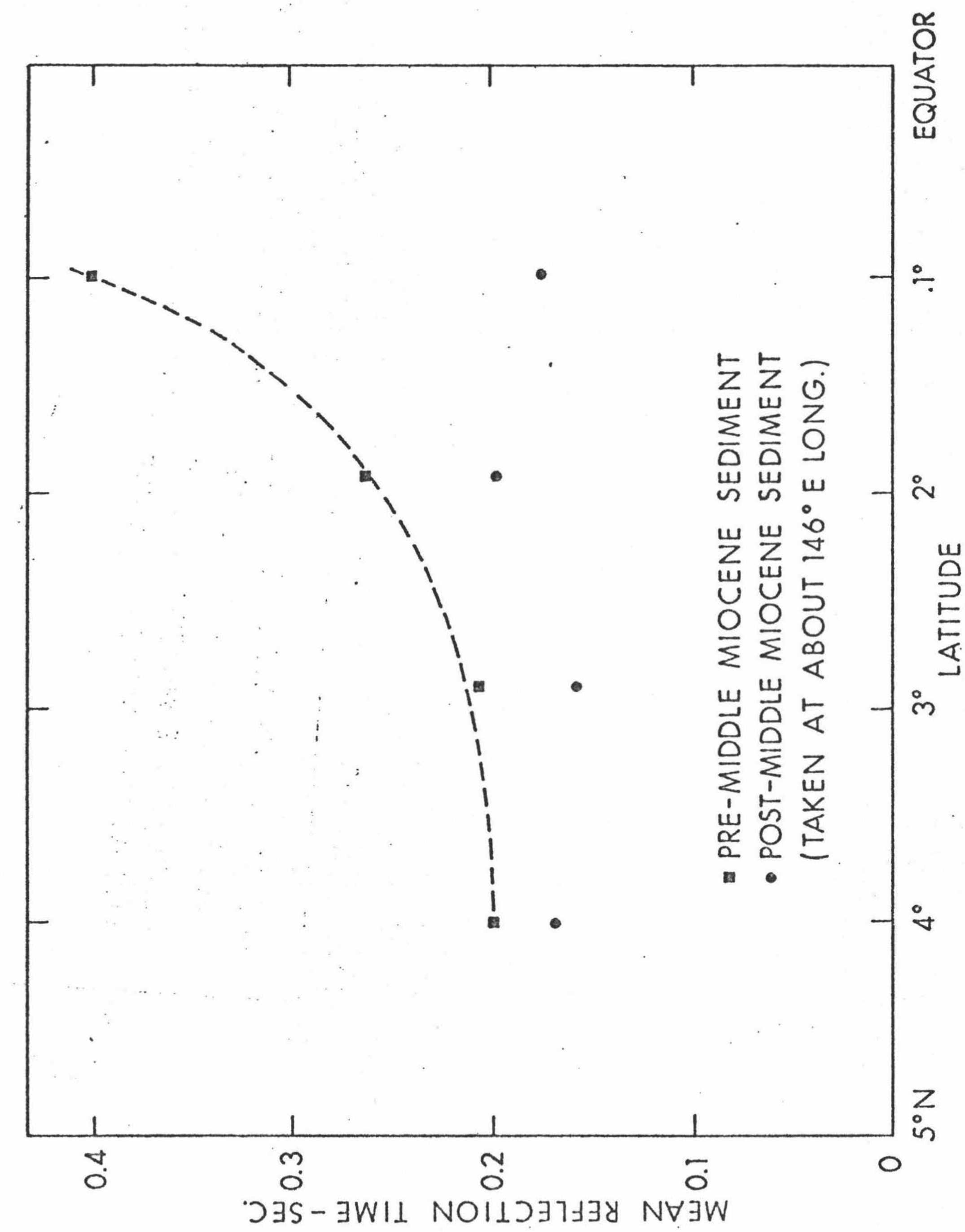
Since the middle Miocene horizon is believed to have been identified and correlated throughout the basin, average sediment accumulation rates can be inferred from the plots. However, caution should be exercised in the interpretation of the results shown by these plots. The thicknesses are uncorrected for the

Figure 3. East-west plots of mean sediment thicknesses (in seconds of reflection time). The profiles used for determination of plots are shown on chart 1.



0.4
0.3
0.2
0.1
0
MEAN REFLECTION TIME - SEC.
144° E
145°
146°
147°
148°
149°
LONGITUDE
PRE-MIDDLE MIOCENE SEDIMENT
POST-MIDDLE MIOCENE SEDIMENT
(AT ABOUT 03°N LATITUDE)
PRE-MIDDLE MIOCENE SEDIMENT
POST-MIDDLE MIOCENE SEDIMENT
(AT ABOUT 02°N LATITUDE)

Figure 4. North-south plot of mean sediment thicknesses (in seconds of reflection time). The profiles used for determination of the plots are shown on chart 1.



PRE-MIDDLE MIOCENE SEDIMENT
POST-MIDDLE MIOCENE SEDIMENT
(TAKEN AT ABOUT 146° E LONG.)
MEAN REFLECTION TIME - SEC.
0.4
0.3
0.2
0.1
0
LATITUDE
5°N
4°
3°
2°
1°
EQUATOR

velocity of sound within the sediments. Also a number of geological processes (discussed in the following pages), if active at some time in the past within the East Caroline Basin, could be expressed as an anomalous datum point.

THE ACOUSTIC REFLECTORS

Principles

In general, the character of a reflector or a series of reflectors that is produced on a record may be attributed to three parameters: (a) the strength and frequencies of the incident sound pulses, (b) the geometry of both the reflector together with that of adjacent reflectors, and (c) the physical properties of rock or sediment corresponding to the reflecting horizons.

Standard principles of acoustics may be applied in the interpretation of the record. For example, high frequency sound pulses fail to penetrate sediment well and are directional. Lower frequencies penetrate well and are less directional. Thus, greater occurrence of interference patterns resulting from non-planer surfaces are seen for low frequencies.

The geometry of the reflectors largely results in the type of interference patterns seen, as well as the degree of scattering and diffraction of the incident energy off the bottom features. For instance, a sharp bathymetric high on the ocean floor results in a lighter (less energy returned) record for this feature. Conversely, well stratified sediments lying horizontally generally reflect energy well, resulting in a darkened record (more energy returned). Another example of the importance of the geometry has been pointed out by Kroenke (1972). Critical spacing of reflectors can result in the reinforcement or cancellation of wave trains depending on the frequencies used.

The geologically and acoustically most important, and therefore most well investigated, factor governing the character of reflectors is that of the physical properties of the sediment or rock that are reflecting the acoustic energy. The percentage of energy reflected from a lithologic unit depends upon the acoustic impedance contrast across the interface between the units where reflection occurs. The acoustic impedance in turn is dependent upon the differences in rigidity and bulk density of the two units.

In addition to the factors just outlined, the type of recording and receiving equipment along with its mode of operation and deployment, water depths encountered, and the degree of bottom roughness, are of importance in the interpretation of reflection records. These matters have been discussed by Hersey (1963) and later by Ewing and Ewing (1971).

The Sediments

The sediments of the East Caroline Basin exhibit well-stratified acoustic reflectors corresponding to thick sequences of pelagic carbonates and clays. The reflectors generally show less stratification with increasing depth. This usually is interpreted as resulting from a combination of geologic processes such as deformation caused by faulting (and in some cases by intrusion), and increased induration and other diagenetically-induced changes with depth.

The profiles taken in the southern part of the basin generally show strong reflectors within both the upper and lower portions of the column. The profiles taken farther north often show strong reflectors within the upper column only. In addition to this regional variation, some smaller-scale lateral variations in strength of individual reflectors occur. A reflector may appear to fade in or out from place to place.

Notwithstanding however, the general overall similarity of the reflectors is probably of more significance than the variations in reflector character. This general similarity in overall appearance encompasses not only the East Caroline Basin reflectors but those of the Eauripik Rise and the West Caroline Basin as well.

Cores retrieved from DSDP site 62 show the sedimentary column to be composed primarily of calcareous nannofossils. The lithology varies from chalk ooze near the surface to chalky limestone near the bottom to dolomite above the contact with the intruded basalt. The sediments have been described as "strikingly uniform in composition from top to bottom, and aside from local contact metamorphism in the basal sediments, the only significant changes are those due to increasing induration" (Winterer, _et al_., 1971). One noticeable horizon containing volcanic glass and ash was found to occur between 90 and 110 meters depth below the surface. Furthermore, some nodular chert was encountered in the lower part of the section.

The significant lithologic differences between the sediments cored at site 62 and those cored at site 63 are the pelagic clays and marly calcareous oozes which compose the upper 100 meters of the column at site 63 (Winterer, _et al_., 1971). Volcanic glass of both intermediate and basic composition was also found here. Beneath the upper 100 meters, calcareous ooze grades down into chalk. Flinty chert was also encountered near the base of the section.

Frazer, et al., (1972) have classified the surface sediments within the East Caroline Basin below about 4400 meters of water depth as pelagic clays. Whereas, they classify nearly all of the other surface sediments as calcareous ooze.

Thus, it appears that the sediments within the Caroline basins and on the Eauripik Rise are primarily pelagic clays and calcareous ooze grading down to chalk and chalky limestone. Volcanic glass and ash, as well as chert, are also present in small amounts and may form some reflectors. Aside from clays within the deeper portions of the basin, the sediments apparently remain quite uniform throughout the basin. This general uniformity is consistent with observations from the reflection profiles.

The Basement

A strong acoustic reflector corresponding to basaltic basement is observed on the reflection profiles for nearly all portions of the area of study. Aside from a few areas in the northern region, the reflecting character of the basement remains the same and is persistent throughout the East Caroline Basin, the Eauripik Rise, and on the two sets of profiles studied within the West Caroline Basin.

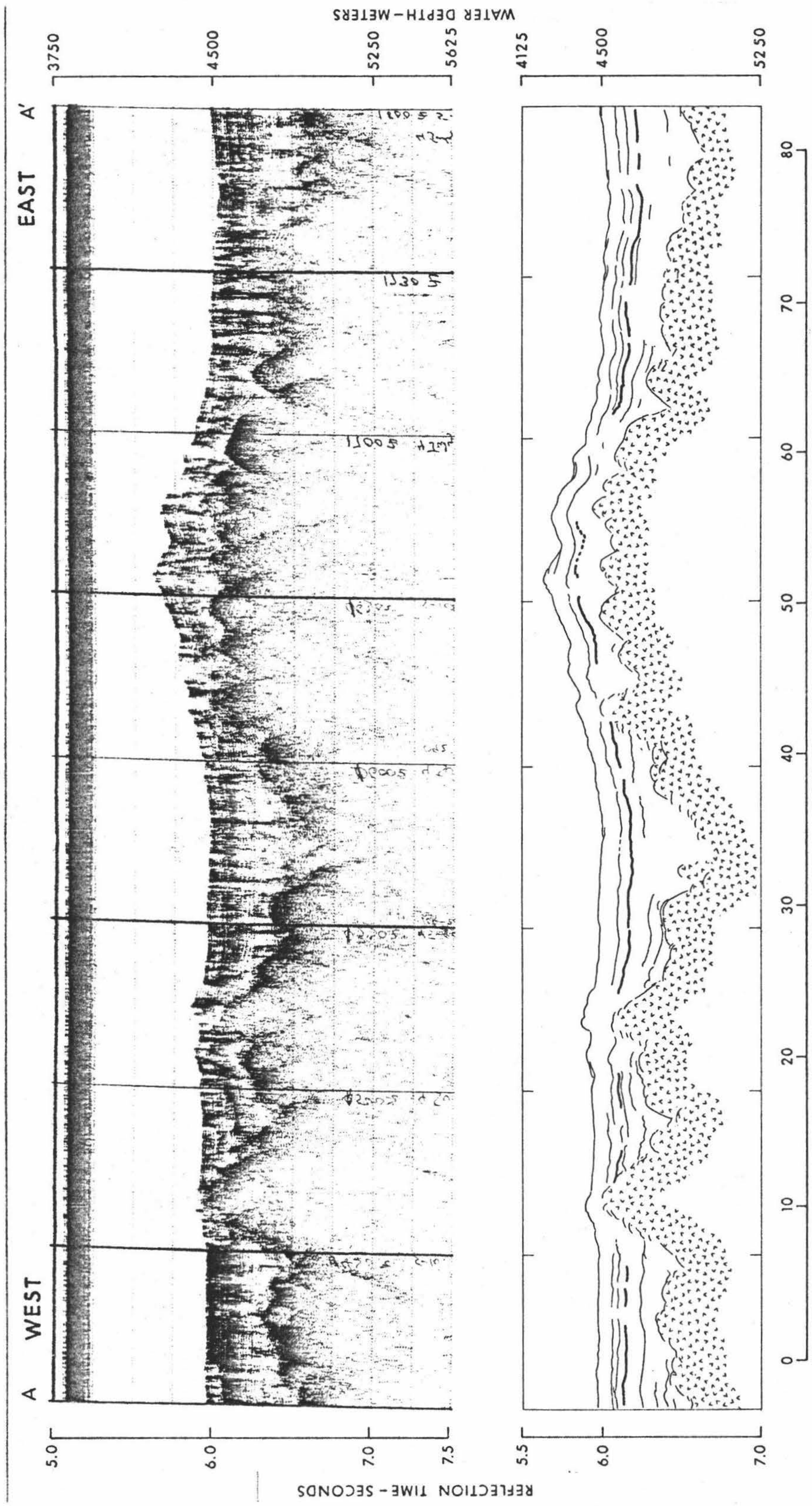
Extrusive basalt was drilled at a depth of 561 meters at DSDP site 63 near the southeastern margin of the East Caroline Basin.

At site 62 on the Eauripik Rise, intrusive basalt was reached at a depth of 580 meters (Winterer, et al., 1971). Near both sites the basement appears typical of the East Caroline Basin, i.e. easily identifiable, pronounced, and reflecting most of the acoustic energy returned to the ship. Except locally near zones of probable igneous intrusion and/or faulting, this reflector is always present.

To the north (near 4°N), there are two areas where the basement character does change. The records taken around 146°E at 4°N lat. show an ill-defined (but relatively strong) basement reflector (Fig. 5). A major period of deformation occurred (Oligocene), when little sediment cover existed. Deformation of both the sedimentary column and the basement to the east (Fig. 6) and to the north (Fig. 7) also appears to have taken place later during the Miocene epoch and to some extent during relatively more recent times. Farther to the east and north large grabens and horsts are encountered. The character of the basement under discussion may have a genetic relationship to these adjoining zones of deformation. Outside of the area of discussion, similar basement character is seen in the proximity of the Sorol Fault in the north (Fig. 8, profile UU') and near the Palau Trench to the east where the basement is not masked by a thick sedimentary cover (Fig. 8, profile TT').

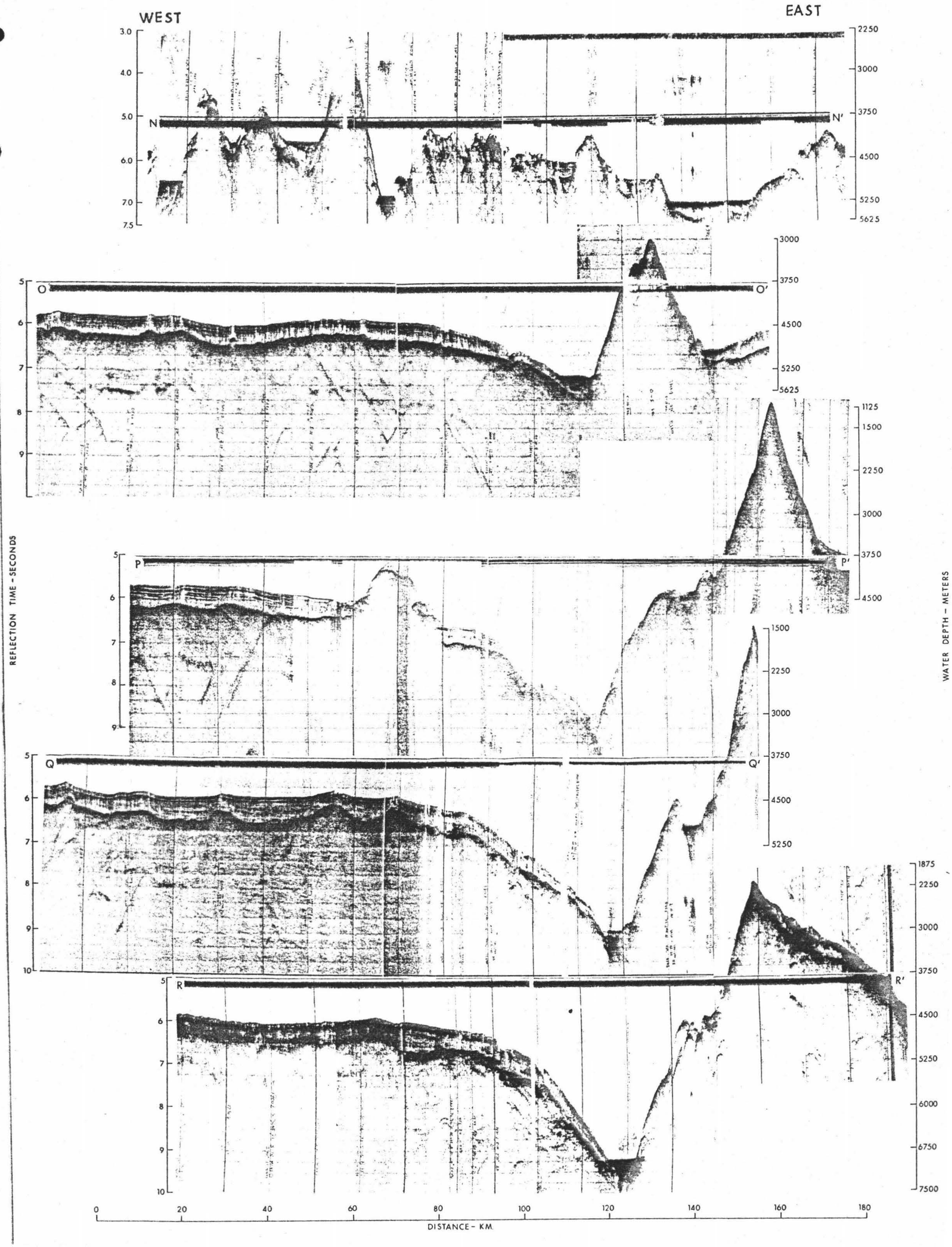
It seems probable that the ill-defined nature of the basement shown in Fig. 5 has resulted from faulting and accompanying deformation of the overlying sedimentary column, perhaps during several stages. Whether or not intrusive activity has played a significant

Figure 5. Reflection profile AA'. Uncharacteristically rough basement in the East Caroline Basin. Evidence suggests a fault-derived origin for the basement features.



A
WEST
EAST
A'
WATER DEPTH – METERS
3750
4500
5250
5625
4125
4500
5250
REFLECTION TIME – SECONDS
5.0
6.0
7.0
7.5
5.5
6.0
7.0
DISTANCE – KM
0
10
20
30
40
50
60
70
80

Figure 6. Composite of east-west reflection profiles across the Mussau Trough. Profile NN' is situated to the north; profile RR' to the south. The depression shown to the right in profile NN' is the northern part of the Lyra Trough; the grabens to the left are part of the northern Mussau Trough.



WEST
EAST
N
N'
O
O'
P
P'
Q
Q'
R
R'
REFLECTION TIME - SECONDS
WATER DEPTH - METERS
DISTANCE - KM.

Figure 7. Reflection profile SS'. The edge of the graben shown to the right is located at the margin of the geographical extension of the Sorol Fault. Basement features were primarily formed before much deposition of the sediment.

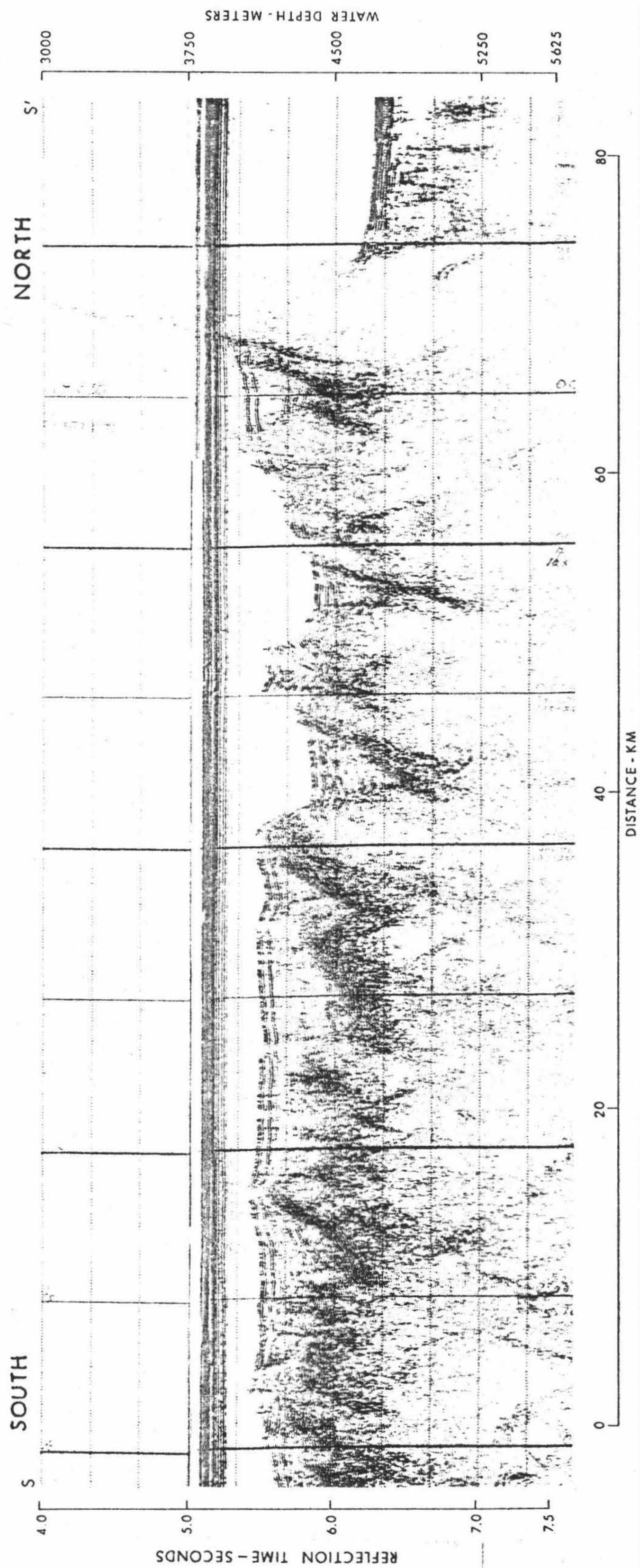
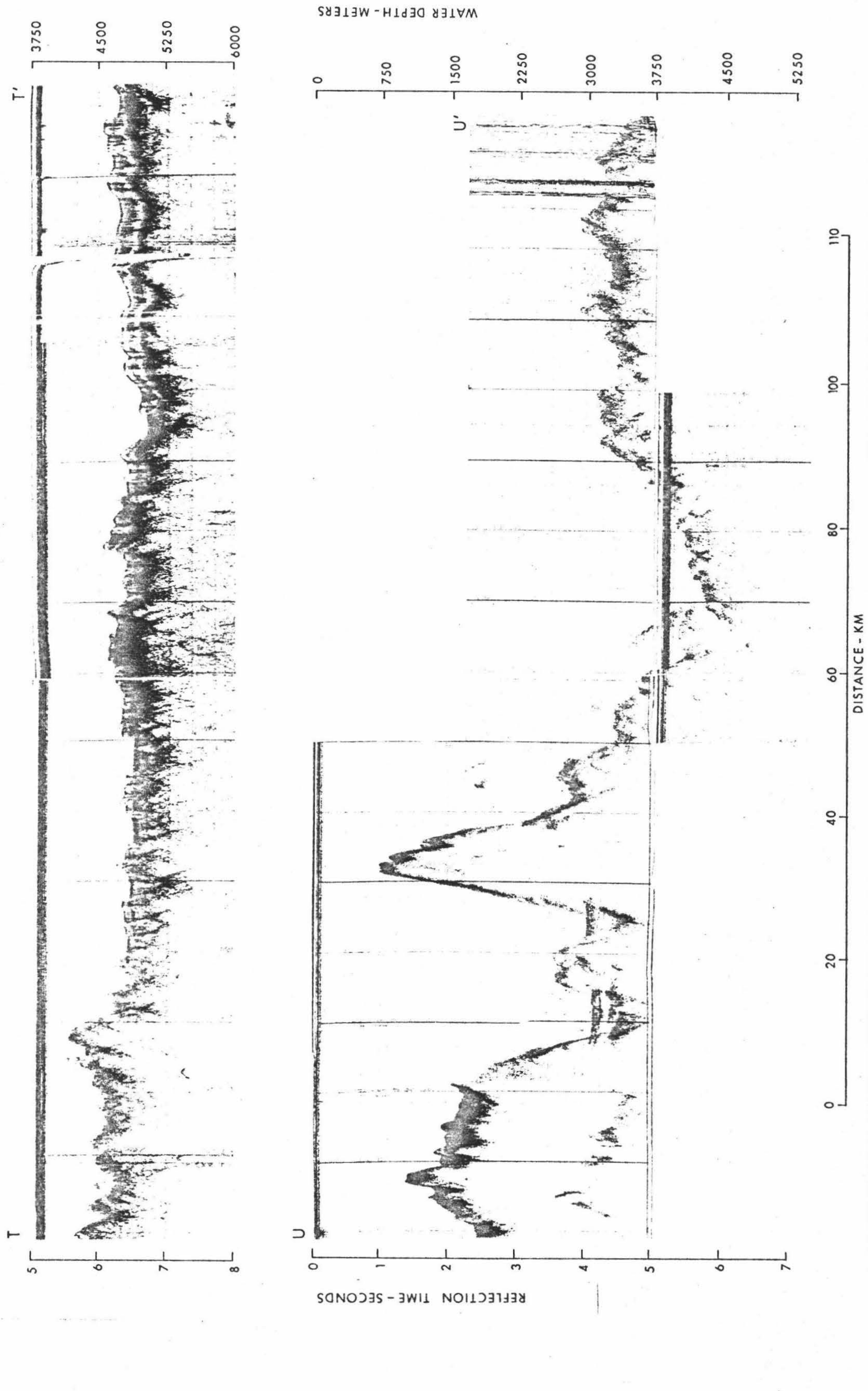

NORTH
SOUTH
S
S'
WATER DEPTH - METERS
3000
3750
4500
5250
5625
REFLECTION TIME - SECONDS
4.0
5.0
6.0
7.0
7.5
DISTANCE - KM
0
20
40
60
80

Figure 8. Profile TT' shows part of the West Caroline Basin relatively close to the Yap Trench. Profile UU' shows the characteristically rough basement of the Sorol Fault near Eauripik Atoll.


T
T'
U
U'
REFLECTION TIME - SECONDS
WATER DEPTH - METERS
DISTANCE - KM
5 6 7 8
0 1 2 3 4 5 6 7
3750 4500 5250 6000
0 750 1500 2250 3000 3750 4500 5250
0 20 40 60 80 100 110

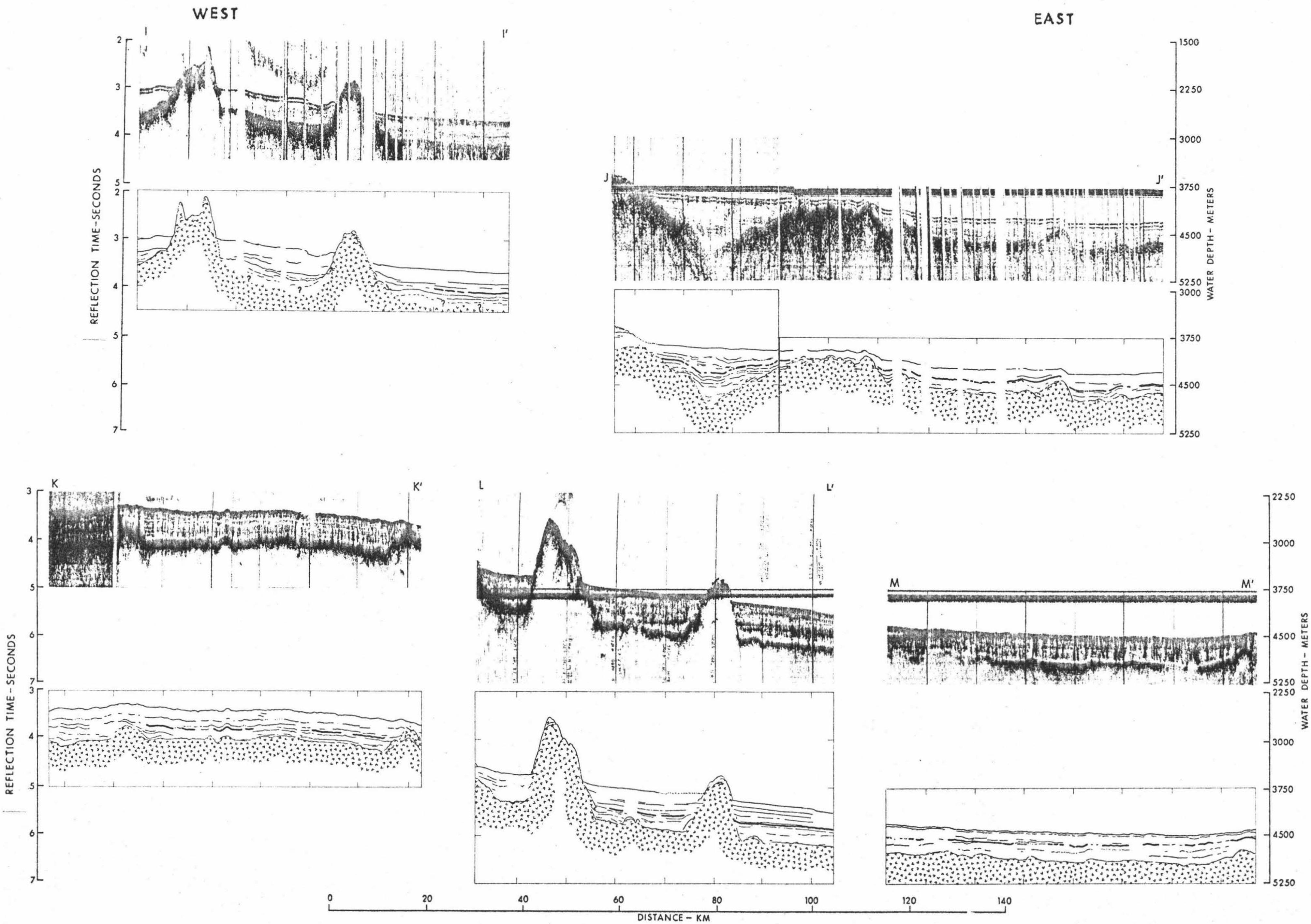
role can not be determined with certainty. Calculation of pre-Miocene, post-Miocene, and total sediment mean reflection times for the record shown in Fig. 5 indicate that the average sediment thicknesses here apparently are not greatly anomalous (Fig. 4, northernmost plot). If igneous intrusion has occurred to any great extent since deposition of most of the sediment, it does not appear to have obscured that sediment.

The second region of atypical acoustic basement within the area of study is found on the Eauripik Rise at around 3 to 4 degrees north latitude and extends north to the Sorol Fault. It is difficult to ascribe the basement to any one reflector here. Although a strong reflector resembling basaltic basement is observed to underlie relatively transparent, well-stratified sediments, other smooth reflectors are seen beneath it (Fig. 9, profile II'). The strong reflector may be due to the intrusion of a thin sill extending laterally down the rise. The presence of several large volcanic features nearby may lend some support to this possibility.

Additional support is found in the configuration of the middle Miocene horizon. Deposition of the horizon just pre-dates the probable subsidence of the Caroline Basin in the north (to be justified later). Sediment thickness underlying it should be at least of the same order of magnitude across the Eauripik Rise at a given latitude (assuming no significant transport of the pre-middle Miocene sediment off of the ridge after subsidence--an assumption that appears to be valid). However, the middle Miocene horizon in the north does not behave in this manner, but closely approaches (and may actually merge with) the strong acoustic basement reflector (Fig. 9, profile II'), enhancing the suggestion that intrusives occurred here.

Aside from the two unusual areas just discussed, the acoustic basement reflector, shown by the DSDP to be basaltic, remains remarkably well defined and persistent throughout the East Caroline Basin and adjoining areas to the west, and with the exception of a few local regions on the northern Eauripik Rise, no higher reflectors resembling the basaltic basement are found.

Figure 9. Reflection profiles on the top and eastern flank of the Eauripik Rise. The heavier line corresponds to the middle Miocene Reflector. Reflection profile KK' is located close to DSDP drill site 62. Profiles are oriented east-west.


WEST
EAST
I
I'
J
J'
K
K'
L
L'
M
M'
REFLECTION TIME - SECONDS
WATER DEPTH - METERS
DISTANCE - KM
0
20
40
60
80
100
120
140
1500
2250
3000
3750
4500
5250

SEDIMENT DISTRIBUTION

Average sediment thicknesses remain fairly consistent on east-west traverses across the East Caroline Basin and onto the Eauripik Rise. However, the sediment thins from roughly 600 meters at $1^{\circ}N$ to about 300 meters at $4^{\circ}N$. The sediment is of Oligocene age or younger. The thick sediment cover found in the region is probably due to the high biological productivity and accumulation rates associated with the equatorial current (Arrhenius, 1963).

Sediment Transport

Minor sediment transport from regions of high topography to regions of low topography appears to have taken place continuously throughout the depositional history of the East Caroline Basin region. This lateral transport acts most noticeably on small features such as seamounts, but has also removed some sediment from the top of the Earuipik Rise. Evidence for transport was observed in the form of micro-slumps and truncated cross-beds in cores from site 62 on the Eauripik Rise (Winterer, et al., 1971).

Weak bottom currents probably account for most of the transport. Symmetrical thickening of sediments on each flank of the Eauripik Rise (Fig. 9, profiles LL' and JJ') indicates movement off the top of the rise. The probable slight ponding of the middle Miocene horizon (dark line seen on profile LL'), in conjunction with pre-middle Miocene sediment distribution, shows that, although transport has been occurring at least since the middle Miocene, the bottom currents have been fairly weak. The stability of the sediment draped over the edge of the Mussau Trough (Fig. 6) also shows that the bottom currents have been weak. It will be shown later that the Mussau Trough is at least as old as Miocene, and further indicates that no strong currents have been effective during most of the depositional history. Although benthic biological activity may account for some sediment movement (Arrhenius, 1963), slight erosional unconformities on the Eauripik Rise (as well as the DSDP evidence) indicate that currents are probably the dominant factor.

There is, however, a short, fault-controlled, erosional valley on the east flank of the Eauripik Rise. It trends northeastward and may channel sediment, mostly in the form of turbidites, to the basin located east of the valley. Nevertheless, the volume of sediment transported there is relatively insignificant compared to the amount deposited as a result of biologic productivity.

Except in the case of seamounts, small hills, and one probable turbidite channel, lateral transport has, however, been relatively insignificant. No major truncation of reflectors was observed within the East Caroline Basin. No reworked older radiolarians were found at site 62, and "practically no reworked older radiolarians were observed" at site 63 (Winterer, et al., 1971).

Since bottom currents have most likely been the dominant mechanism of transport here, and since they appear to have been weak throughout most of the depositional history, it can be concluded that little sediment has been moved about within the East Caroline Basin. At least on a scale of several hundred kilometers, sediment redistribution has been negligible.

Sediment Thicknesses

Since redistribution of sediment over large distances has not occurred, some combination of four principle factors might account for the observed sediment distribution in the East Caroline Basin. The factors are: (a) the length of time in which a section of basement has been available to receive sediments, (b) changes in sedimentation rates through time for a specific area (including movement of a crustal plate and changes in the velocity of a moving crustal plate), (c) the masking of sediments by intrusives, and (d) changes in the carbonate compensation depth with respect to the ocean floor.

Ewing, et al. (1968) have stated that the high rate of equatorial sediment accumulation has persisted within a narrow belt for at least the last half of the Tertiary, and probably for the entire Cenozoic. The high accumulation rates appear to be directly linked to the high rates of biologic productivity associated with equatorial upwelling. Two points should be stressed. First, it appears that high sedimentation rates associated with the paleoequator have occurred continuously through time. Second, the width of this band of high sedimentation rates is relatively large in comparison to the East Caroline Basin. Therefore, any variation in latitude of the paleoequator with respect to the East Caroline Basin should have produced a systematic regional variation in sediment thickness.

Changes in the past configuration of the equatorial current resulting from the northward movement of the Australian-New Guinea plate or from the tectonic uplift of the Solomon Islands are a possibility. Consideration of the size of the equatorial current indicates that any variation in the position of the paleoequator through time should have resulted in a regional variation in sediment thickness. However, since high rates of sedimentation have been established (from DSDP results) for the equatorial region of the East Caroline Basin, the configuration apparently has not changed greatly. Considering the foregoing, systematic regional variation in the post-middle Miocene thickness with respect to the pre-middle Miocene thickness in the East Caroline Basin could then have resulted from: (a) generation of oceanic crust and resulting plate motions, or (b) regional variation with time of the depth of the ocean floor with respect to the depth of carbonate compensation, or (c) some combination thereof. Local variation in the sediment thickness may have resulted from intrusives or local variation in the depth of the ocean floor with respect to the compensation depth.

Along north-south profiles the pre-middle Miocene and post-middle Miocene sediment thicknesses seen for the East Caroline Basin exhibit several interesting trends. The post-middle Miocene sediments show approximately constant thickness. Along east-west profiles, the sediment cover thickens on the Eauripik Rise to more than twice that found in the East Caroline Basin.

The pre-middle Miocene sediments exhibit the opposite trends. Along east-west traverses, approximately the same thickness of sediment cover is observed (even though significant variation is seen near the Mussau Trough and near the Eauripik Rise). Along north-south traverses, however, the pre-middle Miocene sediment thins in the northern regions.

The thinning of the post-middle Miocene sediments in the East Caroline Basin has been attributed to greater solution of the carbonate fraction of the sediment (Winterer, et al., 1971). The high clay content found in the upper Miocene to Recent sediments supports this view. This general trend of thinning is found for all east-west traverses, and indicates probable subsidence of the East Caroline Basin (and West Caroline Basin where the same relationship is found) with respect to the Eauripik Rise.

Figure 9, profiles LL' and JJ', show the position of the middle Miocene horizon on the flank of the Eauripik Rise in the northern portion of the East Caroline Basin. The approximately conformable relationship of the middle Miocene horizon to the basement probably indicates deposition at about the time of subsidence. Subsequently, sedimentation has smoothed the topography.

Profiles KK', LL', and MM' show the position of the middle Miocene horizon on the flank of the Eauripik Rise to the south. The fact that the middle Miocene horizon is ponded slightly against the seamount in profile LL' indicates that subsidence of the basin took place just before deposition of that horizon.

Within the central part of the East Caroline Basin, the regional trend of post-middle Miocene sediment thickness along the east-west profiles (Fig. 3) implies that subsidence started near the Mussau Trough and progressed westward. This is, of course, somewhat speculative because it is based on the assumption that sedimentation rates have been close to equal across the basin.

The approximately constant sediment thickness shown on the north-south plot (Fig. 4) probably is indicative of true sedimentation rates. The fact that post-Miocene sediment along the crest of the Eauripik Rise remains about the same thickness suggests that the foregoing statement is correct. Of course it must be assumed that the Eauripik Rise has not varied in height, with respect to the carbonate compensation depth, through time. This assumption appears to be valid, at least in the southern part of the rise where the ratio of pre-middle Miocene sediment thickness to post-middle Miocene sediment thickness (as found by the DSDP) is close to the ratio of the respective time spans for these columns.

If the post-middle Miocene sediment cover observed along the north-south profile (Fig. 4) actually reflects true sedimentation rates and the east-west variation discussed earlier is due to the subsidence of the East Caroline Basin, speculation on the reasons for the distribution of the pre-middle Miocene sediment thicknesses can be made. More than one hypothesis could explain the observed distribution.

First, the northern region may have been deeper than the southern region with respect to the compensation depth in pre-middle Miocene time. Second, intrusives into the sediment in the north may have obscured much of the lower column. Third, the basin may have moved southward as a single "plate" into the higher productivity zone. The smooth shape of the curve (Fig. 4) for pre-middle Miocene sediment thicknesses on a north-south line suggests that either the first or the third hypothesis is correct.

If the first hypothesis is primarily correct, any number of tectonic histories may account for the sediment distribution, but one factor would be certain: the northern portion of the East Caroline Basin would have been at a greater average depth than the southern portion during most of pre-middle Miocene time. The depths (and lengths of time at particular depths), however, are not determinable from the reflection records.

If the third hypothesis is primarily correct, greater sediment accumulation rates encountered by the southward moving plate (of which the East Caroline Basin would be part of) would account for the observed sediment distribution. If the plate is assumed to have moved at a steady rate (and at a particular depth) into a sedimentation zone where the sedimentation rate increases linearly, the resultant sediment cover on the plate at any point would be the integral of the linear sedimentation curve over the distance the point has moved. In Fig. 3, then, the post-middle Miocene curve would represent a relative sediment accumulation rate curve (this is only valid if the plate has remained approximately fixed with respect to the equatorial current since the middle Miocene). The pre-middle Miocene curve would represent the integral of the post-middle Miocene curve.

EMPLACEMENT OF THE BASEMENT

It has been suggested that the anomalously young basement of the East Caroline Basin might be explained by the massive intrusion of basalt during the Oligocene (Winterer, et al., 1971). An alternate hypothesis would be the creation of new crust at a now inactive spreading center located somewhere to the north of the basin. This section contains a description and discussion of the basement within the context of these two hypotheses.

The crustal thickness of the East Caroline Basin is close to typical oceanic thicknesses (Den, et al., 1971; Hussong, ms. in prep.). The region is lying beneath 4 km. of water and is located oceanward of the andesite line (e.g., Macdonald, 1949). Also, no terrigenous sediments have been observed for this region. Therefore, it seems highly unlikely that any portion of the basin was ever above sea level.

Since the East Caroline Basin has never been exposed to subareal processes, subareal erosion has not shaped the basement topography. Therefore, the basement can be expected to exhibit the morphology of submarine lava flows or intrusives, and faulting. Of course the degree of resolution obtained on the reflection records limits interpretation to the larger features. For instance, Spiess and Mudie (1971) have shown the bottom features believed to be individual lava flows simply do not express themselves well on conventional acoustic reflection records.

Extrusives

The deepest core at site 63 revealed a slightly vesicular, finely porphyritic basalt that has been interpreted as being extrusive (Winterer, et al., 1971). Xenoliths of recrystallized chalk were found within the basalt.

The basement in the immediate vicinity of this site has been heavily faulted. On the reflection records, vertical displacements of several hundred meters are not uncommon. Older faulting has been interpreted where relatively undisturbed sediments form an unconformity with faulted basement topography; more commonly, younger faulting is indicated by the complete displacement of the entire column over much of the region.

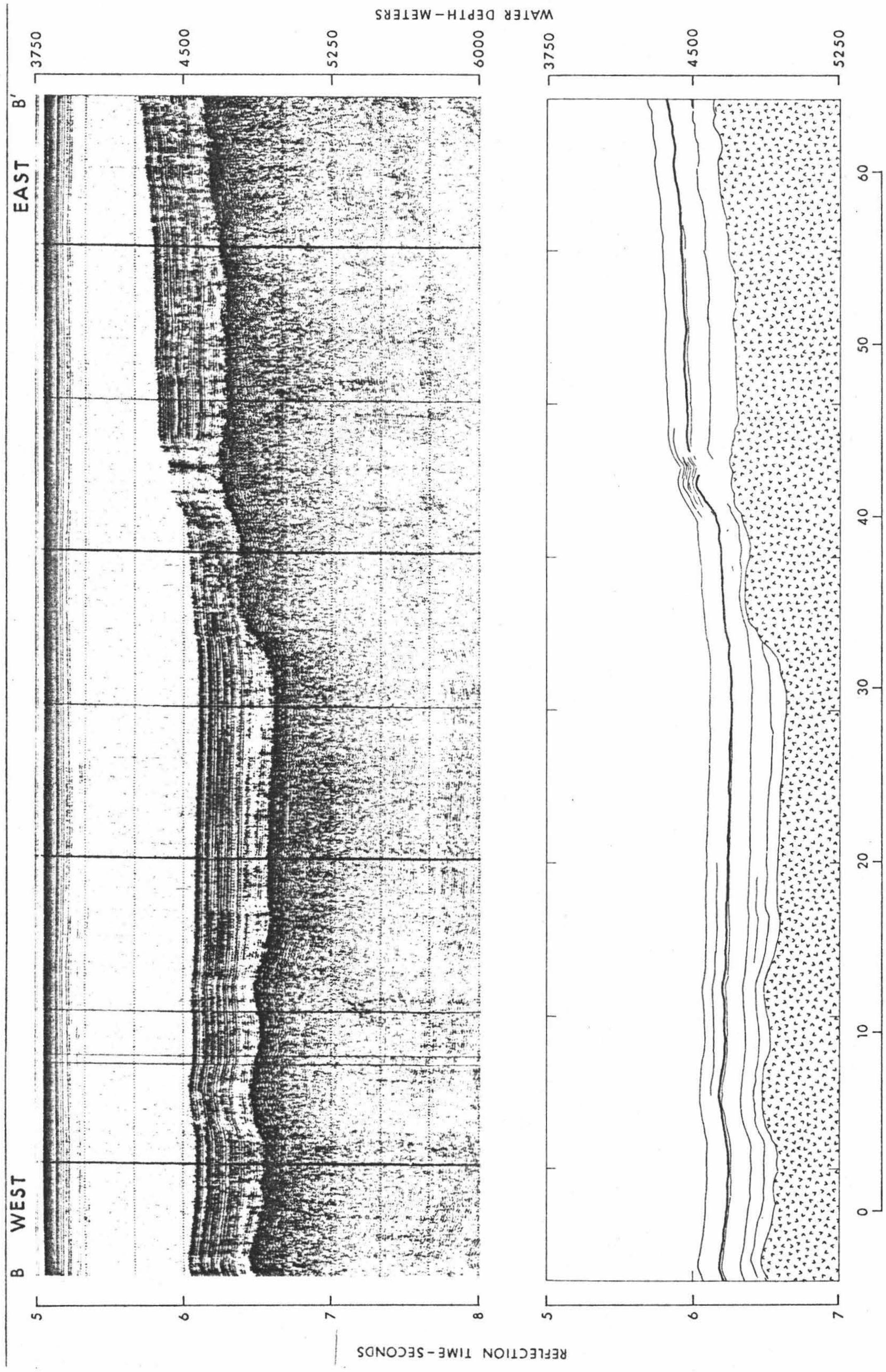
The conformable relationship of the deeper reflectors to the basement (not seen at fault planes where the displacement is great) implies that the basement here represents a roughly isochronous surface. The apparent absence of basement topography that can be clearly attributed to any mechanism other than faulting in the region of the drill hole site, in conjunction with the even sediment thickness and conformable reflectors, strongly suggests that the extrusive nature of the basement encompasses an area extending many tens of kilometers to the east and west.

Close to the Mussau Trough, the interpretation of the records becomes less certain. Although the basement here is more level than at site 63 and the sediment thickness remains about the same, the lower sedimentary column is more disturbed. Farther north near the Mussau Trough, basement features of uncertain origin are seen (Fig. 6, profile QQ') as well as a few cycloidal hills that have been interpreted as intrusive in origin (one is seen in profile OO', Fig. 6).

To the west, within the central eastern portion of the East Caroline Basin, north of site 63, the basement is characterized by a smooth surface broken occasionally by gentle fault scarps (Fig. 10). This same type of smooth basement has also been observed on the north flank of the Caroline Ridge where the basalt that was cored by the GLOMAR CHALLENGER has been interpreted as extrusive (Fischer and Heezen, et al., 1971). The relatively constant sediment thickness, the conformable nature of the lower reflectors with the basement, the lack of features shaped like intrusives, and the occurrence of similar basement on the Caroline Ridge, which is probably extrusive, all imply that the basement of the eastern central part of the East Caroline Basin is extrusive. The probable extrusive nature of the basement at site 63 lends support to this supposition.

The relatively rapid extrusion of very fluid lavas might be a reasonable explanation for the general absence of any large features attributable to anything other than faulting over these hundreds of square kilometers. The thermal history of the site 63 basalt does not appear to detract from this hypothesis. The lack of any large or moderately large first generation phenocrysts in the basalt would seem to indicate that extrusion of the fluid occurred at rather high temperatures. The presence of vesicles

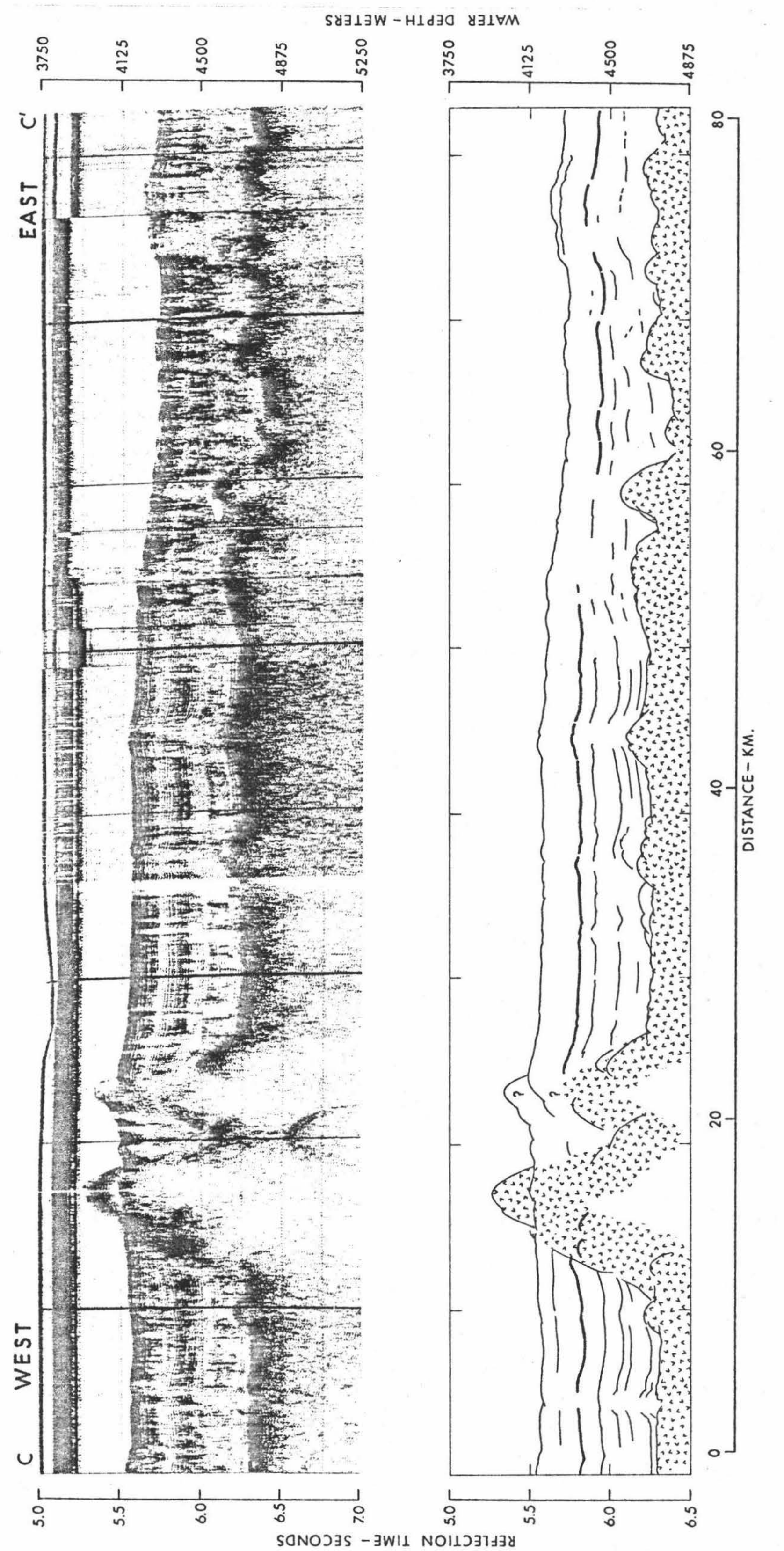
Figure 10. Reflection profile BB'. Smooth basement that characterizes much of the East Caroline Basin. The scarp shown in the profile is at the edge of one of the many troughs that are located within the basin.


WATER DEPTH – METERS
3750
4500
5250
6000
3750
4500
5250
B
WEST
EAST
B′
5
6
7
8
5
6
7
REFLECTION TIME – SECONDS
0
10
20
30
40
50
60
DISTANCE – KM

that presumably have formed at pressures far above 1 atmosphere, would seem to indicate that the volatile content of the lava was significantly high. Both of these factors, the high temperature and the presence of volatiles, would act to decrease the viscosity of the lavas.

The probable extrusive basalt encompasses the region from near the margin of the Mussau Trough to a somewhat arbitrary boundary several hundred kilometers to the west, and from about 3^{o}N to an unknown southern limit. The boundaries are somewhat arbitrary because the basement morphology grades into features that are of uncertain origin away from this area. Of course this is not to say that the region of probable extrusion does not extend past these boundaries, but only that the relationships outlined previously are not so clear farther to the north and west. For example, Fig. 11 shows part of the southern central portion of the basin, and exhibits basement (to the right) that may be intrusive. Menard (1964) has pointed out that basement highs, similar to the one seen at the left of the figure, and which rise above a regional level of the surrounding basement, are best explained as being volcanic in origin. Both of these types of features obviously complicate the picture of a strictly extrusive basement. To the north, features attributable to extensive faulting, along with features of possible intrusive origin, also prohibit the previous arguments for extrusion. Figure 5 shows a profile across part of the most deformed region.

Figure 11. Reflection profile CC'. The basement feature shown to the left is interpreted as volcanic; the basement features shown to the right either may be fault-derived or may be of intrusive origin.


C
WEST
EAST
C'
WATER DEPTH - METERS
3750
4125
4500
4875
5250
REFLECTION TIME - SECONDS
5.0
5.5
6.0
6.5
7.0
DISTANCE - KM.
0
20
40
60
80

Intrusives

DSDP results have shown that basaltic intrusives into deep sea sediments are far from rare. Unfortunately, little is known about the nature of the intrusives, particularly, whether they primarily intrude vertically as dikes, or as "piercements" (meaning a vertically intruded body which may be similar to a plug or a bysmalith) as has been suggested in at least one DSDP initial report (Winterer, et al., 1971). Also, the relative height (with respect to the surface) to which magmas commonly intrude is somewhat uncertain since the ages of the intrusives are usually unknown and thus the thicknesses of the overlying sediments at the time of intrusion are also unknown. In addition, the lateral extent of the intrusives is often a matter of conjecture. However, certain observations concerning intrusives within deep sea sediments have been made, and when coupled with theoretical considerations, yield some very useful information.

McBirney (1963) discussed the primary factors which would seem to govern the nature of emplacement of deep ocean intrusives. He primarily focuses on physiochemical principles. According to McBirney, a magma should rise vertically through the sedimentary column to a height where the weight of the magma column plus the overlying sediments (at some particular level below the top of the column) is equal to the lithostatic load of the sediments (at the same level) plus the inherent resistance to lateral intrusion offered by the sediments. When this height is reached, lateral intrusion commences. The extent of intrusion would depend on how much magma is available as well as the degree of internal and external magmatic friction. The extent of intrusion also depends on the rate of intrusion as compared to the rate of cooling.

Suppressed vesiculation, due to the great pressures in the deep ocean, would prevent the formation of ash, and thus violent igneous activity (McBirney, 1963). The low thermal conductivity of deep sea sediment, as well as the formation of a "finely decrepitated palagonitic glass" which would act as an insulator, points to slow loss of heat from the magma. This would tend to keep the viscosity low. The effects of the factors just mentioned (suppressed vesiculation and low viscosity) point to the intrusion of broad sills with considerable lateral extent, depending of course on how much magma was available.

McBirney's ideas on intrusions appear to be largely correct. The palagonitic selvage has been seen on submarine lavas and intrusives. Piercement structures, sometimes with associated sills, have been reported (Winterer, et al., 1971; Kroenke, 1972). Moreover, Bradley (1965) has presented a strong case, based on the field observations of several workers, for the governing factor of lithostatic load in the determination of the height of lateral intrusives into loosely consolidated sediments. He emphasizes that bedding planes and lithology apparently have little effect on the relative height of the lateral intrusion. He points out that the height depends primarily on the topography of the intruded column.

That is to say, depending on the topographic expression of the invaded sediments, the height of the sill will vary laterally and may even cross bedding planes.

Bonatti (1967), however, has questioned McBirney's argument that suppressed vesiculation of basaltic magma at depths greater than 2 km. will prevent violent igneous activity. His arguments, based on field work, point to the viscosity of the magma as being the factor determining violent versus quiet igneous emplacement.

DSDP results have narrowed the range of uncertainty surrounding many aspects of submarine intrusion. MacDougall (1971), using the fission track method, has dated the DSDP site 10 intrusive as being about 16 million years old. This intrusive has apparently taken the form of a small laccolith. Several important facts should be noted: not only was the basalt intruded into Cretaceous sediments (about 80 million years old), but also the magma was intruded at such a low level that "the igneous rock was encountered approximately at the depth of acoustic basement" (McDougall, 1971). Evidently the sediment bulk density was not great enough to create a lithostatic load capable of forcing the magma to intrude laterally at a significantly high level above the basement. This is important in view of the fact that the sediments were quite old and thick at the time of intrusion (456 meters of sediment overlie the intrusive).

The foregoing apparent characteristic of deep-sea sediments, i.e., the inability to sufficiently support a column of magma such that lateral intrusion will occur high in the sedimentary column, seems to be relatively common. For instance, the basement adjacent to the intrusive at site 62 on the Eauripik Rise, which appears to be a piercement similar to that which McBirney has argued should exist, appears somewhat rough and the moderately disturbed nature of the sediments may have resulted from lateral intrusion directly on top of a pre-existing basement. Figure 9, profile KK', which is located near the site, illustrates this type of rough basement.

The intrusives at DSDP sites 62 and 141 appear to have taken the form of piercements and have risen well above the sea floor (Winterer, _et al._, 1971; Hayes, _et al._, 1971). Vertical injection of magma to relatively high levels in the sediment cover seems certain.

From the previous observations on intrusives, it is evident that another mode of deep sea intrusion may exist. Assuming a sedimentary column having no lateral variation in bulk density and assuming a more dense, very liquid magma, the maximum height of the magma column above a point of lateral intrusion would be roughly representative of the initial resistance offered by the sediments to lateral intrusion. This means that if the piercements observed on the ocean floor were formed by the injection of a very fluid magma, then the sediments near the piercements at the time of injection must have been lithified to the extent that the magma simply was not able to force its way into the sediment with any great ease, even though sills may have formed near the basement. It is clear that the sill formation at a low level does not preclude sills from forming higher in the sedimentary column. If, say, a sill was intruded from the flank of a seamount or from a volcanic island into the sediment cover at a relatively high level, it could be expected to be supported there (even though the density of the underlying sediments was less than that of the magma). The height at which such a sill could be expected to intrude would be roughly determinable from the height of the nearby piercement-sill structures.

Sills have been interpreted by others as forming significantly high in the sedimentary column. Kroenke (1972) has published reflection profiles of features that he interpreted as sills intruded into deep sea sediments at more than 150 meters above acoustic basement, many of which have been injected laterally for distances of at least tens of kilometers.

Apparently, broad sills of great extent may be injected into deep sea sediments. For example, several basaltic layers (hawaiite) that correlate with acoustic basement, but that have been interpreted on petrographic evidence as being intrusive, were cored at DSDP site 165 near the Line Islands (R. Moberly, personal communication). If the sills of hawaiite came from a volcanic ediface, the nearest possible source of the sills is a guyot 50 miles away.

Consideration of the previous arguments and observations provide some elucidation as to the reasons why detection of intrusives within the East Caroline Basin can not always be made with any degree of certainty. Although piercements or dikes are known for some intrusives, there is no assurance that they always do occur. The extent and geometry of intrusives is also variable.

However, the lack of thorough induration of the sediments in the East Caroline Basin, along with the previous observations on intrusives, suggest that lateral intrusion should be expected to take place close to the surface of the pre-existing basement.

The presence of faults cause further uncertainty. Hyperbolic reflections off sharp fault-derived basement features can be confused with vertical intrusives. This is especially true in areas where both faulting and intrusion are suspected.

Nevertheless, numerous intrusions have been identified by the writer within the East Caroline Basin. Where they have been injected vertically into the overlying sediments, deformation of most, or all, of the overlying sediments has occurred. In a few instances, sills are also thought to have been identified. In every case these possible sills have formed close to the basement.

The vertically injected bodies seem to be distributed throughout much of the area west of about 145°E. No spatial pattern for these intrusions is obvious, except that they appear to be more common close to the Eauripik Rise. The fact that nearly all of these bodies have deformed the upper sedimentary column indicates that intrusion of magma has occurred fairly recently over a wide region, although the volume of magma intruded vertically into the sediment has been rather small. Possible intrusives are located at many of the faulted zones within the East Caroline Basin region. However, the faulting that has taken place creates uncertainty in the identification of these possible intrusives.

If the vertically intrusive bodies are actually dikes, then the number seen on the record indicates moderate intrusion of the region. If they are really piercements (as previously defined), the probability of the ship crossing them is much less than if they were dikes, and therefore late intrusion of the region must have been considerably greater. In either case, the volume of late intrusives is far less than what appears to have possibly been intruded in the Oligocene. Occasional basement features that could be very thick sills or flows on top of a pre-existing basement are also found in the western portion of the East Caroline Basin. On the reflection records, the thick sequences of sediments are sometimes seen to thin abruptly at the edge of these thick sills or flows. This abrupt change in thickness, from thick to thin, often persists for many miles. The sediment on both the thick and the thin sides is relatively undisturbed.

It is difficult to ascribe this change in thickness to any particular process. However, the voluminous intrusion of sills early in the depositional (Oligocene?) history might explain it. Intrusion of the sills would then have taken place after some deposition (obscuring that sediment), but before most of the deposition (allowing well stratified, often undisturbed, sediment accumulation on top of the sills). This explanation requires that magma can be intruded (or perhaps extruded) into presumably thin unconsolidated sediments, and flow for considerable distances over a generally level (?) sea floor. Most of these broad, thick sills are located near the Eauripik Rise.

The Eauripik Rise also exhibits a disproportionate number of seamounts (with respect to the East Caroline Basin). A number of seamounts have also been mapped in the Sorol Fault-Caroline Ridge area. The fact that seamounts have formed here, whereas broad fairly level, portions of the ocean floor have been emplaced elsewhere, points to differing factors governing origin. It appears that the presence of numerous seamounts on the Eauripik Rise give impetus to the suggestion that the history of igneous activity was unlike either that of East Caroline Basin or the West Caroline Basin.

Summary

The broad level basement of the eastern half of the East Caroline Basin (south of about 3^{o}N lat.) appears to be primarily extrusive. In contrast to this area, the western portion of the basin and the Eauripik Rise exhibit features that could be broad sills intruded into a thin sediment cover. In a time sequence, this would place the sills as having formed just after the extrusives.

Subsequent faulting throughout the region often appears to have been accompanied by further intrusion, but on a lesser scale. However, difficulty in differentiating the small fault blocks from possible intrusions often prevents positive identification of those intrusions. The last stages of intrusion are represented by piercements or dikes, with occasional sill formation.

Three factors indicate rapid emplacement of the basement in the East Caroline Basin: (1) the general sediment distribution (as discussed in the previous section), suggests a relatively short period of emplacement. The distribution also implies that the basement is youngest to the northwest. However, assuming early intrusion near and on the Eauripik Rise (the location of numerous seamounts and one cored intrusion), the youngest basement (that on which the intrusives rest) may be located to the north. (2) The age of basement (based on the DSDP results) for the Caroline Ridge, the Eauripik Rise and the East Caroline Basin appears to be Oligocene. (3) Reflection profiles suggest that the bulk of the igneous activity occurred between middle and late Oligocene time.

STRUCTURE

The structural features of the East Caroline Basin and the Eauripik Rise have resulted mainly from faulting and igneous intrusion. The forms of the structural features and the resulting sediment deformation (if any) have been described in the proceeding pages. Problems in determining the origin of some of these features have also been discussed. There are, however, places where evidence of faulting is clear.

This section describes the major faults of the East Caroline Basin, and their general distribution, orientation, and ages. No attempt has been made to determine the inclinations of fault planes. References to the ages of faulting are made with the intent that they should be taken generally. Faulting is ascribed to three general time periods: (1) Early, (2) Miocene, and (3) Late. Early faulting occurred in the time span from the formation of the basement to a time by which about 100 meters of sediment had been deposited (basement as used here is synonymous with oceanic crust if the extrusive at site 63 was formed by a sea floor spreading mechanism, but is meant to include an earlier time span as well, if the basin has been massively intruded and the basement is largely secondary). Miocene faulting refers to faulting at or near the time of deposition of the Miocene reflector that was traced throughout the basin. Late faulting refers to faults formed after the Miocene faulting.

Faulting has generally been assigned an age corresponding to the highest stratigraphic level at which sediments abut (in a disturbed configuration) the basement feature that has been interpreted as having been faulted. Where faulting has resulted in the folding or draping of the overlying sediment cover, the subsequent interface created by later deposition on the fold has been taken as the stratigraphic level corresponding to faulting.

Major faults within the East Caroline Basin can be approximately identified on the bathymetric map. They are almost always accompanied by linear changes in depth or lineated depth gradients (see the bathymetric map).

There are, however, several large fault zones outside the region of the bathymetric map. One of these is the zone of the northwest-southeast trending Lyra Trough. The region just to the south of the area of intersection of the Lyra Trough and Mussau Trough is shown in Fig. 6, profile NN'. This profile shows an east-west crossing of the northern Mussau Trough region. The trend of the extensive faulting associated with this region is clearly seen in the bathymetry (chart 2). The gross topography has probably resulted from Early faulting. Some Miocene faulting seems to have occurred (most likely along the earlier fault planes), but does not seem to have significantly altered the earlier topographic expression.

It is almost certain that this fault zone continues in an east-northeasterly direction and becomes alinged with a wide, relatively shallow graben feature that links the Sorol Fault with the Lyra Trough. Profile SS' (Fig. 7) which is oriented north-south, shows the southern edge of this graben to the right of the profile. The faulting and possible intrusion is obvious. Considerable deformation has occurred as late as Miocene.

Farther to the east-northeast, a wide zone marginal to and including the Sorol Fault has been severely deformed. A profile taken near Eauripik Atoll exhibits the rugged and recently deformed topography that appears to be characteristic of the Sorol Fault (Fig. 8, profile UU'). A similar profile was obtained across the Sorol Fault near Sorol Atoll.

The southern region of the East Caroline Basin has probably undergone some Early faulting, but Late faulting has been more extensive both in distribution and in dip-slip displacement. Although the predominant orientation of the traces of the fault planes is not entirely clear, a general north-south orientation appears to be most likely.

Dating of the formative period for the Mussau Trough is uncertain, but probably it was Early. Figure 6 shows that some sediment has accumulated at the axis of the trough. The thinning of the sediment that is draped down the western flank of the trough is due to increased solution of the carbonate grains settling through water, and suggests that the trough existed before most of the sediment was deposited. If the trough was formed after an appreciable amount of sediment had been deposited, the sequences seen near the bottom of the trough would be expected to be about as thick as the adjacent East Caroline Basin.

The thickness of what appears to be subsequent deposition on (and up slope from) the slump shown in Fig. 6, profile PP', probably establishes a minimum age of lower Miocene for the formation of the Mussau Trough.

Faulting within the East Caroline Basin has created shallow troughs and ridges that are primarily oriented in two directions. The general northerly strike of the axes of the troughs and ridges in the eastern portion of the East Caroline Basin could not be . established with certainty. Figure 10 shows one of the scarps at the edge of the trough located within this region. Troughs and ridges oriented with axes striking east-northeast are located to the north of, and generally parallel to, the deep graben which roughly bisects the East Caroline Basin (see chart 2).

Dating the formation of the troughs and ridges, which evidently are all structurally controlled, is difficult because the scarps have small displacements and are gently rounded, e.g., as is seen in Fig. 10. The sediment-basement relationship that characterizes the scarp in Fig. 10, probably indicates both Early and Miocene deformation. A major fault scarp, which strikes east-northeast along the flank of the Eauripik Rise, was probably formed primarily in, or completely during, the Miocene.

The deep graben that was mentioned above and which traverses the East Caroline Basin in an east-northeast direction is shown in Fig. 12 and Fig. 13. Profile DD' in Fig. 13 shows the possible northern extension of the graben. If correlation of the middle Miocene reflector on the upthrown sides of the graben with the

Figure 12. Composite of tracings across the graben which bisects the East Caroline Basin. Profiles GG' and HH' are oriented obliquely to the strike of the graben.

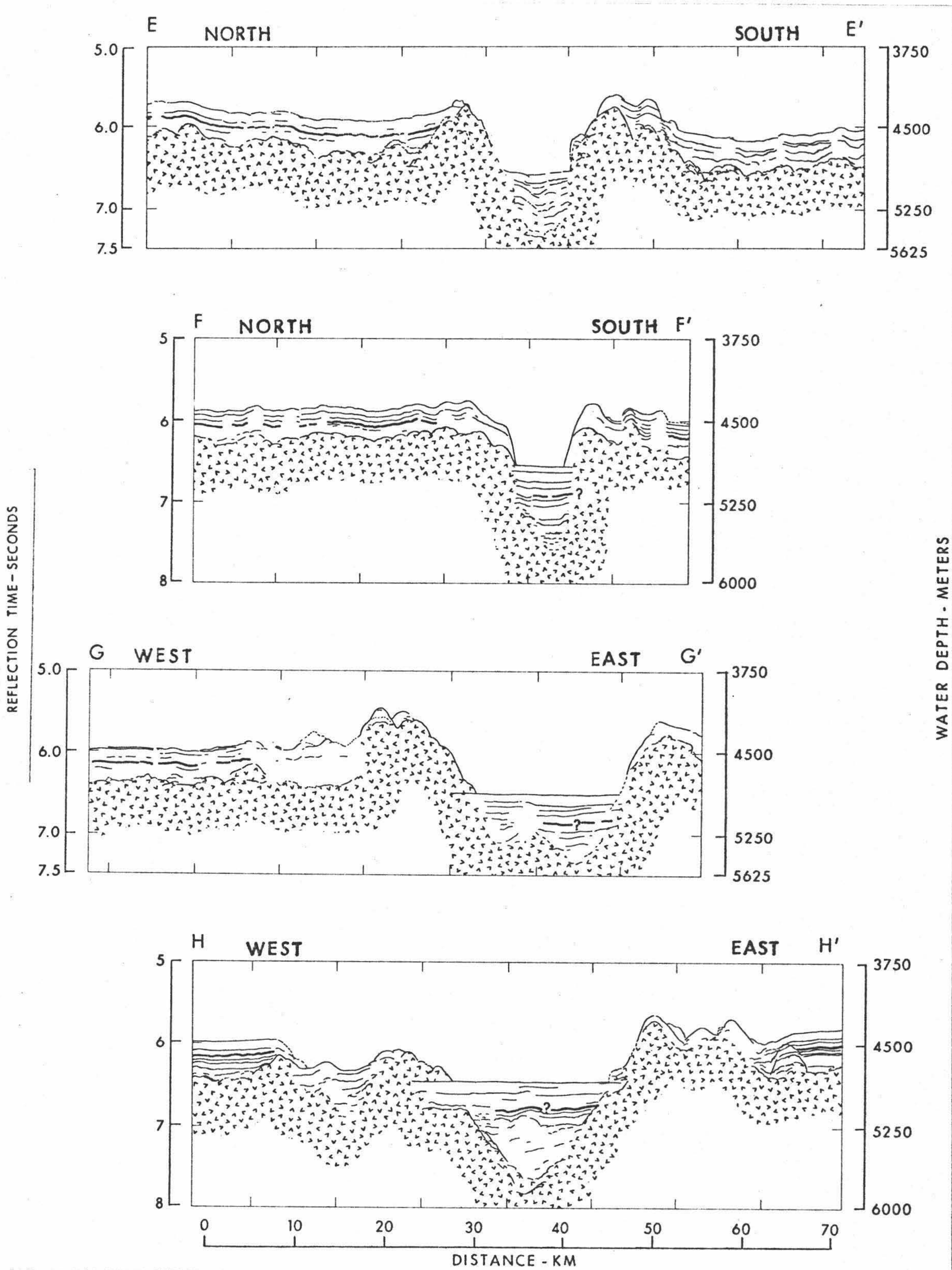
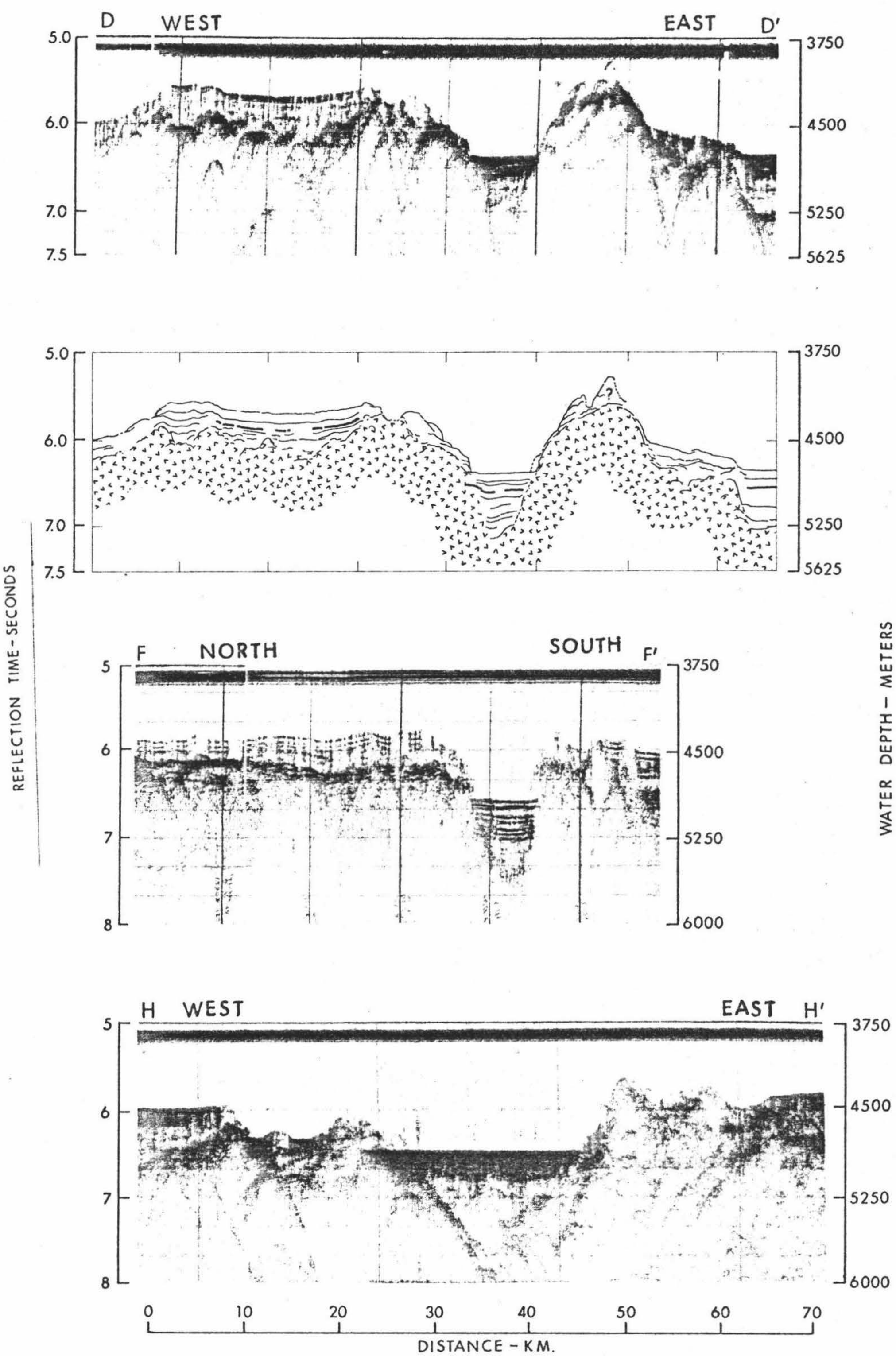

E
NORTH
SOUTH
E'
5.0
6.0
7.0
7.5
3750
4500
5250
5625
F
NORTH
SOUTH
F'
5
6
7
8
3750
4500
5250
6000
?
G
WEST
EAST
G'
5.0
6.0
7.0
7.5
3750
4500
5250
5625
?
H
WEST
EAST
H'
5
6
7
8
3750
4500
5250
6000
?
0
10
20
30
40
50
60
70
DISTANCE - KM
REFLECTION TIME - SECONDS
WATER DEPTH - METERS

Figure 13. Composite of profiles across the graben which bisects the East Caroline Basin. Profile DD' may show the northern extension of the graben.


D WEST EAST D'
5.0
6.0
7.0
7.5
3750
4500
5250
5625
?
REFLECTION TIME - SECONDS
WATER DEPTH - METERS
F NORTH SOUTH F'
5
6
7
8
6000
H WEST EAST H'
0 10 20 30 40 50 60 70
DISTANCE - KM.

reflector on the downthrown block is valid, the end of the period of deformation of the lower column is fixed as about the middle Miocene (Fig. 12, profiles HH' and EE'). However, the little-disturbed sediments shown in profiles FF' and GG' would seem to place an Early date on the formation of the graben at those two locations.

Late deformation resulting from both intrusives and faulting has occurred throughout much of the East Caroline Basin and on the Eauripik Rise. Although the distribution of very late deformation is widespread, stratigraphic displacements are usually so small that differentiation between faults and intrusives often can not be made.

Summary

Faulting to the north, east, and south of the East Caroline Basin first occurred in Early time. In Early time this Oligocene (?) episode of faulting appears to have largely determined the shape of the structural features seen today, with the exception of the southern region where younger faulting is of more significance. Initial formation of the linear troughs and ridges located within the East Caroline Basin may have occurred during this Early time of deformation.

Miocene faulting appears to have occurred over a wide region, including all of the East Caroline Basin and Eauripik Rise. Faulting during this episode possibly re-activated many pre-existing faults, and may have closely corresponded in time with the deposition of the middle Miocene horizon that has been traced. Since the Miocene, modest deformation of the sediment has occurred throughout the entire region, and has been most intense in the south.

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