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SEDIMENT DISTRIBUTION IN THE OCEANS: THE ATLANTIC BETWEEN 10° AND 19°N*

B. J. COLLETTE[1], J. I. EWING[2], R. A. LAGAAY[1] AND M. TRUCHAN[2]

[1] *Vening Meinesz Laboratorium, Utrecht (The Netherlands)*
[2] *Lamont-Doherty Geological Observatory, Palisades, N.Y. (U.S.A.)*

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SUMMARY

Between 10° and 19°N the North Atlantic Ocean has been covered by four east–west crossings and one north–south section at 60°W, using a continuous seismic reflection recorder (air gun). The northernmost section extends to the Canary Islands.

The region comprises a great variety of phenomena: mid-oceanic ridge, fracture zones, oceanic basins, volcanic islands, continental rises and part of a zone of negative gravity anomalies (the Vening Meinesz zone), running from the Puerto Rico Trench over Barbados into Trinidad. A central zone of the Mid-Atlantic Ridge appears to be void of sediment. In the fracture zones (grabenlike depressions that off-set the axis of the ridge) sedimentary thicknesses of the order of 1 km have been found. Evidence was found for the existence of current-influenced sedimentation other than from turbidity currents, and for the occurrence of erosion at depths of more than 5,000 m (the Vidal Channel). In the oceanic basins sedimentary thicknesses occur of maximum 2,000 m in the Cape Verde/Madeira Abyssal Plain and more than 1,400 m (no basement found) in the Demerara Abyssal Plain. The continuity of sedimentation from the continental rise into the abyssal plains proves that turbidites can be deposited on slopes with an inclination of 12′. Locally deposition of turbidites occurs on slopes with a much higher inclination.

The occurrence of horizon A at a distance of 700 km from the axis of the Mid-Atlantic Ridge gives, after a correction for probable tectonic movements, a maximum of 1.2 cm/year possible spreading since the Upper Cretaceous.

The uppermost layer of sediments in the Vening Meinesz zone of about 1 km thickness is only little deformed. This is also true for the Barbados Ridge, which implies that the sediments must be younger than the deformed Tertiary series found at Barbados.

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In discussing the distribution of sediments on the Mid-Atlantic Ridge and the configuration of the ocean basins to both sides, the possibility is considered that both the negative gravity zones and the ridge are secondary and relatively young features with regard to continental drift and ocean spreading. This interpretation would be alternative to the hypothesis that the distribution of sediments should be explained by large variations with time of the rate of spreading (or the rate of sedimentation respectively). The Late Cretaceous and the Miocene orogenies might represent principally different phases of the Alpine orogeny and the Mid-Atlantic Ridge as a topographic feature might be broadening constantly.

INTRODUCTION

In the period from January to July 1965 four east–west crossings (see Fig.1) were made over the Atlantic Ocean between 10° and 19° northern latitude by members of the Lamont-Doherty Geological Observatory and the Vening Meinesz Laboratory on board H.M.S. "Vidal", using the air gun profiler (EWING and TIREY, 1961; EWING and ZAUNERE, 1964). The work formed part of the NAVADO-project. The crossings were made at 10°, 13°, 16°, and 19°N respectively. The 16°N crossing was extended into the Caribbean to Jamaica. The results from this extension will not be given in this paper, but will be incorporated in a study of the Caribbean. The 19°N-crossing was extended from a point 19°N 39°W to the Canary Islands and hence comprises a section over the Cape Verde/Canary Basin. An additional section was made at 60°W between 10° and 19°N, and one approaching the Cape Verde Islands from the southwest.

The region covers a part of the ocean where a mid-oceanic ridge and a negative gravity anomaly zone are separated by a distance of less than 1,500 km. Seismic reflection data have been published previously on a crossing farther north and one farther south (EWING et al., 1964), mainly dealing with the Mid-Atlantic Ridge. EWING et al. (1966) gave an extensive paper on the sediment distribution to the south of our region. VAN ANDEL et al. (1967) reported on a detailed survey of the region of the Vema fracture zone.

The quality of the recordings is rather inhomogeneous, due to the use of different hydrophone arrays and different modifications of the air gun on the respective tracks. The results are therefore presented as line-drawings. Fig.2 shows how the original recording looks like. These line drawings are still time sections. For converting the sections into depth profiles, one should use a water velocity of 1,500 m/sec and a sediment velocity of the order of 2,000 m/sec (for unconsolidated sediments only; cf. HOUTZ et al., 1968).

The reflected signals can be divided into two groups. The first group consists of relatively short and coherent signals and can be related to sediments, the second group consists of long and reverberating signals, probably representing volcanic rock (basement). This classification becomes evident from studying Fig.2 and is

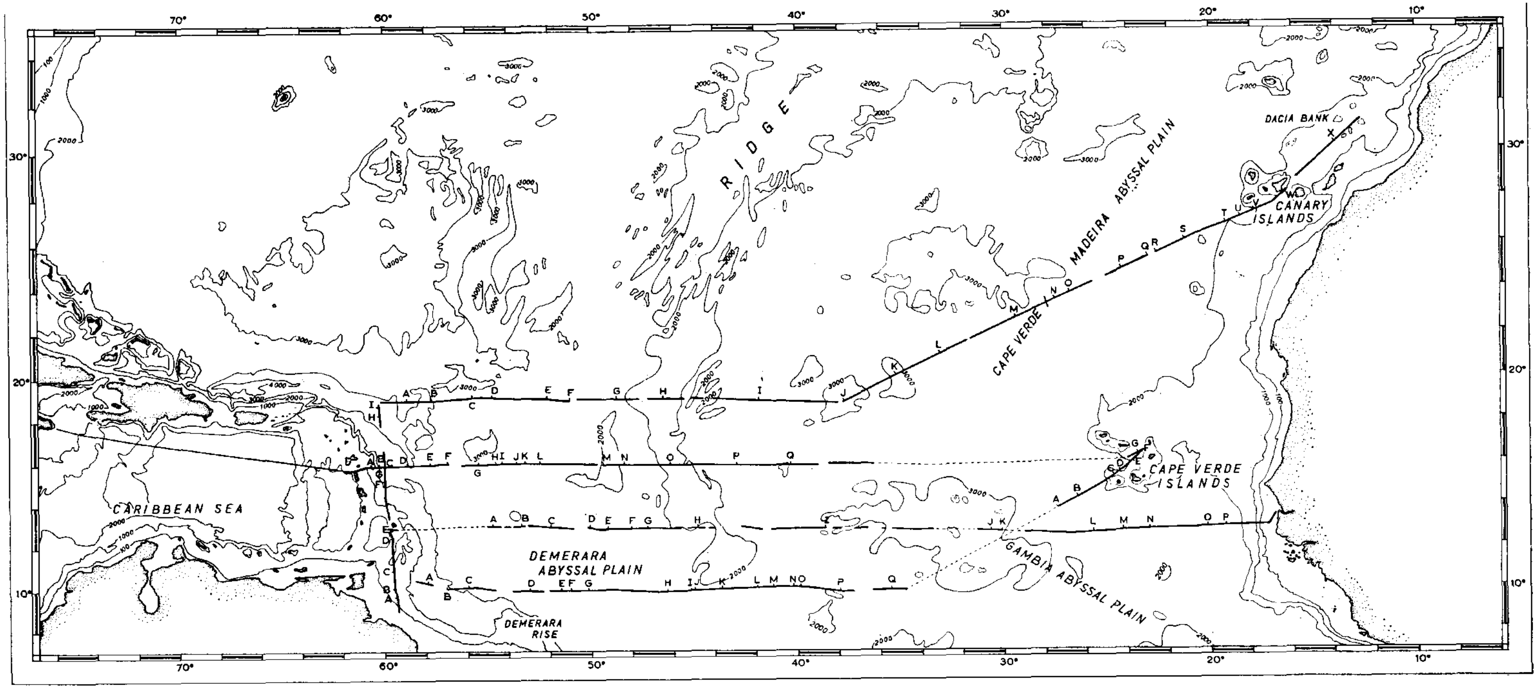

Fig.1. Track chart (H.M.S. "Vidal"); depth contours 100, 1,000, 2,000 and 3,000 fathoms (after H.O. Misc. 15, 254-7).

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corroborated by the outcome of a study by CHASE and HERSEY (1968), proving that the oceanic basement north of the Puerto Rico Trench is formed by Cenomanian basalt flows, possibly interbedded with chert, claystone and limestone and having a compressional velocity near 5 km/sec. The sedimentary reflectors have been drawn in the sections as thin lines, the other group of reflectors as heavier lines. In the eastern part of the region several horizontal or pseudo-horizontal reflections occur that also give a reverberating signal, sometimes even shielding off deeper layers. There is no stringent reason why these reflectors should not be sedimentary. However, these reflectors might represent lava sheets, which then would attain considerable horizontal dimensions.

We further can distinguish between layered sediments and acoustically transparent or homogeneous sediments. The first type in most cases probably consists of turbidites, although evidently non-turbidite sediments may be interbedded. Where the homogeneous sediments are draped uniformly over the basement they are probably pelagic. If the slopes are steep enough, pelagic sediment can be concentrated in the valleys, probably by local turbidity currents. However, this cannot explain all the variations in thickness found in the homogeneous sediments. EWING et al. (1966) therefore proposed that part of the homogeneous sediments are deposited from "nepheloid layers" (EWING and THORNDIKE, 1965) under control of ocean bottom currents.

The significance of this third group of sediments was first recognized in the Argentine Basin where large accumulations of such deposits extended far from continental sources. The ocean bottom current thought responsible here is the Antarctic Bottom Current (WÜST, 1957). It may well be that this current also affected part of the sedimentation in our region.

We will proceed by first giving a description of the sections. This is followed by a systematic treatment of the region combining the results of different sections. Although there are small differences from the situation as sketched in the physiographic diagram of the South Atlantic by HEEZEN and THARP (1961), on the whole this diagram gives a very good picture of our region. We do not believe, however, that the last word has been said on the pattern of the fractures dissecting the Mid-Atlantic Ridge in these latitudes (cf. also HEEZEN et al., 1959, 1964; HEEZEN and THARP, 1961, 1965, fig.5; and the map of the "Atlantic Ocean Floor" recently published by the National Geographic Society, June 1968). The fracture pattern is probably more complicated and in due time a revision of this part of the map will certainly be needed.

THE 10°N-CROSSING

This crossing starts to the southeast of the zone of negative gravity anomalies (BRUINS et al., 1960; cf. also DE BRUYN, 1951) at the point where this zone turns into Trinidad and Venezuela (Fig.3). The sediments appear disturbed. Small

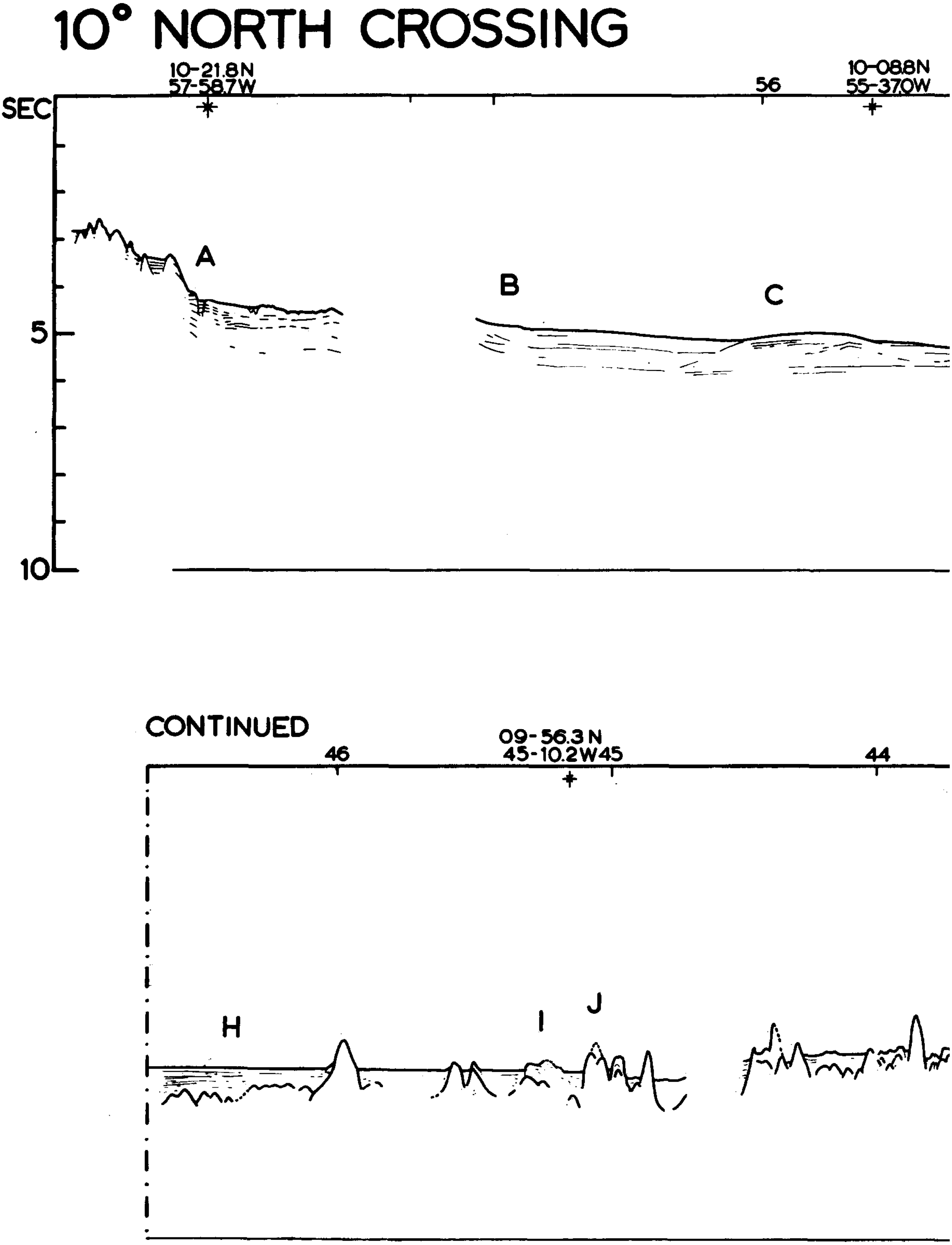
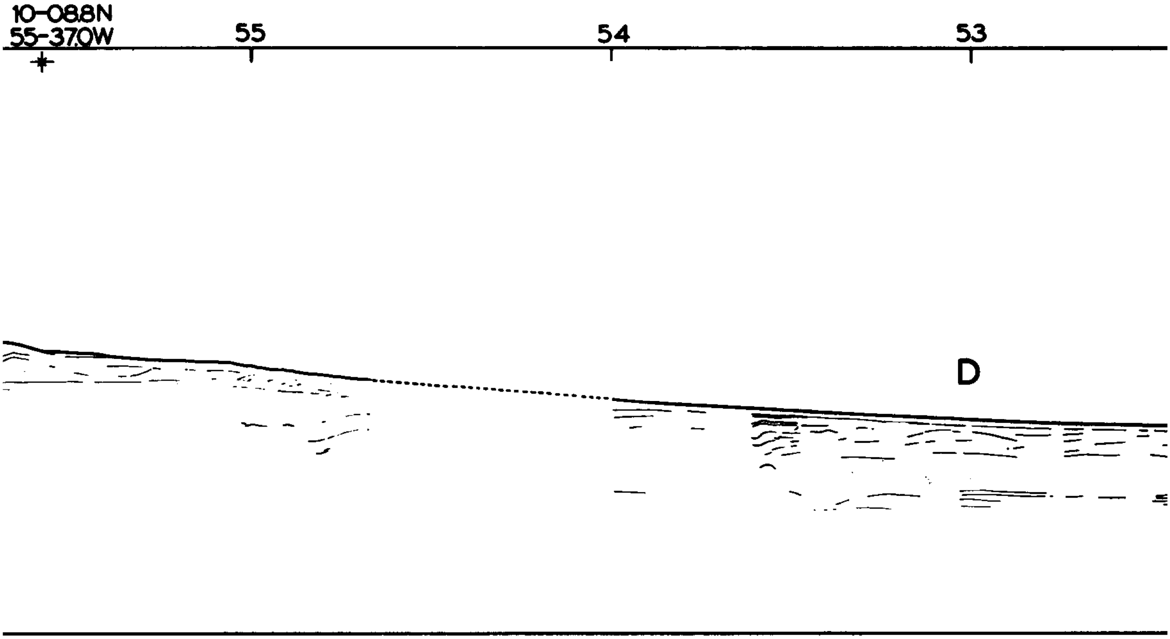
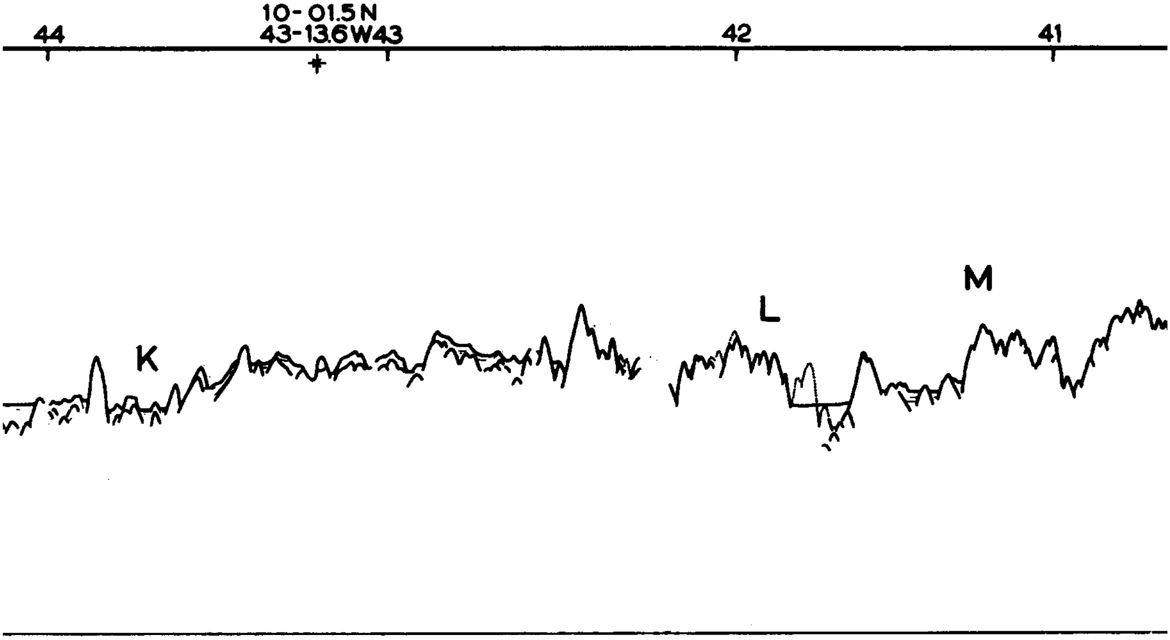
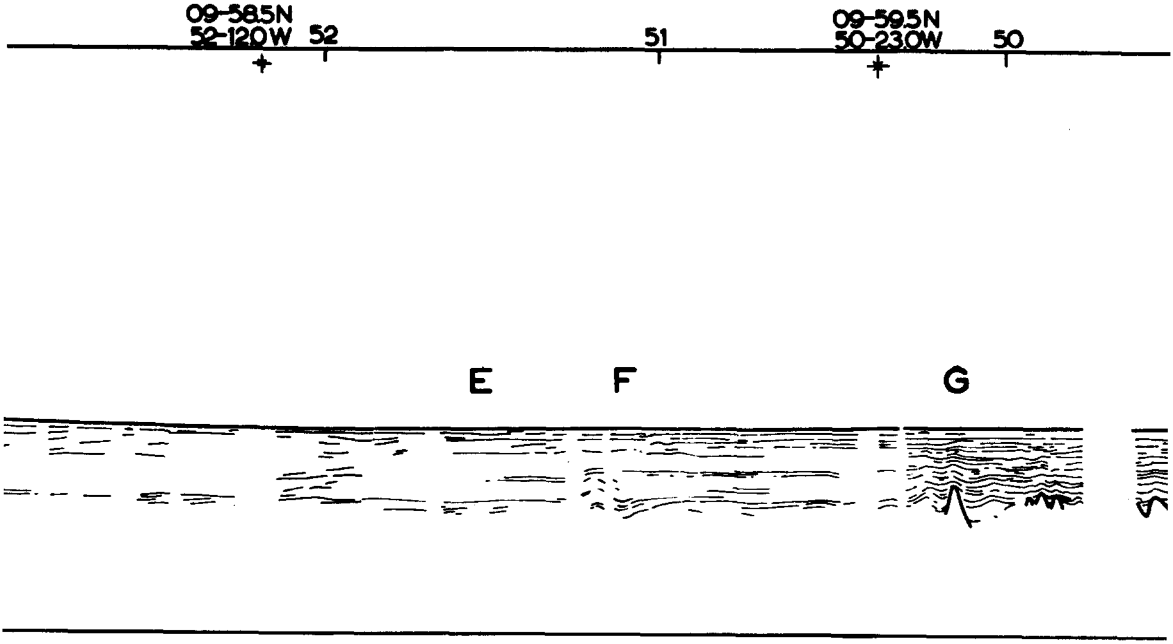
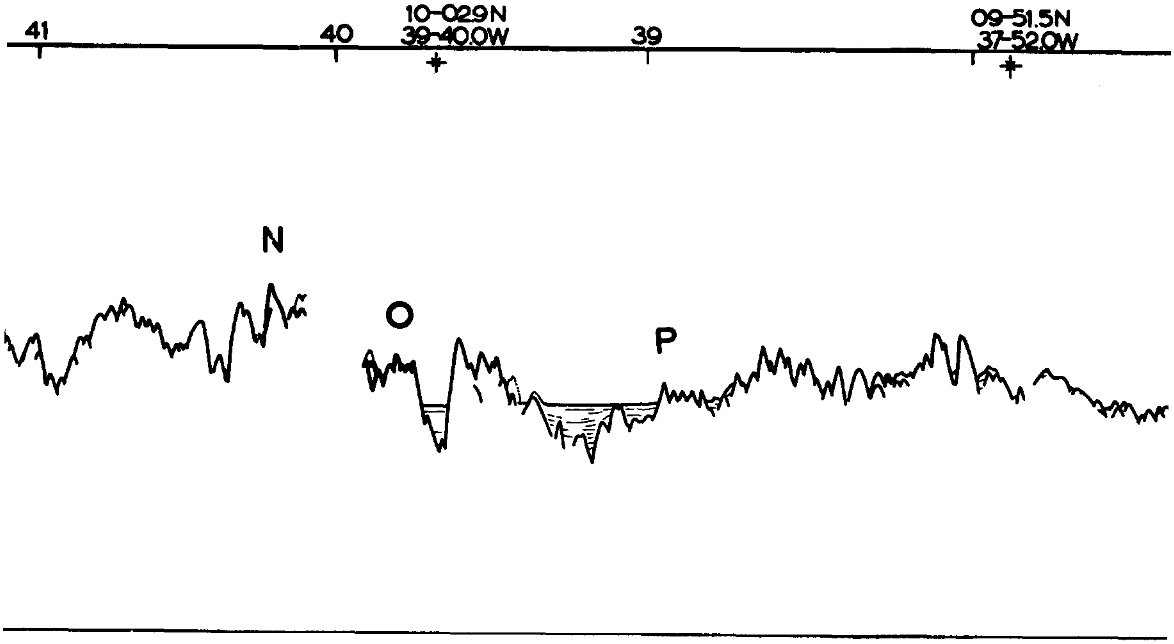


Fig.3. 10°N-crossing. Explanation see text.


10-08.8N
55-37.0W
55
54
53
D


10- 01.5 N
43-13.6 W
44
43
42
41
K
L
M


09-58.5N
52-12.0W
52
51
09-59.5N
50-23.0W
50
E
F
G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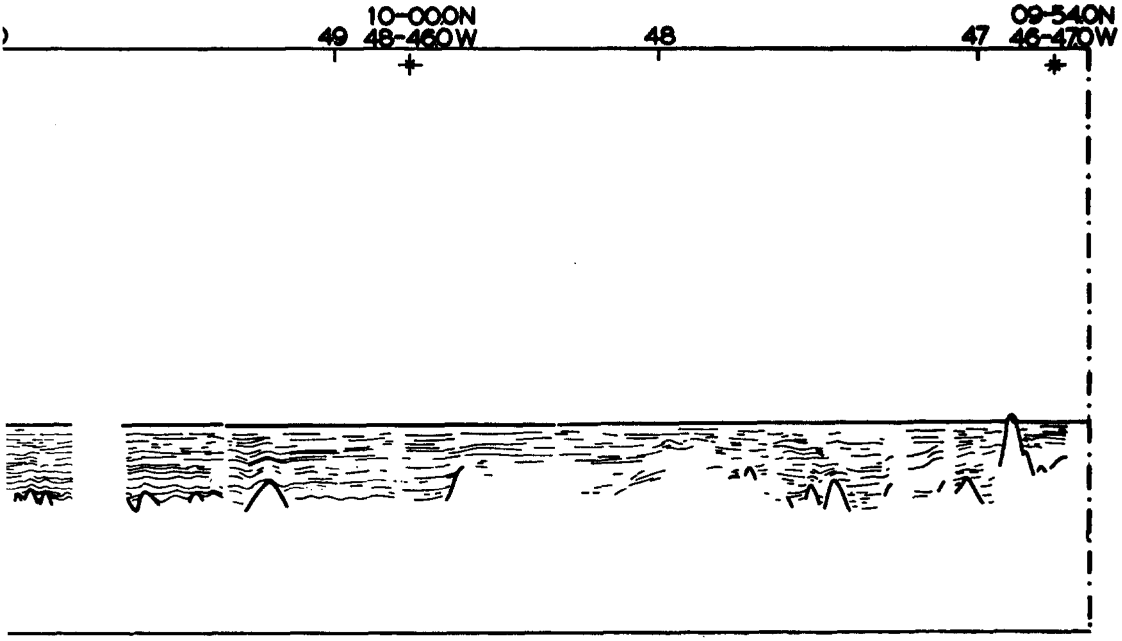
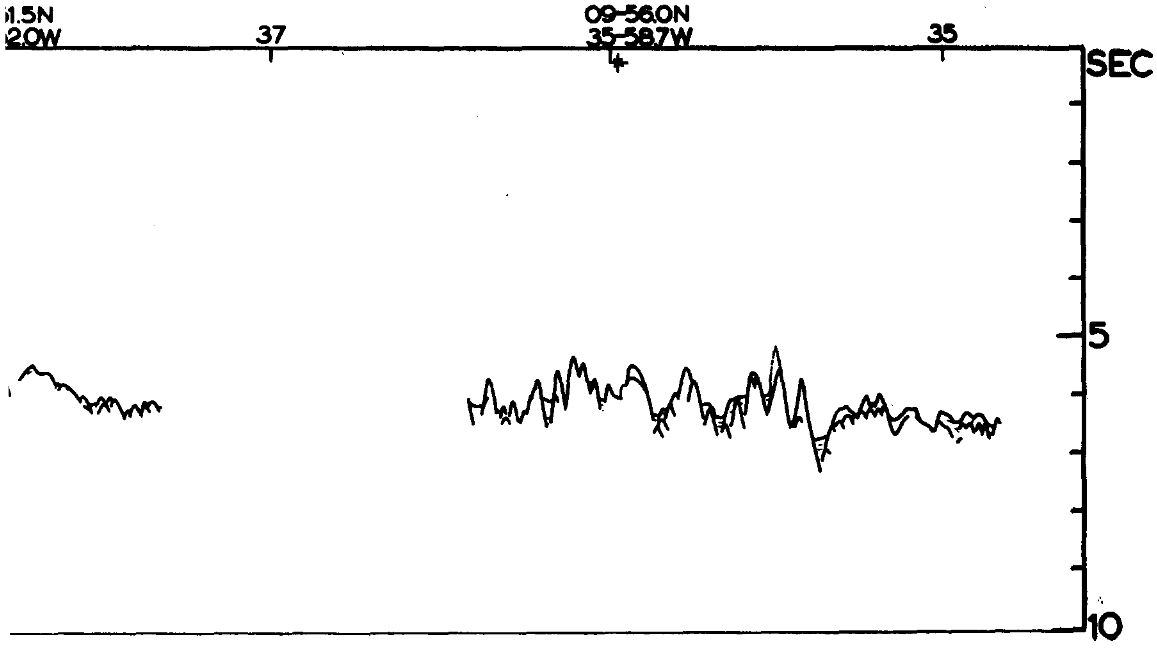
10-02.9N
39-40.0W
39
09-51.5N
37-52.0W
N
O
P


10-00.0N
48-46.0W
49
48
47
09-54.0N
46-47.0W


1.5N
2.0W
37
09-56.0N
35-58.7W
35
SEC
5
10

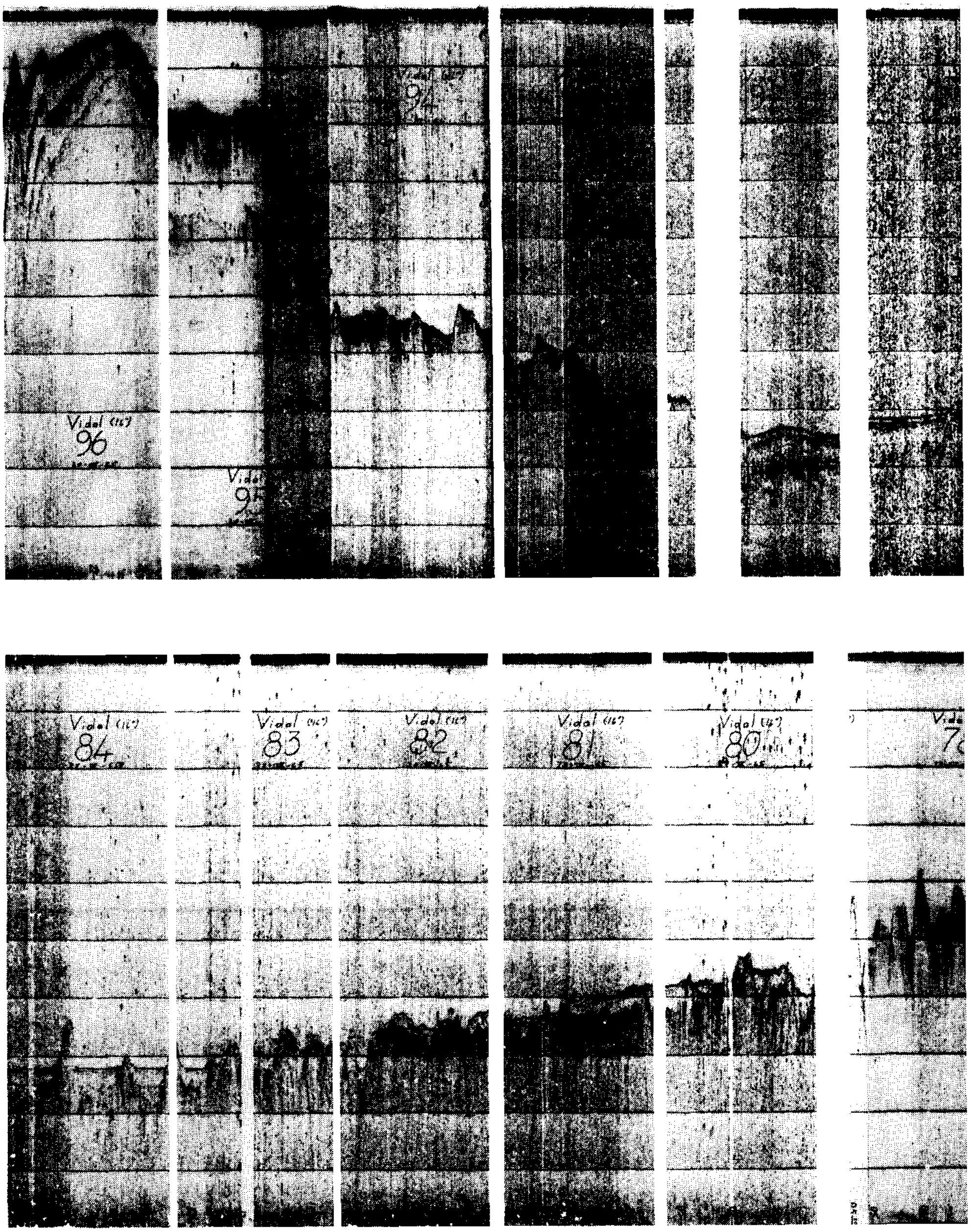
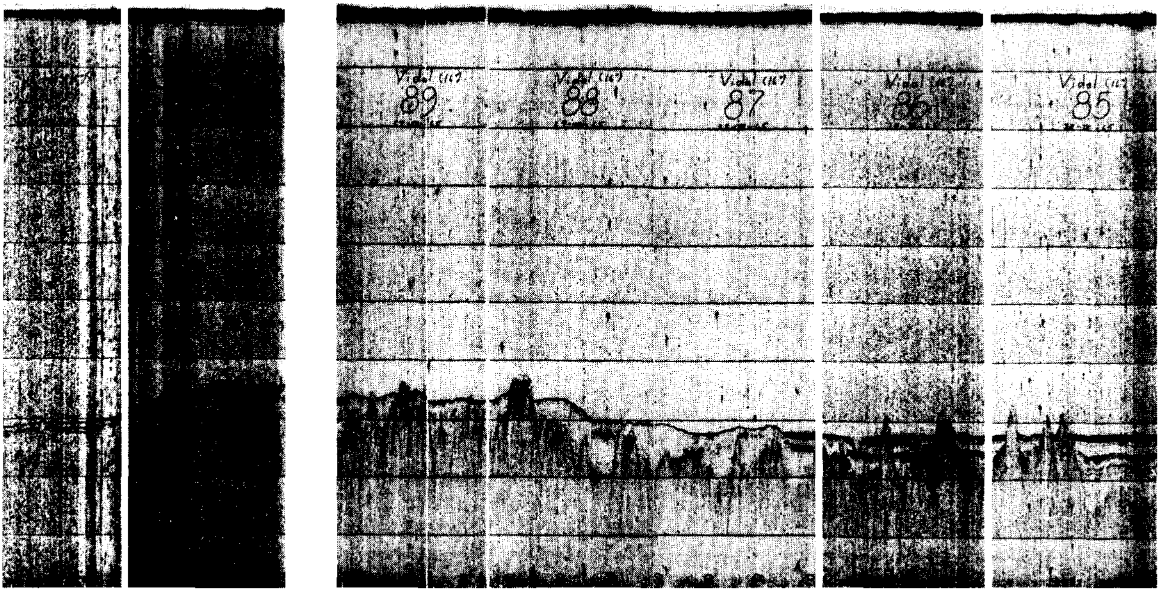
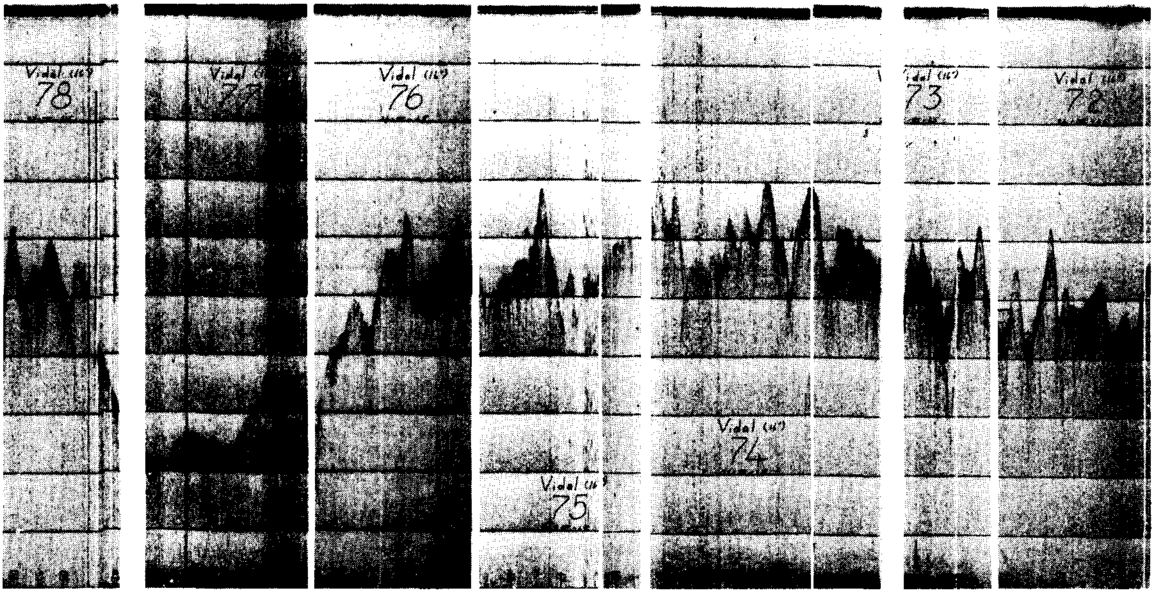


Fig.2. Recording of 16°N-crossing from 61°32′W to 44°55′W. Travel times in sec.


Vidal (167)
89
Vidal (167)
88
Vidal (167)
87
Vidal (167)
86
Vidal (167)
85


Vidal (167)
78
Vidal (167)
77
Vidal (167)
76
Vidal (167)
75
Vidal (167)
74
Vidal (167)
73
Vidal (167)
72

basins have been formed on the deformed continental slope. A small graben can be noticed at position 10-A. The small scale topographic roughness to the east of 10-A may be of sedimentary origin. From position 10-B onwards the layering looks undisturbed.

At position 10-C we cross the northern tip of the Demerara Rise, an outbulging of the continental shelf north of Surinam and French Guiana. The recordings show that at least this part of the bulge is sedimentary. Fig.4 shows this part of the section converted into a depth profile, using the velocities mentioned in the introduction. It then appears that the reflector at 0.8–0.9 sec below the floor is not level as suggested in the time section, but instead mirrors the topography weakly, probably indicating a bending of the crust under the load of sediment. A seismic refraction section in the vicinity of this crossing indicates a thickness of about 2 km of low velocity sediments (EDGAR and EWING, 1968). These authors concluded that "the Demerara Rise is basically a large accumulation of sediment that prograded the continental shelf 150 km seaward of the shelf break defined by the limit of shallow basement (5.7 km/sec) rock".

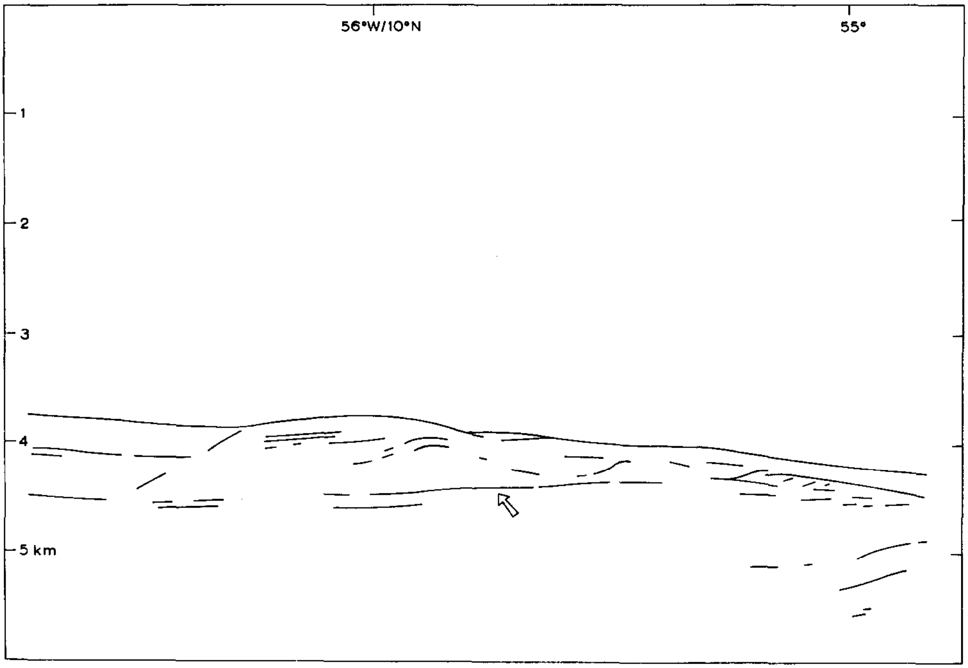


Fig.4. Converted depth profile over the off-shoot of the Demerara Rise, showing that the indicated reflector in reality is not horizontal (vertical exaggeration 25×).

The subsequent recording over the Demerara Abyssal Plain gives a sedimentary thickness of at least 1,400 m, presumably mostly turbidites. From position

10-D onward the deepest reflectors are parallel to the bottom. Before this point the apparent horizontality of these reflectors again is due to the velocity effect. Actually they dip very slightly towards the continent, reflecting the loading of the crust with sediment. The smaller disturbances of the layering in this region should be related to differential compaction of the sedimentary layer over a rough basement. A first sign of a structure due to differential compaction is found at 10-F; the first basement hill is found at 10-G, where a considerable improvement in the recording was achieved. From this point onward the basement slowly rises in an easterly direction. The homogeneous layer is observed from position H in eastward direction. It underlies the layered sediments and forms a blanket over the basement rocks. The structure at 10-I probably is an outcrop of this layer. The turbidites do not continue beyond 10-J even though the depression east of this position is deeper (4,996 m depth) than the level of the abyssal plain. This suggests the presence of a ridge barrier.

It is interesting to note that the plain does not slope uniformly. Its deepest point is found at 10-E (4.928 m) near the continental rise. From there the ocean bottom slowly rises to a depth of 4,850 m at position 10-H. It then becomes deeper again. This slope pattern points to the circumstance that there is more than one direction of sediment transport, namely from the southwest and from the southeast (the Amazon Cone). An alternative interpretation, although less likely, is that some uplift occurred since the deposition of the turbidities.

We then come to the flank of the Mid-Atlantic Ridge. The first point to be noted is that the Ridge is not well developed on this cross-section and that a median rift cannot be recognized. This situation is explained when examining Fig.2 of HEEZEN et al. (1964) from which it appears that the track of H.M.S. "Vidal" lies along a roughly east-west fracture zone off-setting the ridge crest in a sinistral sense. This zone lies south of the Vema fracture zone.

On the ridge we find two broad depressions, at 10-L–10-M and at 10-O–10-P, apparently related to this fracture zone. The maximum depths of the depressions are 4,465 and 4,473 respectively. The easternmost depression, probably a cross-section of the fracture zone, exhibits a flat floor and a fill of stratified sediments comparable to the amount of sediment found by VAN ANDEL et al. (1967) in the Vema fracture zone (about 1 sec). The floor of the zone is considerably shallower than both the Demerara Abyssal Plain and the ocean basin east of the ridge (the Vema fracture zone is deeper than the adjoining part of the Demerara Abyssal Plain). This precludes the possibility of turbidity currents bringing in the sediments via the ocean basins. To what other source such a large fill of sediment near the crustal zone must be attributed, for the moment remains unanswered.

THE 13°N-CROSSING

The recording on this line starts well outside the negative gravity zone east of Barbados (Fig.5). At position 13-A the basement is rather shallow. At position 13-B the topography forms a low and broad ridge, consisting of fairly homogeneous sediments not conformable to the basement, with a slightly undulating surface and absence of strong reflections (see also 16°N crossing). The basement remains roughly at the same level. The section next crosses the Demerara Abyssal Plain (up to position 13-E). The depth (5,050–5,125 m) is slightly greater than on the 10°-crossing, indicating a northerly direction of the sediment transport. The lowest point (5,125 m) of the abyssal plain is found in the *westernmost* part, a situation analogous to that found between positions 10-E and 10-H.

At position 13-C a channel (5,205 m) is found in the abyssal plain that can hardly be anything else than of erosional origin as indicated by the outcropping of a subsurface reflector. We come back to this feature later.

The thickness of the sedimentary layer in the Demerara Abyssal Plain is considerably less than on the 10°-crossing, the maximum being about 1,000 m, the mean of the order of 500 m. About half of the sediments are layered, the rest is formed by the homogeneous layer that can be followed on the recordings over the whole section as a layer lying roughly conformable over the basement. The homogeneous layer is thinner here than on the ridge at 13-B. It crops out at 13-C and 13-D, and as a continuous layer ends on the flank of the Mid-Atlantic Ridge at 13-F. Beyond this point sediment is confined to pockets. At 13-G on the flank of the ridge a major depression is found, probably the cross-section of a fracture zone (HEEZEN and THARP, 1965, fig.5). The sea floor in the depression is about 40 m less deep than at 13-E and, on this cross-section, seems to form one plane with the westward sloping floor of the abyssal plain. The basement depression between 13-C and 13-D and especially the one at 13-E might also be cross-sections of fracture zones.

A well developed rift, presumably the median rift is seen at 13-H. The rift is best described as a yawning fissure. The difference in height between the crest of the mountain to the west and the valley floor is more than 2,700 m. A crestal zone of about 100 km wide is completely bare of sediments. The eastern part of the ridge is characterized by many relatively large valleys (see also the P.D.R.-section in Fig.15) and sediment pockets. Unfortunately, there are quite a few interruptions in the recording. The boundary between flank and abyssal hills region must be sought somewhere near position 13-I.

East of position 13-J we again find evidence for turbidites. The section between 13-J and 13-K is a crossing of the Gambia Abyssal Plain. The sedimentary layer is less than 1,000 m thick. The water depth is greater than in the western basin (6,250 m in the abyssal hills, 5,750 m in the abyssal plain).

Next follows a very long continental rise with a rather thin veneer of mostly stratified sediments (about 400 m). The sea floor here is characterized by a series of steps, dividing the rise into a series of terraces. We do not have information on the third dimension of the terraces and of the basement elevations that can be found under the edges of the terraces. It nevertheless seems a reasonable explanation that the formation of the terraces is due to the presence of these basement elevations either impeding sedimentation on the lee of the elevations or favouring sedimentation in front of them.

Near position 13-L the sedimentary layer becomes thicker (about 1,250 m), mainly due to a thickening of the homogeneous layer in a depression of the basement. Between 13-L and 13-N the basement shallows again, forming a broad and low ridge, and nearly crops out between 13-M and 13-N. This point also marks a decrease in slope towards the African shelf. In view of this it seems not too far-fetched to think of a buried ridge that runs roughly north–south, connecting the Cape Verde Islands with the row of seamounts at longitude 22°W between latitudes 11°N and 6°N, and impeding the flow of turbidity currents to the west of the ridge.

The region between position 13-N and position 13-O has a very gentle slope and could also be considered an abyssal plain. The sediments reach a thickness (near 13-O) of over 1,500 m. The recording is of poor quality and basement was not detected except for a buried mountain at position 13-P. As in the Demerara Plain on the 10°-crossing, the lowermost reflector, when the time section is converted into a depth profile, is dipping towards the continent.

The sediment thickening and the "hummocky" sea floor at the base of the African continental slope, combined with the slightly deformed character of the rim of the shelf, suggests slumping. The penetration on the continental shelf, finally, is less than 1 sec. The section shows beds dipping very gently off-shore.

APPROACH TO CAPE VERDE ISLANDS

This section was made heading for the Cape Verde Islands (Fig.6B) on a course of 61°. The recording starts at the transition from the abyssal plain to the continental rise. The sedimentary layer is relatively thin. At positions CV-A and CV-B the buried hills reach near the surface and are expressed in the topography as small hills or ridges, sometimes forming terraces on the continental rise. The sediments are partly homogeneous, partly layered.

Between positions CV-B and CV-D a strong and reverberating reflector is found close to the surface (see also Fig.7). The reflector shields off signals from deeper layers. At position CV-C, which lies at a distance of about 10 miles north of the island Brava, the layer seems to crop out.

When approaching the island Sal (position CV-F) and steaming back on about return course, the deepest reflector between position CV-E and CV-G again has a reverberating character. The same applies to the reflector at 0.3 sec below the ocean bottom from position CV-G to the end of the section. The section tangential to Brava at CV-C might actually represent a structure comparable to the exposed flank of Sal.

The configuration is highly suggestive that we are dealing with basalts. The

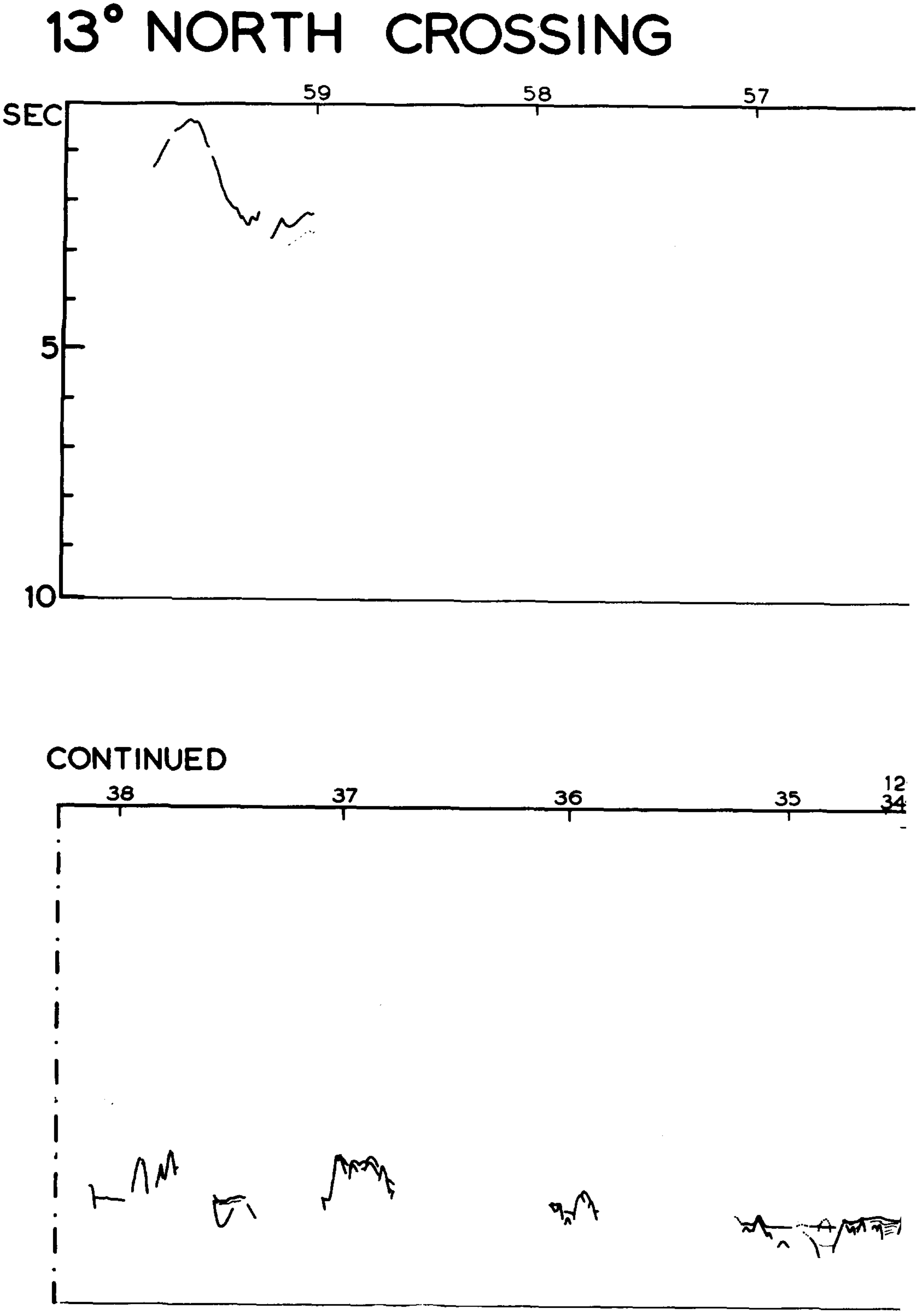
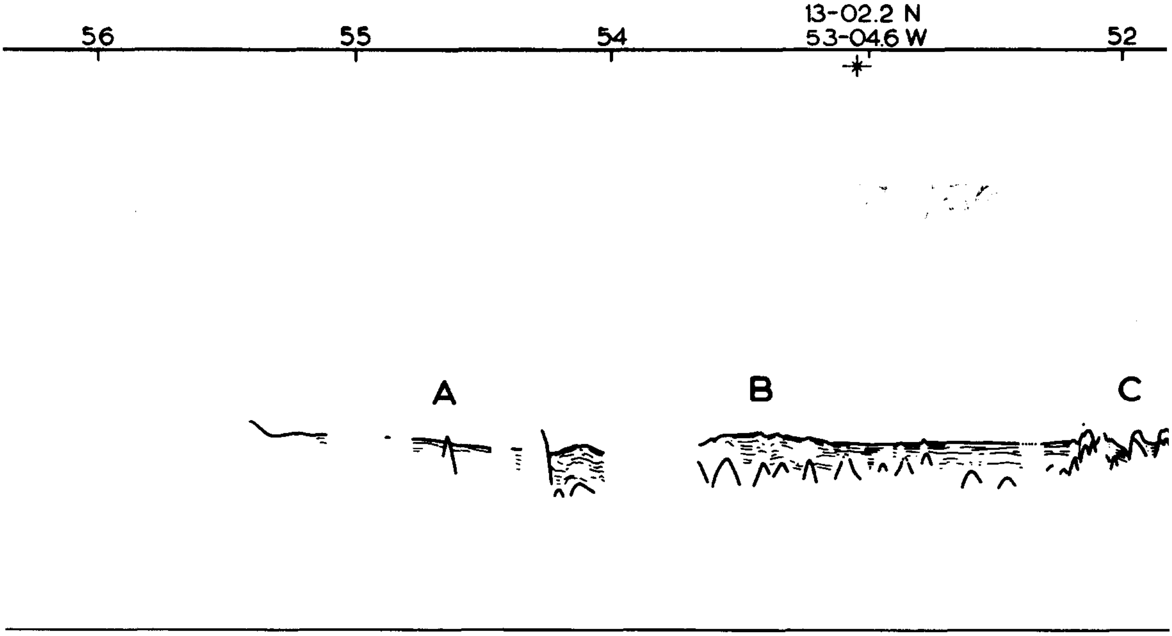


Fig.5. 13°N-crossing. Explanation see text.


56
55
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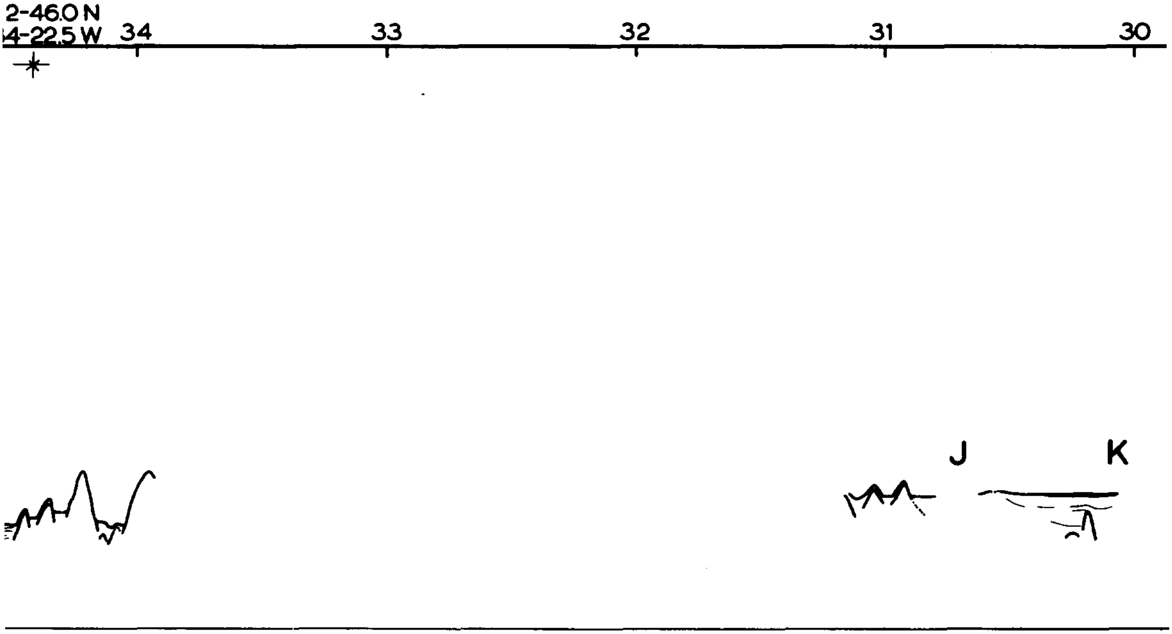
13-02.2 N
53-04.6 W
52
A
B
C


2-46.0 N
4-22.5 W
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J
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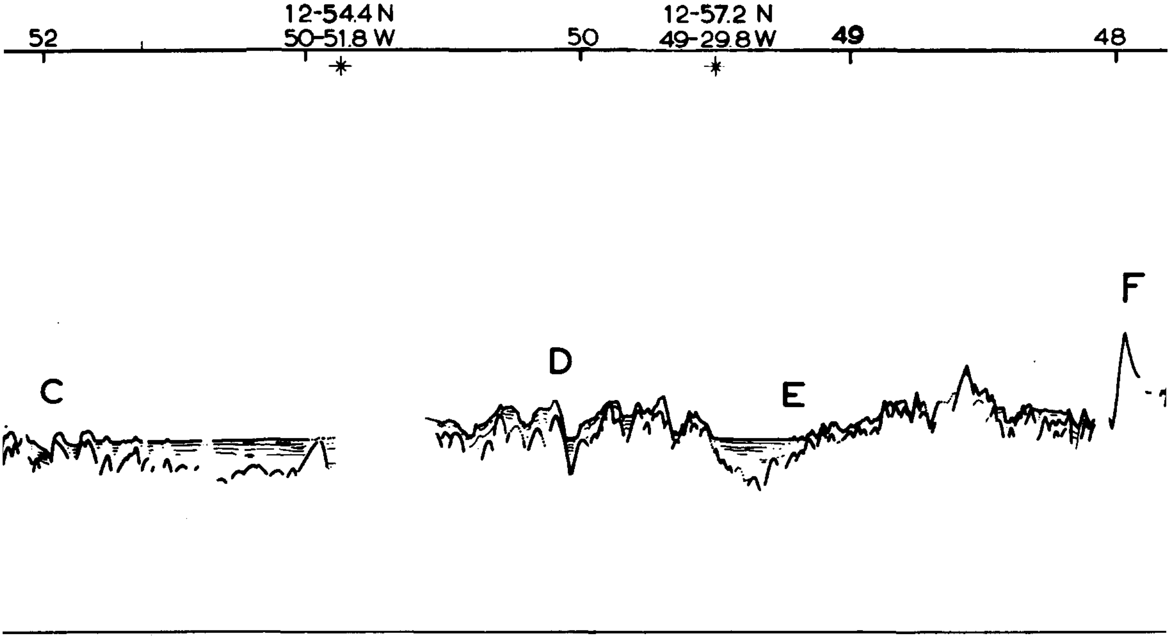
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50-51.8 W
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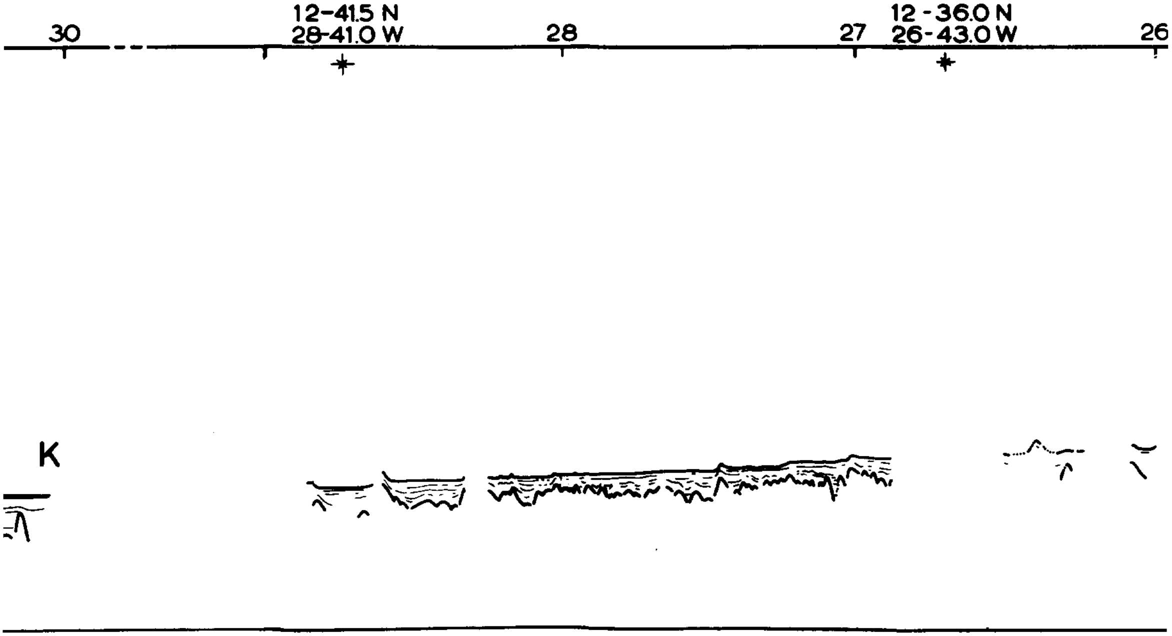
12-57.2 N
49-29.8 W
49
48
C
D
E
F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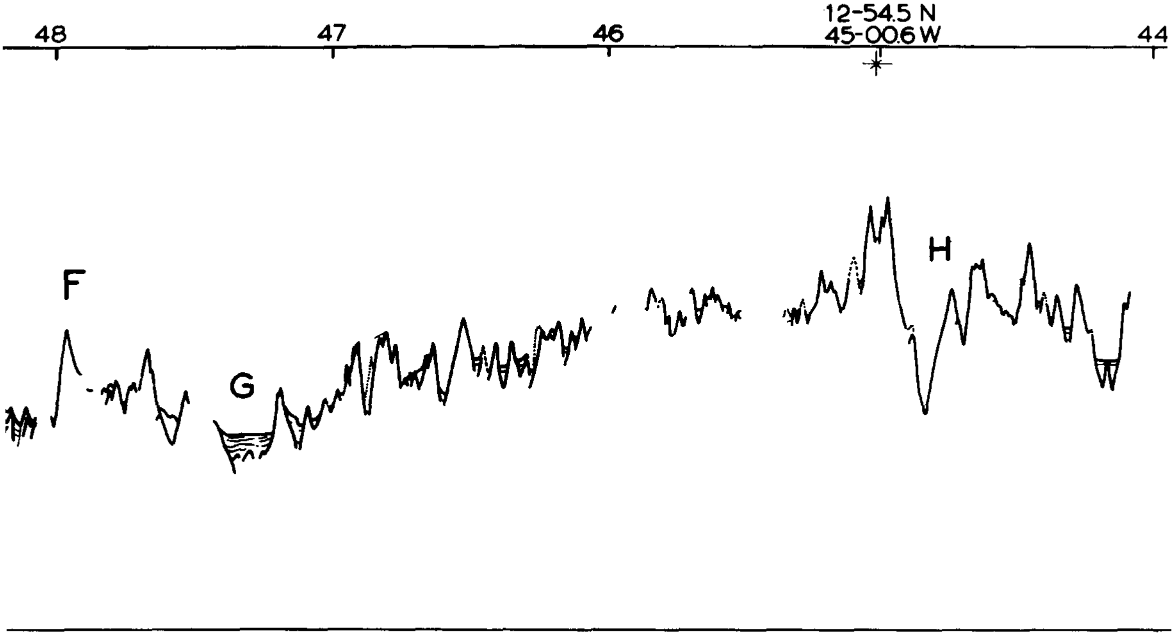
28-41.0 W
28
27
12-36.0 N
26-43.0 W
26
K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45-00.6 W
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44
F
G
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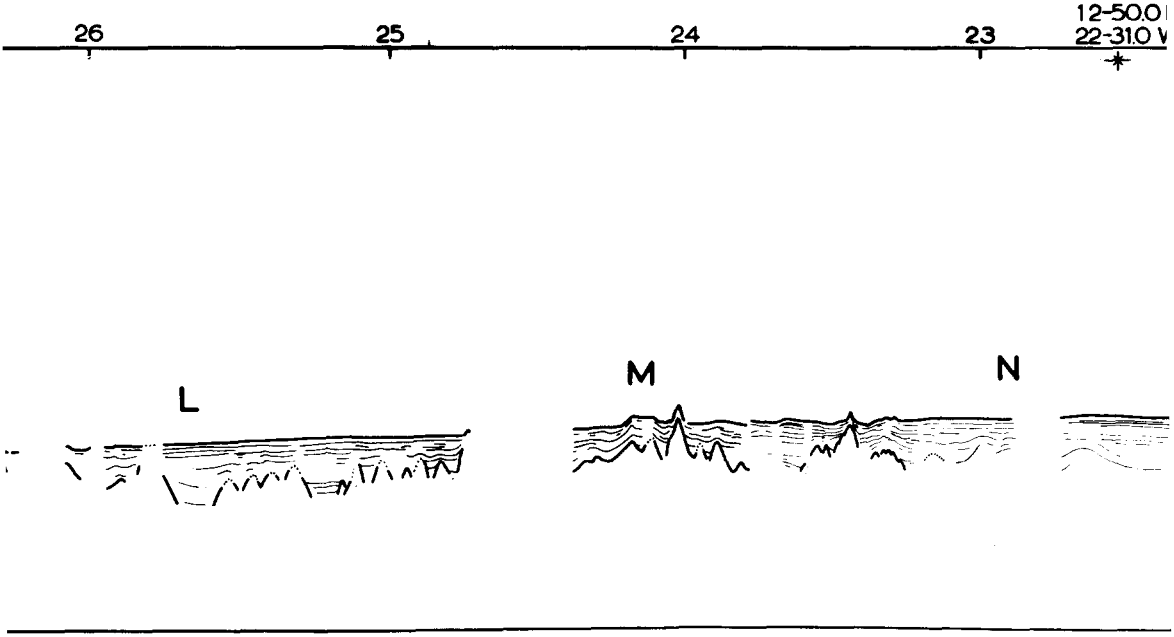
12-50.0
22-31.0
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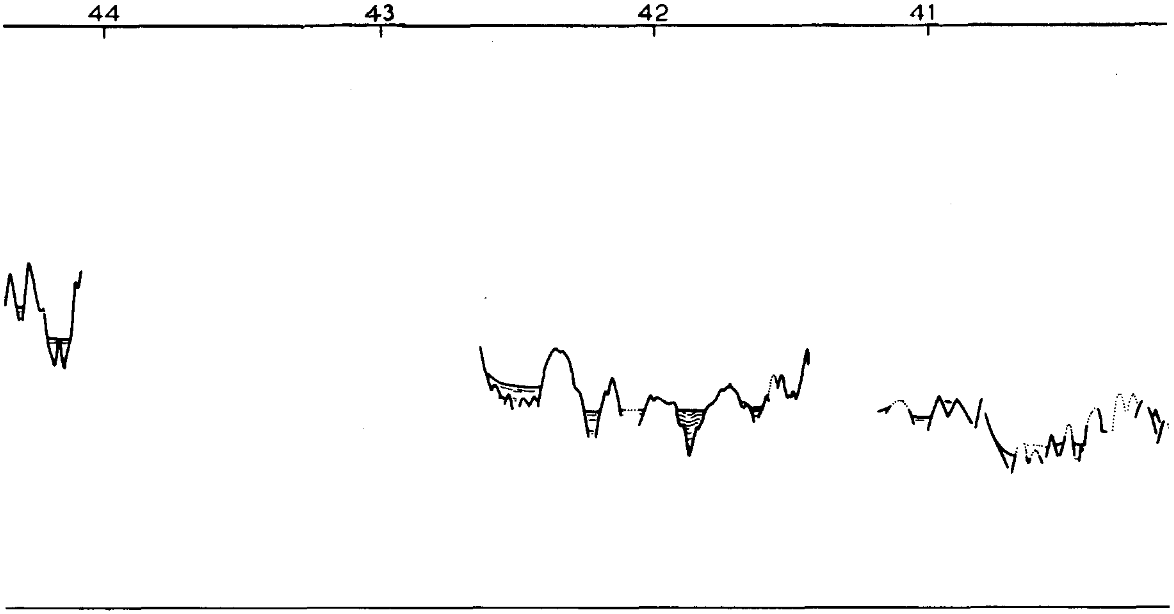
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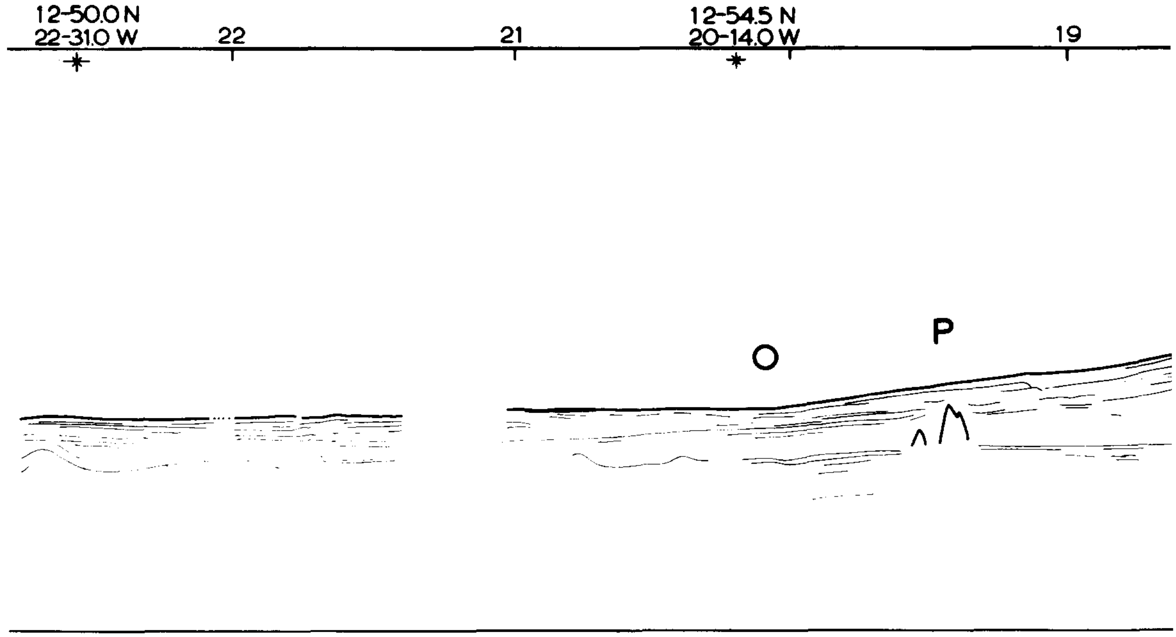
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22
21
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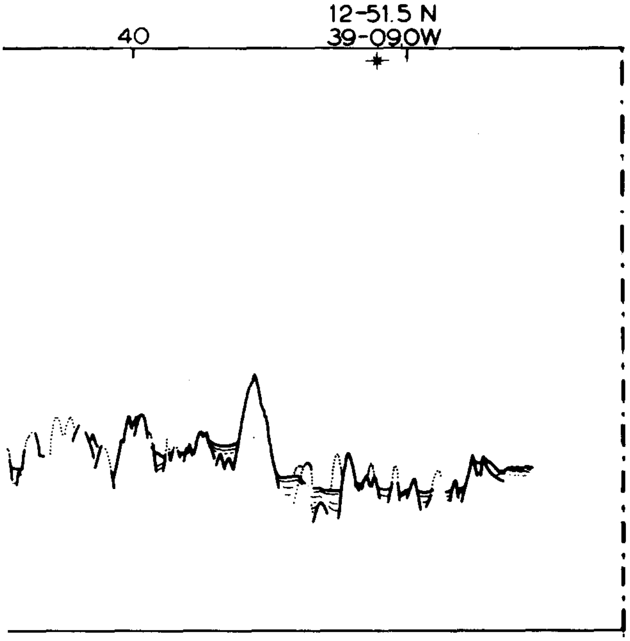
19
O
P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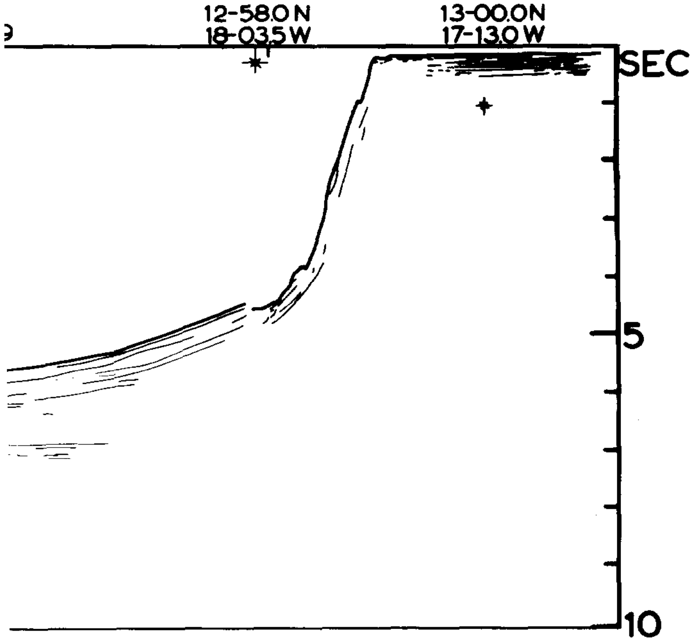
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13-00.0N
17-13.0 W
SEC
5
10

p.p.295–306

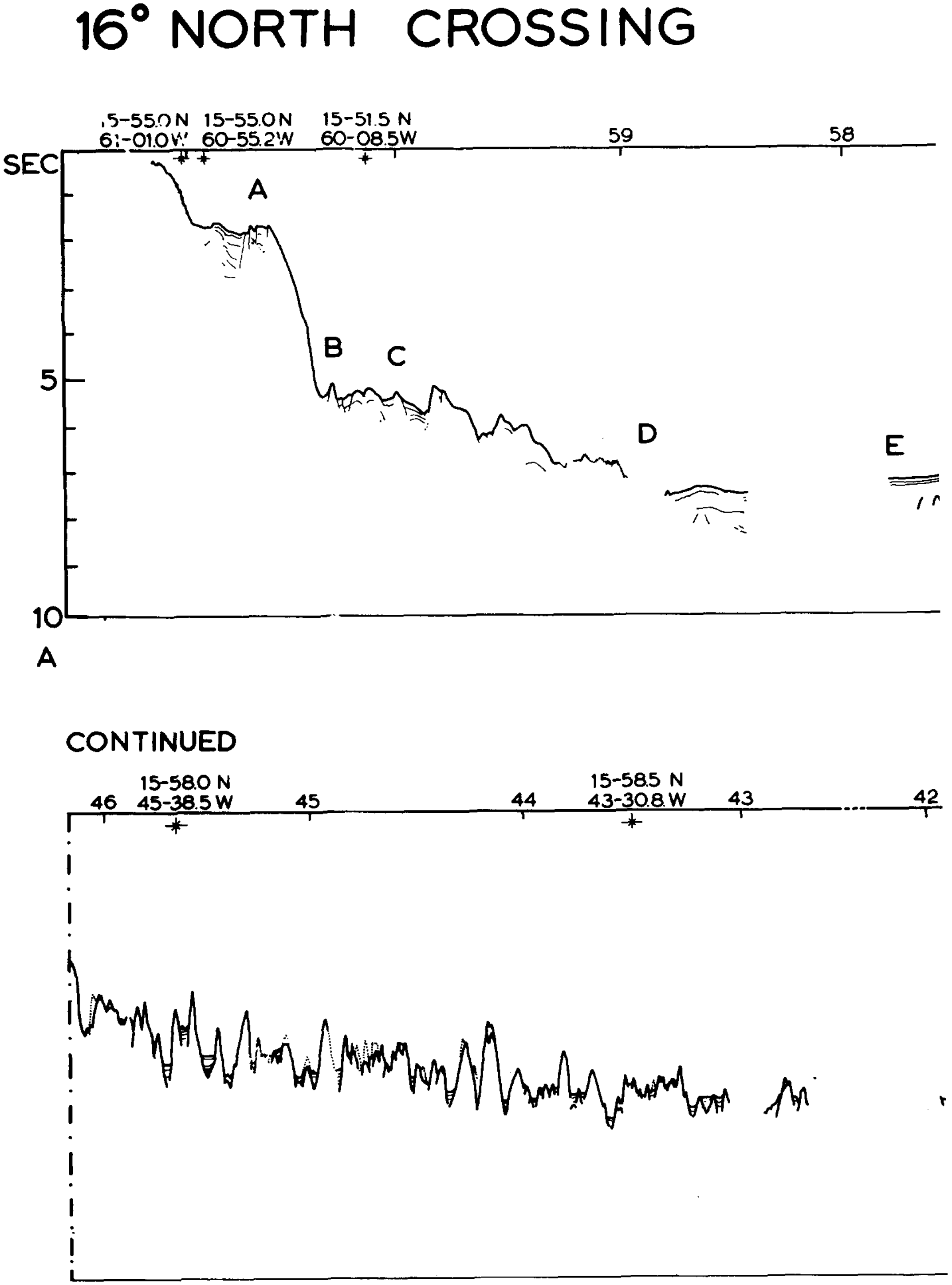
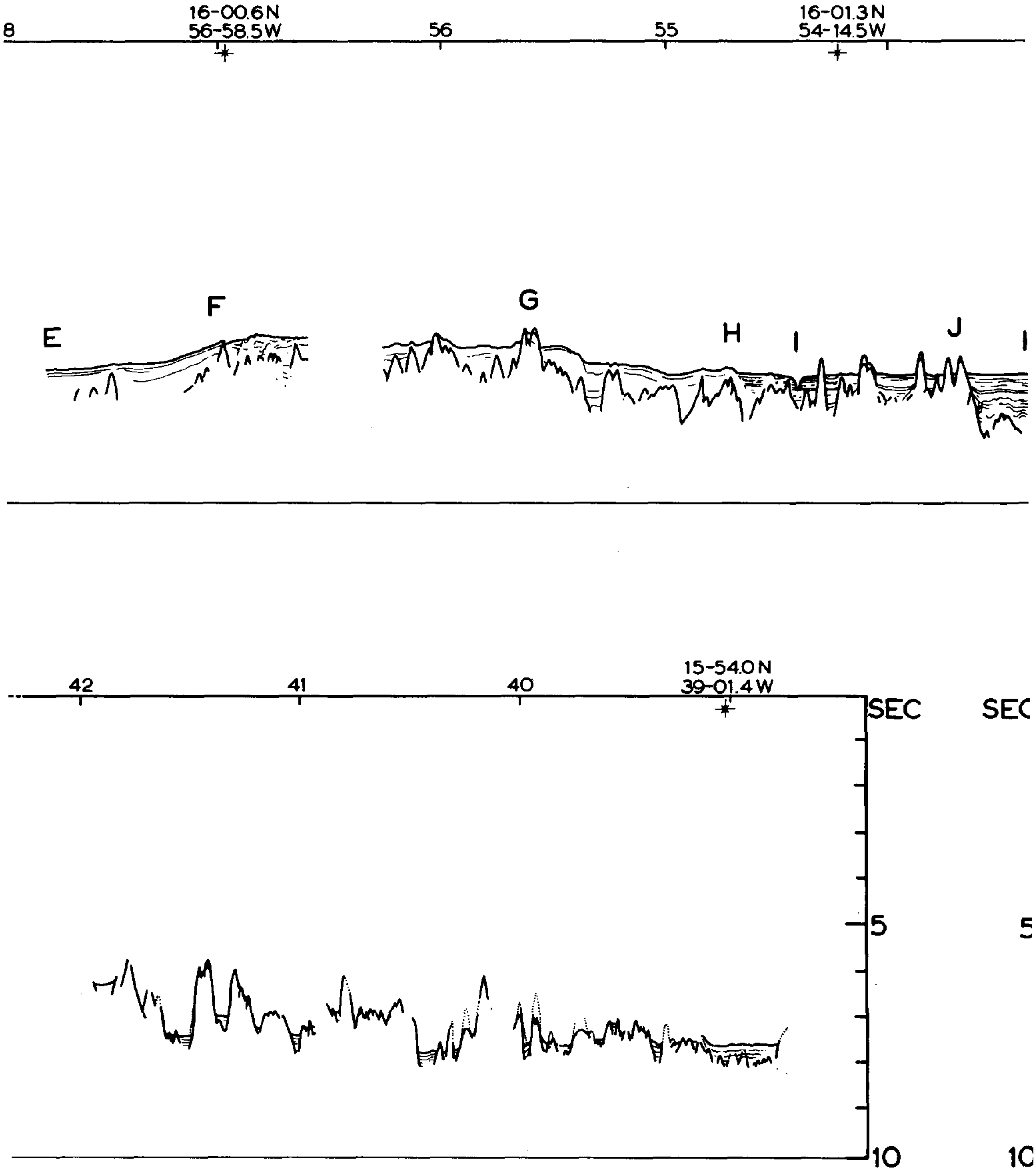


Fig.6. A. 16°N-crossing. B. Approach to Cape Verde Islands. Explanation see text.


8
16-00.6N
56-58.5W
56
55
16-01.3N
54-14.5W
E
F
G
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42
41
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15-54.0N
39-01.4W
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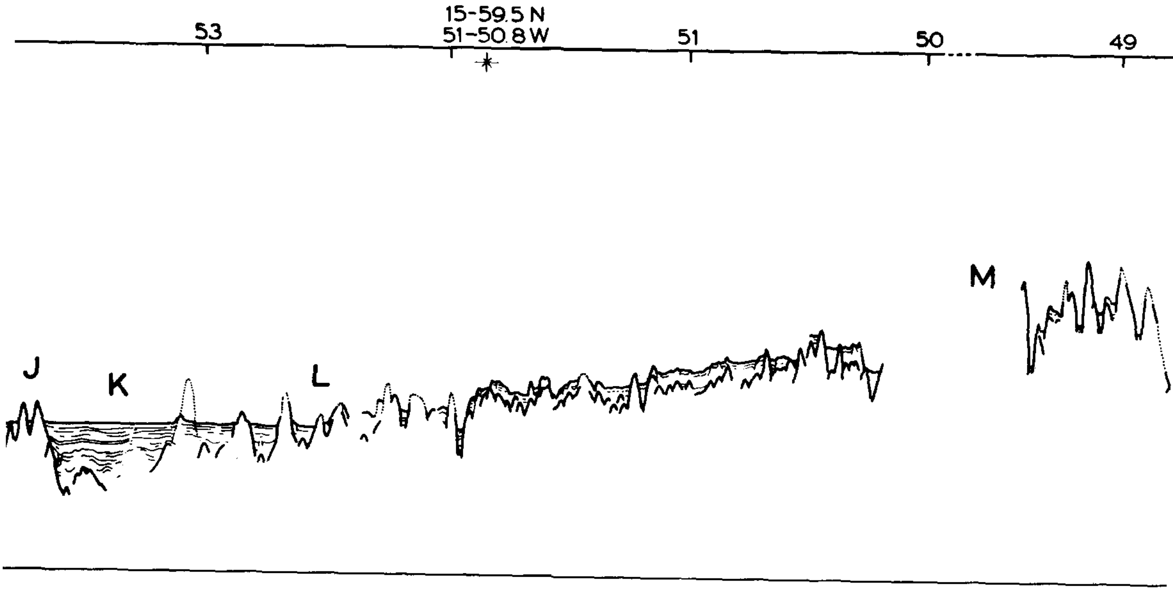
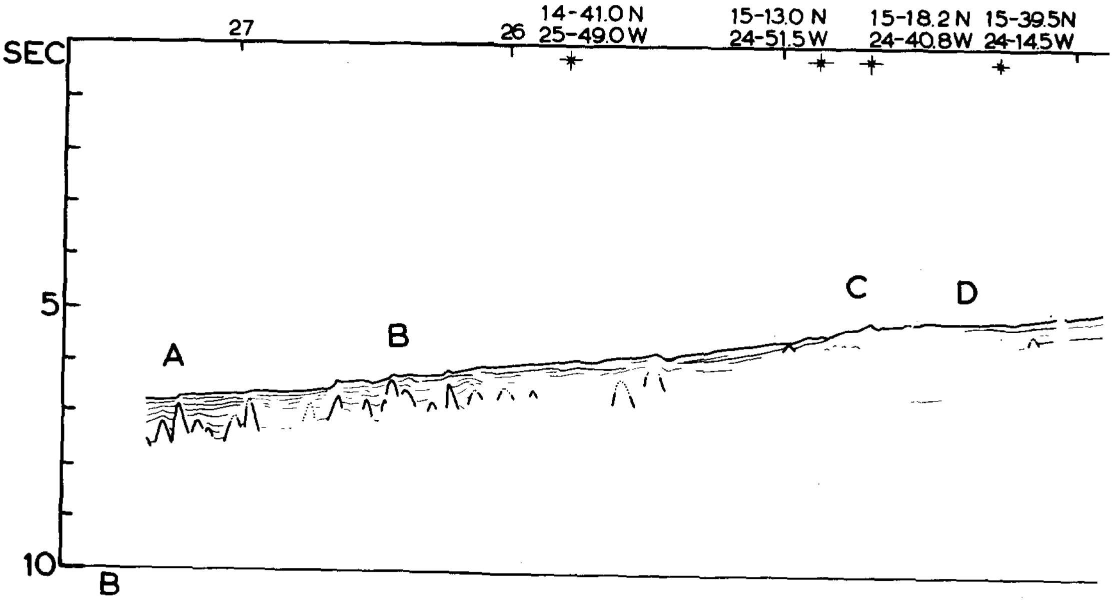
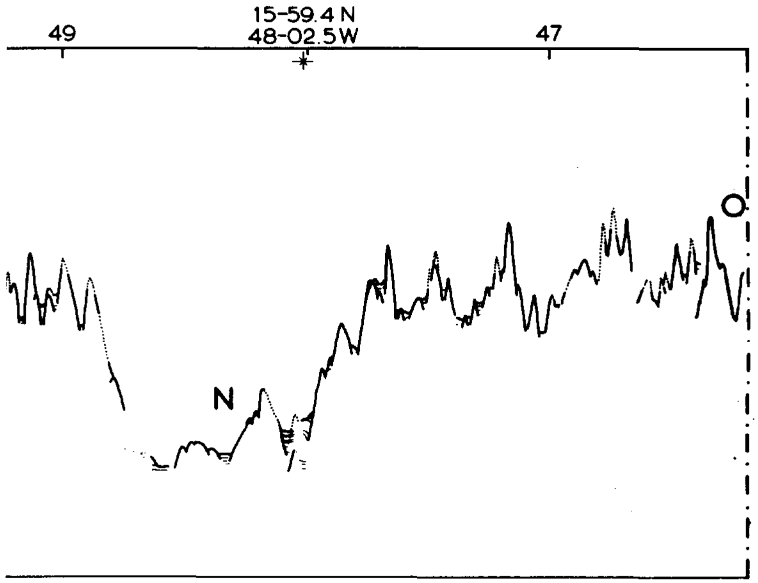
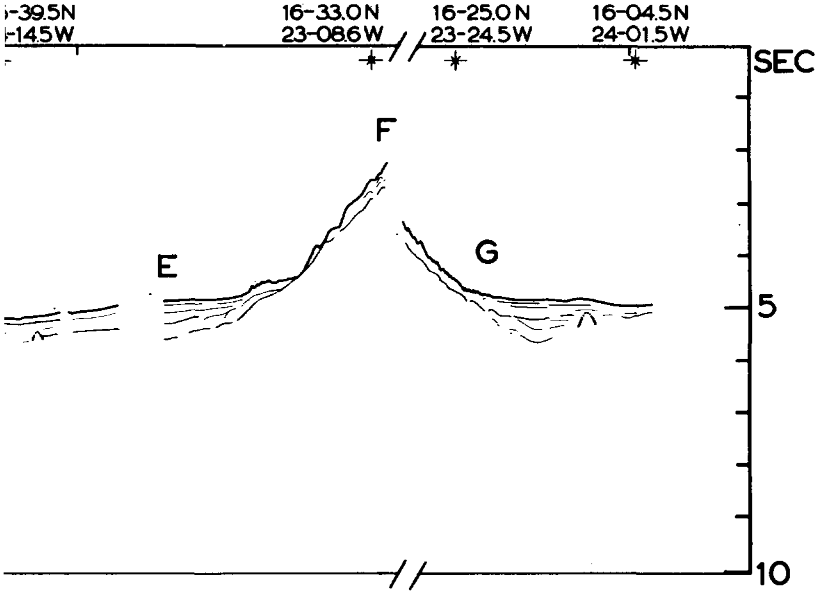


APPROACH CAPE VERDE ISLAND




49
15-59.4 N
48-02.5 W
47
N
O

ANDS


-39.5N
-14.5W
16-33.0N
23-08.6W
16-25.0N
23-24.5W
16-04.5N
24-01.5W
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F
E
G
5
10

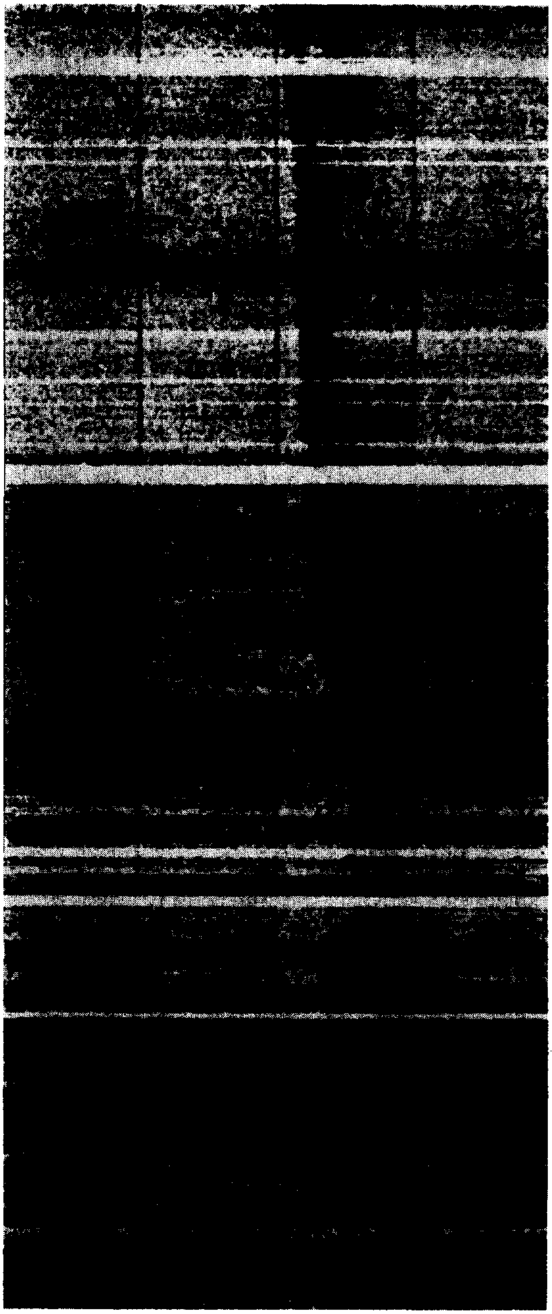


Fig.7. Recording of southwest-approach to Cape Verde Islands from 14°44'N 25°26'W–16°00'N 23°50'W (between 3 and 7 sec).

only way to ascertain this, however, is by sampling the layer in question and by surveying the area in more detail.

We finally draw the attention to the contorted character of the sediments on the slope of Sal. This feature must be due to slumping.

THE 16°-N CROSSING

This crossing shows over a relatively short distance a great diversity of phenomena (Fig.6A, see also Fig.2). It starts in the passage between the islands Marie Galante and Dominica. First there is a kind of plateau (16-A) at a depth of about 1,300 m, with distorted sediments in which some faults can be recognized.

Between positions 16-B and 16-D the zone of negative gravity anomalies (the Vening Meinesz zone) is crossed. The appearance of the sediments is entirely different from that found in the basin farther east. To start with, the penetration is small. The area is further characterized by small scale topographic roughness. Both phenomena are probably a result of tectonic deformation of the sediment and are typical of the zone of negative gravity anomalies as has also been pointed out by EWING et al. (1967). In the zone some smaller basins can be discerned, that also show signs of deformation. At 16-C the 60°W section crosses the present traverse. This section contains more information on the Vening Meinesz zone.

The section between 16-E and 16-F shows a thin sedimentary layer on the otherwise homogeneous sediments, that has the appearance of a turbidite deposit, except for its non-horizontality. If this layer indeed consists of turbidites the non-horizontality might be caused by a bending down of the ocean crust towards the Vening Meinesz zone.

The low basement rise between 16-E and 16-G is a crossing of the southernmost part of an east–west oriented structure known as the Barracuda Ridge (Fig.8; cf. also PAITSON et al., 1964). It must be stressed that to the north the Barracuda Ridge is much higher. It rises more than 1,800 m above the adjacent Demerara Abyssal Plain. The supposed fault to the north of the Barracuda Ridge might be the extension of a fracture zone of the type dissecting the Mid-Atlantic Ridge crest. The available data, however, are insufficient to ascertain this (cf. KRAUSE, 1964).

The homogeneous layer covering the Barracuda Ridge shows short wave length undulations of the sea floor and, near 16-F, weak sub-bottom reflections. These features are considered as typical for current controlled sediments. The homogeneous layer clearly continues below the stratified sediments of the Demerara Abyssal Plain which starts at 16-H and extends to 16-L. The mean depth of the basement under the abyssal plain is somewhat greater (about 0.5 sec) than in the section from 16-F to 16-H. However, the parts of the section immediately west and east of 16-H have about the same mean basement depths. This implies that the rate of sedimentation of the homogeneous layer can vary over relatively short distances, and that here this layer is older than the turbidites.

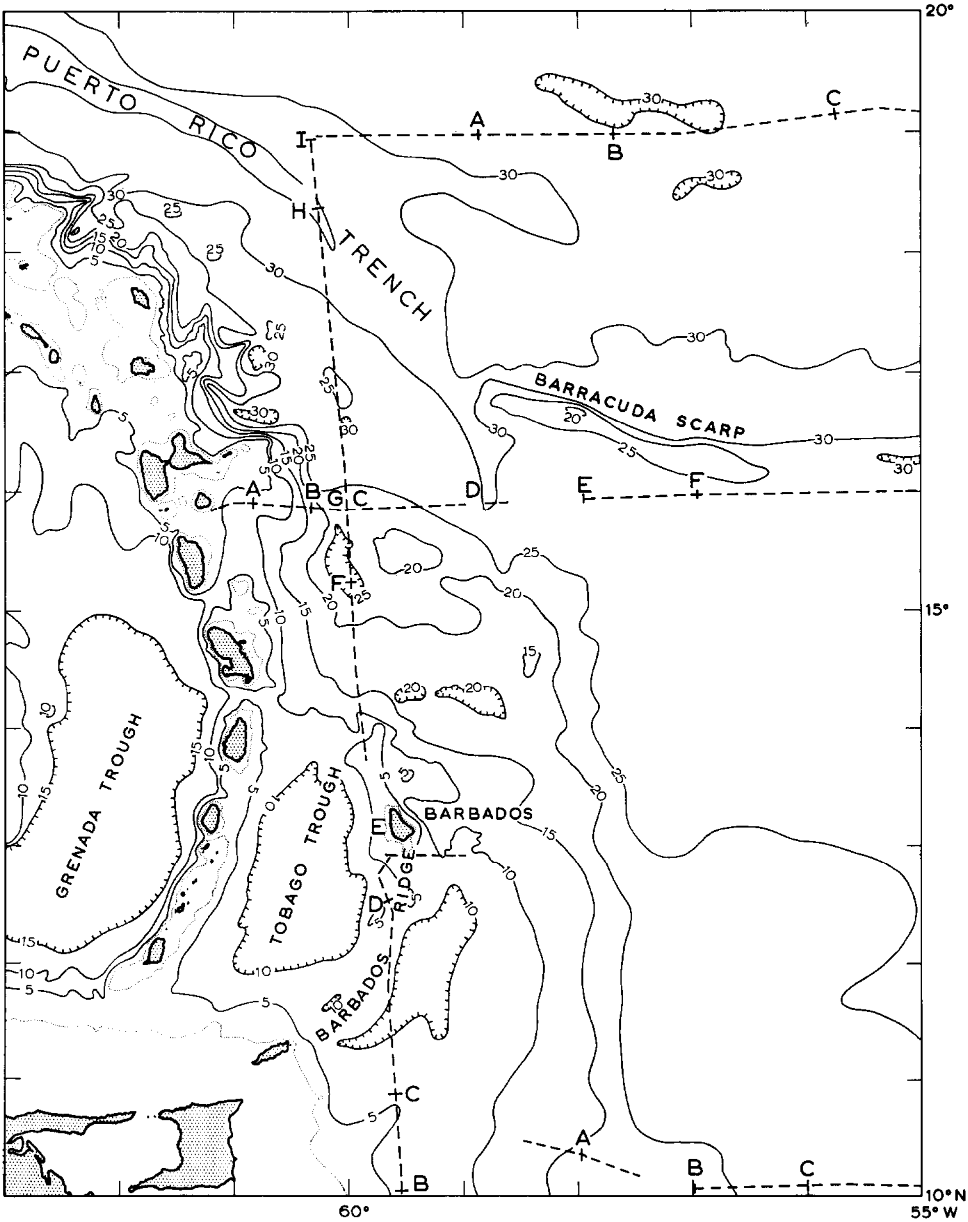


Fig.8. Bathymetric chart of the western part of the surveyed region (after HESS, 1966).

The depth of the plain does not differ significantly from west to east as it did on the 10° and 13°N-crossings. At position 16-K the abyssal plain sediments attain their greatest thickness (about 1,300 m). The sub-bottom structures observed here are a fine example of differential compaction structures.

Over the whole length of the abyssal plain a strongly developed subsurface reflector is found at 0.3 sec under the surface (see also Fig.2), presumably horizon A (cf. EWING et al., 1964, 1966). This is the only section in the Demerara Plain where this horizon was clearly recorded.

At 16-I an erosion channel of 220 m deep can be seen, cutting into the horizon. This channel has also been found on the P.D.R.-record of a crossing 4 miles to the south, made by H.M.S. "Vidal" in 1963 (Fig.9). We propose to name it "Vidal Channel". In late 1966 R.V. "Vema" surveyed the Vidal Channel from about 15°30′ to 16°30′N and took several cores in an attempt to sample horizon A. Only a thin layer of recent clay was found, overlaying unfossiliferous sand (J. I. Ewing, personal communication). The position of the Vidal Channel on the present track is 16°00′N 54°26′W, on the 1963 track 15°56′N 54°26′W. It may be recalled that also an erosional valley was found at position 13-C (12°59′N 52°00′W). In late 1965 H. Neth. M.S. "Snellius" found a channel at 14°29′N 53°48′W and a less pronounced gully at 14°29′N 54°31′W. The line connecting the valleys at latitudes 13°, 14°30′ and 16°N is not straight. Depths are greater to the north-northwest. Later Lamont cruises verified that we are dealing with one and the same valley.

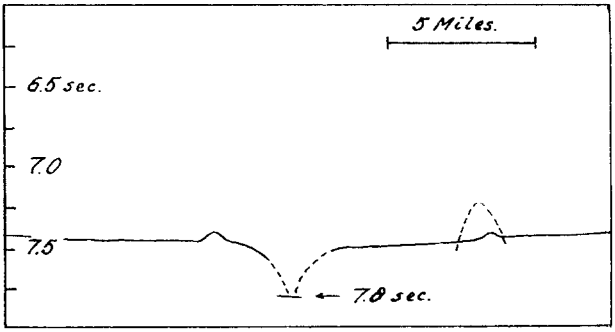


Fig.9. Precision depth recording of the Vidal Channel at 15°56′N 54°26′W (H.M.S. "Vidal", 1963).

The flank of the Mid-Atlantic Ridge starts at position 16-L and is draped by a continuous cover of fairly transparent sediments, ranging in thickness from 250–500 m, up to the vicinity of position 16-M. The large depression at 16-N is apparently an oblique crossing of a fracture zone. The floor of the depression is about 400 m lower than the nearest point of the abyssal plain. There is no appreciable sedimentary fill.

The rift at 16-O probably is the median rift, although it cannot be precluded entirely that the median rift has to be placed 40 km to the west. A zone of the crestal region about 110 km wide is completely bare of sediments. The rest of the crest province shows only small pockets of sediment. On the upper flank the pockets become somewhat greater. Finally, the transition from flank to abyssal hills province is not sharp.

THE 60 °W-SECTION

This section (Fig.12A) starts on the continental shelf off British Guiana and runs east of the Antillean island arc over the Barbados Ridge to the Puerto Rico Trench (Fig.8), i.e., over its entire length over the zone of negative anomalies.

From 60-A directly north of the Guiana continental shelf until 60-C the track runs roughly parallel to the depth contours of the continental slope. This part of the area is characterized by highly stratified sediments about 1,000 m thick overlying an uneven subbottom giving rise to differential compaction structures. On position 60-B we observe a small graben on top of what seems to be an anticline structure. The records are not conclusive on the nature of the basement, but our suggestion is that the more transparent sediments north of 60-C continue to the south under the highly stratified sediments. These latter sediments are presumably turbidites, coming in from the west and deposited on the slope which has an overall inclination of 1.2‰. The elevation at 60-C must have acted as a barrier preventing any flow northward.

Right north of 60-C the El Pilar fault might be crossing our section. The El Pilar fault is a major, sinistral, east–west running transcurrent fault passing south of the Trinidad mountain range. The slight deformation of the ocean floor and the sedimentary layers north of 60-C then might be interpreted as resulting from some overriding of the south block over the north block.

From 60-C to Barbados (60-E) first a minor trough is passed and next the Barbados Ridge. The Barbados Ridge coincides with the Vening Meinesz zone. Sea floor and sediments are slightly undulating, the younger interfaces being conformable to the deeper reflector (cf. also EWING et al., 1967, regarding the west slope of the Barbados Ridge). Only at position 60-D the basement steeply rises nearly reaching the seafloor. EWING et al. (1957) published a refraction section in this neighbourhood. The "basement" protrusion at 60-G might belong to their 4 km/sec layer, then identified as "lithified sediments, volcanic rocks, or possibly metamorphosed sediments". At Barbados itself strongly deformed Tertiary rocks are found (BUTTERLIN, 1956). No strong deformations are seen on the ridge. The undulations if reduced to a true depth section represent dips of the order of 2–3 °. The situation seems to be different on a section north of Barbados, described by HURLEY (1967), who found "a thick section of strongly deformed rocks".

For a good understanding of the following part of the section one should also consult Fig.8. From Barbados to 60-G the section runs about perpendicularly to the depth contours which here do not show a simple relation to the Vening Meinesz zone. The long and gentle slope configurates the termination of the Barbados Ridge in axial direction. The section (see also Fig.10) shows a thick layer of sediment resting on the slope with indications for a slump of large dimensions. At the foot of the slope we find two pockets of younger and layered sediment. By vague reflections at 60-F and 60-G the underlying sediments are suggested to be

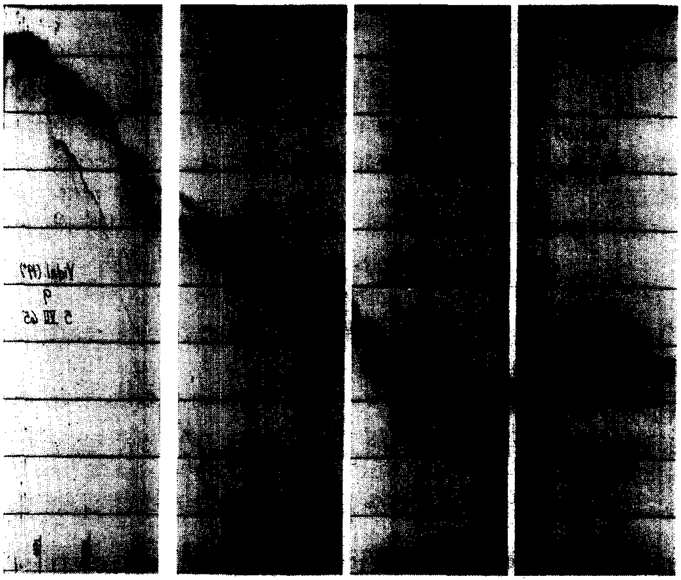


Fig.10. Recording of part of the 60°W-section (13°44'N 59°50'W–16°08'N 60°01'W).

folded and possibly faulted. Although the section is impressive, we should not forget that the dips shown are still only 2–4°. The vertical exaggeration is such that an inclination of the order of 10° already would become subvertical. The intersection point with the 16°N-crossing is 60-G. The area that follows is characterized by an irregular topography and a lack of coherent subsurface reflections all the way to the axis of the Puerto Rico Trench at 60-H. We already mentioned in the discussion of the 16°N section that this seems to be typical for the Vening Meinesz zone. The lack of good penetration is apparently due to sediment characteristics, not to the absence of sediment as becomes clear from a seismic refraction section running northeast from the island Barbuda across the Puerto Rico Trench which indicates a considerable fill of low velocity material (OFFICER et al., 1959). The presence of a considerable thickness of sediments is also suggested by the sudden disappearance of the basement a few kilometers south of the trench axis at 60-H.

The topographic irregularities deserve closer attention. Just south of 60-G we can observe that part of this roughness is only superficial, i.e., due to either sedimentation or erosion. It reminds of the current influenced sediments at the Barracuda Ridge at 16°N. Again the possible influence of the Antarctic Bottom Current that enters the trench, should be mentioned. To the north of 60-G the topographical irregularities have a different character and might be caused by actual deformation of sediment. The 16°N-crossing only shows topographic irregularities of the latter kind in the Vening Meinesz zone. No turbidites are present in the trench itself (60-H), a situation different from what has been found further west in the trench (EWING and EWING, 1962).

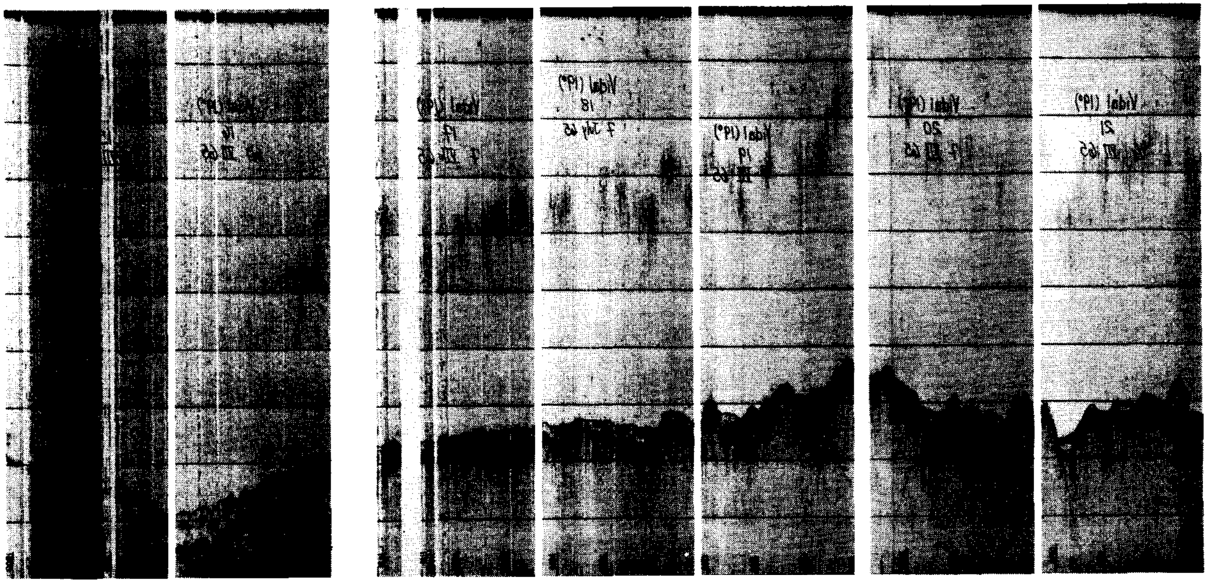


Fig.11. Recording of part of the 60°W-section (17°47'N 60°13'W–18°51'N 60°20'W) and of the 19°N-crossing (18°59'N 60°11'W–18°59'N 57°54'W), showing the eastern tip of the Puerto Rico Trench and the adjoining abyssal hill province.

Finally, the rising of ocean floor and basement revealed between 60-H and 60-I at the northeast side of the trench suggests a downbending of the ocean floor towards the trench (see Fig.11).

THE 19°N-CROSSING—APPROACH TO CANARY ISLANDS

This crossing starts north of the Puerto Rico Trench (Fig.12B, 13). The most conspicuous feature west of the Mid-Atlantic Ridge is the total absence of turbidites. The depths are greater than on the other crossings (maximum depth 5,870 m near position 19-B). However, the northward slope of the Demerara Abyssal Plain, if extrapolated, undercuts the topography on this latitude. This means that the turbidite sedimentation simply did not yet reach this basin.

The first part of the section might be a crossing of the "outer ridge" (19-A). Its continuation this far east cannot be ascertained, however, from the available bathymetric maps. The sedimentary layer, about 200 m thick, is draped conformably over basement and exhibits weak reflections. This layer would correspond to the "transparent" sediments comprising the outer ridge directly north of Puerto Rico, described by EWING and EWING (1962) and BUNCE and HERSEY (1966), which are, however, not conformable and often show an undulating surface.

From positions 19-C to 19-K the recordings are rather poor, due to instrumental difficulties. At position 19-D an asymmetric ridge is crossed with a steep scarp facing east, at position 19-E a rift valley, probably a fracture zone.

The transition from the abyssal hills province to the ridge flank is not sharp. HEEZEN et al. (1959) place it near 19-E. On the flank (19-F) the sedimentary layer is much thinner (considerably less than 150 m). At position 19-G another scarp or fracture zone is crossed. The ridge does not have a pronounced character at this latitude. There is no clear median valley (possibly just east of the large peak at 19-H). A central area of about 200 km wide is completely void of sediments.

The eastern flank also has a very thin cover. A series of narrow valleys filled with horizontally layered sediments and level floors is found near position 19-I. The abyssal hills province reaches a maximum depth near position 19-J, right after the turn in the section from azimuth 090° to 065°. This part of the basin is separated from the Cape Verde/Madeira Abyssal Plain by a low and broad elevation (from 19-K to 19-M), the Krylov Rise. The extrapolation of the westward slope of the abyssal plain undercuts the ocean floor in this part of the region, which implies that the Krylov Rise does not necessarily act as a barrier to the transport of sediments from the east. At position 19-L a scarp is crossed with a small rift valley to the east, presumably a fracture zone.

From position 19-M the section shows a very thick turbidite series (cf. JONES et al., 1966). The section (see also Fig.14) shows beautiful examples of differential compaction. It is not possible to label one of the many strong reflections as horizon A. At positions 19-N, 19-O and 19-Q terrace-like steps are observed,

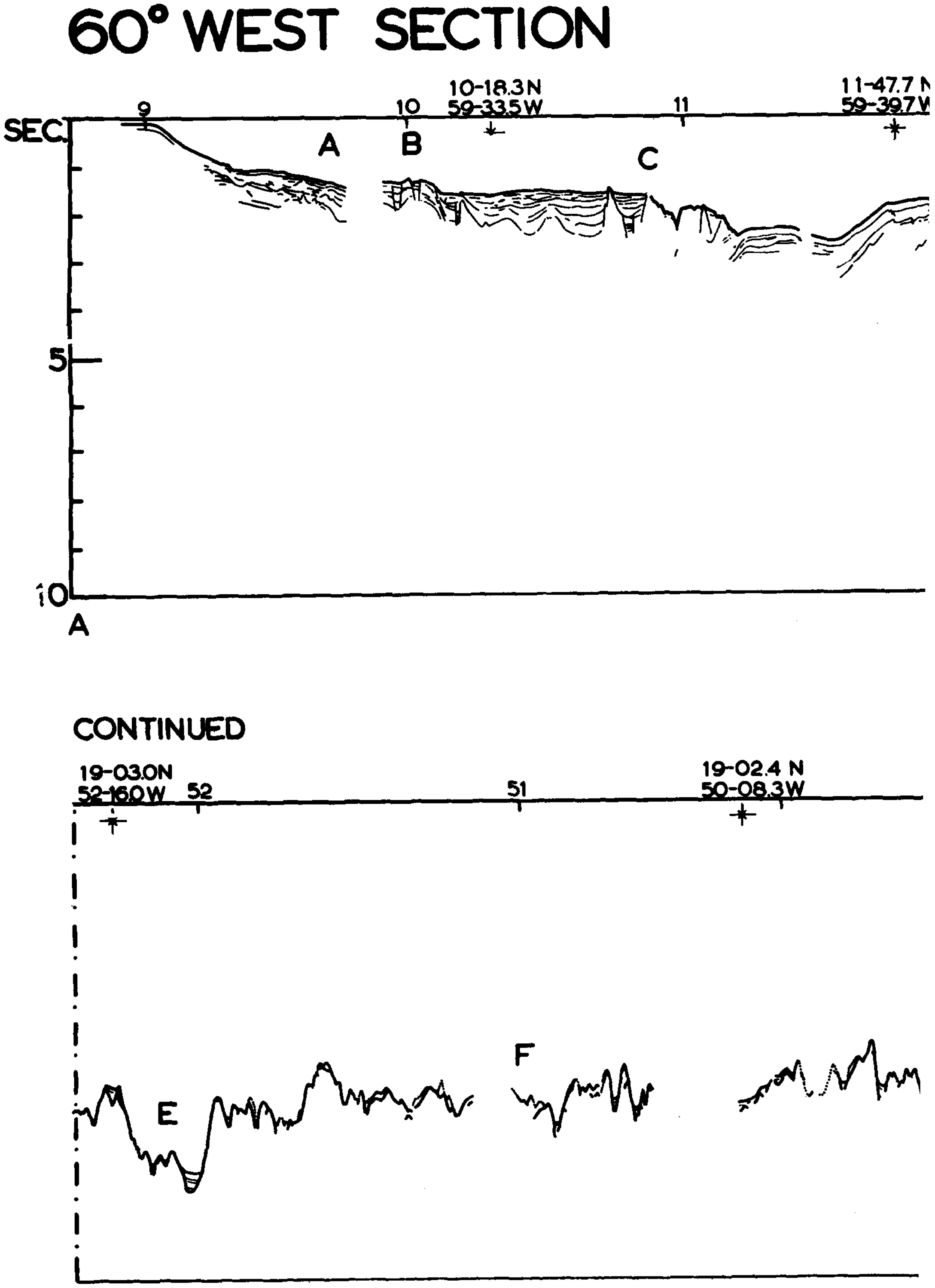
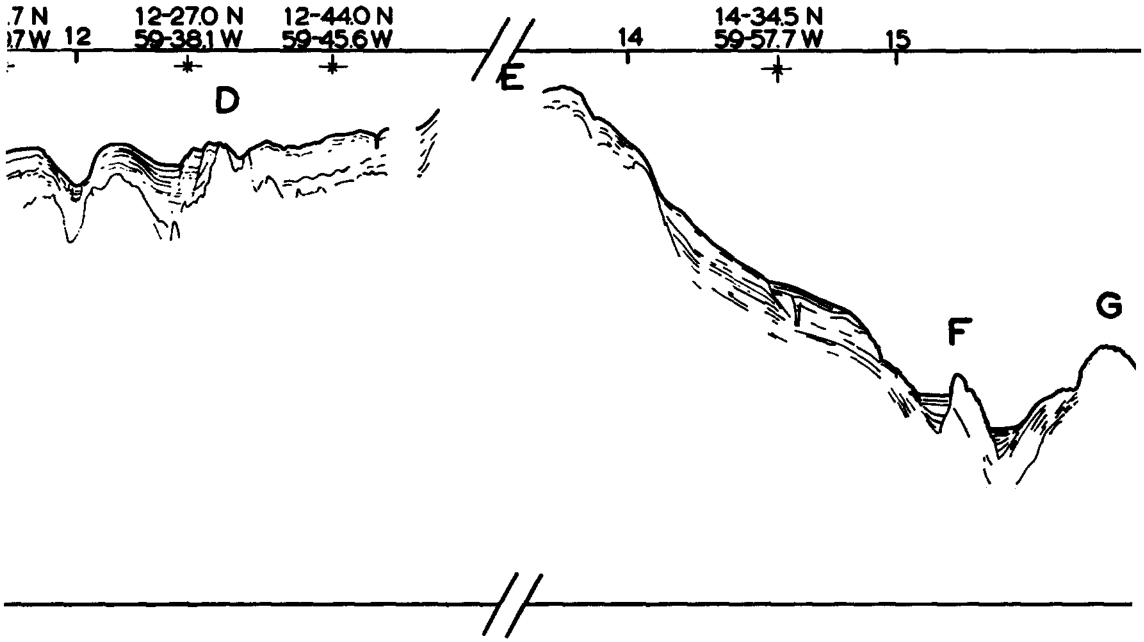
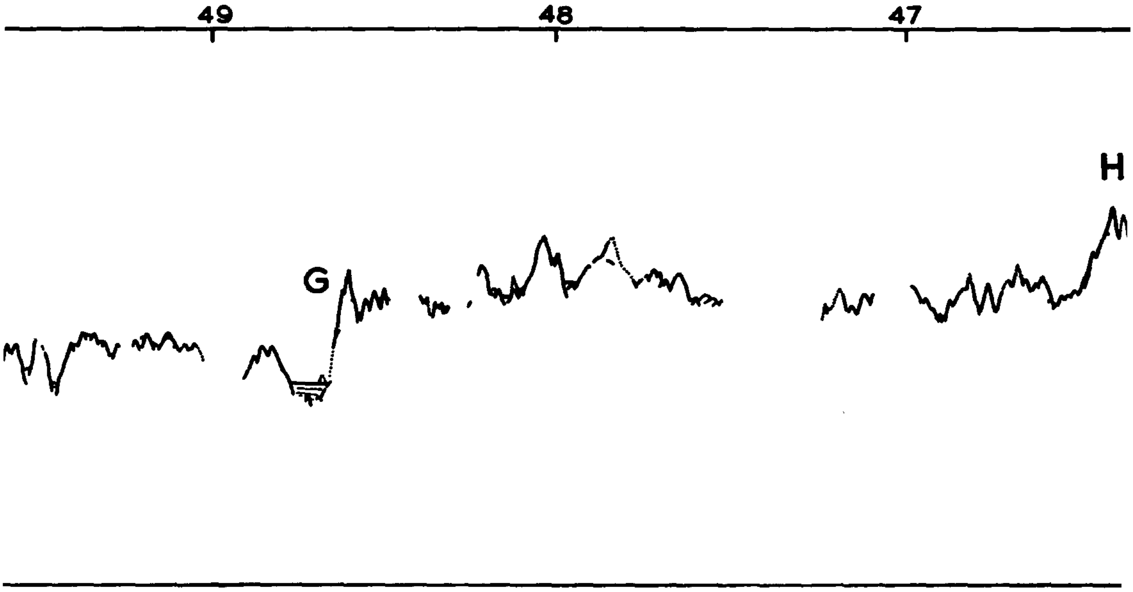
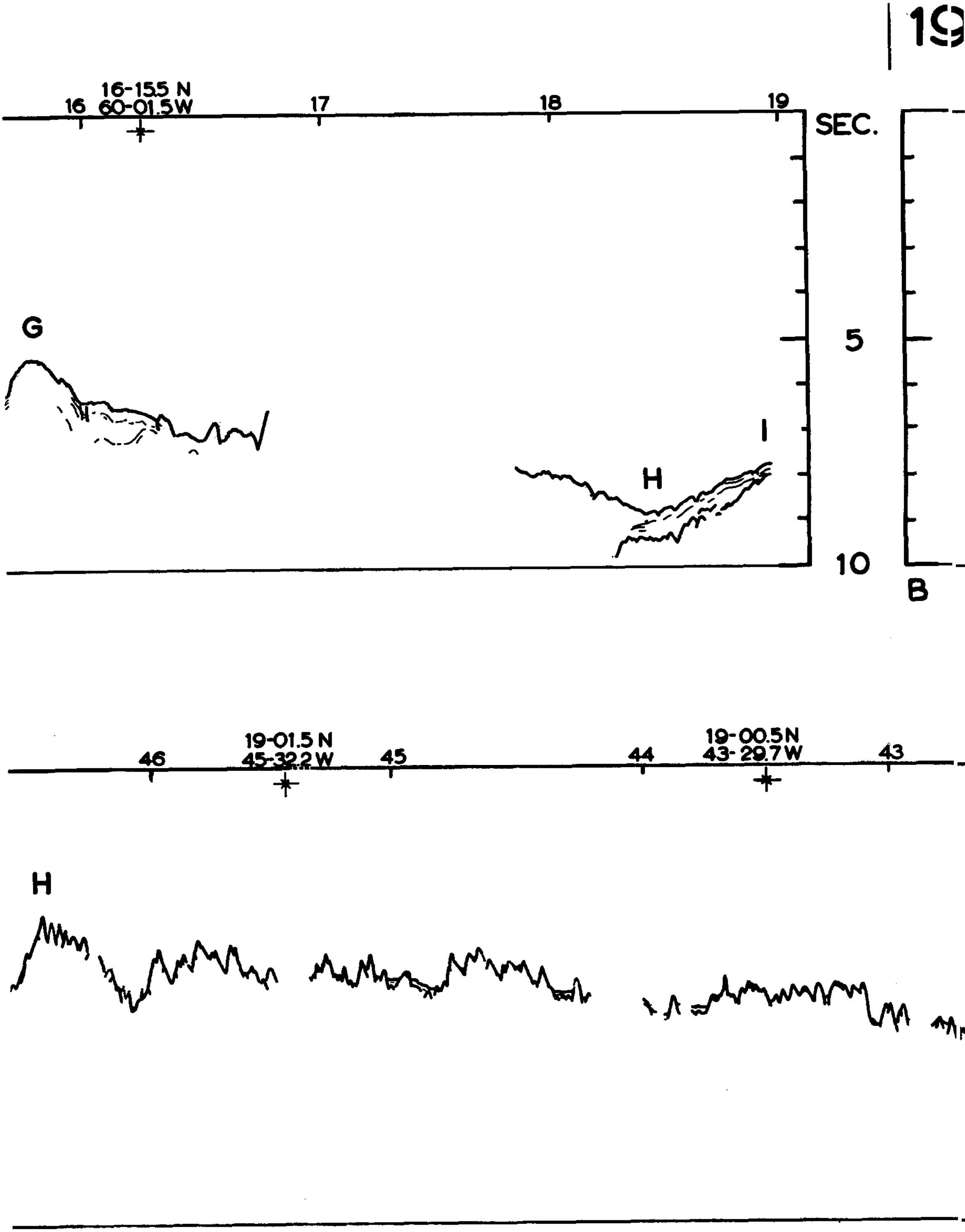


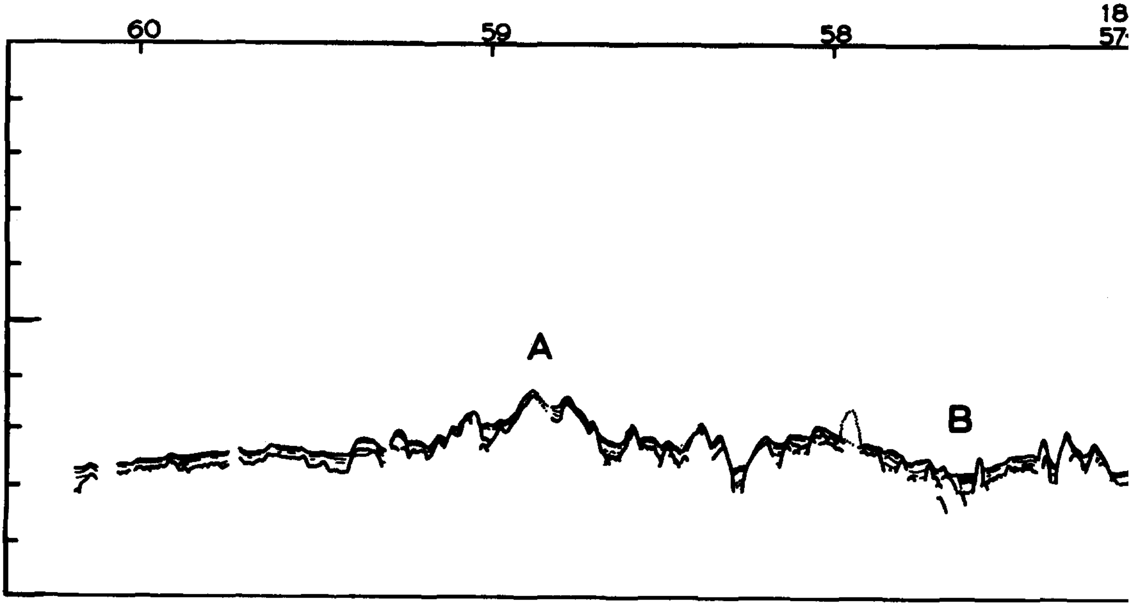
Fig. 12. A. 60°W-section. B. 19°N-crossing. Explanation see text.


.7 N
7 W
12
12-27.0 N
59-38.1 W
12-44.0 N
59-45.6 W
14
14-34.5 N
59-57.7 W
15
D
E
F
G

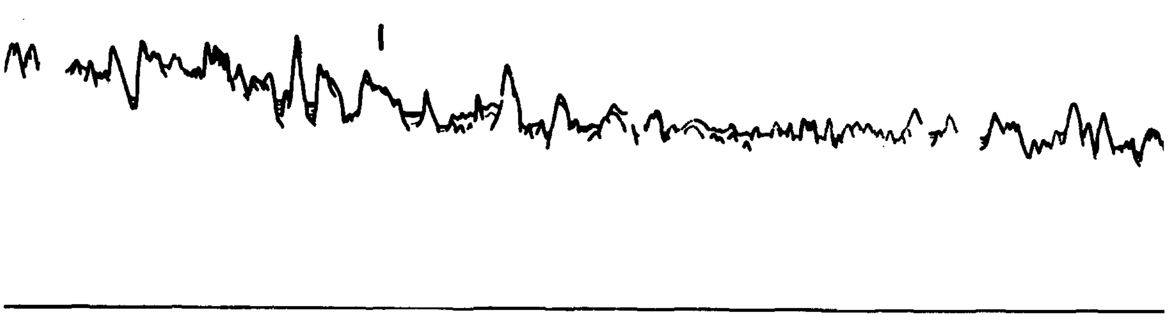

49
48
47
G
H

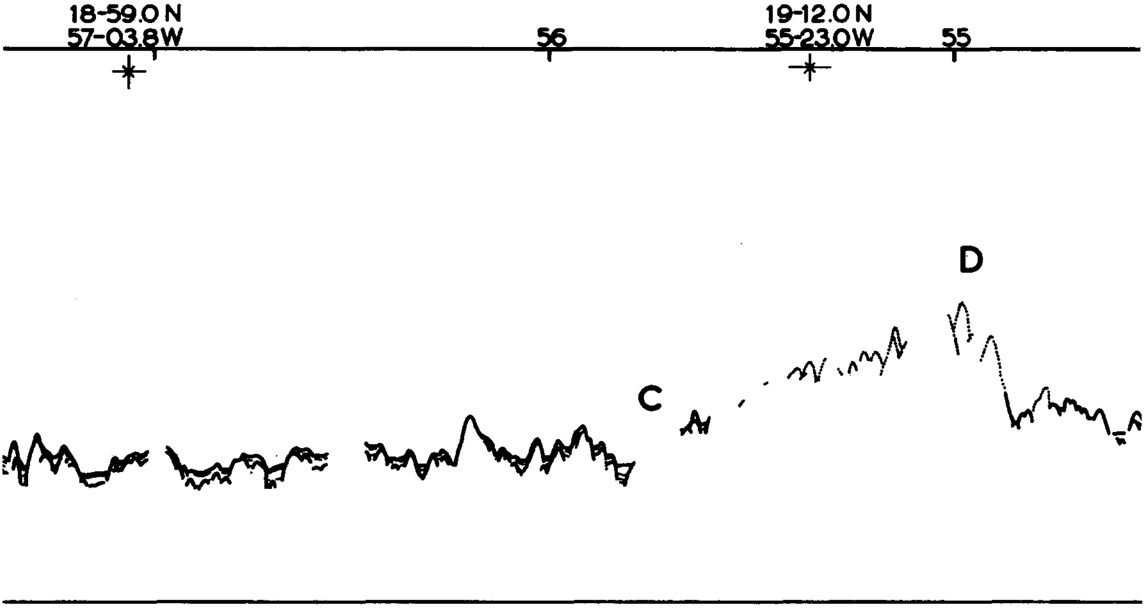

19
16-15.5 N
60-01.5 W
16
17
18
19
SEC.
5
10
G
H
I
B
19-01.5 N
45-32.2 W
46
45
44
19-00.5 N
43-29.7 W
43
H

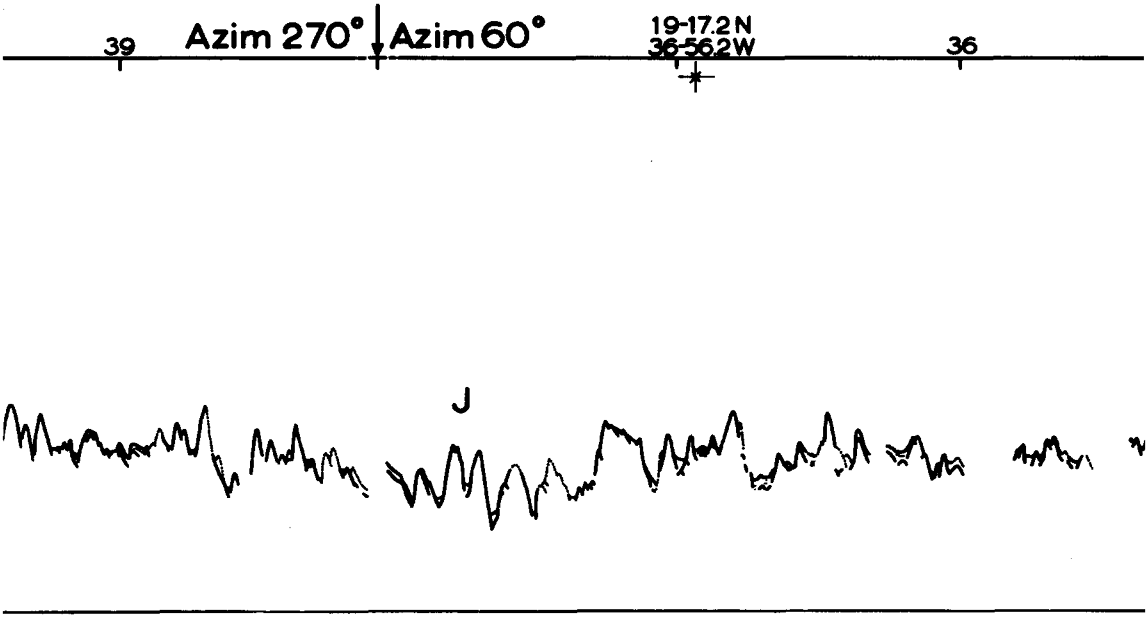
19° NORTH CROSSING

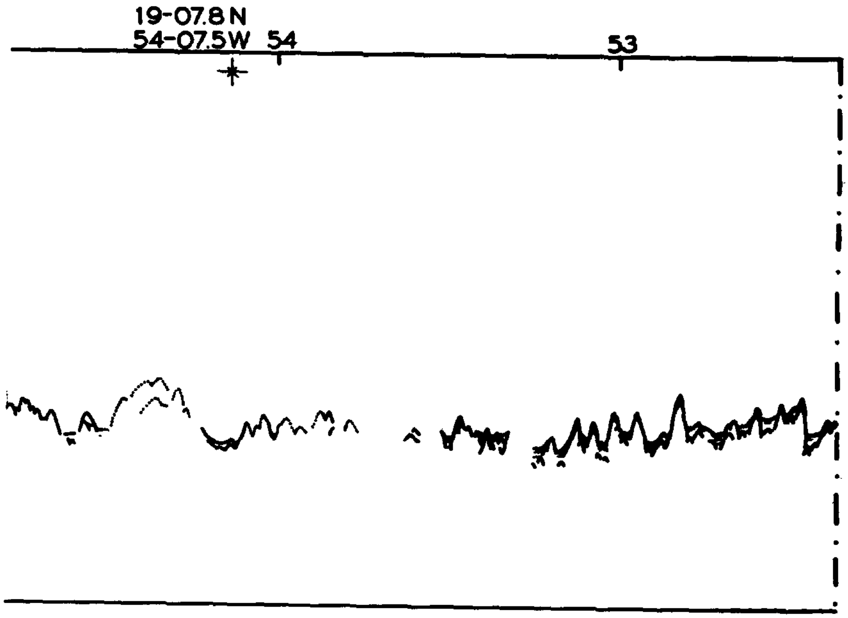


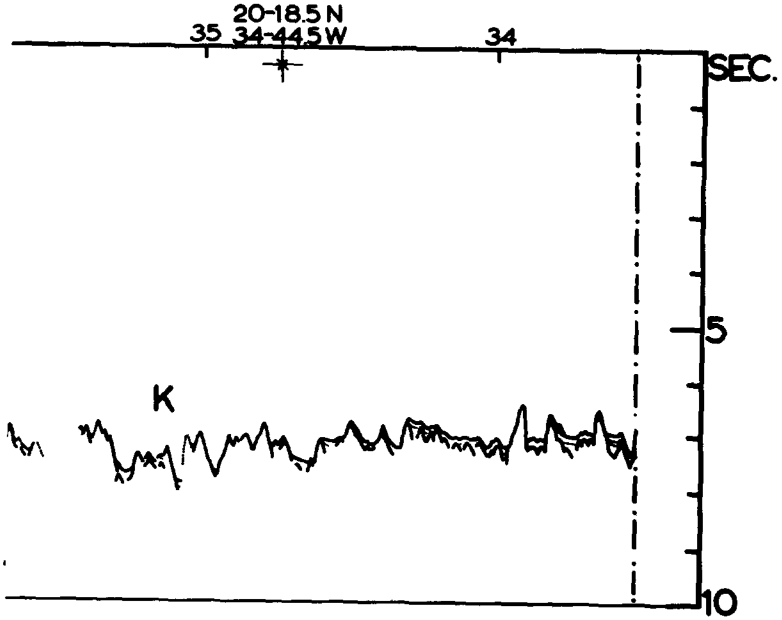
B




18-59.0 N
57-03.8W
56
19-12.0 N
55-23.0W
55
C
D


39
Azim 270°
Azim 60°
19-17.2 N
36-56.2W
36
J


19-07.8 N
54-07.5 W
54
53


20-18.5 N
34-44.5 W
35
34
SEC.
5
10
K

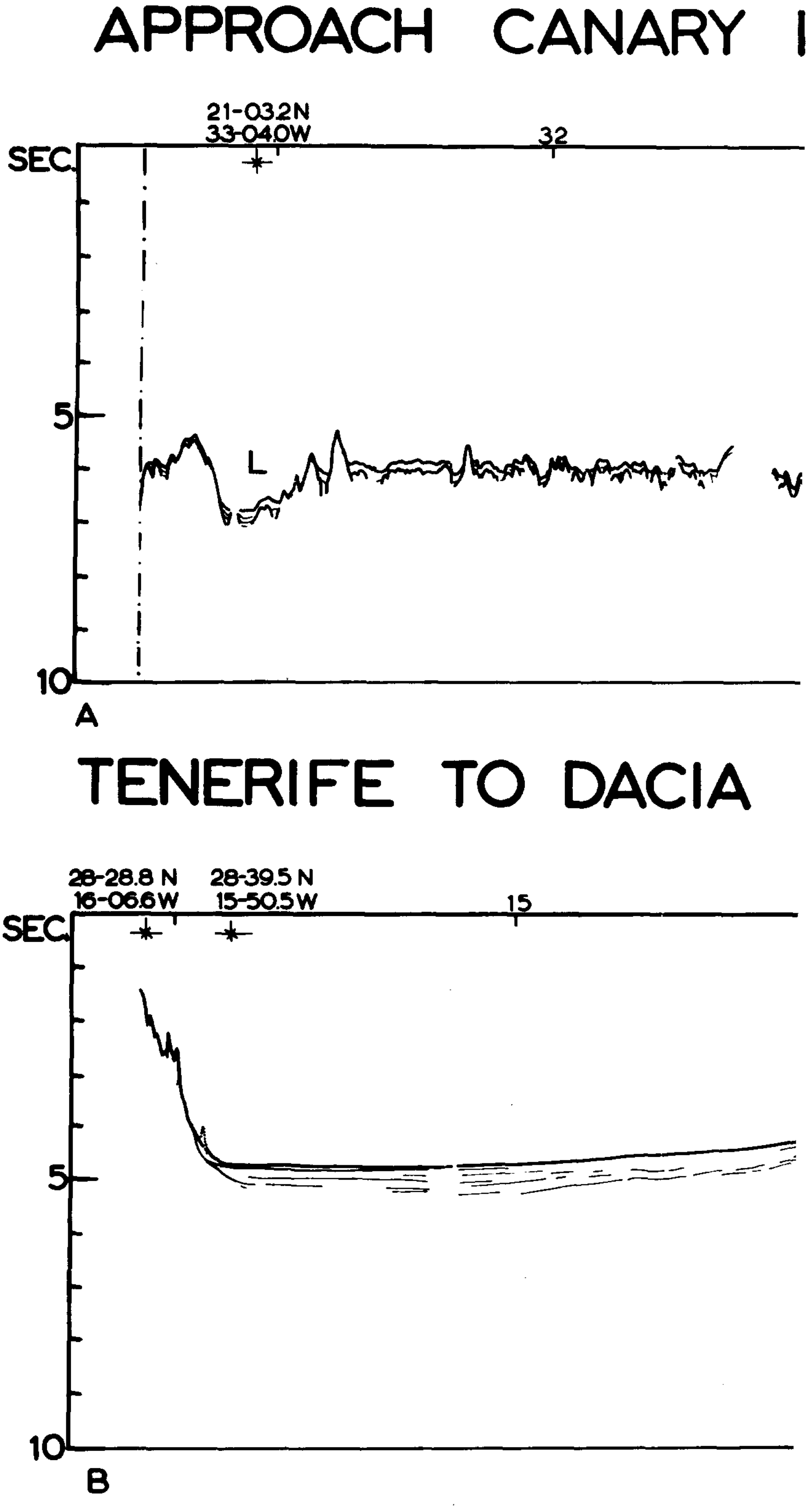
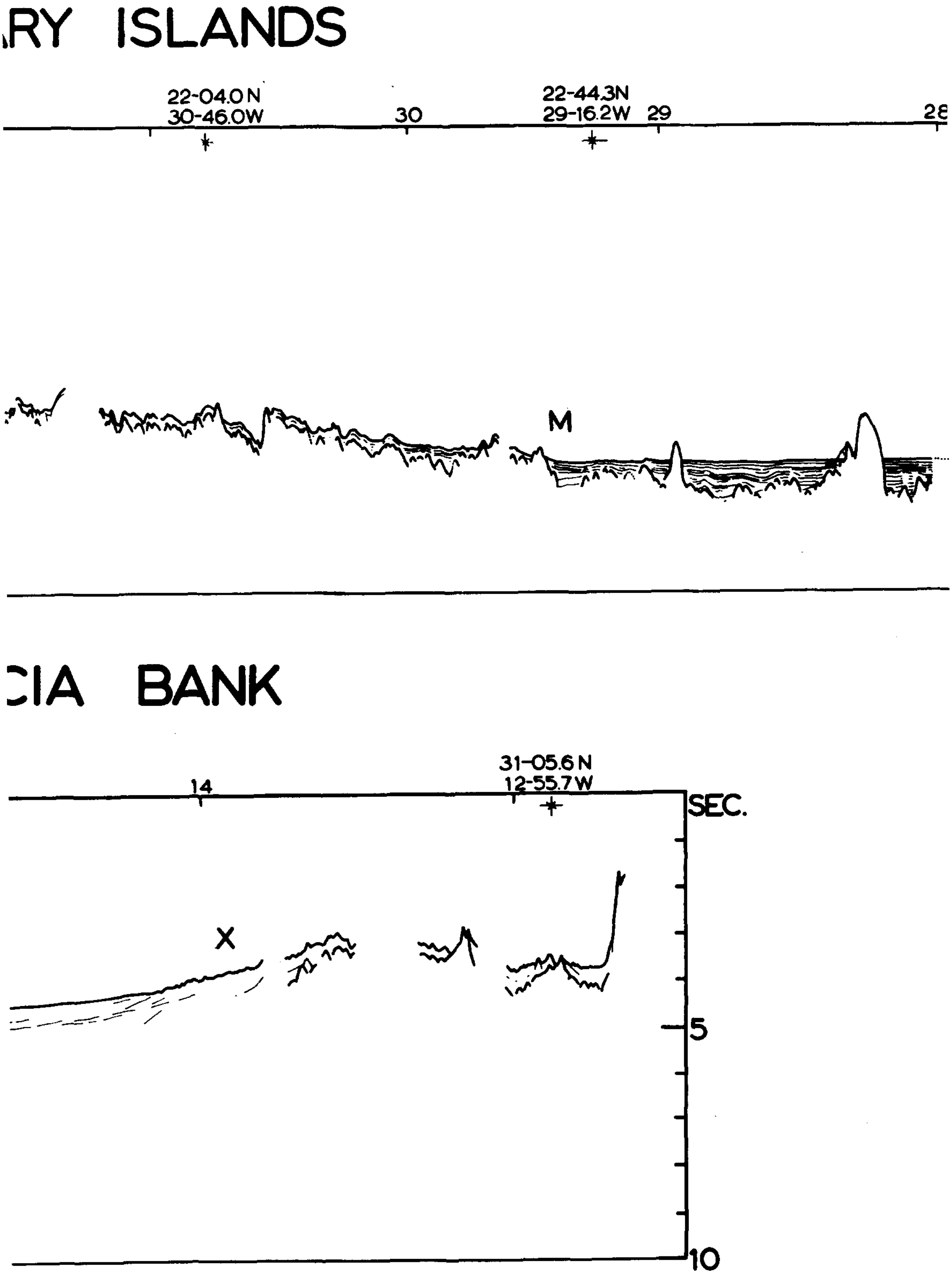
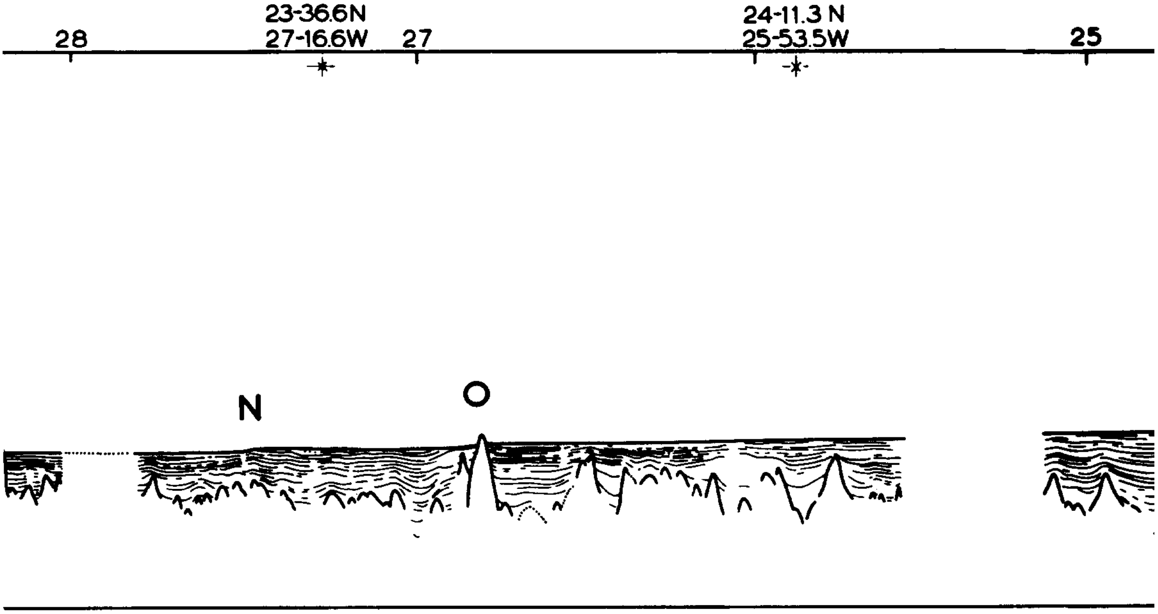
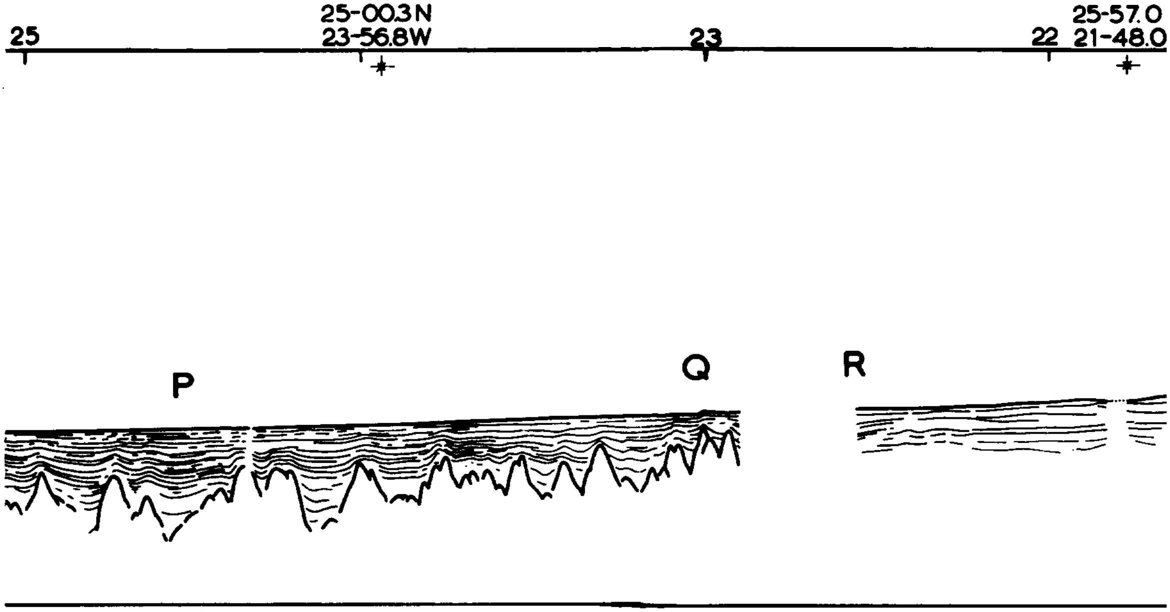


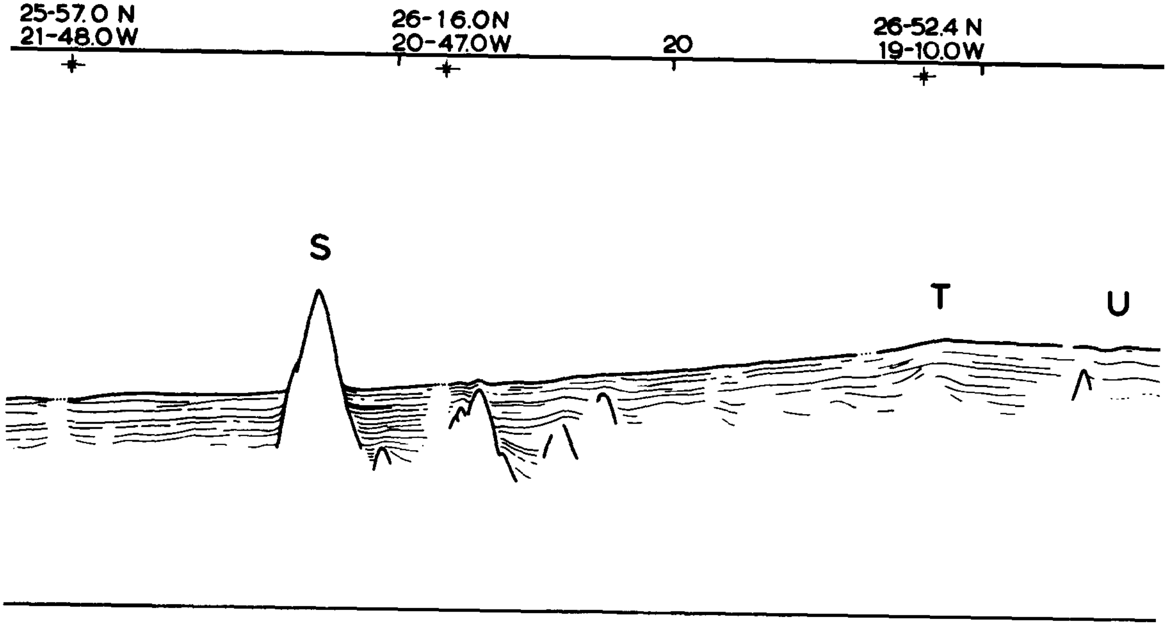
Fig.13. A. Approach to Canary Islands. B. Tenerife–Dacia Ba

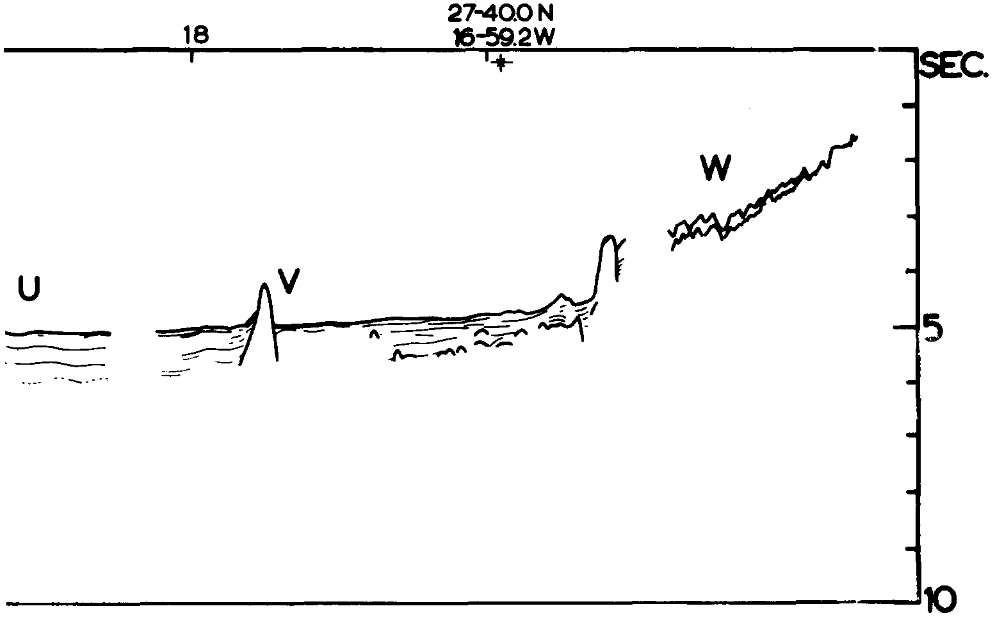


rife–Dacia Bank section. Explanation see text.


23-36.6N
27-16.6W
24-11.3 N
25-53.5W
28
27
25
N
O


25
25-00.3N
23-56.8W
23
22
25-57.0
21-48.0
P
Q
R


25-57.0 N
21-48.0 W
26-16.0 N
20-47.0 W
20
26-52.4 N
19-10.0 W
S
T
U


27-40.0 N
16-59.2 W
18
SEC.
5
10
U
V
W

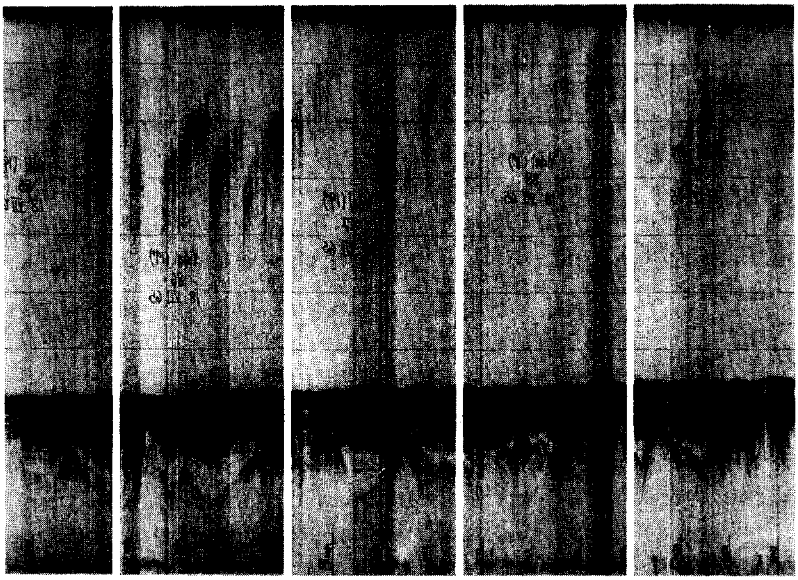


Fig.14. Recording of the Cape Verde/Madeira Abyssal Plain between 24°39'N 24°47'W and 25°24'N 22°52'W.

associated with basement elevations (cf. the Cape Verde Islands section and the 13°N-crossing between 13-K and 13-N). The maximum thickness of the sediments is 2,000 m (2 sec) near 19-P. The average thickness of the sedimentary layer is well over 1,200 m between 19-O and 19-U. From position 19-R the recording is worse again due to the use of a different air gun, which explains the lack of information on the basement. We notice the large seamount at position 19-S.

The change in slope near position 19-T marks the tip of an outbulging of the depth contours of the continental rise off Africa. The records do not give conclusive information on the nature of this structure, but it is suggested that it is a basement structure of possibly volcanic origin. It may be that east of position 19-U some of the reflectors consist of lavas, considering the character of the returning signal. The subsurface reflector at position 19-V shields all deeper structures. The small seamount crossed here lies to the southeast of the island Hierro and possibly forms part of its pedestal. The slope of the island Tenerife (19-W) probably consists of basalt and is clad with a thin layer of loose material. The last part of the section shows a cross-section through the Canary inter-island basin. The Canary Islands together with submarine volcanoes belonging to the archipelago (e.g., the Dacia Bank) form a nearly closed ring comprising this basin (cf. the physiographic diagram of the North Atlantic; HEEZEN et al., 1959; HEEZEN and THARP, 1961). The penetration is poor and no basement was found. The (volcanic) basement becomes shallow again near position 19-X to the end of the section east of the Dacia Bank. This latter part of the section, though deeper, is comparable to the southwestern slope of the island Tenerife.

THE PRECISION DEPTH RECORDINGS

Fig.15 (pp.331–338) gives a mounting of the P.D.R.-data obtained during the crossings. Most features have been dealt with in the discussion of the profiler results. We here mention one important structure on 16°N 35°28′W, where we find a step in the ocean floor of about 1,800 m, i.e., to the west depth suddenly decreases. The general slope remains westward. This configuration might indicate that we are dealing with a fault of very large dimensions. There are no profiler data on this part of the track.

DISCUSSION OF RESULTS

General

As has been mentioned, three types of sediments can be distinguished: layered sediments (presumably for the greater part turbidites), homogeneous pelagic sediments and also homogeneous current-influenced sediments. Evidence for current-influenced sediments was found in the occurrence of surface ripples on the foot hills of the Barracuda Ridge at 16°N and on hills in the zone of negative anomalies at 16°N 60°W. The homogeneous layer can vary in thickness over relatively short distances, for example at 16°N 54°40′W. This is also reckoned to indicate the effect of current.

The continuity of sedimentation from the continental rise into the abyssal plains proves that turbidites can be deposited on slopes with an inclination of 12′. Rims of sediment against obstacles demonstrate that locally deposition of turbidites is possible on slopes of 2.5° (cf. the sea mount at position 19-S on the 19°N-crossing).

The Vidal Channel, first discovered at the 16°N-crossing and since followed over a considerable distance, is proof of the occurrence of bottom currents that can erode. Whether these currents are continuous or have an intermittent or a catastrophic character cannot be said yet.

We continue our discussion with a review of the different oceanographic provinces that have been crossed.

The zone of negative gravity anomalies

The 60°W-section gives an interesting picture of the configuration of the zone of negative gravity anomalies in areas of entirely different morphology. North of Puerto Rico the zone is associated with a trench, then it passes into a submarine ridge to continue over the island Barbados and to disappear finally via Trinidad in the South American continent. The continuity of the zone of negative anomalies over entirely different morphological structures has repeatedly been brought forward by VENING MEINESZ (e.g., 1948, p.34). Here we see it illustrated. In a compilation of seismic refraction and gravity data, WORZEL (1965a) comes to the conclusion that the zone of negative anomalies can be explained geometrically by a crustal downwarp of a few kilometers and that no crustal thickening is needed to account for the negative gravity effect. This is not only true for the trenches, but also for those parts of the negative zone where it passes over submarine ridges, islands and into the continent (cf. LAGAAY, 1969, on the negative zone north of Curaçao). The change of insight is due to the findings of huge amounts of sediments in the negative gravity zone (e.g., OFFICER et al., 1959). Instead of in the mantle beneath the crust, the greater part of the mass deficiency can now be placed at a high level in the crust. This implies that if the crust would be allowed to come to isostatic equilibrium, no huge mountain ridges of the Alpine type will result. Only on those places where the present depth is small or zero, a fairly low topography will result.

The present data do not contribute greatly to the solution of the problem whether the zone is a tensional or a compressional feature. The small grabens in the superficial layers in all the sections must be regarded as secondary phenomena which have no direct bearing on the problem. For the rest, the Barbados Ridge is covered with a thick layer of only slightly undulating sediments, presumably Late Tertiary to Recent in age, that shield all deeper structures.

The ocean basins

In several cases the homogeneous "layer" can be followed to continue *under* the layered sediments, at the same time becoming thinner. This does not imply that the entire homogeneous layer as such should be older than the turbidites. Two adjoining sections, one with turbidites and one exclusively with homogeneous sediments, may both represent the same period of time. The explanation would be that the deposition of homogeneous sediments is continuous and that the layered section comprises both homogeneous sediments and turbidites, covering the former sediments again and again. That frequently a homogeneous layer is found beneath the layered sediments can be explained by a gradual expansion of the abyssal plains at the expense of the abyssal hills provinces, by the simple process of filling the basin. The abyssal hills provinces then can be described as those parts of the ocean basins that have not yet been reached by turbidity currents. This may be the result of the existence of a ridge separating the provinces, but in several instances we could observe that the slightly sloping level of sediments in the abyssal plain simply is not yet high enough to allow the turbidity currents to continue their way into neighbouring abyssal hills. Two of the abyssal plains crossed deserve some special attention:

The Demerara Abyssal Plain. We recall our remark on the westerly slope components of the Demerara Abyssal Plain in the 13 °N and part of the 10 °N-crossing. This feature is probably related to the direction of sediment transport. The general slope of the plain is northwest, the sediments evidently originating partly from the Amazon Cone.

Wherever the penetration was large enough, we found a rough basement, comparable to the basement of the abyssal hills province.

A feature of major importance is the oceanic channel found first on the 16°N-crossing, the Vidal Channel.

On the 16°N-crossing over the Demerara Abyssal we found a well-developed reflector that might be horizon A. A first attempt to sample this layer in the Vidal Channel has not been met with success. However, the channel remains a perfect location to confirm the probably Cretaceous age of horizon A (EWING et al., 1966). The reflector at 1.4 sec below the bottom on the 10°N-crossing might also be horizon A. If so the post-Cretaceous sediments would attain a remarkable thickness.

The Cape Verde/Madeira Abyssal Plain. This abyssal plain is outstanding for its well-developed reflectors. It is not possible to label one of them unambiguously as horizon A. The section is further noteworthy for its many examples of differential compaction structures, reflecting the form of the basement. In several instances the buried basement structures are still apparent in the topography, forming steps in the general slope. The maximum sedimentary thickness is 2,000 m (2 sec), the average being well over 1,200 m.

The Mid-Atlantic Ridge and the fracture zones

The sections over the ridge confirm the earlier findings (EWING et al., 1964; EWING et al., 1966), which can be summarized as follows: virtually no sediment in the axial zone, a thin veneer of sediments on the flanks and in several instances concentration of these sediments in secondary valleys. The thickness of this veneer does not vary significantly from upper flank to adjoining basin (cf. EWING and EWING, 1967). The width of the "barren" axial zone is of the order of 200 km at 19°N and 110 km at 16°N and 100 km at 13°N. The broken-up character of the axial zone at 10° does not permit an estimate of its width at these latitudes.

Only the 13°N-crossing shows a well-developed median rift. The 10°N-crossing becomes intelligible only against the background of the structural maps by HEEZEN et al. (1964) concerning the Vema fracture zone.

The large depressions on the west-flank of the ridge on 13° and 16°N must be cross-sections of fracture zones.

Regarding the term fracture zone we want to make a comment. On the cross-sections the fracture zones all appear as rift valleys, i.e., elongate depressions in the crust bounded by scarps (faults or flexures). We refrain from actually calling them so in order to avoid confusion with the median rift. However, when trying to account for the fracture zones, the rift valley character and the sedimentary

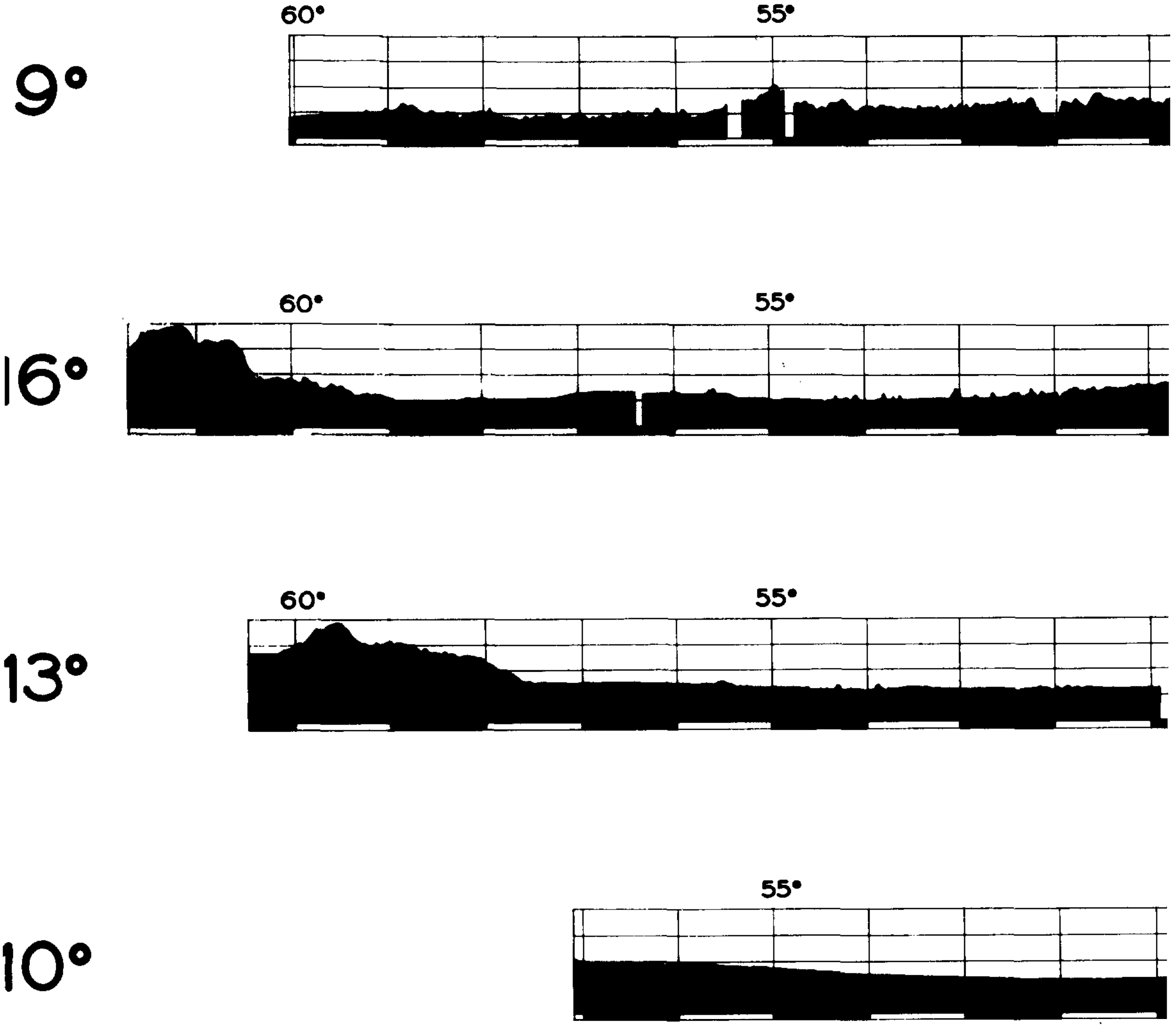
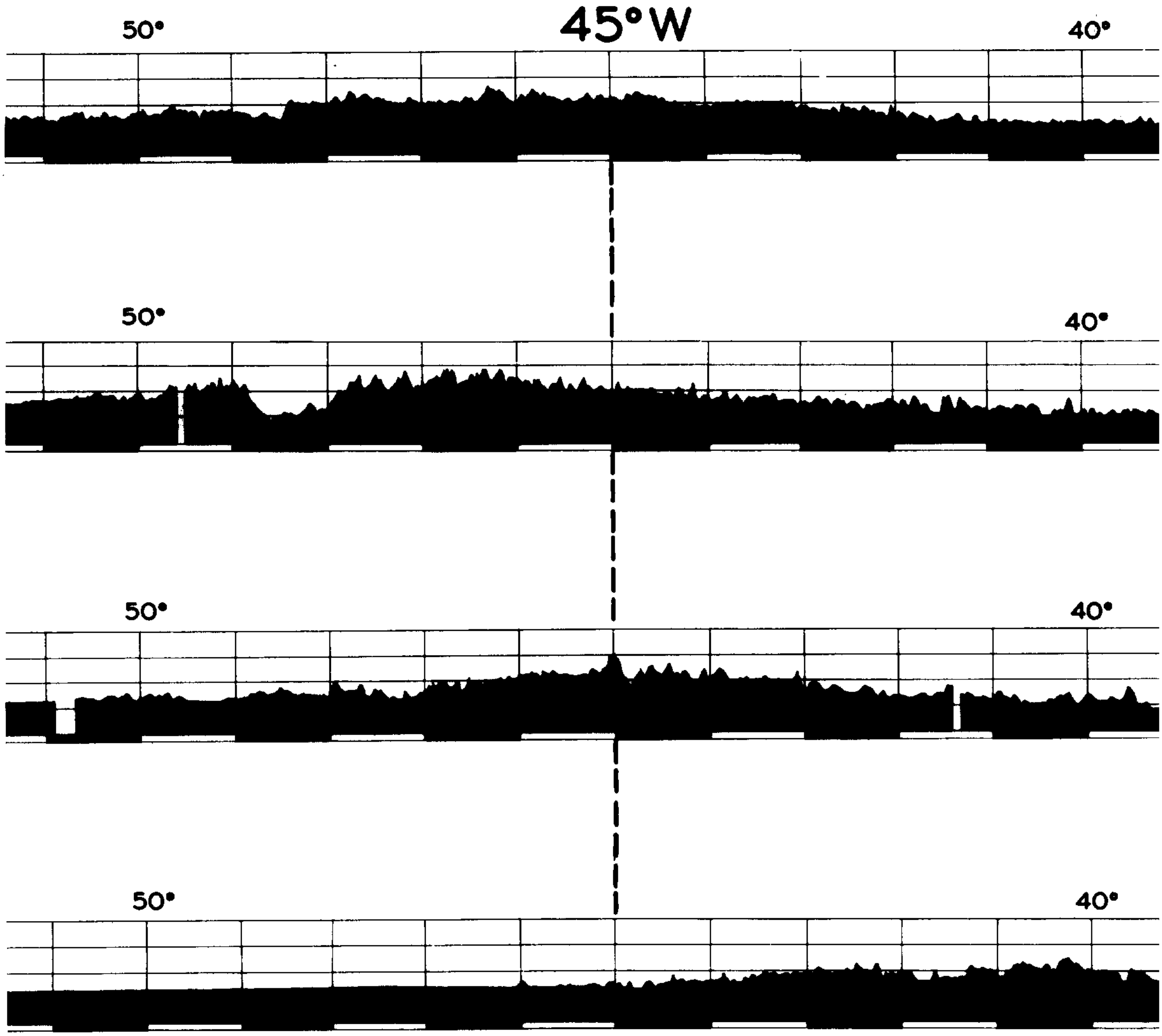


Fig.15. Diagram of the P.D.R.-recordings of the crossings.


45°W
50°
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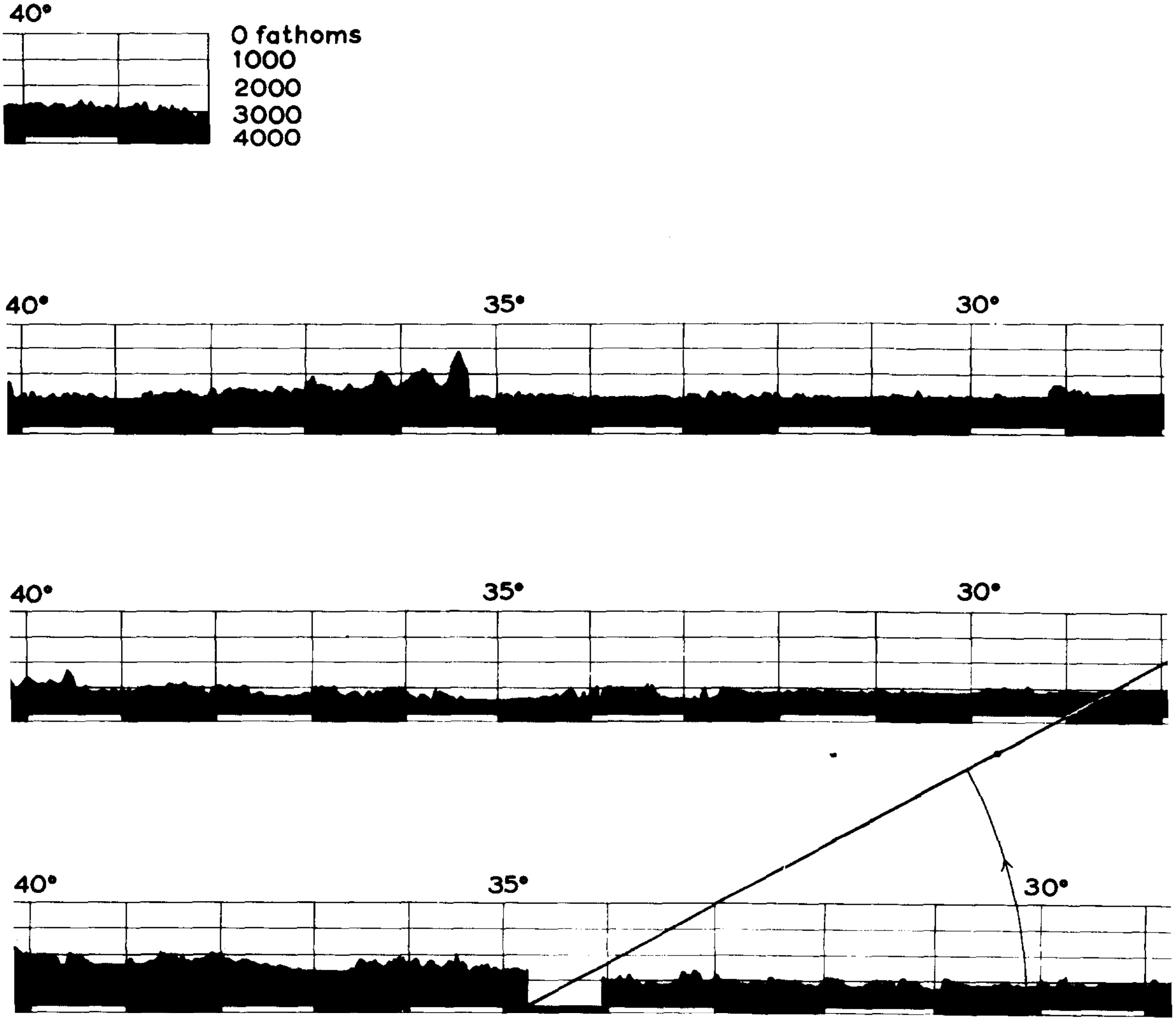
40°


40°
0 fathoms
1000
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4000
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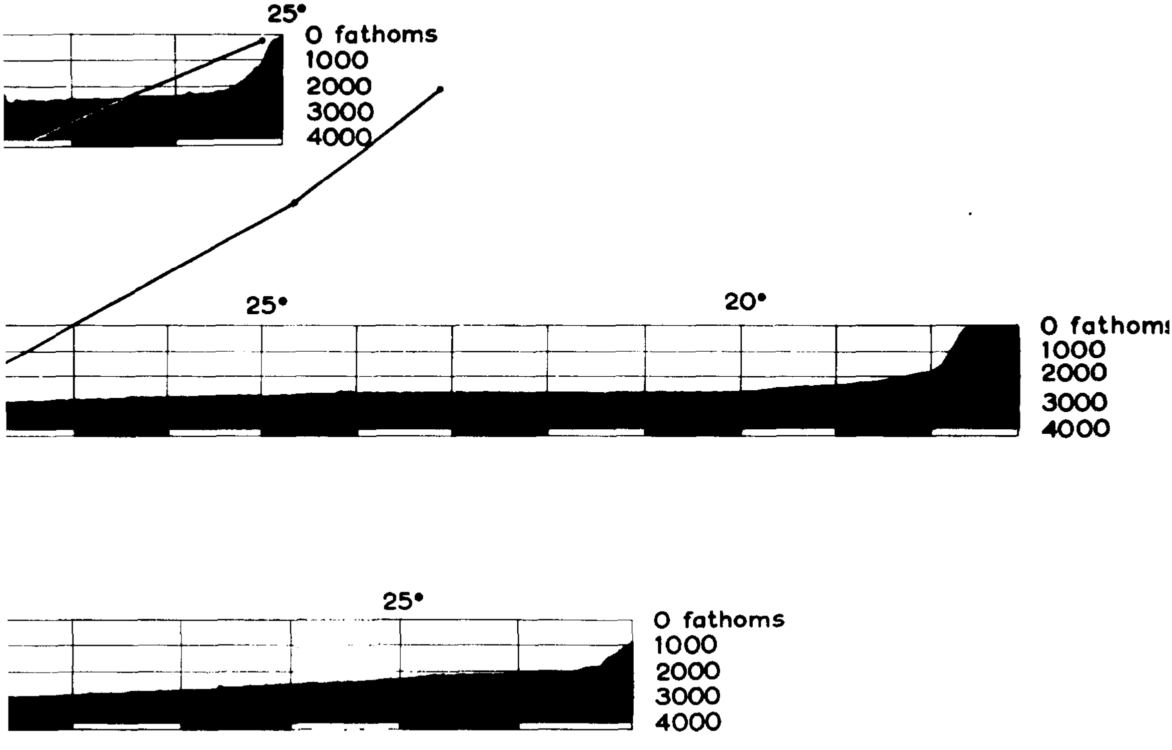
25°
0 fathoms
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4000
25°
20°
0 fathom
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25°
0 fathoms
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fill of some of the fractures zones should not be overlooked (see also VAN ANDEL et al., 1967).

For the rest the asymmetric position of the Mid-Atlantic Ridge on these latitudes should be mentioned. This asymmetry most probably should be seen in relation to the sinistral fracture-zones system to the south, and the dextral fracture zones to the north.

The volcanic islands

The approaches to the Cape Verde Islands and the Canary Islands are interesting for showing reflections that possibly represent sheets of lava interbedded in the sediment. The volcanic character of these layers might be surmised from the reverberations of the returning signal. The slope of the islands is fairly rough. Slumping most probably can explain many of the distorted features on the slopes.

The continental rises and the continental shelf

Both on the South American and on the African continental rise we lost contact with the basement. The lowermost reflector, when the section is converted into a depth profile, dips towards the continent, thus indicating an isostatic response to loading of the crust with sediments. The penetration on the African shelf on 13°N was only about 1 sec. No basement was found.

Ocean floor spreading

Regarding the problem of ocean floor spreading (VINE and MATTHEWS, 1963; HESS, 1965; DIETZ, 1966) and the related magnetic findings (VINE, 1966; PITMAN and HEIRTZLER, 1966) the following can be remarked. The oceanic basement (layer 2 with seismic velocities of the order of 5 km/sec), wherever it was found, i.e., everywhere except under the continental rises, probably is of volcanic character. There is no fundamental difference or discontinuity between this basement and what is seen at the surface on the Mid-Atlantic Ridge. On the other hand, there are no indications that the abyssal hills formerly were situated at a smaller depth and belonged to the ridge. The horizontality of the layered sediments in the abyssal plains shows clearly that from the moment that this kind of sedimentation started, no changes in level occurred, apart from a possible general re-adjustment under the load of the sediment. A similar reasoning applies to the continental side of the Demerara Abyssal Plain; here too no deformation occurred since the layered sediments were deposited. Or in other words, there is no indication that the present abyssal plain is being carried into the zone of negative gravity anomalies.

These observations put a limit to the amount of movement that may have occurred since the deposition of the layered sediments started (in view of the age of horizon A well before the Upper Cretaceous). The only morphologic and structural indication that large horizontal crustal movements occur or occurred, may be found in fracture zones (cf. WILSON, 1965, on transform faults and SYKES, 1967, on the mechanism of earthquakes along the east–west faults).

However, the total picture suggests a relatively young age of the floor of the Atlantic Ocean and generally speaking, fits the concept of continental drift. Further, as argued by EWING and EWING (1967), the distribution of sediments *on* the ridge might easily be interpreted in terms of spreading. Their graph of the thicknesses of the sediment on 40°N and on 45°S in the Atlantic Ocean shows a barren crestal zone of about 250 km wide and a sedimentary cover of about 500 m on the flanks of the ridge, that does not increase in thickness from crest to adjoining basins. It was put forward that this peculiar distribution, *when interpreted in terms of spreading*, can be explained as a result of the occurrence of major changes in the rate of sedimentation (assuming a constant rate of spreading), or alternatively in the rate of spreading of the sea floor (assuming a constant rate of sedimentation).

The latter idea was worked out as follows:

(*1*) An earlier cycle (or cycles) of spreading occurred, during which possibly Gondwanaland and Laurasia were broken up; the pieces moved approximately to their present locations. The spreading during this cycle was extensive enough to sweep all of the Paleozoic sediments from the Pacific floor. Its duration was probably considerably shorter than the following period of quiescence.

(*2*) The early spreading cycle terminated probably in the Late Mesozoic or Early Cenozoic and was followed by a period of quiescence, during which most of the observed sediments were deposited on a static crust.

(*3*) A new spreading cycle commenced about 10 million years ago, which has generated the pattern of magnetic anomalies of the crest and has produced the strip of thin sediments. The ridge axes of the latest cycle follow those of the preceding one with remarkable accuracy.

This hypothesis will be disproved if drilling fails to recover old sediments on the flank of the ridge near the sediment discontinuity. In that event we will apparently have to accept extreme changes in sedimentation rates about 10 million years ago, that is, in Late Miocene. The intermittent character of the convection suggested by the sediment distribution is consistent with the idea that the rate of generation of heat seems inadequate to maintain continuous convection motion. Bearing in mind the limited accuracy of our estimates of the convective phases of the last two cycles, it seems worthwhile to point out that these times agree reasonably well with the Late Cretaceous and Miocene orogenies.

A third explanation is that the pattern of distribution of the sediments should not be interpreted as the result of a variation in the rate of spreading or the rate of sedimentation, but is caused by other processes, e.g., a covering of the sediments with lava flows on the crest of the ridge or a (not yet explained) much lower rate of sedimentation on the topographically higher axial zone. We then could make a distinction between primary and secondary effects of spreading.

The primary effects would be the breaking up of Gondwanaland and Laurasia, the formation of the Atlantic Ocean with a primaeval mid-oceanic ridge and the Alpine mountain ranges, the secondary effects the formation of the ridge in its present form and of the zones of negative anomalies as we know them now. In this respect we recall what has been said on the zones of negative anomalies, viz. that they will not give rise to huge mountain ranges when isostatic equilibrium is restored. Most of the zones of negative anomalies seem further to be formed during the Miocene, and so a relation between the formation of these zones and of the ridge in its present form is not unlikely.

In this concept the Late Cretaceous and the Miocene orogenies would not be equivalent but an earlier and a later stage of the Alpine orogeny. The Mid-Atlantic Ridge might furthermore be broadening constantly and no mechanism is needed to account for the disappearance of the ridge and its isostatic compensation on the flanks (cf. WORZEL, 1965b; TALWANI et al., 1965). An indication that the flanks of the ridge are only moving in a horizontal sense and do not collapse to become a part of the deeper ocean basin basement, may be found in the circumstance that in principle the Quaternary turbidites of the Demerara Abyssal Plain do not flow farther eastward than horizon A reaches.

Additional data on the variation of the rate of spreading with time can be obtained by measuring the minimum distance from the ridge at which we find well-defined horizons, e.g., horizon A. If we allow for a sinistral displacement of 150 km along the fracture zone at 16 °N we find the Upper Cretaceous (horizon A) at a distance of 850 km from the axis. This gives a *maximum* rate of 1.2 cm/year for the past 70 million years. This figure should be reduced slightly, since we have to allow for a finite width of the supposed "primaeval" ridge. The result (of the order of 1 cm/year) does not differ significantly from the figure found from magnetic data for the past 10 million years for the North Atlantic.

As a matter of fact, the rate of spreading can easily have been much larger before the Upper Cretaceous. The collision of Africa and Europe may have reduced the crustal spreading rate and this again must have influenced the events in the ridge province. What actually caused the changes in Miocene times, cannot even be guessed from the present data. Going into this subject would lead us too far into the realm of speculation.

CONCLUSIONS

Our findings can be summarized as follows:

(*1*) The sedimentary cover on the Mid-Atlantic Ridge is only thin. No sediment is found on the crest in a strip of about 200 km width at 19 °N, 110 km at 16 °N and 100 km at 13 °N. There is no significant increase of average thickness of the sediment on the flanks from the barren crestal zone to the abyssal hills or plain. On 10° and 16° we find more sediment on the west-flank than on the east-flank of the ridge.

The ridge is situated asymmetrically in this part of the Atlantic. This asymmetry is related to the pattern of fracture zones.

(*2*) The oceanic basement could be followed everywhere except under the continental rises and in the zone of negative gravity anomalies (the Vening Meinesz zone). The basement structures, which are probably volcanic as shown by the reverberating character of the reflected signal, are not different from the mountains of the Mid-Atlantic Ridge.

(*3*) The thickness of the sediment in the Demerara Abyssal Plain is at least 1,400 m, but probably more, in the Cape Verde/Madeira Abyssal Plain the maximum thickness is 2,000 m. Both basins show differential compaction of the sediment over an uneven basement. The homogeneous layer generally can be followed under the layered sediments. (This does not necessarily mean that the first layer in its totality is older than the turbidites. It is more probable that the layered section comprises both turbidites and homogeneous sediment.)

The abyssal plains seem to grow at the expense of the abyssal hills by what can be best described as overflowing. In the Demerara Abyssal Plain horizon A was found at 16°N (at 0.3 sec). It seems to outcrop in a newly discovered oceanic channel, the Vidal Channel. In the Cape Verde/Madeira Abyssal Plain it was not possible to identify horizon A. This abyssal plain is noteworthy for its many well-developed reflectors.

The data support the hypothesis of current-influenced deposition of homogeneous sediments (presumably by relatively slow suspension currents) besides deposition by turbidity currents and pelagic sedimentation.

(*4*) The sediments of the abyssal plains do not show any sign of deformation apart from differential compaction. This implies that those ocean basins, that have been filled with turbidites, obtained their present shape before the turbidity currents reached that particular basin. There are no indications for a continuous development from ridge into ocean basin, i.e., we found nowhere that (part of) an ocean basin formerly was situated at a depth comparable to the mean depth of the ridge.

(*5*) An estimate of the maximum rate of ocean spreading that may have occurred can be derived from the presence of well-defined horizons, such as horizon A, at a certain distance from the axis of the ridge. On 16°N horizon A is found at a distance of 700 km from the axis. After a correction for possible transverse faulting, we thus arrive at a *maximum* figure of the order of 1 cm/year since the Upper Cretaceous.

(*6*) The pattern of sediment distribution on the ridge has been interpreted previously (EWING and EWING, 1967) in terms of a varying rate of spreading or of sedimentation with regard to time. A third possibility is that we are confronted with a not yet understood sedimentary process resulting in a thinner cover of sediments on the crest of the ridge, or with the effect of intensified volcanic action burying any older sediments. If so, it seems not too far-fetched to think of a correlation between the development of the ridge in its present form and the origin of the zones of negative anomalies in a later phase of the spreading process. In this concept the Mid-Atlantic Ridge would be broadening constantly.

(*7*) When the sections over the continental rises are converted into depth profiles, the deepest reflector dips towards the continents. This indicates readjustment of the isostatic equilibrium under the load of the sediment.

(*8*) The sediments revealed by the profiler do not show indications for large deformations in the zone of negative gravity anomalies. This zone here runs over a trench, a submarine ridge, an island and into the south American continent. The Barbados Ridge is clad with only slightly deformed sediment probably of Late Tertiary to Recent age. This might imply that the maximum deformation occurred before that time, a conclusion that conflicts with the magnetic data on spreading, and with the ideas of OLIVER and ISACKS (1967) on the function of the deep-earthquake zones that cut obliquely under the island arcs. We do not see an easy reconciliation of this conflicting evidence.

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