Reports

Tertiary Sediment from the East Pacific Rise

Abstract. *More than 50 cores ranging in age from Pliocene to Lower Miocene have been recovered from the East Pacific Rise. Near the crestal regions the sediment cover is thin or lacking, and only Pleistocene sediments were recovered. On the flanks, the sediment thickness increases and pre-Pleistocene sediments are encountered. This pattern of increasing age and increasing sediment thickness away from the axis of the rise is in agreement with that predicted for spreading of the ocean floor.*

Recent progress in the study of anomalies of the magnetic field over the oceanic ridge system (*1, 2*) supports the "ocean floor spreading" hypothesis of Dietz (*3*) and of Hess (*4*). Important to this hypothesis is a knowledge of the distribution and age of sediments lying on the crest and flanks of the ridge system.

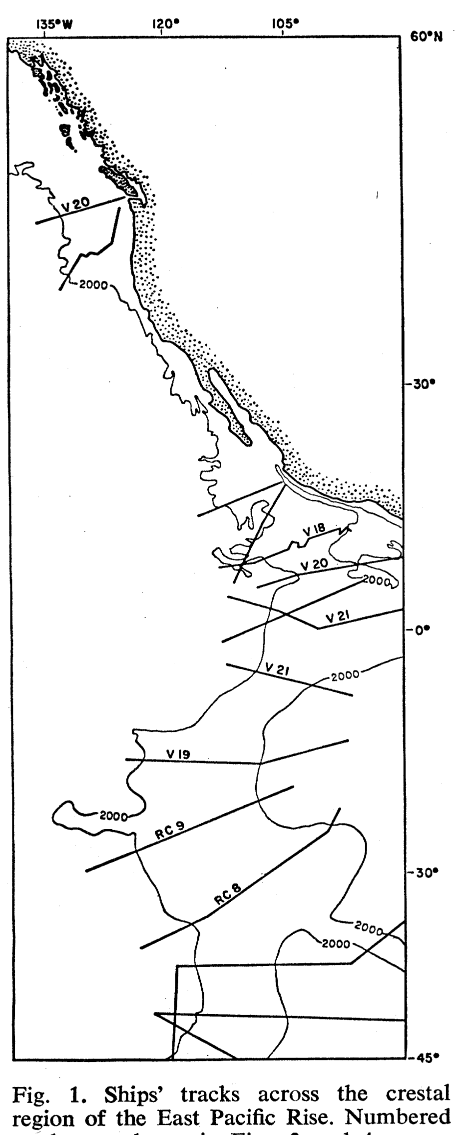

Fig. 1. Ships' tracks across the crestal region of the East Pacific Rise. Numbered tracks are shown in Figs. 3 and 4.

Since 1962, twelve crossings have been made of the East Pacific Rise by research vessels of the Lamont Geological Observatory (Fig. 1). Two crossings were made in the North Pacific around 46°N, eight in the equatorial Pacific, and two in the South Pacific above 30°S. In addition, several cruises of the U.S.S. *Eltanin* have crossed the southern end of the rise. Of approximately 200 cores taken on these various cruises, more than 50 pre-Pleistocene cores, ranging in age from Lower Miocene to Pliocene, have been recovered from the flanks and crest (Fig. 2) (*5*). These pre-Pleistocene cores range in length from less than 1 m to over 12 m and show a variable lithology ranging from biogenous oozes to red clays. In general, the biogenous oozes (foraminifers, coccoliths, Radiolaria, and diatoms) occur on the crest and upper flanks of the rise, while the red clay cores occur in the lower flanks and in the adjacent abyssal plains. In several cores from the lower flanks the red clay overlies a carbonate ooze containing microfossils from the Lower Miocene.

Since the position of the cores in relation to the axis of the rise is important to the hypothesis of spreading of the ocean floor, we will address ourselves here exclusively to this problem. The paleontology of the cores cited in this report will be included in a larger publication, now in preparation, on all pre-Pleistocene cores in the Lamont collection (*6*).

Figures 3 and 4 show bottom topography, sediment thickness, core sites, and age of cores for various crossings of the East Pacific Rise. These crossings have the following characteristics in common. (i) The crestal regions are almost entirely free of sediment cover. (ii) In general, the sediment thickness increases away from the crest (*7*). In crossings where there is no continuous sediment cover, the number of sediment-filled pockets increases with distance from the crest. (iii) Frequently, cores taken in the crestal regions hit rocks or penetrated only a meter or so of sediment before being stopped, and these cores usually contained pieces of fresh volcanic glass in their bottom portions. (iv) The age of the oldest sediment increases away from the axis of the rise. Characteristics (i) and (ii) are self-evident from Figs. 3 and 4 and will not be included in our discussion. It might be instructive, however, to review (iii) and (iv) in view of the bearing they have on spreading of the ocean floor.

The cores taken near the axis of the rise are Quaternary in age and generally consist of biogenous clays (foraminifers, coccoliths, and diatoms) and pieces of fresh volcanic glass; this glass was

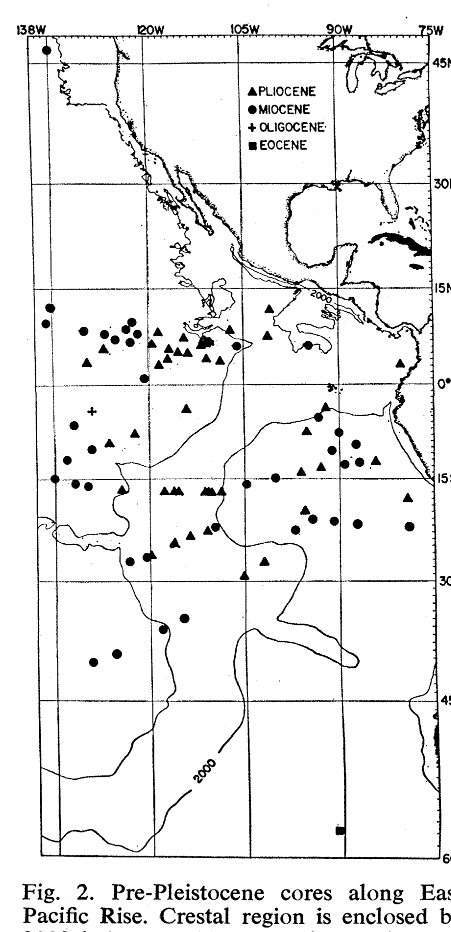

Fig. 2. Pre-Pleistocene cores along East Pacific Rise. Crestal region is enclosed by 2000-fathom (3660-m) isobath.

finely disseminated through the bottom of the core or in large cobbles at the bottom. These cores did not achieve much penetration and, apparently, were stopped by the rocky bottom. Further evidence of this are the badly smashed cutting edges of the piston corer and, in many cases, bent coring pipe.

Along the upper flanks of the rise, away from the axis, cores were encountered that penetrated through Pleistocene into Pliocene sediments. These are generally foraminiferal clays with a few cores in the equatorial region containing diatoms and Radiolaria. The cores that ranged into Pliocene sediments usually had a deeper penetration and did not encounter rocks. Distribution of Pliocene cores in relation to the axis of the rise and in relation to the cores of Pleistocene age is best shown on the *V-19* crossing (Fig. 4). In this traverse, the length of each core pipe was the same; that is, each core was taken with a core head and a single 22-foot pipe (6.7-m). Pliocene cores taken on the upper flanks had a deeper penetration, by a factor of 2 to 3, than Pleistocene cores taken from the crest.

On the middle flanks of the rise, cores of Middle and Upper Miocene age, as well as of Pliocene and Pleistocene age, are encountered. These cores are generally foraminiferal clays, with some diatoms and radiolarian clays near the equator. On the *V-20* track a Lower Miocene core (*V* 20-80) consists largely of a diatomaceous ooze (Fig. 3). Again, as with the Pliocene cores in the upper flanks of the rise, no rocks were recovered.

On the lower flanks of the rise, sediments ranging as old as Lower Miocene were recovered. These cores generally consisted of red clays overlying calcareous oozes. Paleomagnetic investigations of these cores showed that they have discontinuities (*8*) which, however, probably do not occur at the contact of red clays and carbonate oozes, since the change in lithology appears to be transitional. We suggest that this sequence (red clay overlying carbonate ooze) on the lower flanks is due to lateral downward movement of the basement from the crest of the East Pacific Rise.

Additional pre-Pleistocene cores have been recovered from areas in the East Pacific other than the East Pacific Rise, and their distribution in relation to the rise is pertinent to this discussion. In general, they also show a pattern of increasing age farther away from the crest of the rise. The Oligocene core nearest to the crest, and in fact the only Oligocene core obtained in the area under consideration, is at a distance of 1600 km. It consists of a medium brown calcilutite overlying a dirty white to pale orange calcilutite.

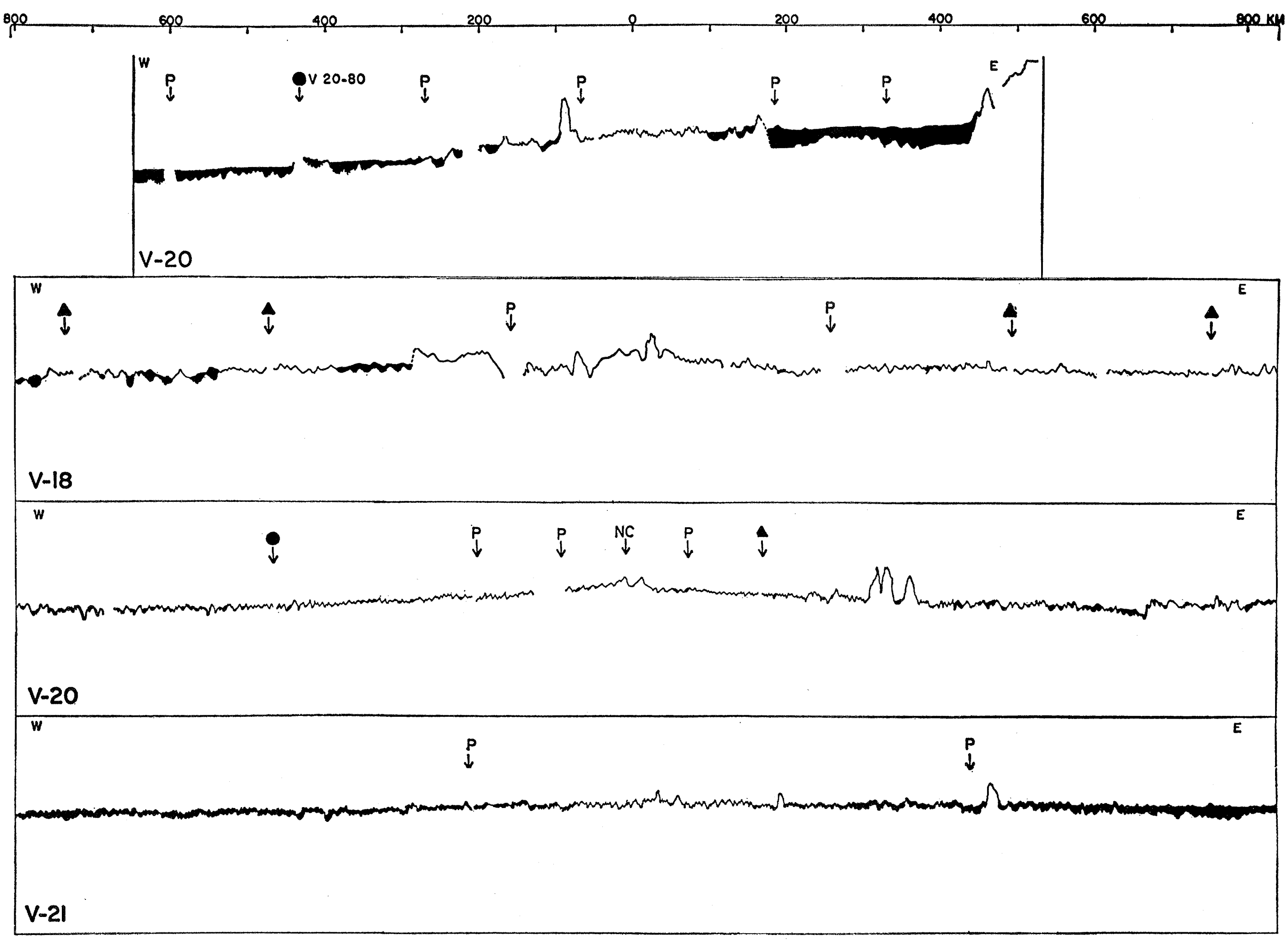

Fig. 3. Seismic reflection profile records across East Pacific Rise. Arrows indicate core sites, and symbols above them indicate age of core. Where no core was obtained, the corer encountered rock. *NC*, no core; *P*, Pleistocene; triangles, Pliocene; and circles, Miocene. *V-20, V-18,* and *V-21* are ships' tracks; *V 20-80* is a Lower Miocene core.

Eocene sediments have been recovered from the southeast Pacific, the western part of the Tuamotu Ridge, and to the south and southeast of Hawaii (*9*). The first two of these areas contain Eocene calcareous oozes, while the cores recovered near Hawaii generally consist of radiolarian oozes. No deep-sea Cretaceous sediments have been reported east of the East Pacific Rise. On the western side of the rise, the nearest known Cretaceous is a reworked Maestrichtian foraminiferal fauna from the eastern scarp of the Manihiki Plateau (*9, 10*). In addition, Hamilton (*11*) reported a Lower Cretaceous (Aptian-Cenomanian) coral-rudistid fauna from the mid-Pacific mountains. Deep-sea Lower Cretaceous (Albian) sediments have also been reported from the Shatsky Rise in the northwest Pacific (*12*).

Pitman and Heirtzler (*1*) and Vine (*2*), on the basis of magnetic profiles across the southern part of the East Pacific Rise, calculated spreading rates of 4.5 and 4.4 cm/year, respectively. It might be instructive, therefore, to compare their data with the age and distribution of sediment cores on the rise. If we assume the Plio-Pleistocene boundary to be 2 million years old, then, using a spreading rate of 4.5 cm/year, Pliocene sediments should first appear at about 90 km from the crest. As can be seen in Figs. 3 and 4, the Pliocene core nearest to the crest is approximately 100 km away.

If we assume the Pliocene-Miocene boundary to be at 7 million years (*13*), then upper Miocene sediment should first appear at more than 315 km from the crest. Figures 3 and 4 show that the Miocene cores closest to the crest are more than 350 km distant; this is also true for Middle and Lower Miocene cores. Thus, the distribution of pre-Pleistocene sediments along the southern part of the East Pacific Rise is not in contradiction to spreading rates obtained by study of magnetic anomalies.

In the northern part of the East Pacific Rise, a core that penetrated into Miocene (*V 20-80*) was recovered from the western flank at a point where the basement comes close to the surface (Fig. 3). On the basis of magnetic anomalies, the basement at this core site is about 22 million years old (*24*). Foraminifers indicative of the *Globigerinatella insueta–Globigerinoides bisphericus* zone, such as *Praeorbulina glomerosa glomerosa* (Blow), *P. glomerosa circularis* (Blow), *Orbulina suturalis* Bronnimann, *Globorotaloides suteri* Bolli, *Globorotalia praescitula* Blow, and *Globigerina praebulloides* Blow are present. The fauna represented in this core is just below the *Orbulina* datum (*15*) which marks the top of the Burdigalian stage (*16*) and is about 20 million years old. Thus, in the northern part of the East Pacific Rise the evidence from fossils is in agreement with rates of spreading based on evidence from magnetic anomalies (*17*).

Distribution of pre-Pleistocene cores

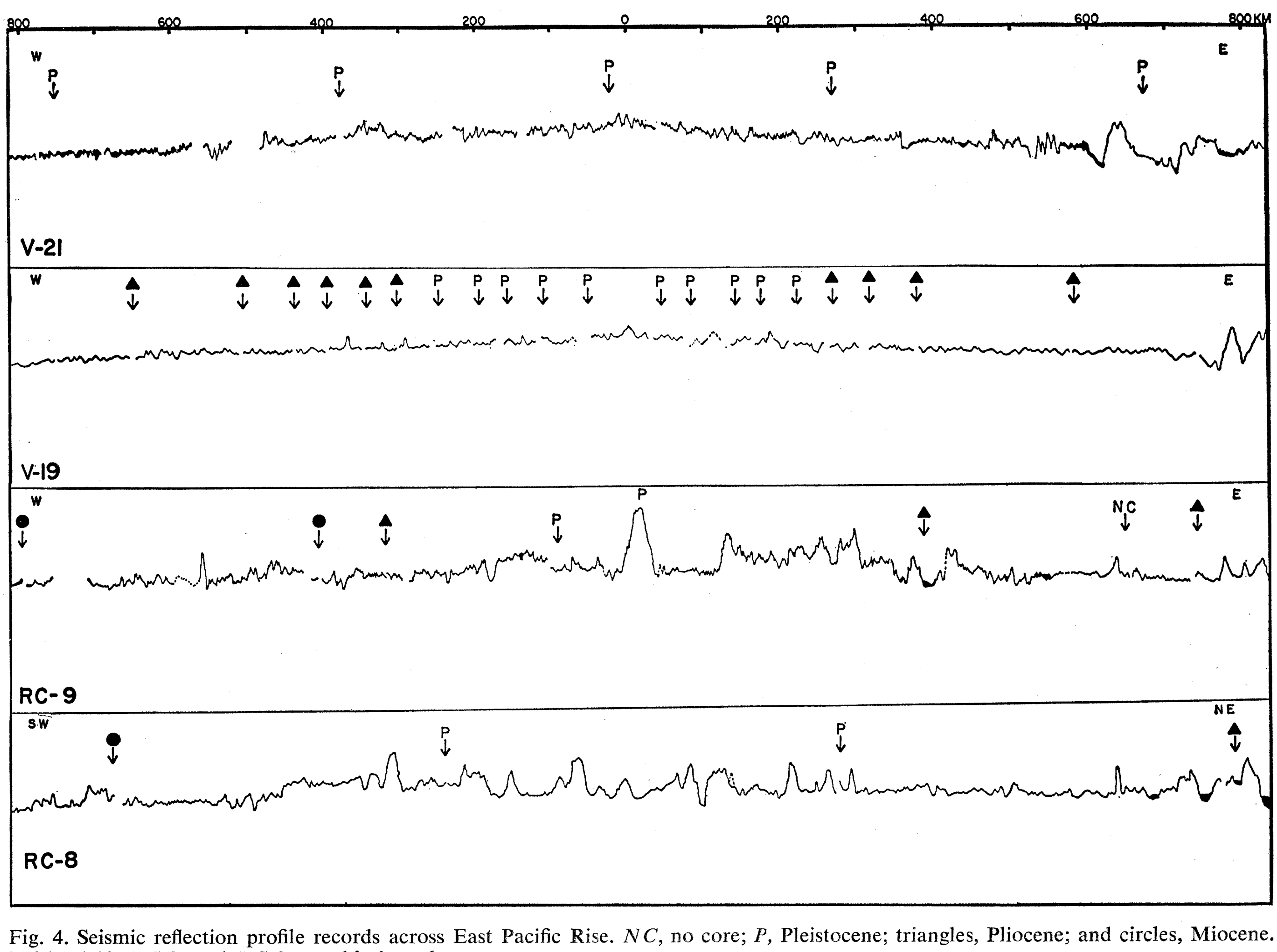

Fig. 4. Seismic reflection profile records across East Pacific Rise. *NC*, no core; *P*, Pleistocene; triangles, Pliocene; and circles, Miocene. *V-21, V-19, RC-9*, and *RC-8* are ships' tracks.

in the eastern Pacific has furnished strong evidence in support of the hypothesis of the spreading of the ocean floor. Many additional cores are needed from this area, however, to determine whether the spreading movement has been continuous or intermittent (7).

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References and Notes

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2. F. Vine, *ibid.*, p. 1405.
3. R. S. Dietz, *Nature* **190**, 854 (1961).
4. H. H. Hess, in *Petrologic Studies: A Volume in Honor of A. F. Buddington* (Geological Society of America, New York, 1962), p. 260.
5. We define the limits of the East Pacific Rise after H. W. Menard [*Science* **155**, 72 (1967)].
6. Our Lower Miocene includes Zone N2 to N8; Middle Miocene, N9 to lower half of N15; and Upper Miocene, from upper half of N15 to N18 of Banner and Blow [*Nature* **208**, 1164 (1965)].
7. J. Ewing and M. Ewing [*Science* **156**, 1590 (1967)] observed an abrupt change in sediment thickness between the crest and flanks of the mid-ocean ridge system. They consider this as evidence of a major discontinuity either in the rate of spreading of the sea floor or in the rate of accumulation of sediment. Based on the spreading rate determined by the magnetic anomaly pattern they postulate that the present cycle of spreading of the sea floor began about 10 million years ago.
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14. Age determination of the basement rocks on the basis of the magnetic pattern was made by W. Pitman III.
15. W. H. Blow, *Micropaleontology* **2**, 57, (1956); O. L. Bandy, *ibid.* **10**, 11 (1964).
16. F. T. Banner and W. H. Blow, *Nature* **208**, 1164 (1965).
17. Recently, Budinger and Enbysk [*J. Geophys. Res.* **72**, 2271 (1967)] reported the occurence of a basalt boulder from a seamount near the crest of the northern extension of the East Pacific Rise which dated at 27 ± 6 million years. Although this occurrence is in direct conflict with spreading rates based upon magnetic anomaly patterns (2), it might be explained by assuming that the addition of new crust occurred in such a way that patches of older crust were left behind in the crestal area rather than being swept away from the axis [T. Saito, M. Ewing, L. H. Burckle, *Science* **151**, 1075 (1966)].
18. We thank J. R. Heirtzler, X. LePichon, W. Pitman III, and W. R. Riedel for review and discussion of the manuscript. Supported by NSF grant GA 558 and Nonr 266(48). Lamont Geological Observatory contribution No. 1080.

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Radiolarian Evidence Consistent with Spreading of the Pacific Floor

Abstract. *In sediments west of the East Pacific Rise between the equator and 20°N, Eocene microfossils are recorded no farther east than 134°W; Oligocene, no farther east than 125°W; while Miocene and Pliocene occurrences extend closer to the crest of the rise. This distribution may result from post-Eocene spreading of the sea floor here averaging about 8 centimeters per year.*

It is an inevitable consequence of the hypothesized spreading of the sea floor (*1*) that the sediment immediately above the igneous basement should be progressively younger toward the crest of the ridge at which the spreading originates. Burckle *et al.* (*2*) have indicated that the ages of the oldest cores (Pliocene and Miocene) that they have obtained in the eastern South Pacific increase with increasing distance from the crest of the East Pacific Rise. Evidence extending this type of observation as far back in time as Eocene has now been culled from the numerous cores collected (*3*) in the area bounded by latitude 0° and 20°N and longitudes 115° and 150°W (Fig. 1).

At some of the sampling localities in this region, Tertiary sediments outcrop on the sea floor or are disconformably overlaid by a layer of Quaternary sediment thin enough to be penetrated by commonly used corers capable of penetrating 1.5 to 10 m. Comparison of the distribution of these *in situ* samples representing the various Tertiary epochs (Fig. 2) reveals that some Oligocene occurrences are farther east than the easternmost Eocene occurrence, and that some Miocene occurrences are farther east than the easternmost Oligocene occurrence, as would be expected in accordance with the hypothesized spreading of the sea floor and if the techniques now in use sampled the oldest sediments occurring in an area.

This latter condition is unlikely to be fulfilled, but some information on the nature of generally deeply buried sediments can be obtained by investigation of older microfossils reworked into younger sediments. Over a large proportion of the sea floor in the area under consideration the sediments deposited throughout the Cenozoic contain radiolarians, and at many localities microfossils as old as Eocene are reworked into Quaternary sediments (*4*). These siliceous microfossils are especially useful as tracers of the presence of Tertiary sediments, since they do not dissolve as readily as calcareous skeletons and therefore can probably survive several cycles of erosion and redeposition. At least over the area of the Pacific floor that is now considered, the discrete pattern of microfossil assemblages, and the fact that some Quaternary sediments scattered throughout the area do not contain reworked Tertiary microfossils, indicate that sediment components are not transported great lateral distances by reworking processes; therefore the occurrence of Oligocene radiolarians in a Quaternary sediment, for example, may be taken as evidence of the occurrence of Oligocene sediments in that vicinity. The information available from such reworked microfossils

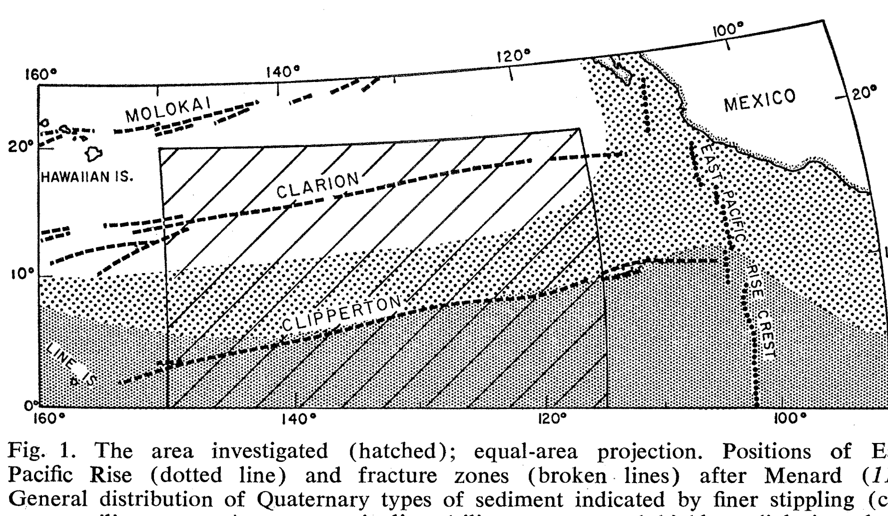

Fig. 1. The area investigated (hatched); equal-area projection. Positions of East Pacific Rise (dotted line) and fracture zones (broken lines) after Menard (*11*). General distribution of Quaternary types of sediment indicated by finer stippling (calcareous-siliceous ooze), coarser stippling (siliceous ooze and highly radiolarian clay), and no stippling (clay with few or no microfossils). Latitude, N; longitude, W.