STRUCTURE AND TECTONICS
OF THE
MURRAY FRACTURE ZONE
WEST OF THE HAWAIIAN RIDGE

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ABSTRACT

The Murray fracture zone is a continuation of an older fracture zone, which was active during the formation of the Hawaiian lineations. The older zone is defined by the termination of the Hawiian lineations west of Midway Island. There is some structural and topographic evidence of the older zone on the deep sea floor. Sediment cover in the area is undisturbed by faulting on the zone.

Some magnetic lineations have been identified south of the fracture zone, however they do not fit into the Hawaiian sequence, and the residual anomalies are not similar to those found east of the Hawaiian sequence, in the magnetically smooth zone. This magnetic province may be related to a complex reorientation of spreading patterns between the Hawaiian and Phoenix sequences.

Introduction

The presence of long submarine scarps on the floor of the Pacific ocean off California was known in the late 1930's (Murray, 1939). The information available increased slowly with the improvement in echo-sounding equipment, and the increase in deep sea soundings from various agencies enabled a general picture of the deep sea floor to be constructed. By the early 1950's the major outlines of oceanic topography were known and several submarine scarps, and their extension into bands of ridges and troughs, were known to extend across the Pacific sea floor for thousands of kilometers. The relief across some of these features was known to be of the order of some thousands of meters.

The regional changes in depth of the level sea floor between some of the north Pacific fracture zones were thought to be due to variations in crust-mantle density, or to variations in sediment thickness, or to combinations of both (Menard, 1955). The offset of equal depth contours across a fracture zone was also hypothesised to be the result of strike-slip faulting (Menard, 1960).

The identification and correlation of magnetic anomalies across fracture zones led to the modern interpretation of fracture zones as major sea floor spreading features. Mason (1958) pointed out that linear magnetic anomalies on either side of the Murray fracture zone could be correlated with offsets similar to that of the bathymetric contours.

The known offsets across fracture zones in the North Pacific were then explainable in terms of a simple strike-slip faulting mechanism, because only one side of a mid ocean ridge system was being considered. When the offsets across North Atlantic fracture zones determined,and it was found that the sense of the offset was reversed in going from one side of the ridge system to the other (Vine,1966),simple strike-slip faulting was no longer a viable mechanism.

In 1965 Wilson had proposed the hypothesis of transform faulting, which explained the reversal of offsets on either side of a mid ocean ridge in terms of initial ridge offsets and sea floor generation.This hypothesis avoided two of the major objections to the strike-slip mode of formation of fracture zones.

These two objections were the lack of earthquake activity along such major faults, in contrast to the activity found on major faults on continents, and the difficulty of accepting large [illegible] on the continents, and the change in strike bearing along the faults. Neither of these objections had seemed particularly serious when the strike-slip mechanism was first proposed, mainly because the lack of an adequate seismometer network could explain the first, and the lack of good bathymetric surveys the second. However the increase in the quality and coverage of the seismograph station net, and the increasing amount of accurately controlled bathymetry brought the above two objections to the fore, and necessitated an alternative to the strike-slip mode of origin.

The objections having been disposed of by the transform fault hypothesis, which appeared to be supported by Vine's (1966) magnetic data, the sea floor magnetic lineations were then used as an age scale by Heirtzler, et al. (1968), thus enabling changes in offsets across fracture zones to be dated.

The sea floor spreading hypothesis was extended and elaborated in its application to fracture zone development and topography by Menard and Atwater (1969), Vogt, et al. (1969), Sleep and Biehler (1970), and Lachenbruch and Thompson (1972).

In the light of the work of the above investigators two major problems remain to be examined, although this is not to imply that all the answers to the earlier problems of genesis and structure have been found. ~~The~~ These two above mentioned problems may be related; the first is how do the fracture zones we find on the sea floor today terminate, and the second is what is the relationship between fracture zones generated during the latest sea floor spreading episode, and those generated during previous episodes. The answer to the first problem may be best answered by examination of Atlantic fracture zones due to the apparently simpler structure and oceanic history there compared to the Pacific, due to recent work which has commenced to unravel the history of the older sea floor (Larson and Chase, 1972; Larson and Pitman, 1972).

This ~~paper~~ study throws some light on the second problem, although the surveys reported here were originally intended to attempt to trace the Murray fracture zone through the Hawaiian ridge and further west.

Navigation control

Historically the availability of precision navigational aids has controlled the accuracy of deep sea surveys.

The older reconnaissance surveys were carried out using celestial fixes and dead reckoning; the lack of the capability to obtain frequent accurate fixes obviously limited the usefulness of closely spaced survey lines. However much old, though useful, data was obtained from routine sounding carried out by ships in transit. Under these conditions of constant course and speed, with careful navigation, the errors in position were likely to be comparatively small. In contrast, on a local survey, with frequent course and speed changes, the old style of navigation was not sufficiently accurate for detailed surveys. The advent of Loran A and C eased the problem considerably, providing accurate navigation control, but only in limited areas off the west coast of North America and around the Hawaiian Islands. With increasing range and the use of skywaves the obtainable accuracy deteriorated, and it was not until the U. S. Transit satellites and VLF-Omega systems became available for research ship use that precision surveys in mid-ocean were practicable. This means that deep sea surveys carried out before the mid-1960's can be considered as reconnaissance surveys only, although within Loran range the older surveys may have sufficient precision.

In practice the above does not alter any significant conclusions, as the bulk of the work done was intended for reconnaissance only; few surveys were intended to provide definitive charts of the fracture zones. Operation Seamap is the major example of a definitive open ocean nonclassified survey in this field. Of the other fracture zone surveys mentioned only the Murray fracture zone surveys of Malahoff and Woollard (1970) and the continuation reported herein have the close track spacing and control to be considered for the classification of definitive, as far as the Pacific area is concerned.

Previous Surveys of Fracture Zones

Topographic surveys of various fracture zones have been carried out and published by several investigators, however most of these were essentially reconnaissance surveys, due to time and navigational limitations. Such reports have been published on the following fracture zones: Mendocino (Menard and Dietz, 1952), Clipperton (Menard and Fisher, 1958), Blanco (McManus, 1965), Emperor (Erickson, et al., 1970), and Gibbs (Fleming, et al., 1970).

With the development of magnetic interpretation for fracture zone identification, many additional fracture zones have been found, e. g., Emperor (Erickson, et al., 1970, Ecuador, and Costa Rica (Grim, 1970).

Geophysical surveys of fracture zones in order to determine the structure of the zone itself are very few. Talwani, et al. (1959) used two-dimensional gravity models to determine the structure of the Mendocino near California, and similar simple models of structure using gravity data were reported by Burns and Malahoff (1970) for the Murray and Clarion fracture zones.

Seismic refraction work has been very limited, of necessity, as the complicated topography essentially negates the possibility of shooting in a fracture zone. Hence seismic control is best utilised on either side of a zone to furnish crustal sections which can be extrapolated into the fracture zone using gravity profiling. Such work has been reported for the Mendocino (Dehlinger, et al., 1967).

Seismic reflection and magnetic data have been analysed and published for the Murray fracture zone, which is the best surveyed of all major zones.

Von Heune (1969) published seismic reflection profiles run across the zone between the California continental slope and 126° west longitude, while Malahoff and Woollard (1970) published topographic, seismic reflection, and magnetic profiles, including magnetic source body analyses, between 127° - 165° west longitude. Operation Seamap surveys across the Murray fracture zone extend from 156° to 174° west longitude. Seamap data available varies from area to area, but generally includes bathymetry, magnetics, and gravity. Some of this data has been published by Rea and Naugler (1971), Naugler and Erickson (1968), and Lucas (1971).

General Topography of Fracture Zones.

The most dramatic topographic features of fracture zones are those first discovered, the great scarps, extending over thousands of meters in height. They are now believed to be the natural consequence of transform faulting, in the younger sections of the fracture zones, their initial height being due to a combination of the degree of initial offset of the ridge segments, the spreading rate, and the age-depth relationship of the ocean crust (Sclater and Francheteau,1970;Sclater, Anderson, and Bell, 1971).The above referenced papers by Sclater and others,derive a mathematic -al relationship between the depth of the ocean floor and the age of the crust which underlies that floor. The relationship is based on theoretical considerations of heat flow through the crust,and the expansion coefficient of the rocks which are believed to comprise the crust and underlying mantle.Their theory proposes that as the crust moves away from the ridge crest it cools down, and as the crust and underlying mantle cool, they contract. The theoretical curves have been shown, by the above authors, to fit the observed age depth profiles quiet closely, after adjustment of various parameters to fit each particular spreading rate case. Deriving the age from the depth is fairly reliable out to some 40mybp., older than this the method loses accuracy as the curves become asymtotic, as do the dep depths.Thus an initial ridge segment offset generates an initial scarp out to approximately 40mybp., the height of the scarp at any point depends on the age difference of the crust across the fracture zone at that point. Where the fracture zone is older than 40mybp. there should be no scarp, at least not one so generated.The ridges and troughs found on several fracture zones past the point on the zones where they could be explained by the above mechanism are probably caused by the processes believed to be operative in a leaky fracture zone.

The concept of a leaky fracture originated with Menard and Atwater (1969),as their studies of sea floor spreading processes showed that fracture zones and ridge segments have not always been orthogonal,as is required for a simple ridge-fracture system.It became apparant that there had been many small changes in the orientation of the spreading centers , and the associated fracture zones, in the past.The analysis of the consequences of changes of orientation of the sea floor spreading system was carried farther by Vogt,et al.(1969),while the hydrodynamic and viscosity factors which affect the upwelling of material in a leaky fracture zone were considered by Sleep and Biehler (1970).

The above investigators, while able to explain much of the mechanics of fracture zone formation, particularly as seen in the Atlantic, have not explained the cause of the'great ridges' as described by Menard and

Atwater(1969), and the bifurification of the fracture zones as they splay out into a band of troughs and ridges in the central north Pacific ocean. The great ridges are probably caused by extrusion in a leaky fracture zone, as there is some evidence that the ridge segments were not orthogonal to the fracture zones in the area of the great ridges, as shown by the linear magnetic sea floor spreading anomalies.

While the great ridges could be caused by normal volcanism, as a chain of seamounts, it is unlikely that a feature of such regularity would so originate. There are some isolated seamounts on fracture zone scarps, such as Erben guyot, but these are isolated examples, and show no signs of forming a ridge.

There does not appear to be any explanation, at present, of the bifurication of the fracture zones.

Topography of the Murray Fracture Zone from the coast of California to the Musicians seamounts

There have been several surveys of the Murray fracture zone between these limits. Commencing with the U. S. G. S. (Von Heune, 1969) off California, the surveys were continued by the Hawaii Institute of Geophysics (HIG)(Malahoff and Woollard, 1970), and then by NOAA, in Operation Seamap (Rea and Naugler, 1971). The location of these surveys is shown in Fig. 1, and detailed bathymetric charts are shown in Figs. 2, 3, 4, keyed to Fig. 1. These surveys show the classic shape of the fracture zones, as originally described by Menard (1955).

Topography west of the Musicians seamounts

Lucas reported the results of an Operationa Seamap survey north of the Hawaiian Islands (Fig. 5) and the latest bathymetric charts of the area (H. O. Pub. No. 1302, 1971) can be used to fill in the gaps in Seamap coverage. West of the Hawaiian Islands the results of NOAA and HIG surveys have been added to the raw soundings used to make chart No. 1905-N (H. O. Pub. No. 1302, 1971), to obtain detailed topography (Figure 6). As a major topographic feature, the Murray fracture zone ceases at the Musicians seamounts. To the north and south the Mendocino and Molokai fracture zones can still be seen (Figure 7). However although the Mendocino fracture zone continues westwards from the Musicians region,its topography is confused by the presence of the Mellish bank structures, east of the Hawaiian ridge and to the west of the ridge, it appears as a broad band of low horsts and grabens associated with a broad regional depression, unlike the sharp differentiation between fracture zones and the normal sea floor, found east of the Musicians seamounts area. Similarly the Molokai fracture zone is seen only as an area of elongate troughs and ridges, whose relief west of the Hawaiian ridge is much subdued relative to what it is east of the Hawaiian ridge.

An examination of the bathymetric charts shows that a similar pattern exists for the Clarion and Clipperton fracture zones to the south where they cross the Line Islands ridge, which apparantly affects these two fracture zones in a similar manner to that in which the Musicians seamounts affect the Murray and Mendocino fracture zones. This appears to confirm the theory that the Musicians seamounts and the Line Islands ridge are both localities which mark some type of tectonic boundary, or where that boundary has been in the past.

Detailed consideration of the bathymetric charts shows the change in relief patterns across the Musicians seamounts area. Examination of Figure 8 shows that off California the Murray fracture zone starts as a basement trough feature which grades into a prominent north-facing scarp, backed by a band of complex topography, Figure 9 shows the increasing complexity of the topography westwards. (Location of the profiles in Figures 8 and 9 is shown in Figures 10 and 11.) The great ridge is clearly seen in Figure 9, as is the location of Erben guyot. The last few profiles in Figure 9 indicate the commencement of the bifurication of the fracture zone, which is clearly evident in Figure 12 (profile location shown in Figure 13).

Considering the profiles shown in Figure 12, and the bathymetry of the area shown in Figure 4, we can determine the changes in quantitative relief across the seamount province. To the east, we have a southern ridge-trough system, with a relief of 400 to 500 meters, and a more continuous northerly one, with approximately 1000 meters of relief. West of the seamount province, examination of bathymetric charts (H. O. Pub. No. 1302, 1971) indicates that the northerly ridge-trough complex is still dominant, exhibiting some 500 meters relief, while the southern complex exhibits only some 200 meters. Both complexs appear to die out at longitude 166° west.

The elongation of the southern Musicians seamounts into the Musicians ridges, which appear to be related to the Necker lineations (Naugler and Erickson, 1968; Rea and Naugler, 1971) can be seen in the southern section of Figure 4.

In the adjoining Seamap area to the west (Lucas,1971) the bathymetry (Figure 5) indicates no obvious topographic lineation which would indicate the presence of the fracture zone.

In the area west of the Hawaiian Islands which was surveyed by the Hawaii Institute of Geophysics and the Pacific Oceanographic Research Laboratories (NOAA), no obvious obvious topographic lineations were present either.However the topographic expression of two differing [illegible] structural provinces can be seen on the chart (Figure 6). The southern and eastern sections show generally smooth topography, which reflects comparatively thick sediment cover, up to 0.5 secs. of two-way reflection time, while the north-central section shows small scale relief, indicating, through generally uniform sediment cover, an acoustic basement which is broken up to form

form low horsts and grabens. In the northWestern section of Figure 6 depths of over 6000 meters are seen,these deep areas lie on, or near the location of the Mendocino fracture zone, as located by magnetic anomaly offsets.

Erickson and Naugler (1968), using magnetic anomaly trends, traced the Murray fracture zone from the area of the Musicians Seamounts to the Hawaiian ridge in the vicinity of Laysan Island.Examination of bathymetric charts of the ridge near Laysan discloses possible fault traces near Midway Island (Malahoff and Woollard,1971), but not near Laysan. As the Hawaiian ridge in this area is estimated to be approximately 20my old whereas the age of the sea floor is at least 80mybp, there should be no trace of movement across the fractur fracture zone visible on the ridge structure(Larson and Chase,1972; Heirtzler, et al.,1968,Jackson, et al.,1972).However bathymetric charts of the area (a simplified version is shown in Figure 7) show that where the Murray and Mendocino fracture zones intersect the ridge, the volume of the Hawaiian ridge does not attain that found in the intervening section. A similar effect is seen at the intersection with the Necker ridge, however this reduction in volume is not apparent at the intersection of the Molokai fracture zone and the Hawaiian ridge.

[illegible]

It would appear that the pre-existing fracture zone structures have exerted some control on the volume of basalt which was available for constructing the Hawaiian ridge, but that movement along the fracture zones had ceased by the time the construction commenced.

Magnetic anomalies

Introduction

Hayes and Pitman (1971) and Larson and Chase (1972) have published magnetic anomaly lineations west of Midway Island. Due to lack of data they were not able to determine whether the lineations intersected the Mid Pacific mountains. The additional data presented here indicate that the Hawaiian lineations (Larson and Chase, 1972) are either terminated or offset by the extension of the Murray fracture zone west of the Hawaiian Islands. The locations of the magnetic profiles used, and the generalised bathymetry are shown in Figure 14.

The analysis of the magnetic data shows that there are obvious differences in the character of the magnetic anomalies found in the various regions around Midway Island. These character differences appear to be related to the relative ages and structures of the corresponding sea floor regions, and can hence be regarded as indicating the presence of magnetic provinces.

A particular point of interest is the magnetic anomaly profile along Project Magnet track 327A(figure 15), the two large anomalies seen are due to seamount structures, but in between the smooth magnetic field is typical of the magnetic quiet zone between anomaly 32 (Heirtzler, et al. , 1968) and anomaly M-1 (Larson and Chase,1972). Reference to Plate 2 of Hayes and Pitman(1970) shows that the ofset of anomaly 32 across the Murray fracture zone is right lateral,if the same sense and amount of offset exist for anomaly M-1,then M-1 south of the Murray would be under the Mid Pacific mountains. If this is the case then the magnetic anomalies betweenthe Mid Pacific mountains and the Murray fracture zone should correspond to those seen in the quiet zone between anomalies 32 and M-1 north of the Murray fracture zone.Obviously this is not the case. The amplitude of the anomalies found south of the Murray is much larger than those found over correspondingly smooth sea floor in the quiet zone. Also the anomalies south of the fracture zone do not fit into the sequence of the Hawaiian lineations, hence it does not appear that the offset was simply less than that of anomaly 32 to the east. The history of the sea floor in this anomalous area must have been quite different from that of the above mentioned queit zone sea floor.

Interpretation observed magnetic anomalies

The magnetic anomaly sequence known as the Hawaiian lineations (Larson and Chase, 1972) is shown in Figure 15, in this figure the sequence has been extended from the previously identified 22 anomalies to 24 on the basis of the recently acquired data. Examination of Figures 16 and 17 shows that while in the western portion of the sequence the anomaly pattern is a simple uni-directional one, to the east the pattern becomes more complex, with sets of shorter wavelength anomalies superimposed. The apparent long wavelength of the anomalies in the western section of Figures 16 and 17 is due to the acute angles between the strike of the anomalies and that of the profiles. In the eastern section of the diagrams the short wavelength anomalies form a set of local, approximately east-west trending magnetic lineations. In contrast to sea floor spreading anomalies which correlate over great distances, these short wavelength anomalies do n not do so, but they appear to be caused by local irregular intrusions.

When the anomaly patterns in Figures 15,16 and 17, are compared it can be seen that the different anomaly patterns are mutually co-existing , not mutually exclusive. It is also apparant that the change from one to more than one co-existing anomaly pattern occurs at approximatly 180°.

The short wavelength magnetic anomalies seen in the northeastern section of the survey area may be due to the formation of the Hawaiian ridge. After the extrusion of basalt to form the ridge, which may have lasted only some 5my in a particular area, isostatic adjustment took place. As the mass of the ridge sank, the surrounding crust was bowed up to form the arch, it is possible that local intrusions occured on the crest of the arch, at the point of greatest weakness. These intrusions would probably have been sub parallel to the ridge, and may have developed as a semi-circular ring in front of the leading edge of the ridge. Which section of the arch underwent the greatest degree of intrusion would depend on the ratio of the speed of advance to the rate of isostatic adjustment. Variations in this ratio could lead to variations in the angle between the axis of advance and the strike of the 'ring dikes' on either side of the axis,thus accounting for any variations in the strike of the short wagelength anomalies.

The other set of major irregular anomalies,of large amplitude but short wavelength, appear to be associated with the extension of the Murray fracture zone west of the Hawaiian ridge. These anomalies lie in a narrow band (Figure 17). Correlation of some of the more prominent anomalies,e.g. on tracks C-C',D-D',E-E', is possible only over short distances. The amplitude and irregularty of these anomalies indicate that they may be generated by a set of intrusions along the trace of the fracture zone. In figures [illegible] 16,and 17, the trend of the Murray fracture zone, as identified by Naugler and Erickson (1968), and by Rea (1970), to the north of the Hawaiian ridge, is shown. It can be seen that the trend derived from the magnetic anomalies presented here is more southerly than that found to the north of the ridge. The proposed trend is more closly parallel to that already found on the Mendocino fracture zone to the north, and hence is easier to reconcile with the geometry of sea floor spreading than the projection of the trend north of the ridge would be.The change in strike direction appears to take place at the intersection of the fracture zone and the Hawaiian ridge, however this may be fortuitous.

Examination of bathymetric charts (figures 5 and 6) and seismic reflection profiles(Figures 19 and 22) in the area of the fracture zone yields mixed results. North of the ridge the available seismic data shows no evidence of a fracture zone structure, however this is not very surprising as the tracks cross the zone close to the islands, where extrusive basalt and overlying sediment may have eliminated the evidence. To the south the seismic reflection profiles (Figures 19 and 23) show a correlation of structure with the traces of the fracture zones identified by the displacement of the Hawaiian lineation anomalies (Figure 15). However the bathymetric chart (Figure 6) does not any sign of elongate ridges in the areas where the fracture zones are located, the bathymetric chart has many more tracks in this area than there are seismic reflection tracks. Figure 18, superimposed magnetic and bathymetric profiles across the Murray extension,shows some correlation of bathymetry and the fracture zone boundaries, however the great vertical exaggeration of the bathymetry on this figure makes any firm conclusions suspect.

The basement between the two southern fracture zones is deeper than that to the north and south, and it is now covered with a greater thickness of sediment, so that the surface relief is not as great as the basement relief in this southern part of the survey area.It is this sediment filled trough or basin between the two fracture zones which can be seen on Figure 18, the surface depression is probably due to differential compaction affecting the greater thickness of sediment in the trough than on either side.

Both to the north (Naugler and Erickson,1968) and to the south of the Hawaiian ridge the Murray fracture zone magnetic anomaly trend is diffuse, and it is not clear where the exact boundary is,or which of the short wavelength anomalies is associated with the fracture zone, and which with the ridge generated stresses.

The strike of the Hawaiian lineations becomes more nearly perpendicular to that of the fracture zone, going from west to east, thus simplifing the necessary geometry of spreading ridges and fracture zones(Figure 15). The Murray extension terminates the Hawaiian lineations, however, just to the north of the Murray the sequence is offset right-laterally a small distance by another fracture zone.South of the Murray fracture zone ~~normal-sea-floor-spreading-lineations-are-seen,-however,superimposed-on-these lineations~~ is a separate pattern of large amplitude anomalies, lying in a narrow band (Figures 16 and 17).These anomalies are irregular,and may be the result of a band of intrusives associated with the formation of the Murray.Such a band might be expected to be associated with a 'leaky' fracture zone.

South of the band of high amplitude anomalies the anomaly pattern is complex, with few obvious lineations.The amplitudes are to large to be associated with a period of sea floor formation during a magnetic quiet period, however they appear to be either smaller than the usual sea floor spreading anomalies, or so large as to be most probably associated with some tectonic structure rather than with sea floor spreading. Several lineations have been identified in this magnetic province, with trends generally similar to that of the Hawaiian lineations. Examinations of aeromagnetic profiles east of the Midway region, in a generally accepted magnetic quiet zone, confirms that even the smaller anomalies south of the Murray are too large for formation in such a quiet period, assuming no difference in the composition and magnetic characteristics of the sea floor (Figure 20).

Further to the south the magnetic profiles over the Mid Pacific mountains show the large and complex anomalies expected in such a region, (Figure 15).

Conclusions from magnetic evidence.

West of the Hawaiian ridge the Hawaiian lineations are terminated by the extension of the Murray fracture zone. Another major fracture zone offsets the lineation sequence right-laterally just to the north of the Murray, the relationship between these two fracture zones is at present unknown. Some smaller fracture zones just west of Midway appear to be continuous with proposed faults in the vicinity of Midway Island, the faults being inferred from the configuration of the bathymetric contours around the island (Malahoff and Woollard, 1971). The magnetic lineations south of the Murray fracture zone do not appear to be part of the Hawaiian lineation sequence, and the larger amplitude anomalies may be of tectonic origin

Seismic reflection studies in the Hawaiian ridge area.

North of the ridge there is little relevant data,the only available profiles inthe area are located just west of Midway Island(Figure 21). The profiles themselves (Figure 22) show no sign of tectonic disturbances, or structures, typical of a fracture zone configuration. In view of the age difference between the presumed ages of the fracture zone and the Hawaiian ridge in this area,some 60my.,this is not surprising.There has been ample time for basalt and sediment from the ridge to obliterate any fracture zone traces close to the ridge.

South of the ridge the available data is much more extensive,records from three cruises having been examined (Figure 21).The correlation between tectonic structures seen on the seismic reflection records and the fracture zones identified on the basis of magnetic evidence has already been discussed.

Comparison of the seismic records in the survey area north of the Mid Pacific mountains with those obtained further to the west, discloses that there is a difference in the character of the acoustic basement north of the Murray and associated fracture zones,ie. north of the 0.5 sec.isopach (Figure 27) and the area to the south of this ~~zone~~ isopach. To the north of this isopach the acoustic basement is typically formed of low horsts and grabens, with only some 0.2-o.3 secs.

of sediment cover. In the vicinity of the Hawaiian ridge this cover is increased by the sediment derived from the ridge, which forms an archipelagic apron (Figure 19). To the south, the acoustic basement is typically smoother, with up to 0.6 secs. of sediment cover. Figure 23 illustrates the difference in character of the basement, it also shows, in the southern section of 'C-B', the sedimentary basin which is formed between the Murray fracture zone and that fracture zone immediately to the north. This basin has a normal sea floor, generated by sea floor spreading, but the basement is lower than that closer to the ridge. While the sediment cover to the north of the 0.5 sec. isopach appears to be predominantly pelagic in origin, being evenly distributed in both the horsts and the grabens, that found in the basins between the Murray fracture zone and the 0.5 sec. isopach just to the north again, was apparantly deposited by some bottom transport mechanism. The deeper reflectors in the basins pinch out against the basin sides, although the reflectors are depressed in the deeper parts of the basins, this may be due to differential compaction, being more pronounced in the thicker sedimentary sections.

This deep sedimentary section, composed mainly of bottom transported sediment, appears to be genetically related to thick sedimentary sections found in the area of the Mid Pacific mountains, and to the immediate north of the intersection of the Necker and Line Islands ridges.

Although there is only intermittent structural evidence for the fracture zones in the main survey areas, just west of the Mid Pacific mountains there are good examples of simple fracture zone scarps similar to those seen off the coast of California (Figure 25)at longitude 168°E on section Y-Y', and at longitude 172°40'E on section N-O). These scarps are probably not on the same fracture zone, but on two different fracture zones. In both cases, there appear to be regional depth changes across the scarps. The scarp on section N-O is shown in detail in Figure 26, section 2. Further north, on profile Y-Y', is a complex basement structure, which may be related to the most northerly of the Midway fracture zones,this structure is shown in detail in section 1,Figure 26. The basement troughs in this structure appear to be filled with bottom transported sediment(the sediment is not draped over the basement elevations,as would be expected if it were of pelagic origin).

Consideration of the available data in the area of profiles Y-Y' and N-O yields no obvious reason for the dramatic change in the structural configuration of the fracture zones,between the areas first examined, to the south of Midway Island,and the area of the above two profiles. One possibility is that the sea floor adjacent to the Mid Pacific mountains has a slightly thicker crust than normal, or for some reason has not subsided with age as much as would be expected,and thus still preserves some, or all of the original scarp elevation.However, when the lack of survey data is considered, the possibility that the two fault, or fracture zone scarps are not related to the fracture zones previously defined cannot be ruled out.

The only presently available evidence of the age of the sediments themselves is that obtained from DSDP site 45 (Heezen et al,1971),which lies close to the position of anomaly M-3,dated at 114mybp (Larson and Pitman,1972). The drilling at site 45 reached a reflector approximately 0.1 secs. below the surface of the sediments, core catcher fragments from the vicinity of this reflector are identified as being of cenomanian age, aproximately 96mybp. The total sedimentary thicness at this point, above horizon B', acoustic basement, is 0.35 secs..Accepting the above ages, it appears that the bulk of the sediment was deposited in a period of some 18my., with slower subsequent deposition.

Discussion

It has been proposed that the Emperor and Musicians seamounts, and the Necker and Line Islands ridges mark the location of the spreading center at the commencement of the present spreading episode (Wilson, 1970; Handschumacher, 1973).

The spreading patterns in the western Pacific identified by Larson and Chase(1972) indicate a different pattern of spreading centers in the mesozoic than more recently, thus although the orientation of the Hawaiian lineations is similar to that of anomaly sequence 1-32 (Heirtzler et al, 1968), between the Murray and Mendocino fracture zones, each of these fracture zones is probably the result of two historically different spreading episodes, each with a different arrangement of spreading centers, and thus the break in structural continuity at the old boundary can be accounted for. The continuity of the fracture zone trend can be explained by the old fracture zone acting as an initiator for the formation of the new fracture zone, at the start of the new spreading episode.

The diminution of bulk of the Hawaiian ridge at the intersection with the Mendocino, Murray, and Necker structural trends may be related to the structure of the crust in the vicinity of these trends. If the crustal structure in these old sections of fracture zone is similar to that found on the Mendocino off California, then the crust in the immediate vicinity of the fracture zones is much thicker than the normal oceanic crust (Dehlinger et al,1967). This thick crust could have provided an obstacle to the hot spot, or whatever mechanism generated the magma which created the shield volcanoes of the Hawaiian ridge.However the lack of such a diminution of volume at the intersection with the Molokai fracture zone is difficult to explain.

The similarity in position and strike of the faults postulated by Malahoff and Wollard (1971) and the small fracture zone just west of Midway Island (Larson and Chase,1972) is difficult to explain, considering the difference in ages of the two features, unless there is some way in which the old fracture zones can exert some control over the extrusion of basalt in their vicinity, thus leaving the appearance of a straight topographic feature,which could be interpreted as a fault from the topographic data.

The lack of any major topographic feature usually associated with fracture zones in the area west of the Musicians seamounts, as far as the Murray is concerned, can be explained by the age of the crust. If the original fracture zone were a simple scarp, then when the mantle cooled the scarp would disappear,as the original temperature difference creating it would have disappeared, leaving only some minor ridges and troughs.The prominant scarp west of the Mid Pacific mountains may be related to the sea floor around the mountains themselves being slightly elevated, and thus perpetuating the scarp after it has disappeared from places where the sea floor was of the same crustal thickness on both sides of the fracture zone.

From the magnetic evidence the most southerly of the fracture zones in the survey area west of Midway Island (Figure 15) is the Murray fracture zone.This is the fracture zone which either terminates, or displaces far to the west, any south eastward continuation of the Hawaiian Lineation sequence, the more northerly fracture zones only displace the sequence to a minor extent.The area south of the Murray has a different magnetic character to what would be expected if the Hawaiian sequence had merely been displaced westwards,the magnetic character not being that of a quiet zone.

Larson and Chase (1972) describe the Hawaiian and Phoenix lineations and show that they are at very different orientations, even though they are of the same age. This difference in orientation is explained as being the result of a magnetic bight, similar to that found off Alaska.

So far, no lineations have been found in the area between the two above mentioned lineation sequences, which support the bight theory,neither does the available data deny the theory.A definite answer must await a special survey, as much of the presently available data is of little use.However, the unusual character of the magnetic anomalies south of the Murray fracture zone hints at a complex tectonic history of the crust between the two lineation sequences, and the fact that the complex anomalies start just south of the Murray implies that the bight, or rotation, which caused the different orientations of the anomaly sequences commences just south of the Murray fracture zone.

Thus we have a strong indication that the Murray fracture zone in the area in question is a major tectonic boundary,between normal sea floor to the north (the Hawaiian lineations) and the transition to the sea floor generated by that section of spreading ridge which generated the Phoenix lineations.It is possible that the Mid Pacific mountains are in some way related to this transition in spreading direction. Presently work on the tectonics and history of this transition area is being carried out by D. Handschumacher, with particular reference to the magnetic anomalies in the area.

Conclusions

Fracture zones appear to be very persistant features,their initial formation is apparantly localised by some pre-existing weakness in the crust,which may be an older fracture zone. In this way a fracture zone could theoretically extend completely across the Pacific basin,having been active through several spreading episodes.

In the case of the Murray fracture zone, it has now been traced from the coast of California to the Mid Pacific mountains,and may extend further west yet.The determination of the full extent of the Murray will have to await fresh survey data.

The tendancy of the sea floor to reach an equilibrium depth after 40my. obviates the necessity to explain the lack of any regional changes across the fracture zones,the lack of any continuous ridge and trough zone is partly due to the decline in depth differences with increasing age, and partly to subsequent sedimentation. It is possible that the old fracture zones were similar to the Murray off California,with a simple scarp structure,in which case the scarp would probably disappear with increasing age,leaving the type of low-relief basement that is found on most of the fracture zones west of Midway Island today.

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List of Figures

Figure 15 Selected magnetic profiles, showing Hawaiian lineations, M-1 - 24, after Larson and Chase (1972), and magnetic anomalies south of Murray fracture zone extension.

16 North-south magnetic profiles.

17 North northwest - south southeast magnetic profiles.

18 Profiles of magnetic anomalies across Murray fault zone superimposed on corresponding bathymetric profiles. Keyed to locations shown in Figures 16 and 17.

19 Photographs of seismic reflection record obtained on Kana Keoki (1971) track heading south from Midway towards Mid Pacific Mountains. Location of track, at longitude 179°20'west, shown on Figure 21.

20 Magnetic anomalies in area between Murray fracture zone and Mid Pacific Mountains - Necker ridge topography. Also shown are magnetic anomalies east of Midway.

21 Location of tracks along which seismic reflection records were examined.

22 Tracings of seismic reflection records obtained north of Laysan island, and east of Midway island.

23 Selected seismic reflection records, showing two different types of basement structure, north and south of the Murray fracture zone. The deep sedimentary basin in the south is also shown. Keyed to locations shown in Figure 21.

24 Generalised isopachs (in secs of two-way reflection time) north of Mid Pacific Mountains, and location of major sedimentary basin, identified by seismic reflection data collected by R/V Kana Keoki, and USNS Bartlett (T-AGOR 13). (Basin shown by zipitone)

25 Seismic reflection profiles west of the Mid Pacific Mountains, showing fracture zone-like features, located on projected line of identified zones.

26 Enlargements of sections of seismic reflection records shown in Figure 25. Upper section shows rift-like feature on eastern section of profile Y-Y', lower shows fracture zone on eastern section of profile N-O.

27 Structural trends of fracture zones, topography and generalised isopachs in region between Hawaiian ridge and the Mid Pacific Mountains.

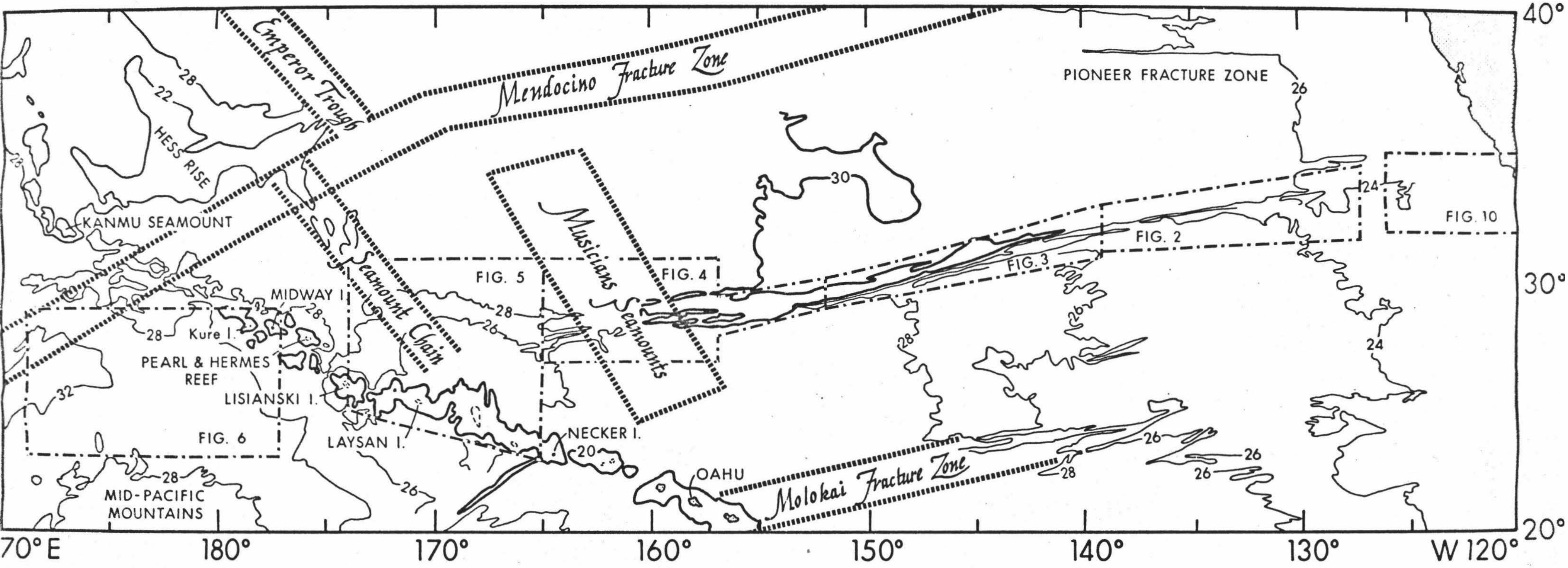
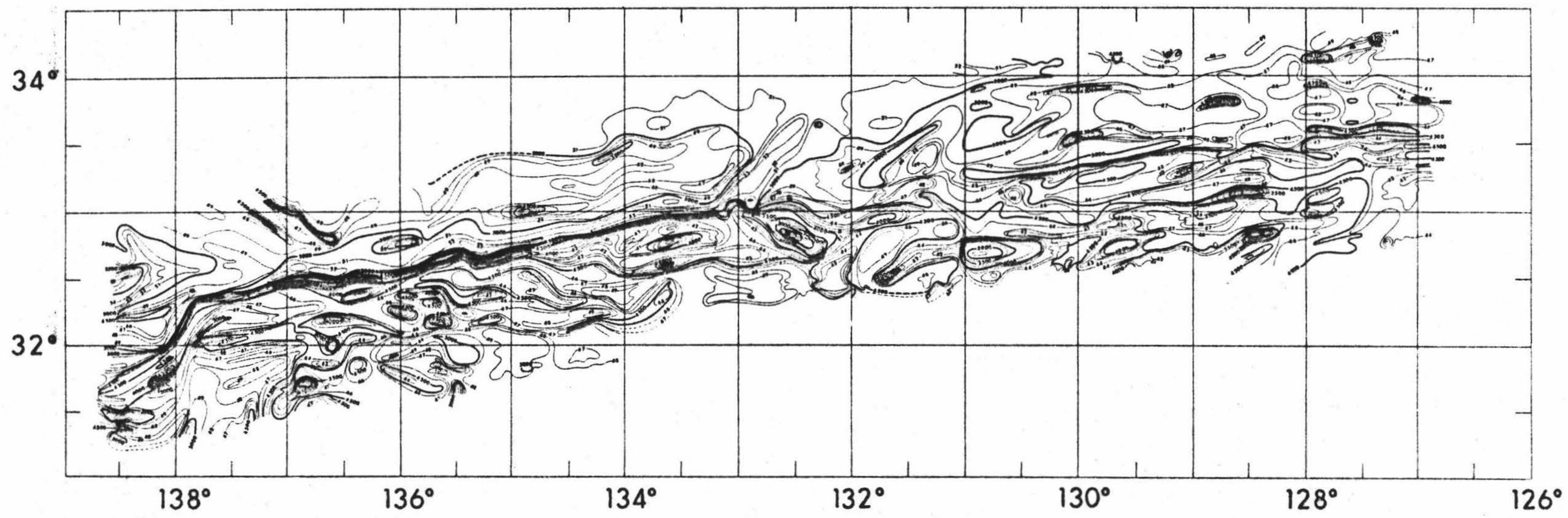

Emperor Trough
Mendocino Fracture Zone
Seamount Chain
Musicians Seamounts
Molokai Fracture Zone
PIONEER FRACTURE ZONE
HESS RISE
KANMU SEAMOUNT
MIDWAY I.
Kure I.
PEARL & HERMES REEF
LISIANSKI I.
LAYSAN I.
NECKER I.
OAHU
MID-PACIFIC MOUNTAINS
FIG. 2
FIG. 3
FIG. 4
FIG. 5
FIG. 6
FIG. 10
28
22
30
32
26
24
20
40°
30°
20°
170° E
180°
170°
160°
150°
140°
130°
W 120°

Figure 1



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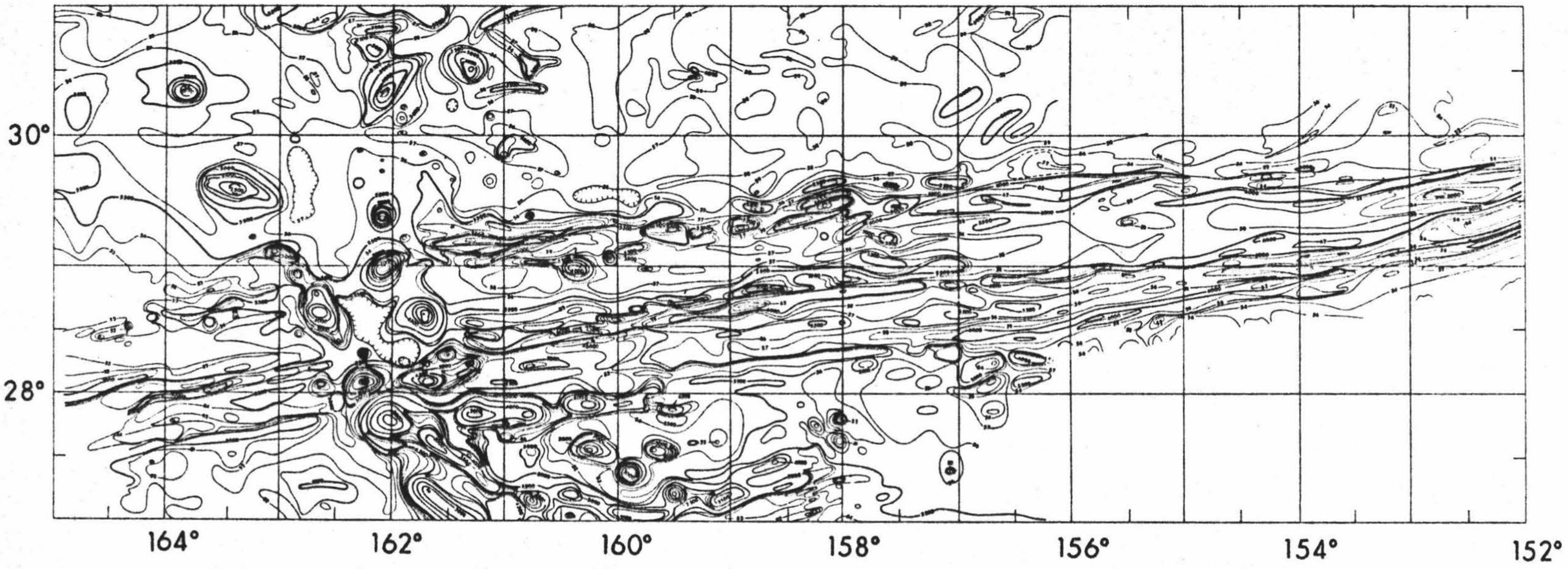

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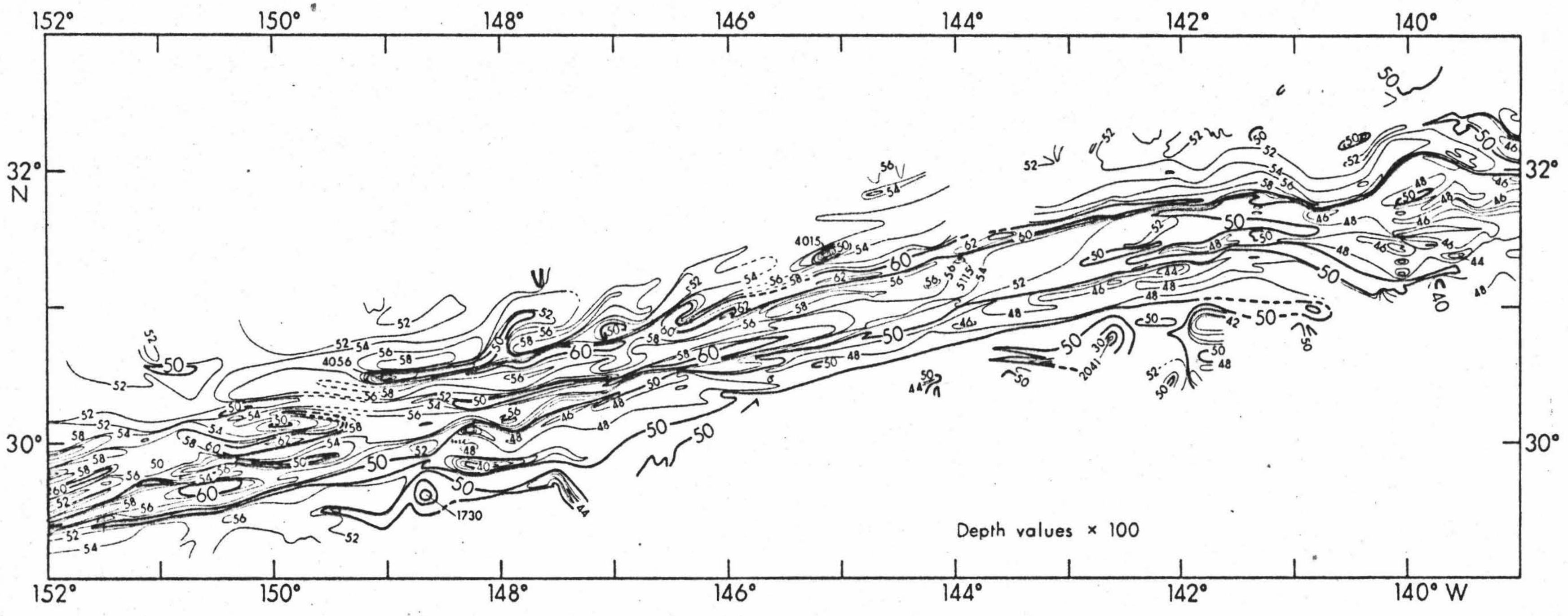

152°
150°
148°
146°
144°
142°
140°
32°
N
30°
140° W
Depth values × 100
4015
4056
5115
2041
1730

Figure 3

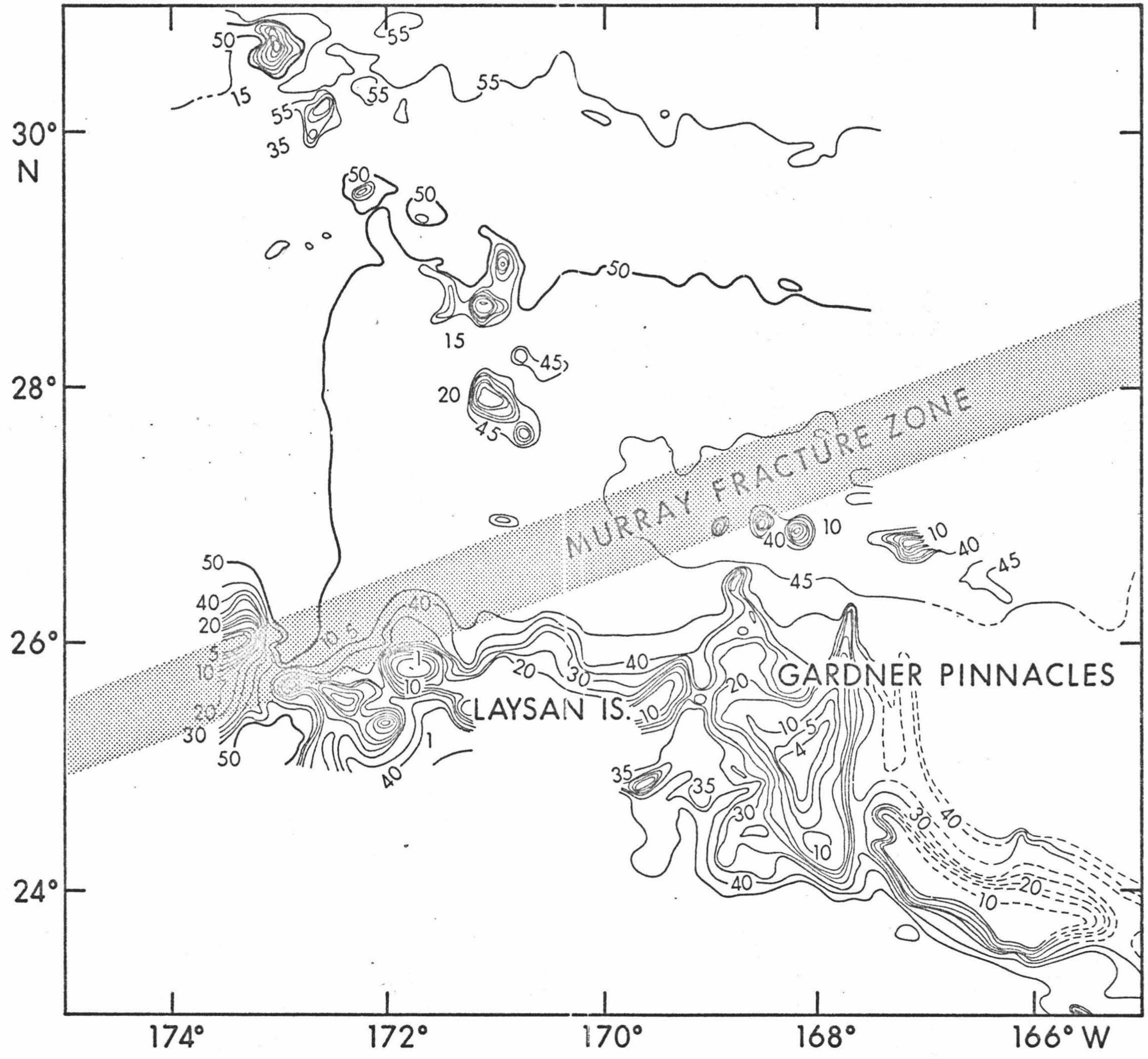

30°
N
28°
26°
24°
174°
172°
170°
168°
166° W
MURRAY FRACTURE ZONE
LAYSAN IS.
GARDNER PINNACLES
50
55
55
55
15
55
35
50
50
50
15
45
20
45
10
40
10
40
45
45
50
40
20
5
10
20
30
50
40
10
5
1
10
1
40
20
30
40
10
35
35
20
10
5
4
30
10
40
30
40
20
10

Figure 5

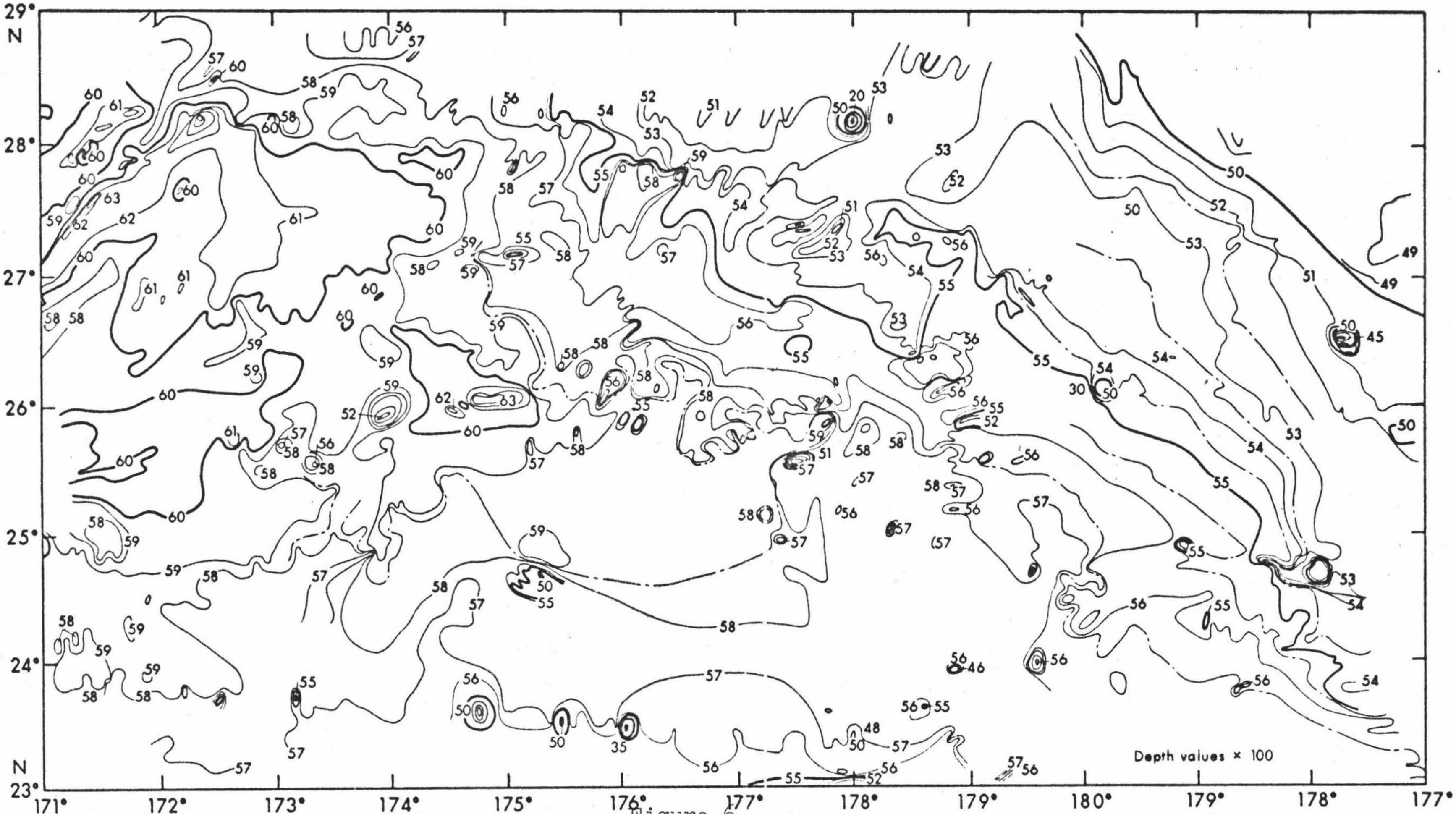

29° N
28°
27°
26°
25°
24°
N 23°
171°
172°
173°
174°
175°
176°
177°
178°
179°
180°
179°
178°
177°
Depth values × 100

Figure 6

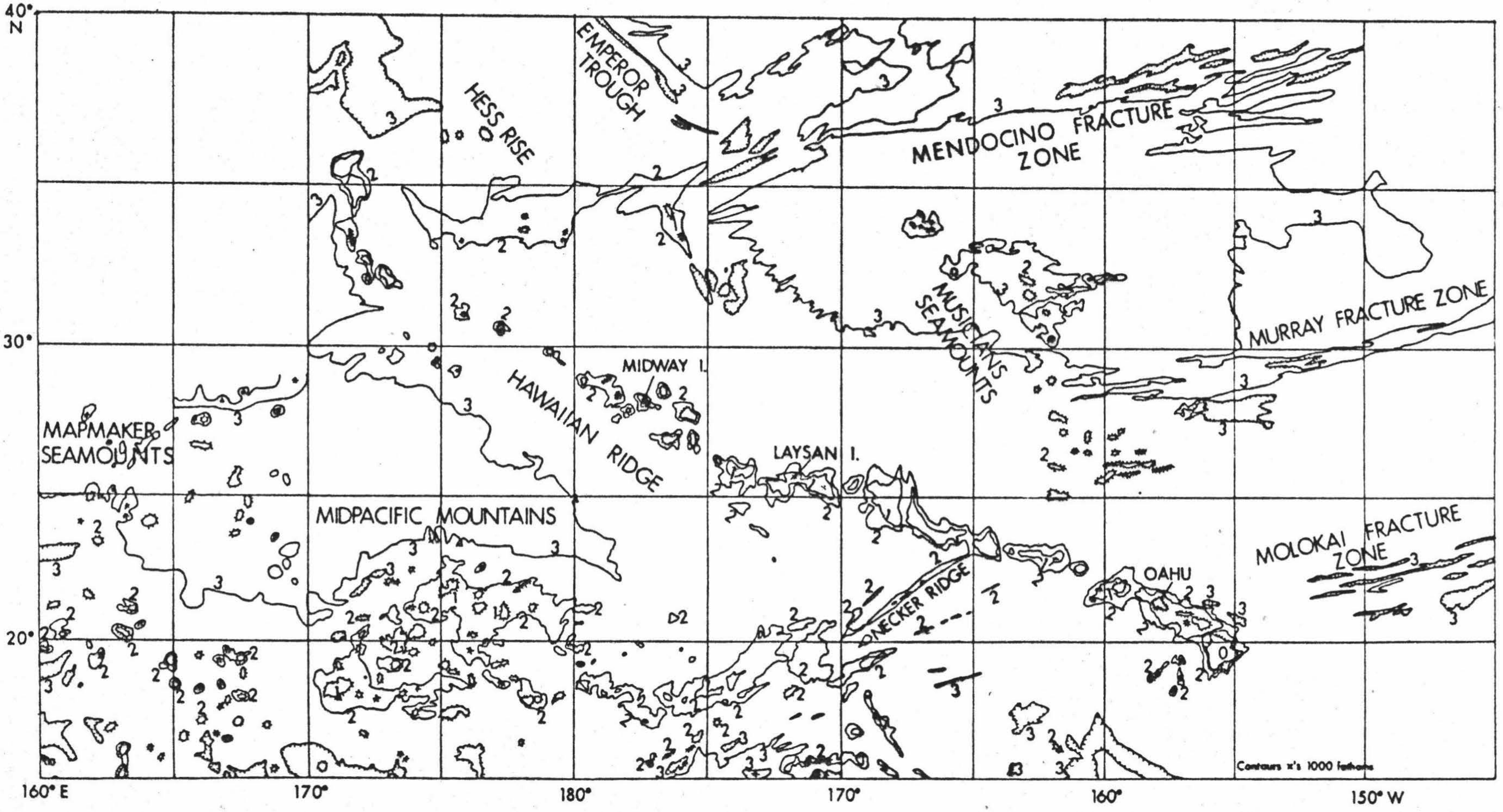

40° N
30°
20°
160° E
170°
180°
170°
160°
150° W
HESS RISE
EMPEROR TROUGH
MENDOCINO FRACTURE ZONE
MUSICIANS SEAMOUNTS
MURRAY FRACTURE ZONE
MIDWAY I.
HAWAIIAN RIDGE
MAPMAKER SEAMOUNTS
LAYSAN I.
MIDPACIFIC MOUNTAINS
NECKER RIDGE
OAHU
MOLOKAI FRACTURE ZONE
Contours x's 1000 fathoms

Figure 7

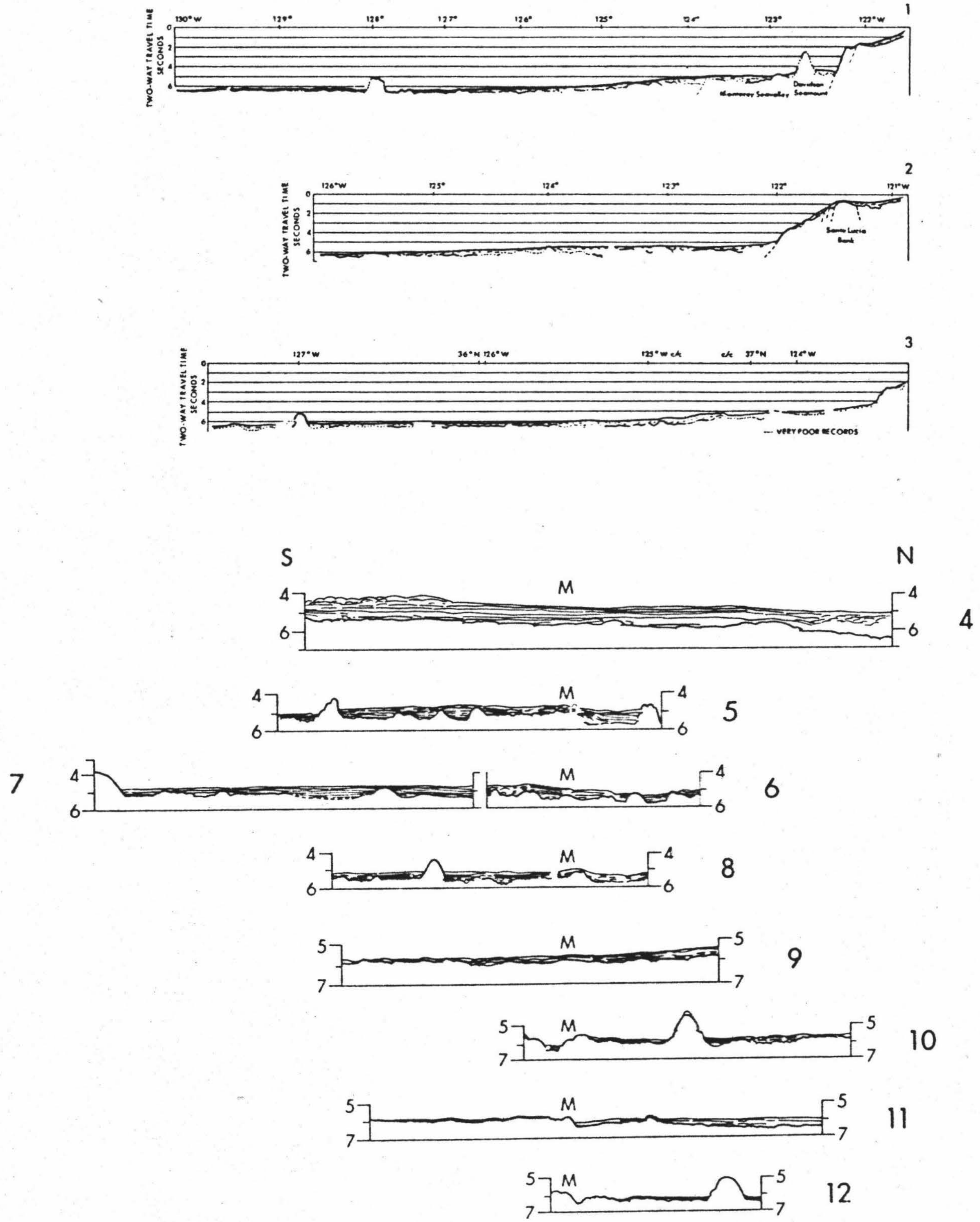
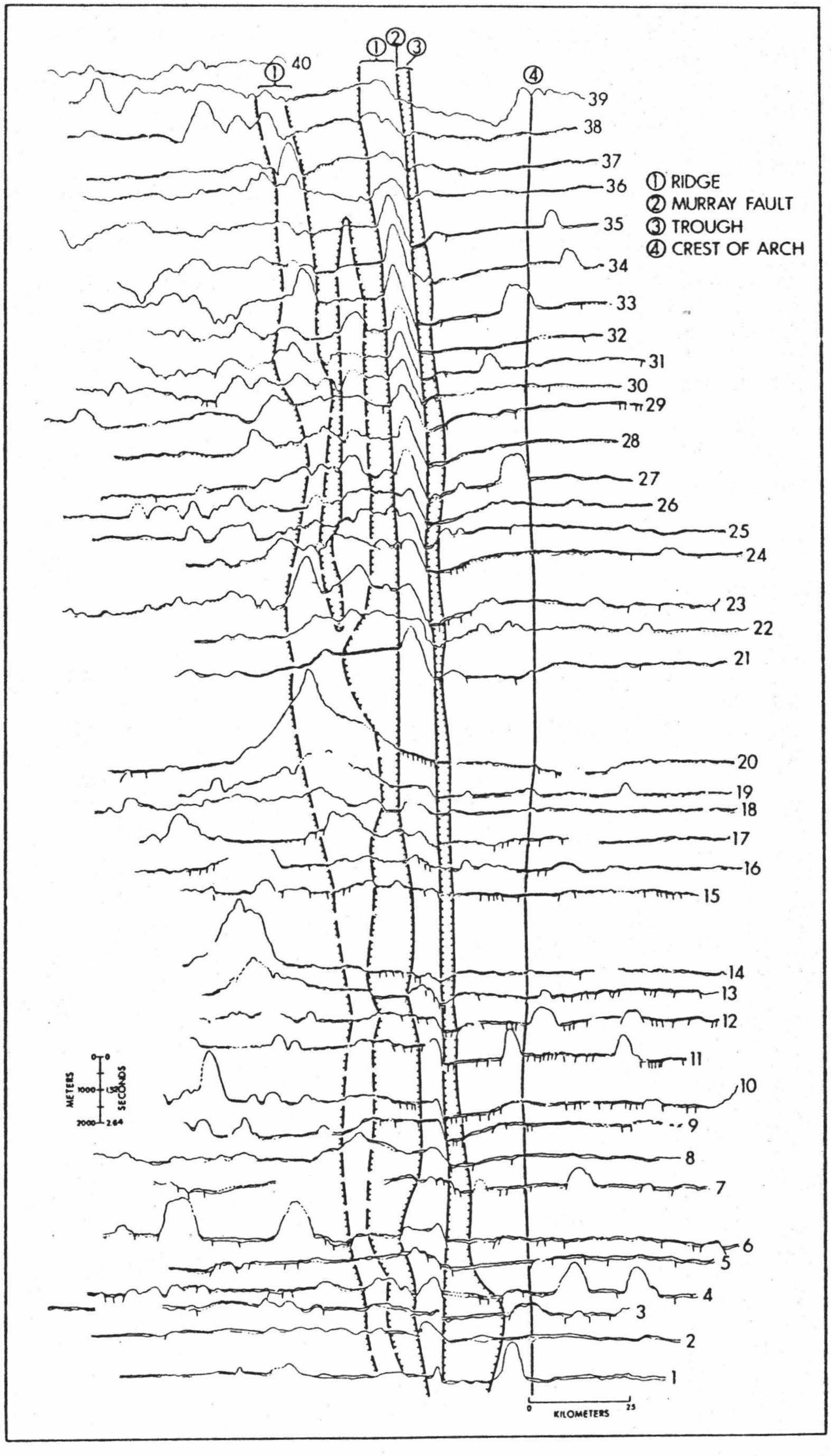

1
TWO-WAY TRAVEL TIME SECONDS
130° W
129°
128°
127°
126°
125°
124°
123°
122° W
0
2
4
6
Monterey Seavalley
Davidson Seamount
2
126°W
125°
124°
123°
122°
121°W
Santa Lucia Bank
3
127° W
36° N 126° W
125° W c/c
c/c
37° N
124° W
VERY POOR RECORDS
S
N
M
4
5
6
7
8
9
10
11
12

Figure 8



① RIDGE
② MURRAY FAULT
③ TROUGH
④ CREST OF ARCH
①
②
③
④
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
METERS
SECONDS
0
1000
2000
1.32
2.64
0
25
KILOMETERS

Figure 9

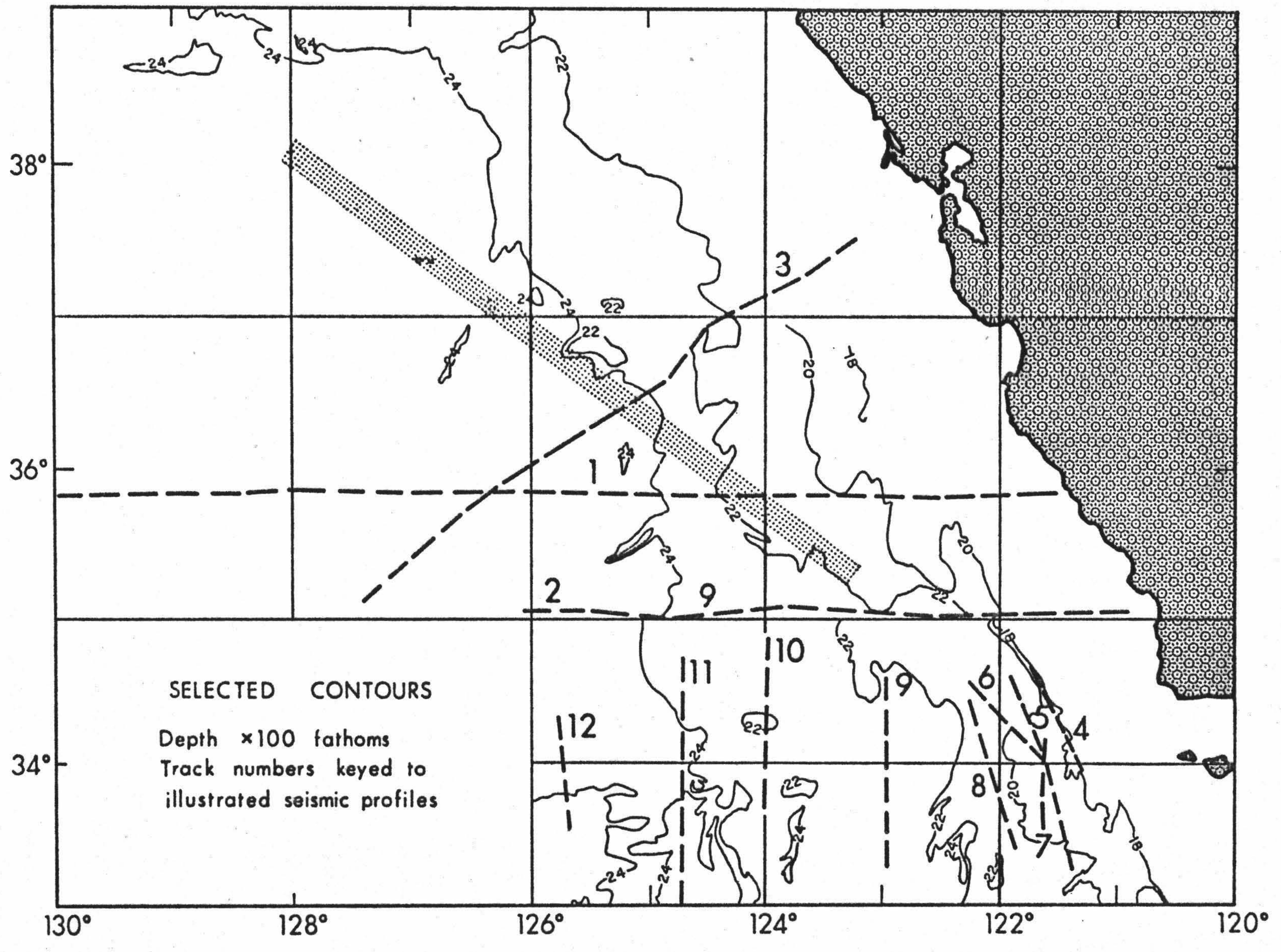

SELECTED CONTOURS
Depth ×100 fathoms
Track numbers keyed to
illustrated seismic profiles
38°
36°
34°
130°
128°
126°
124°
122°
120°
1
2
3
4
5
6
7
8
9
9
10
11
12
18
20
22
24

Figure 10

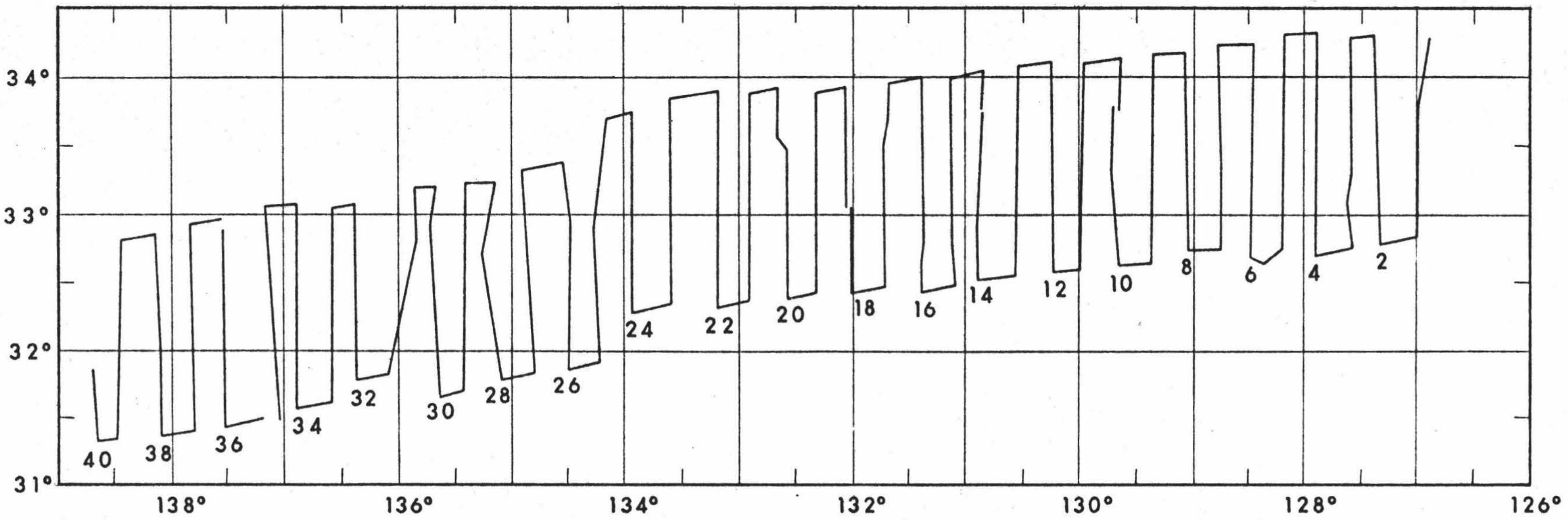
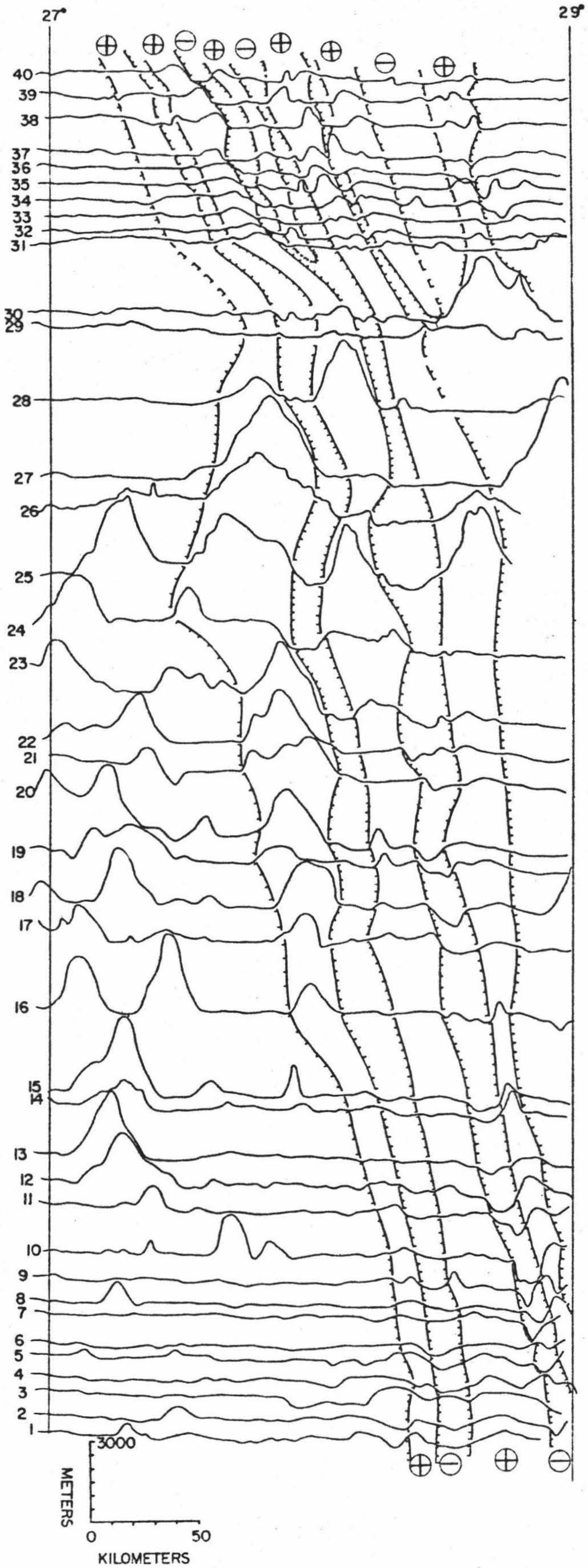
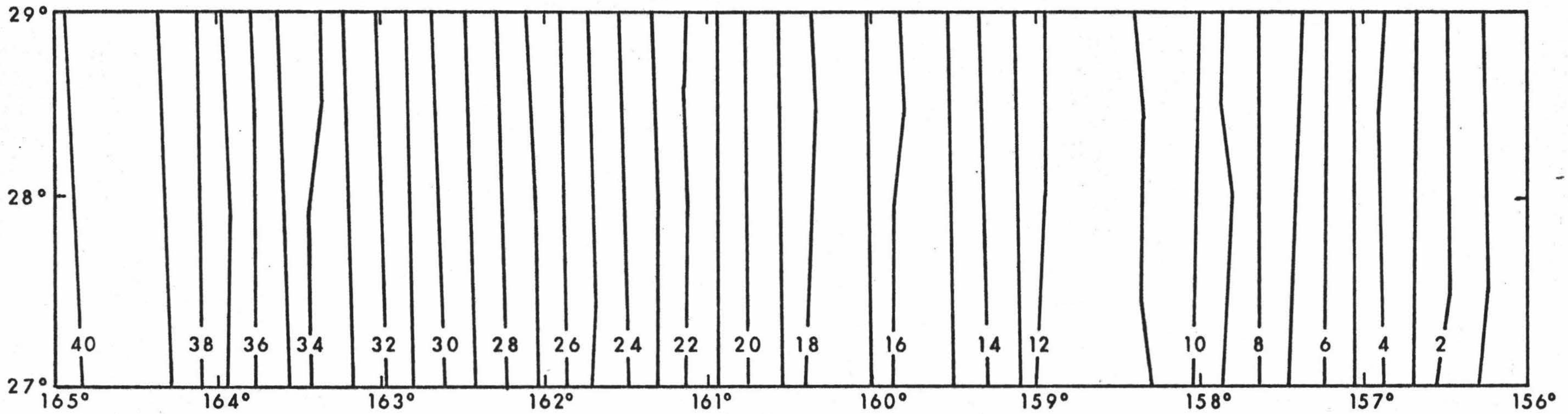

34°
33°
32°
31°
138°
136°
134°
132°
130°
128°
126°
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2

Figure 11



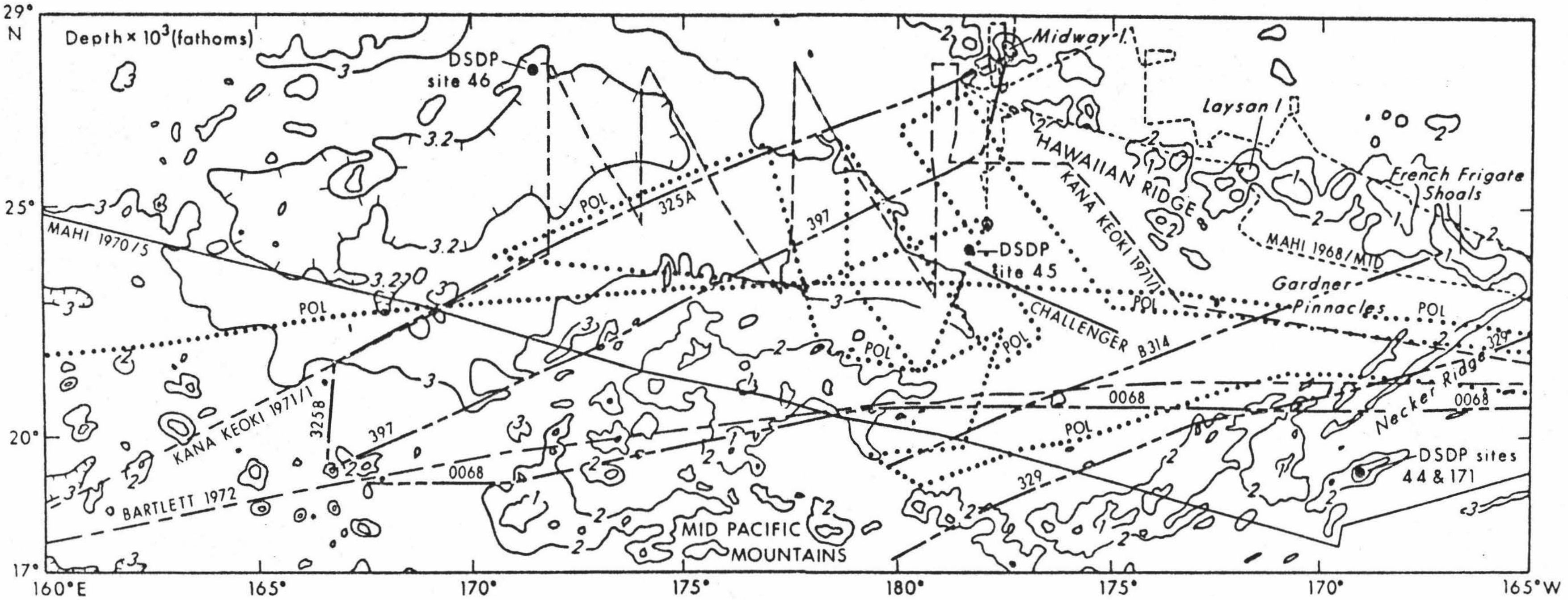
27°
29°
⊕ ⊕ ⊖ ⊕ ⊖ ⊕ ⊕ ⊖ ⊕
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
⊕ ⊖ ⊕ ⊖
3000
METERS
0
50
KILOMETERS

Figure 12



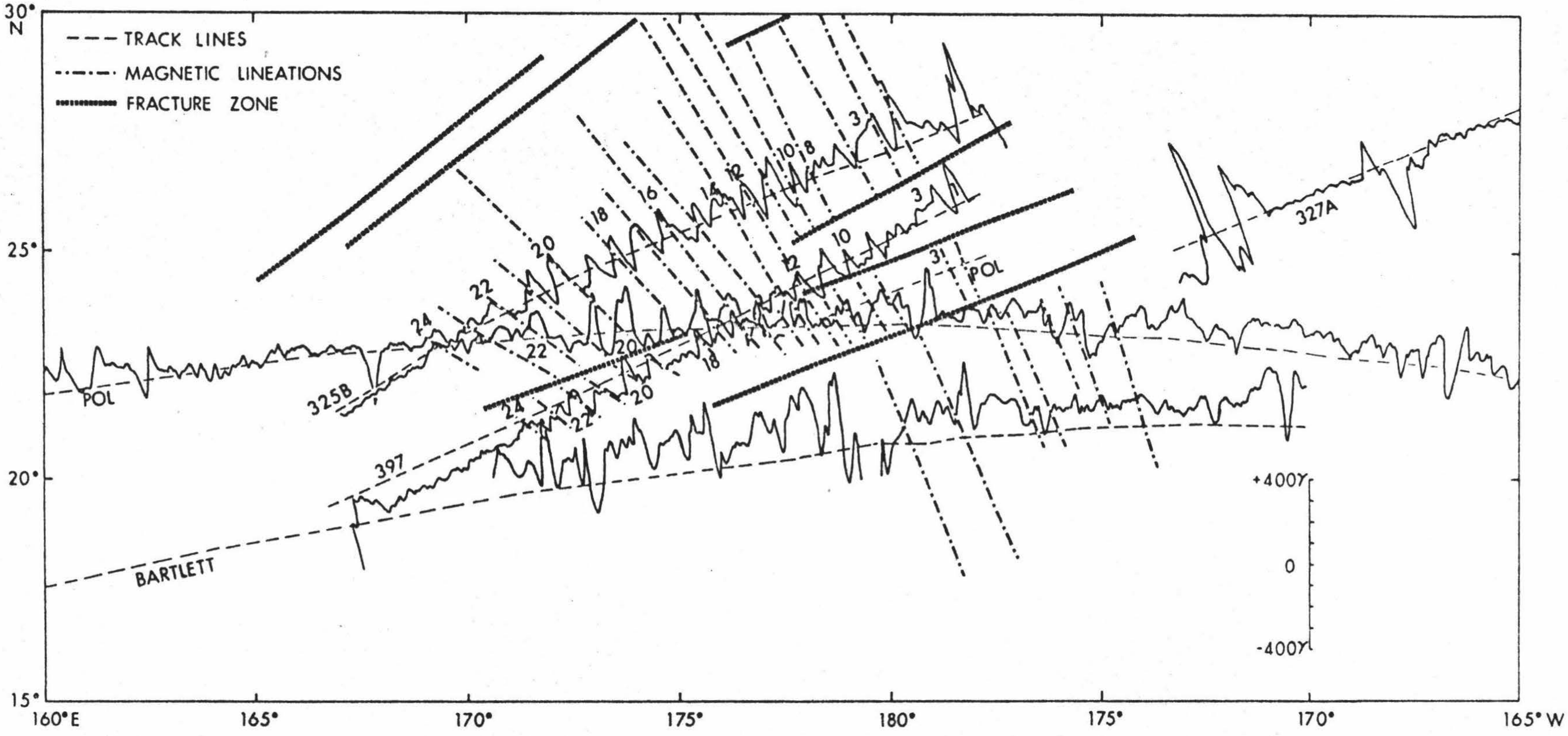
29°
28°
27°
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
165°
164°
163°
162°
161°
160°
159°
158°
157°
156°

Figure 13



29° N
25°
20°
17°
160°E
165°
170°
175°
180°
175°
170°
165°W
Depth × 10³(fathoms)
DSDP site 46
DSDP site 45
DSDP sites 44 & 171
Midway I.
Laysan I
French Frigate Shoals
Gardner Pinnacles
Necker Ridge
HAWAIIAN RIDGE
MID PACIFIC MOUNTAINS
MAHI 1970/5
MAHI 1968/MID
KANA KEOKI 1971/1
BARTLETT 1972
CHALLENGER B314
POL
325A
397
3258
0068
329
3
3.2
2
1

Figure 14



30° N
25°
20°
15°
160°E
165°
170°
175°
180°
175°
170°
165° W
TRACK LINES
MAGNETIC LINEATIONS
FRACTURE ZONE
POL
325B
397
BARTLETT
327A
3
8
10
12
14
16
18
20
22
24
+400γ
0
-400γ

Figure 15

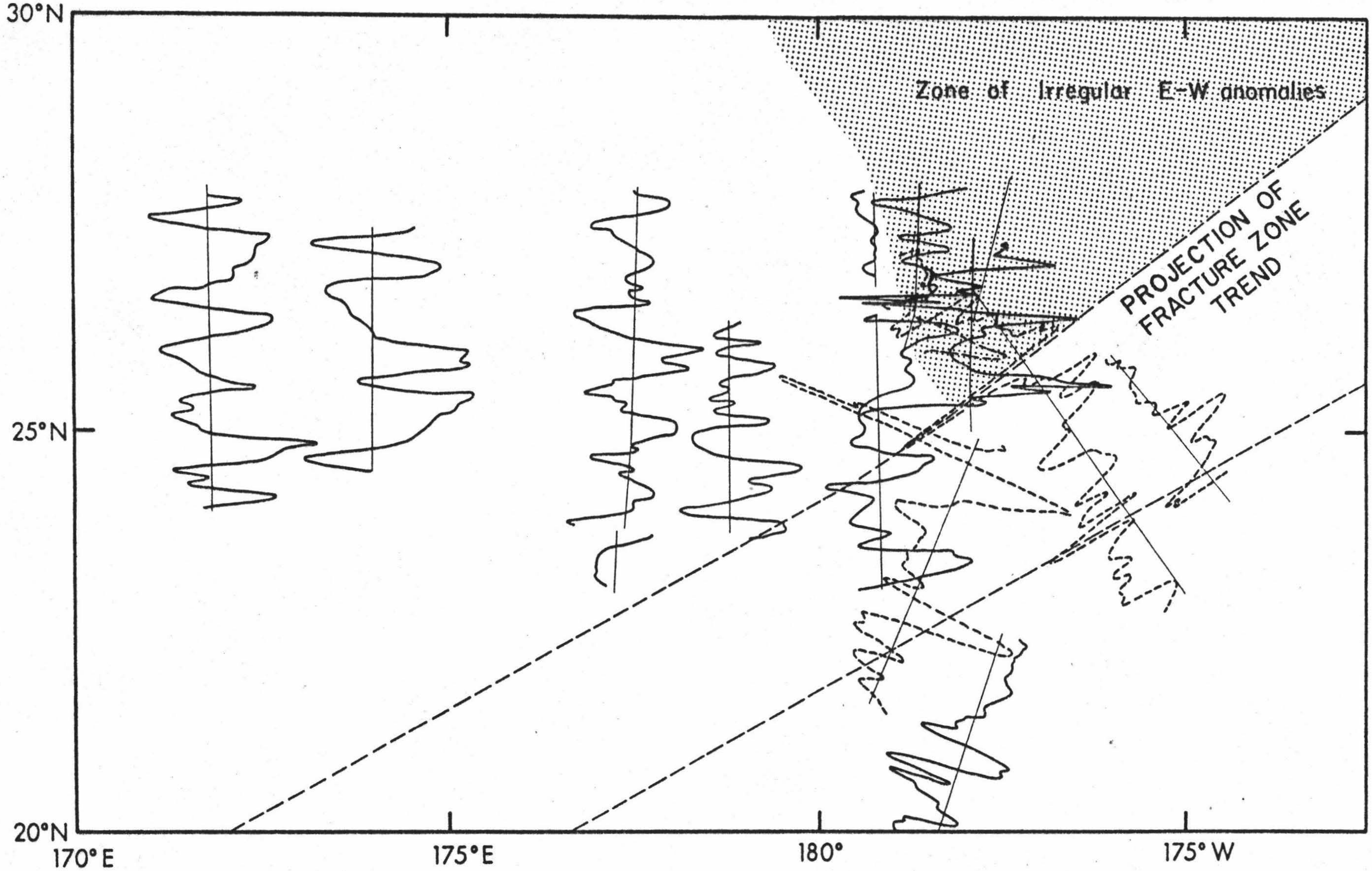

30°N
25°N
20°N
170°E
175°E
180°
175°W
Zone of Irregular E-W anomalies
PROJECTION OF FRACTURE ZONE TREND

Figure 16

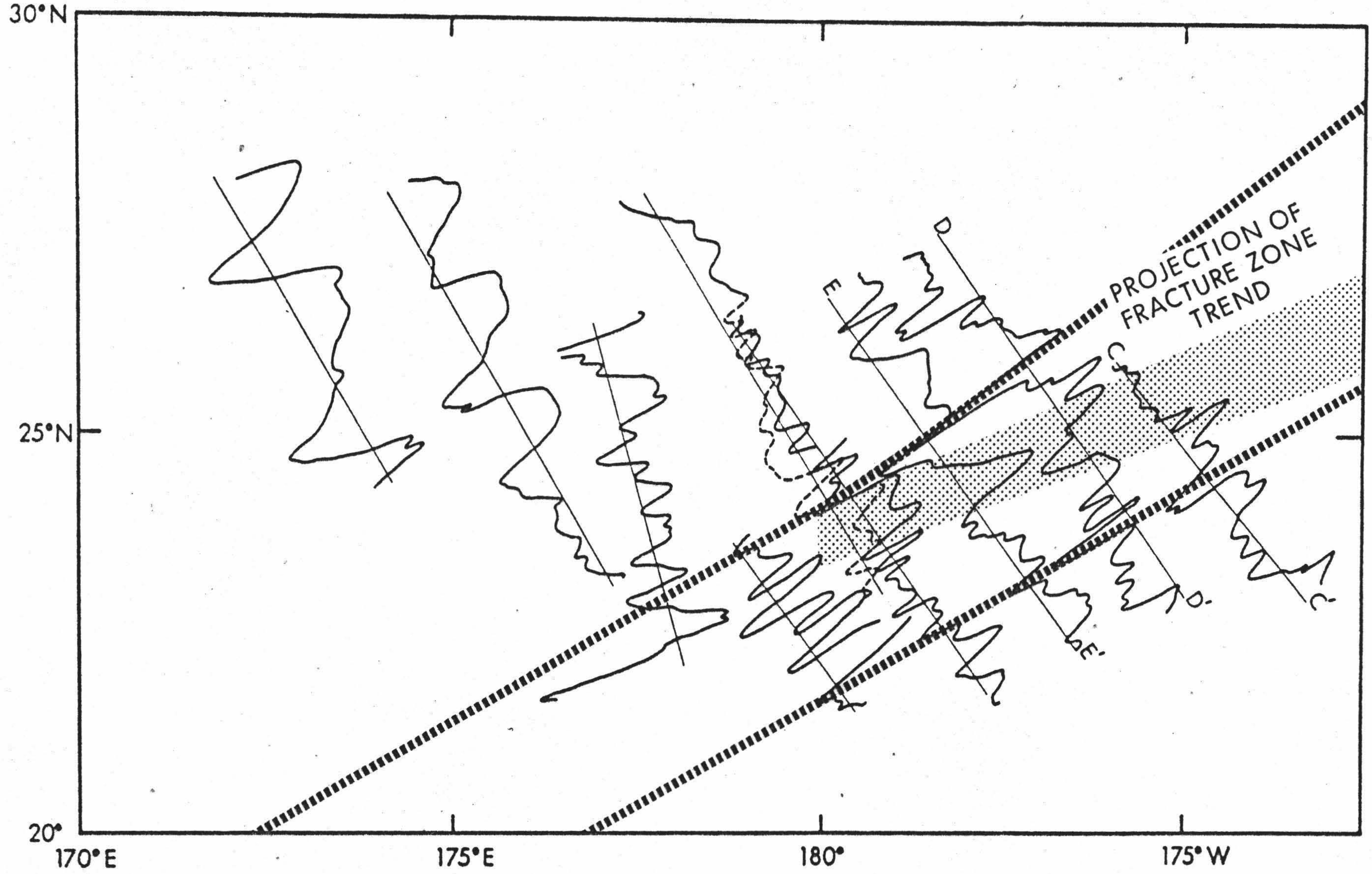
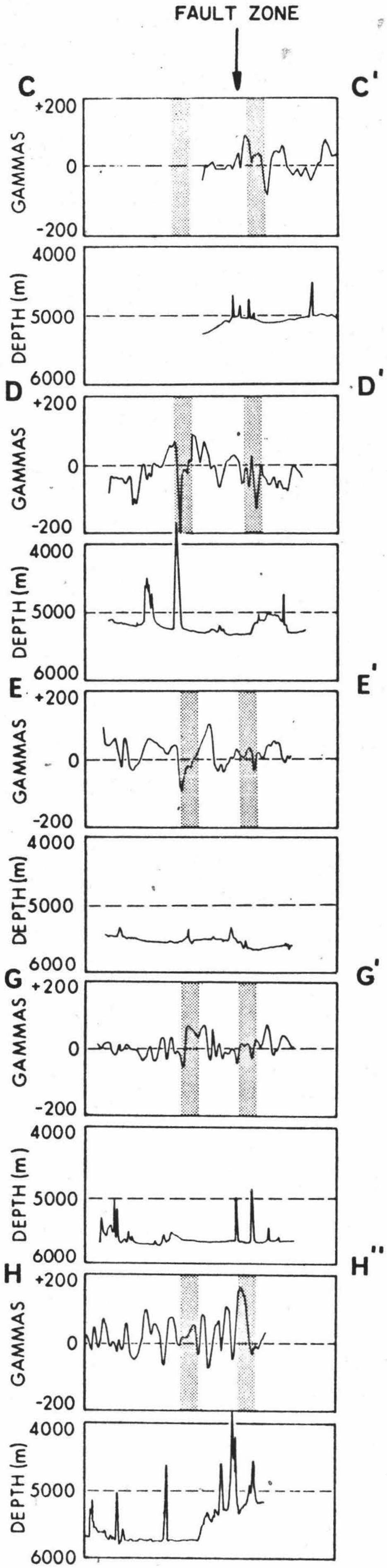

30°N
25°N
20°
170°E
175°E
180°
175°W
PROJECTION OF
FRACTURE ZONE
TREND
C
C'
D
D'
E
E'

Figure 17



FAULT ZONE
C
C'
+200
GAMMAS
0
-200
4000
DEPTH (m)
5000
6000
D
D'
+200
GAMMAS
0
-200
4000
DEPTH (m)
5000
6000
E
E'
+200
GAMMAS
0
-200
4000
DEPTH (m)
5000
6000
G
G'
+200
GAMMAS
0
-200
4000
DEPTH (m)
5000
6000
H
H"
+200
GAMMAS
0
-200
4000
DEPTH (m)
5000
6000

Figure 18

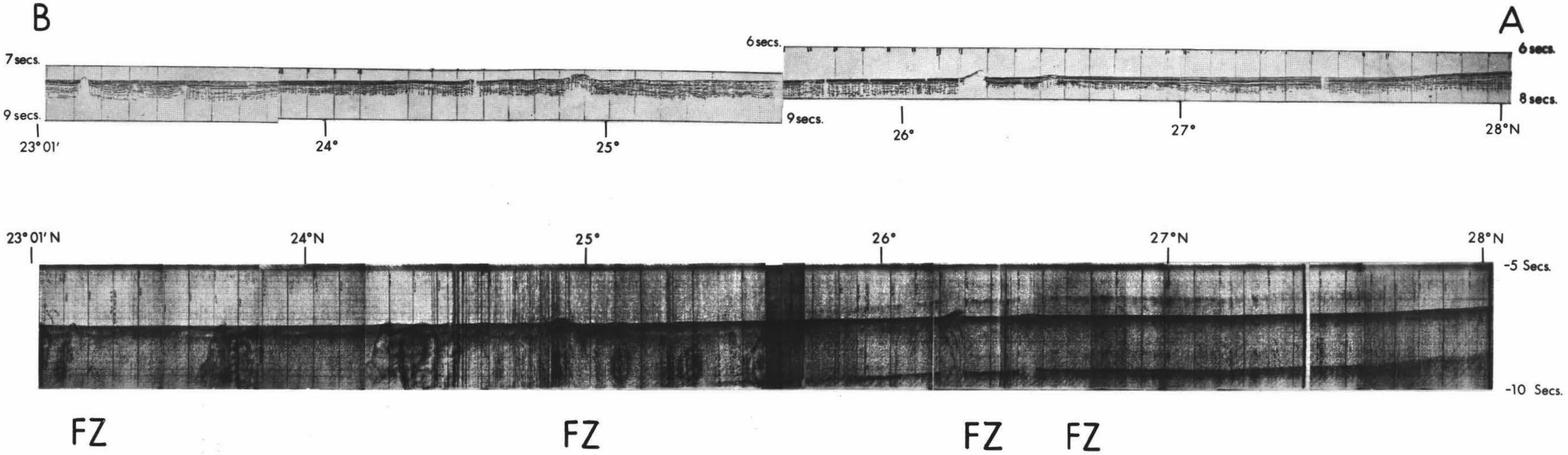

B
A
7 secs.
9 secs.
6 secs.
9 secs.
6 secs.
8 secs.
23°01'
24°
25°
26°
27°
28°N
23°01'N
24°N
25°
26°
27°N
28°N
-5 Secs.
-10 Secs.
FZ
FZ
FZ
FZ

Figure 19

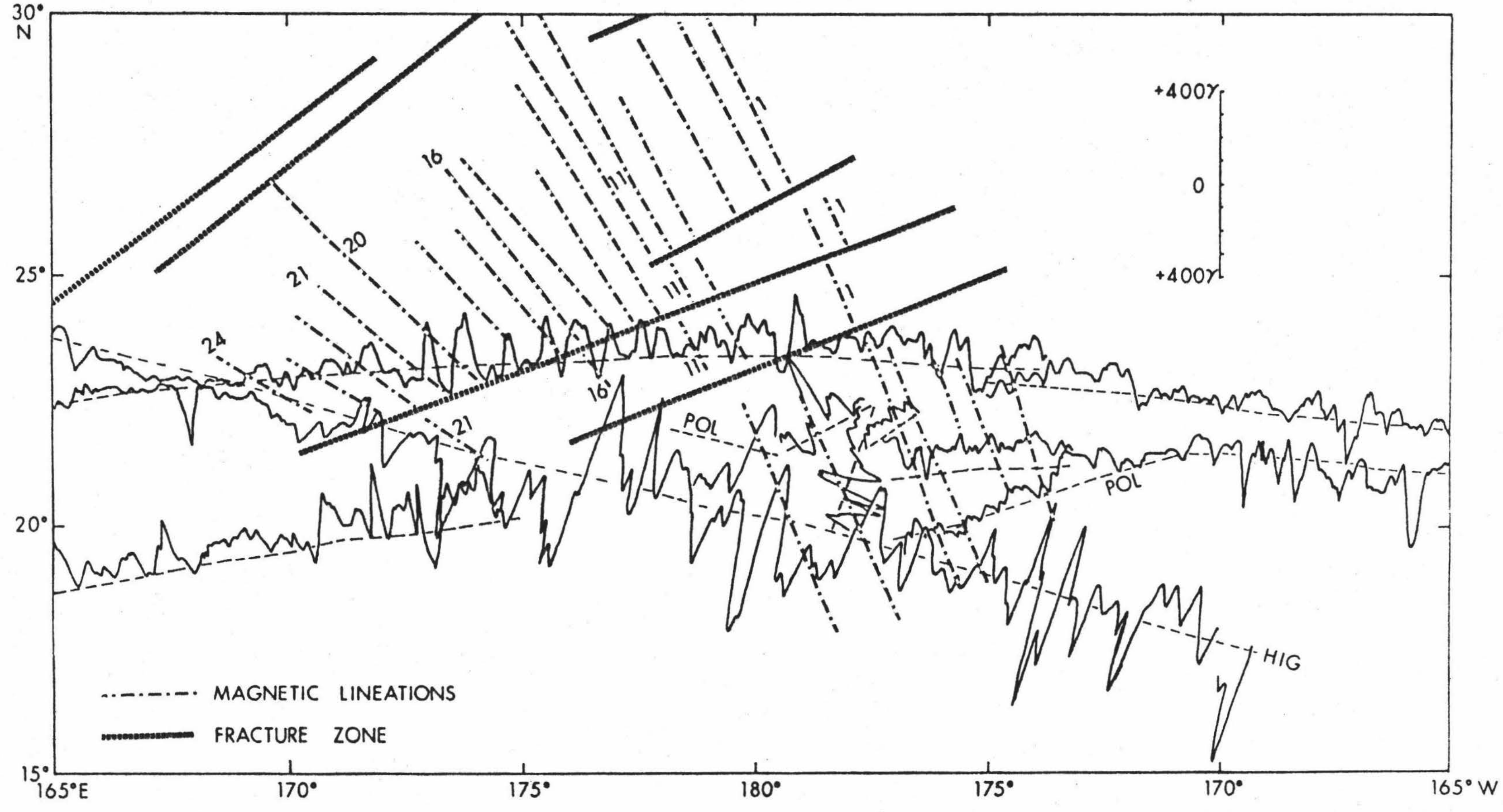

30° N
25°
20°
15°
165°E
170°
175°
180°
175°
170°
165° W
+400γ
0
+400γ
16
20
21
24
21
16
11
11
11
11
1
1
1
POL
POL
HIG
MAGNETIC LINEATIONS
FRACTURE ZONE

Figure 20

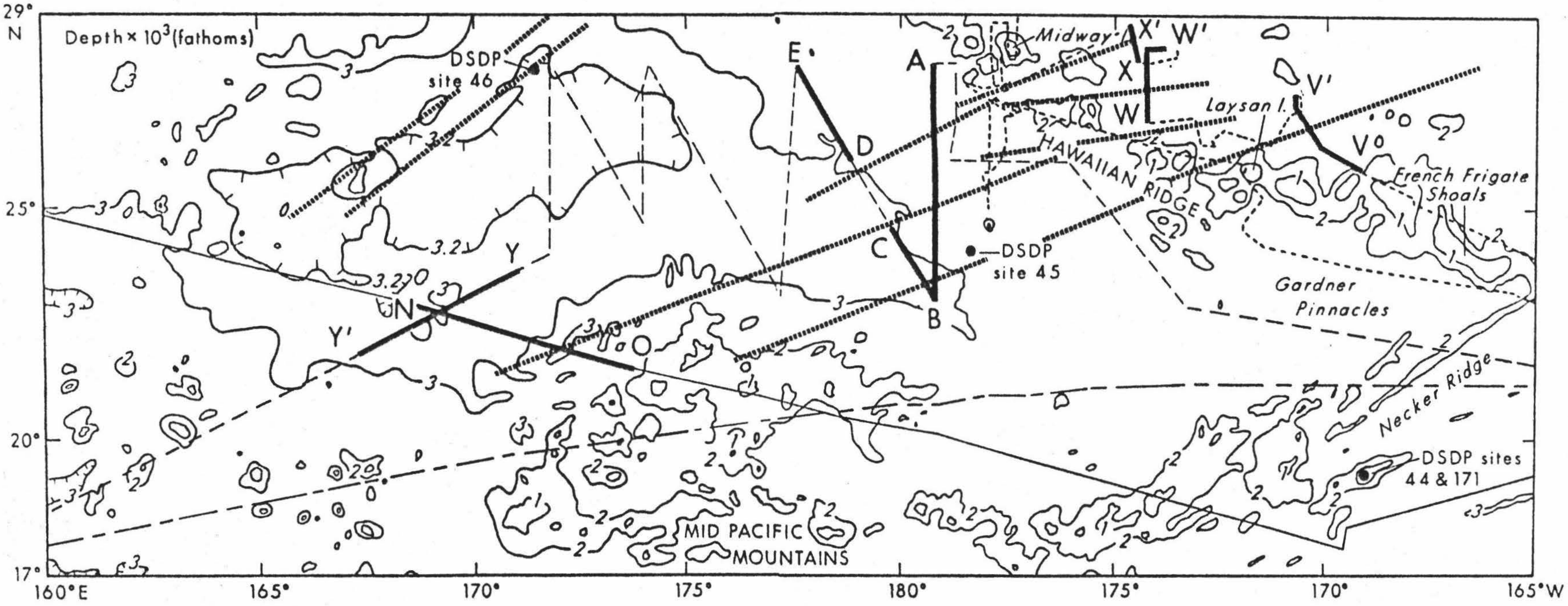

Depth × 10³ (fathoms)
29° N
25°
20°
17°
160°E
165°
170°
175°
180°
175°
170°
165°W
DSDP site 46
DSDP site 45
DSDP sites 44 & 171
Midway
Laysan I.
HAWAIIAN RIDGE
French Frigate Shoals
Gardner Pinnacles
Necker Ridge
MID PACIFIC MOUNTAINS
A
B
C
D
E
N
O
V
V'
W
W'
X
X'
Y
Y'
1
2
3
3.2

Figure 21

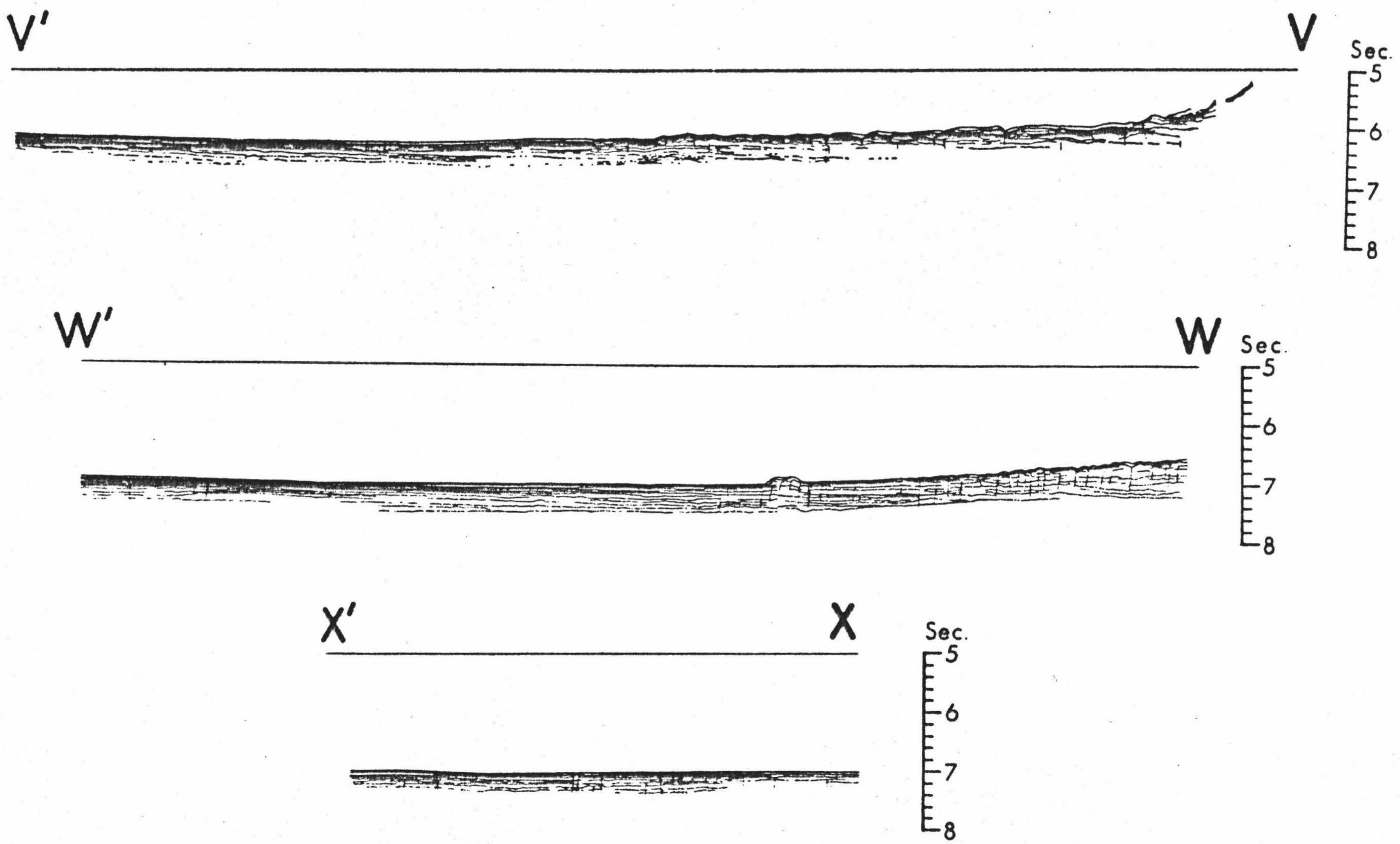


Figure 22

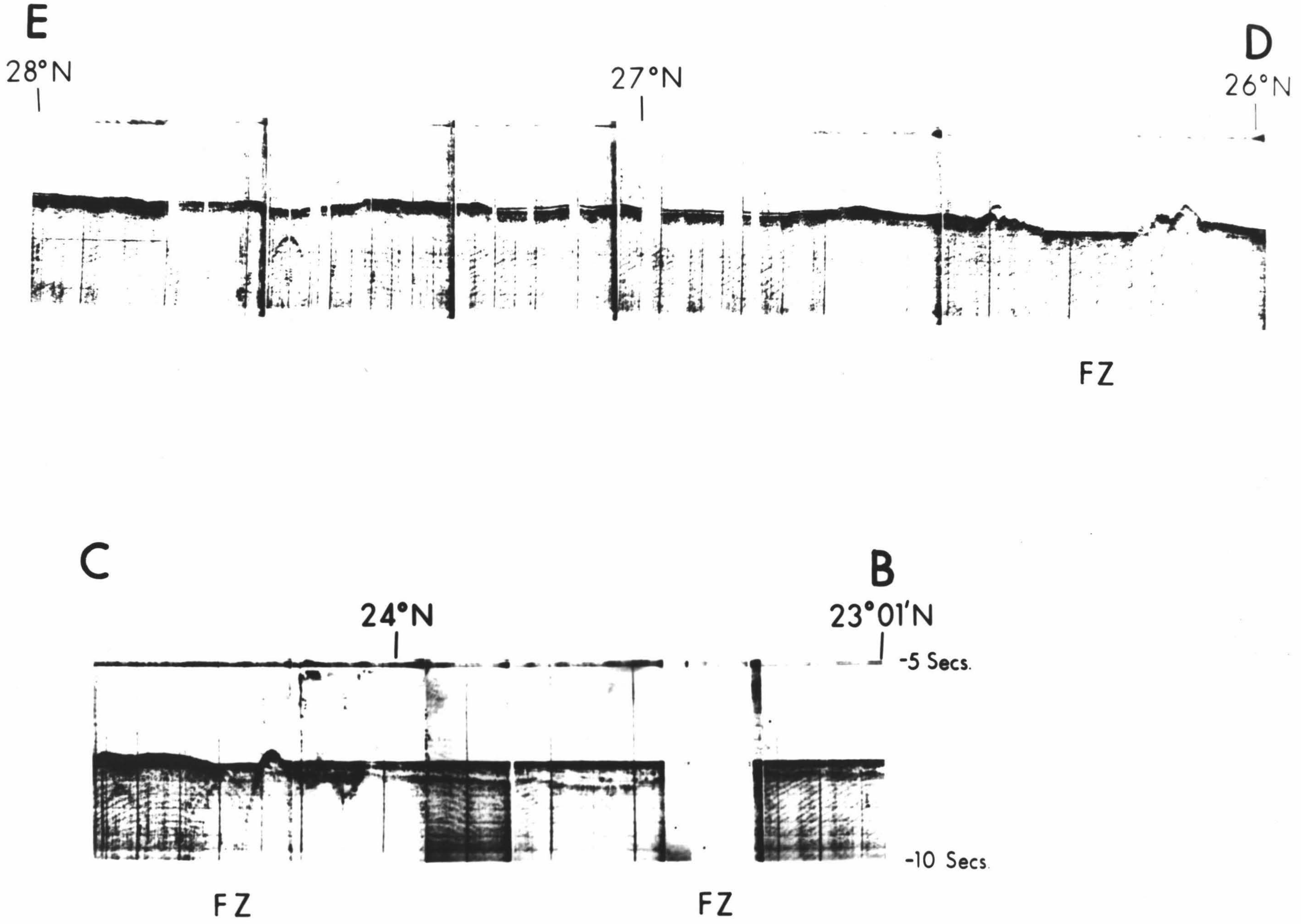


Figure 23

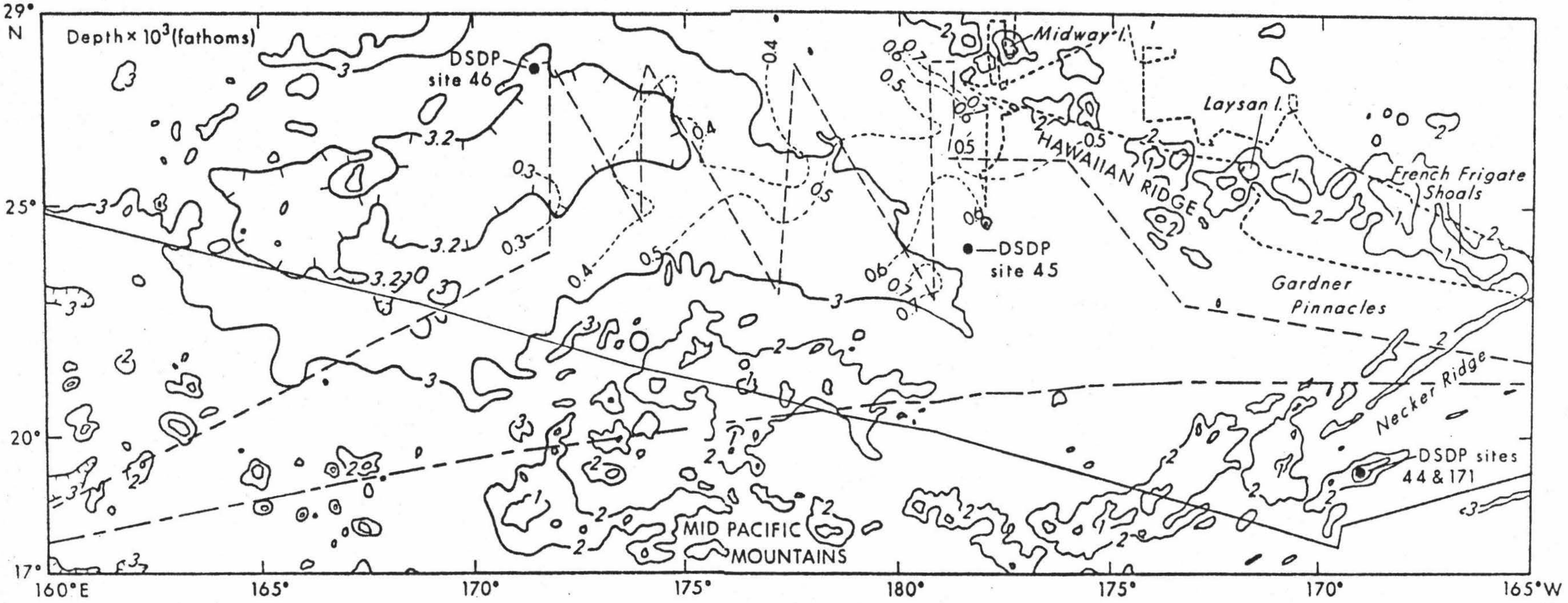

Depth × 10³ (fathoms)
29° N
25°
20°
17°
160°E
165°
170°
175°
180°
175°
170°
165°W
DSDP site 46
DSDP site 45
DSDP sites 44 & 171
Midway I.
Laysan I.
HAWAIIAN RIDGE
French Frigate Shoals
Gardner Pinnacles
Necker Ridge
MID PACIFIC MOUNTAINS
3
3.2
0.3
0.4
0.5
0.6
0.7
2
1

Figure 24

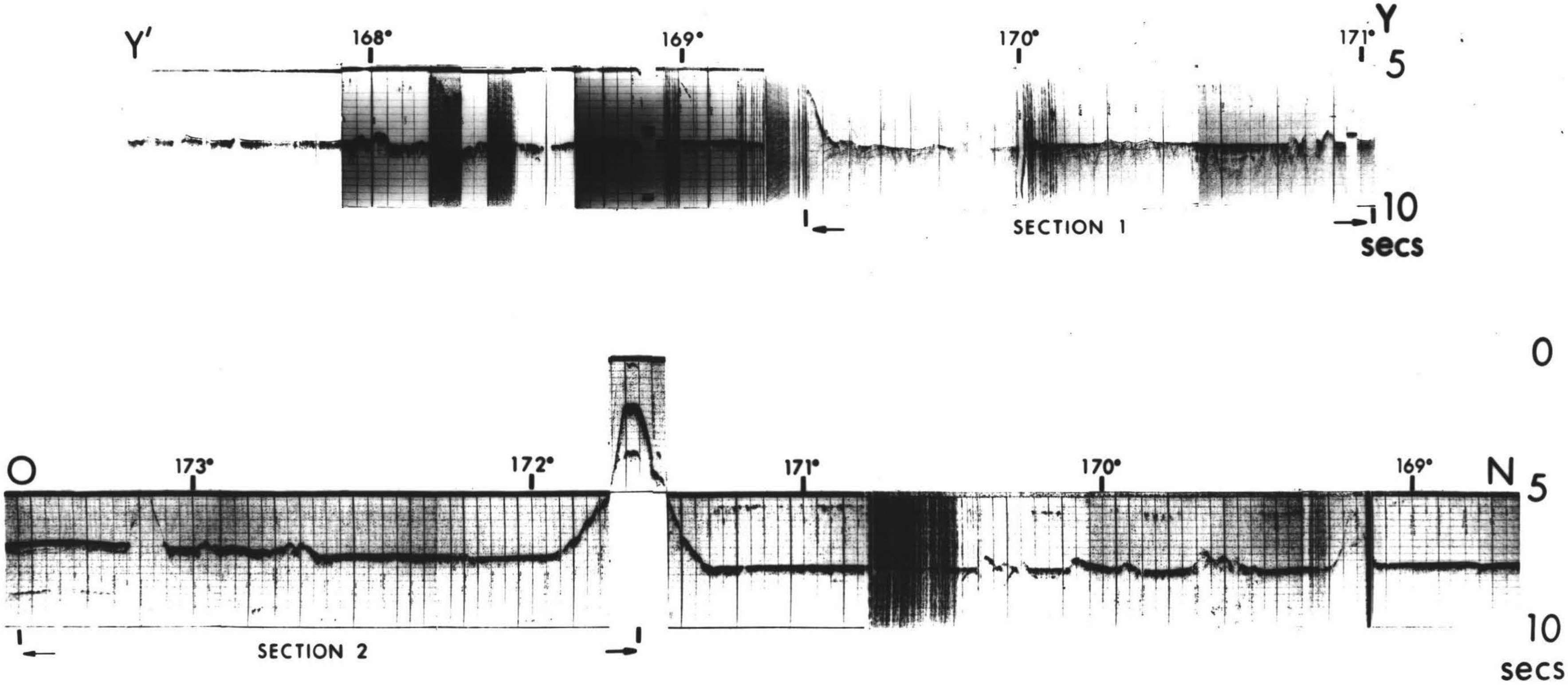
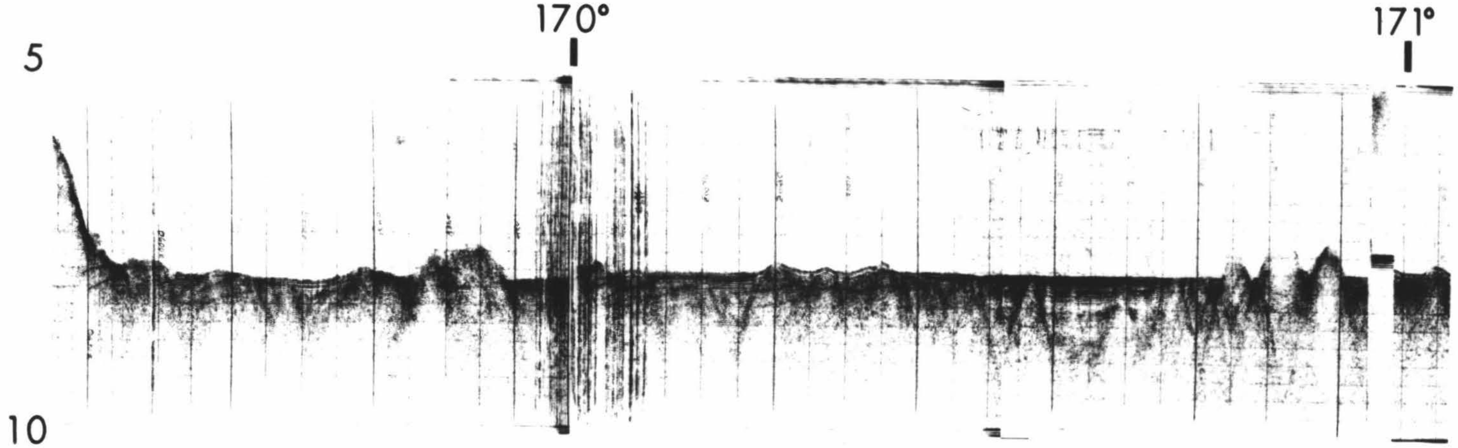
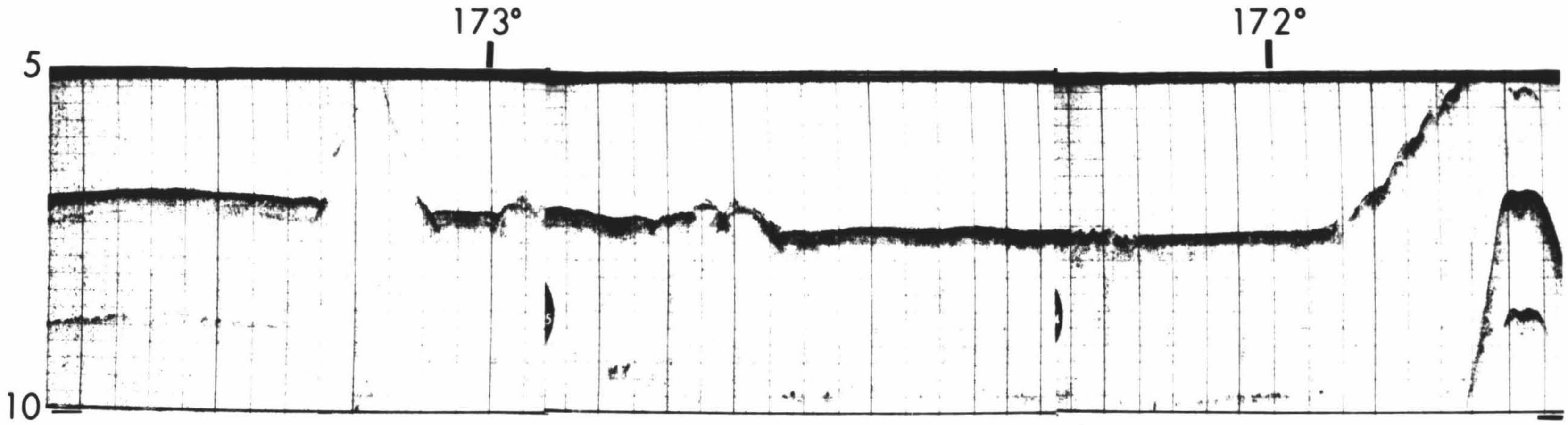

Y'
168°
169°
170°
171°
Y
5
10
secs
SECTION 1
0
O
173°
172°
171°
170°
169°
N
5
10
secs
SECTION 2

Figure 25



SECTION 1



SECTION 2

Figure 26

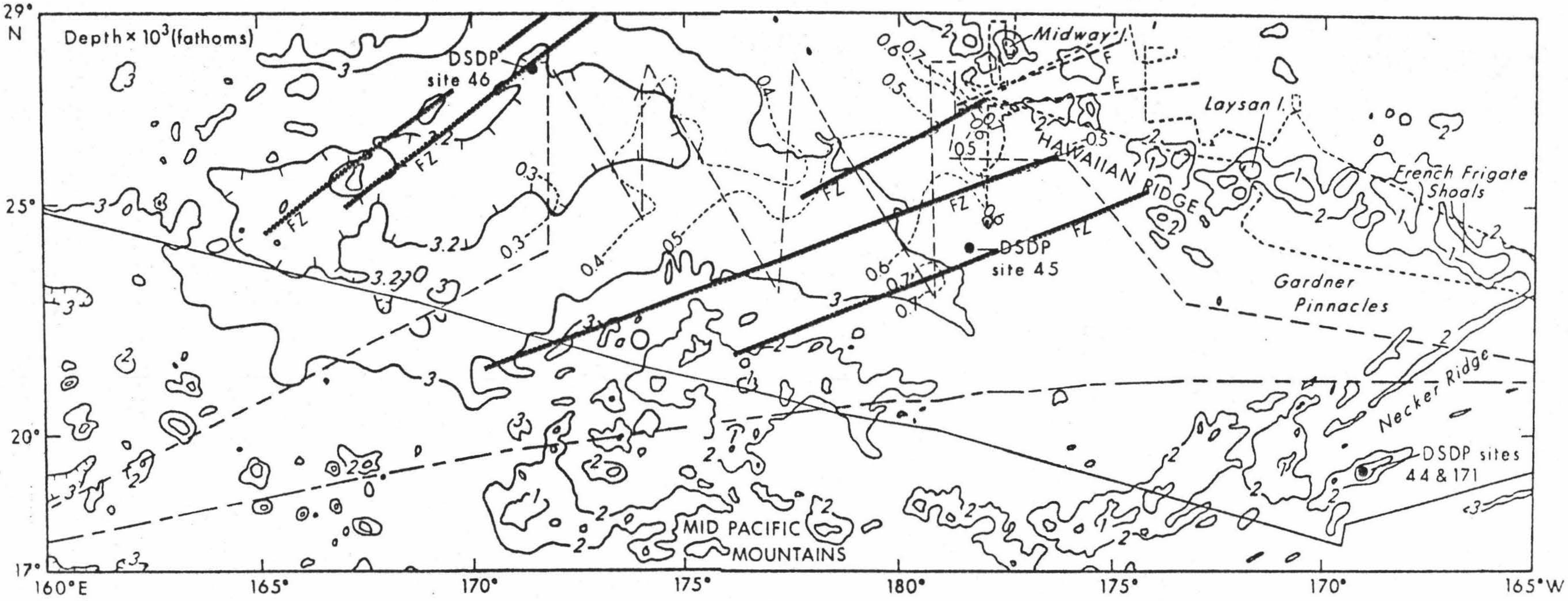

Depth × 10³ (fathoms)
29° N
25°
20°
17°
160°E
165°
170°
175°
180°
175°
170°
165°W
DSDP site 46
FZ
Midway I.
Laysan I.
HAWAIIAN RIDGE
French Frigate Shoals
DSDP site 45
Gardner Pinnacles
Necker Ridge
DSDP sites 44 & 171
MID PACIFIC MOUNTAINS

Figure 27