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Cenozoic Migration of the Pacific Plate, Northward Shift of the Axis of Deposition, and Paleobathymetry of the Central Equatorial Pacific

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Cenozoic Migration of the Pacific Plate, Northward Shift of the Axis of Deposition, and Paleobathymetry of the Central Equatorial Pacific

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ABSTRACT

Cenozoic northward migration of the Pacific plate is documented by magnetization vectors of seamounts and by volcanic lineations resulting from drift over fixed melting spots in the mantle. The rotation with respect to the spin axis of the Earth can also be established from the northward shift with time of the equatorial axis of maximum deposition. Data from Deep Sea Drilling Project sites in the equatorial Pacific indicate a pole of rotation for the past 45 m.y. at lat 67° N., long 59° W., in satisfactory agreement with locations derived from other evidence. The best fit is obtained for an initial rate of 0.25°/m.y., which accelerated to 0.8°/m.y. about 25 m.y. B.P. With this rotation scheme and the subsidence history of the individual drill sites, the paleobathymetric evolution of the central equatorial Pacific during Cenozoic time and the position of the ancestral East Pacific Rise can be established.

Northward migration of the Pacific plate was demonstrated by Francheteau and others (1970) and Hammond and others (1974) on the basis of magnetization vectors of Pacific seamounts and sediment. Plate drift was also invoked by Tracey and others (1971), Hays and others (1972), and van Andel and Heath (1973) to account for the progressive northward shift with age of the zone of maximum deposition in the equatorial Pacific. Simultaneously, Morgan (1972) showed that linear volcanic trends in the Pacific can be interpreted as drift trails over fixed melting spots in the mantle. Morgan, Winterer (1973), and Clague and Jarrard (1973), among others, used this evidence to determine the rotational history of the Pacific plate with respect to the spin axis of the Earth.

The principal evidence for such reconstructions comes from the Hawaii and Emperor volcanic chains. It indicates that during Cenozoic time, the plate rotated around two successive poles (Morgan, 1972). The position of the first pole, defined by the Emperor chain, is about lat 23° N., long 108° W. (Clague and Jarrard, 1973; Morgan, 1972; Winterer, 1973). The position of the Hawaii pole, defined also by other volcanic lineaments, is given as lat 72° N., long 83° W. by Clague and Jarrard, but the circle of confidence is large and includes poles at lat 67° N., long 73° W. (Morgan, 1972) and lat 67° N., long 45° W. (Winterer, 1973). Minster and others (1974) estimated pole positions for all plates, using instantaneous motion indicators and melting spot trails as separate and independent lines of evidence. They obtained a best fit for a Pacific pole at lat 67° N., long 59° W.

The time of transit from the Emperor to the Hawaii pole is not yet well established. Estimates range from 20 to 30 m.y. (Jackson and others, 1972; Winterer, 1973; Clague and Jarrard, 1973) to 40 to 50 m.y. (Morgan, 1972; Clague and Jarrard, 1973; Clague and Dalrymple, 1973; Dalrymple and others, 1974). Shaw (1973) suggested more than 50 m.y., a figure supported by recent drilling (Larson and others, 1973). Because this age is earlier than the basement age of all but two of the drill sites used below, it is a convenient first assumption, that will be checked later.

Rotation rates proposed for the Hawaii pole range from 0.80° to 0.85°/m.y. (Morgan, 1972; Minster and others, 1974) to more than 1°/m.y. (Winterer, 1973). Clague and Jarrard (1973) presented evidence that from 44 to 20 m.y. B.P., rotation was slow to negligible, and they assumed 1.3°/m.y. since 20 m.y. B.P. The supporting data are mainly from the Hawaiian chain and are strongly influenced by extrapolation of a fairly complete record for the last 5 m.y. Shaw (1973) and Dalrymple and others (1974) pointed out that linear extrapolations for a complex sequence of events like the volcanic history of Hawaii are hazardous. Furthermore, the entire reasoning depends upon the assumption that melting spots are fixed with respect to the spin axis of the Earth. Winterer (1973) and Molnar and Atwater (1973) have questioned this assumption, but conclusive evidence is not available.

The rotation history of the Pacific plate is not yet fully established. Independent evidence is thus of great importance. Such evidence is provided by an observed migration of the zone of maximum deposition parallel to the equator during Cenozoic time. Because of greatly enhanced biologic productivity in the equatorial convergence zone, deposition rates along the equator are much greater than those 300 to 400 km north and south. The existence of a well-defined zone of maximum deposition can be traced as far as middle Eocene time (Tracey and others, 1971; Hays and others, 1972; van Andel and Heath, 1973). With increasing age, this zone shifts northward to reach about lat 15° N. for deposits of Eocene age. The shift measures the rate and direction of migration of the Pacific plate across the equator. Various authors (Clague and Jarrard, 1973; Winterer, 1973) have used

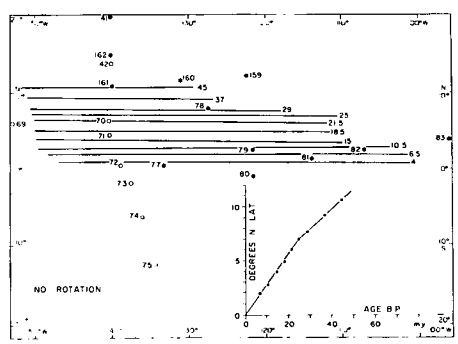

Figure 1. Northward shift of axis of maximum sedimentation with age. Axes derived from sedimentation rate maps for intervals shown at right of each line (in millions of years). Numbered dots, drill sites. Insert: latitude of axes at 130° W. plotted against age.

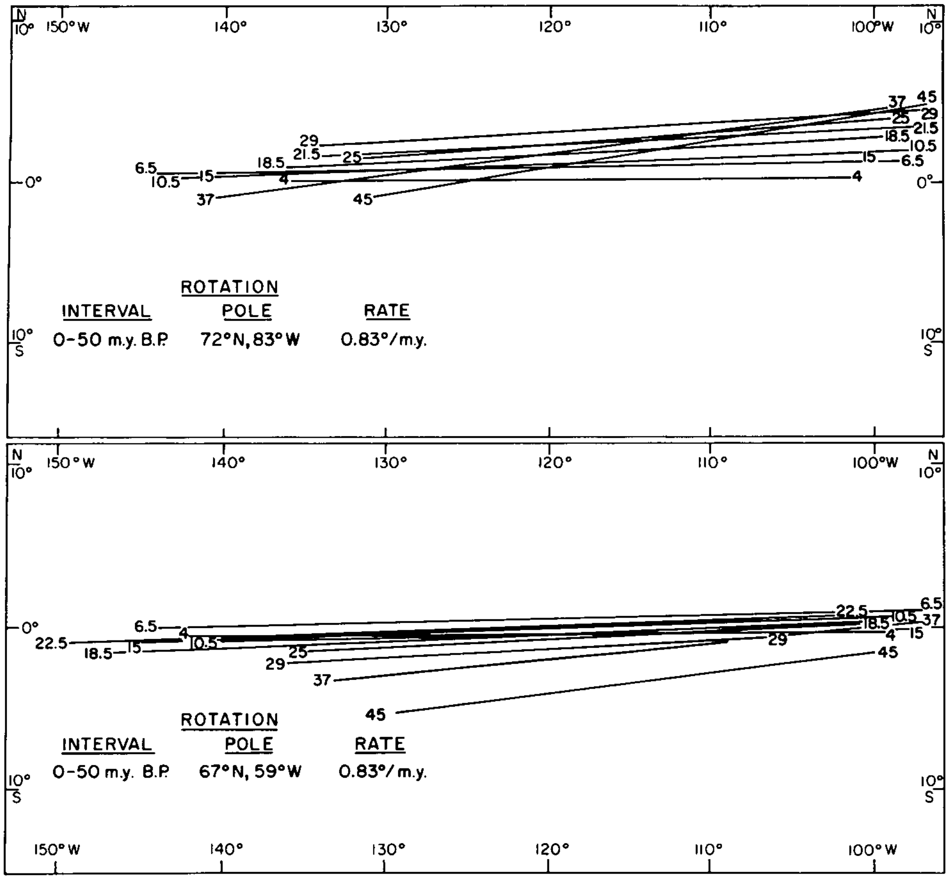

Figure 2. Axes of sedimentation rotated to paleopositions appropriate for age (at right of axis in m.y.). Top, rotation around pole of Clague and Jarrard (1973); bottom, rotation around pole of Minster and others (1974).

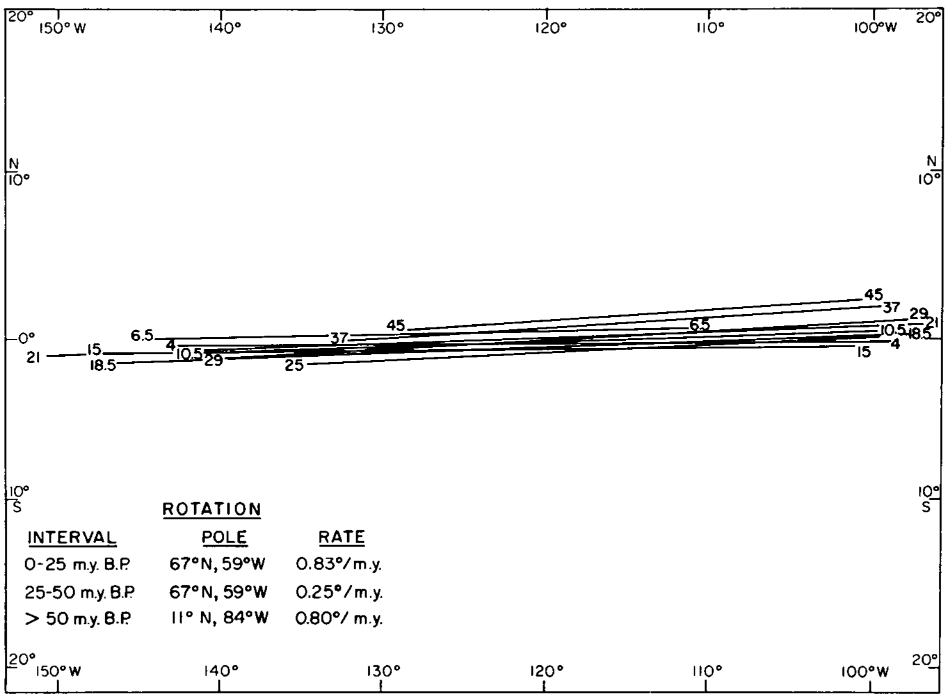

Figure 3. Rotation of axes of maximum sedimentation adjusted with change in rate at 25 m.y. B.P. Rotation around pole of Minster and others (1974). Age of axes in millions of years shown at right.

sedimentation rate maxima in drill sites to support their proposed rotation schemes. However, the rate of deposition in the equatorial Pacific also increases sharply just above basement at shallow paleodepth (Berger, 1973). In addition, van Andel and Leinen (1974) have shown that sedimentation rates also varied with time and that numerous maxima and minima, not primarily related to shallow depth of deposition or to latitudinal position, have occurred during the past 45 m.y.

In the context of a regional synthesis of Deep Sea Drilling Project data for the central equatorial Pacific, maps depicting the regional variation of sedimentation rates for 11 brief intervals since middle Eocene time were constructed. The ages of the intervals were established by correlating foraminiferal, radiolarian, and calcareous nannofossil zones with the absolute time scale of Berggren (1972). Data and procedures are given by van Andel and others (in prep.). These maps are based on all data from 20 drill sites and permit discrimination between maxima related to equatorial position and maxima resulting from other causes. East-trending zones of maxima deposition are well defined on all maps, and their axes can be established with an azimuth error of less than ±10° and a distance error to the equator of less than ±200 km. The errors are somewhat larger for the oldest two maps. After rotation to their paleopositions according to the scheme discussed below, the maps are reproduced in Figure 4.

In Figure 1, the axes of maximum sedimentation rate are plotted in their present positions relative to the equator. The northward shift is evident, as is a change in the rate of movement about 25 m.y. B.P. The poles and rotation rates discussed earlier can be used to rotate the axes back to positions appropriate to their ages. If we assume initially that the shift from the Emperor to the Hawaii pole took place more than 45 m.y. ago, the only pole involved is the Hawaii. For trial purposes, poles are used at lat 72° N., long 83° W. (Clague and Jarrard, 1973), and at lat 67° N., long 59° W. (Minster and others, 1974). A reasonable rate of rotation might be about 0.8°/m.y. Figure 2 shows that rotation around the first pole results in an excessive inclination with respect to the equator and a large scatter, especially for the Oligocene and Eocene axes. Rotation around lat 67° N., long 59° W. produces a reasonable alignment within the limits of the azimuth error and good clustering at the equator for the period 0 to 25 m.y. ago. For the older axes, the adopted rate is clearly too large.

Much better clustering is obtained by reducing the rate for the period 25 to 45 m.y. ago to 0.25°/m.y. (Fig. 3). The 45-m.y. axis is still not well placed, but it is poorly defined because the control points are sparse and located close to the ridge crest, where the equatorial zone tends to be poorly defined (Fig. 4). A change in rotation rate at 20 to 30 m.y. B.P. was postulated on independent grounds by Clague and Jarrard (1973) and is supported by a recent age of 30 m.y. for the sea floor near Midway Island (Larson and others, 1973). Obviously, better clustering could be achieved for the pole at lat 72° N., long 83° W. by a change in rate near 25 m.y. ago, but this would require an unreasonable 50 to 75 percent increase in the younger rate and would not eliminate the excessive inclination.

The pole and rate of rotation of the Pacific plate can also be obtained directly from Figure 1. This procedure is sensitive to azimuth errors and involves uncertainties of ±2 m.y. in the age estimates (van Andel and others, in prep.). The pole so obtained is at lat 64° N., long 55° W., and the rates are 0.8° to 0.9°/m.y. for the period 0 to 25 m.y. B.P. and 0.2° to 0.3° for the earlier interval. The pole contains within its confidence circle both poles used in Figure 2. Obviously, this computation does not significantly improve the quality of estimates based on other data. The reasonable fit of Figure 3 supports the choice of pole and rate of rotation, and it shows the assumed time for the shift from the Emperor to the Hawaii pole to be reasonable. The sedimentation rate patterns, when rotated back to the appropriate paleopositions, invoke convincing relations to the paleoequator (Fig. 4).

Berger (1973) showed that paleobathymetric histories of drill sites can be reconstruced using Sclater and others' (1971) relation between basement age and subsidence. With a procedure similar to Berger's, paleobathymetric records were computed for the 20 drill sites in the central equatorial Pacific (van Andel and others, in prep.). The paleobathymetry of the region was reconstructed for various intervals of middle and late Cenozoic time (Fig. 5), using this information combined with the migration paths of the drill sites. The maps were constructed by rotating the present fracture zones to appropriate positions, interpolating the crest of the ancestral East Pacific Rise from initial drill site positions, and contouring the paleobathymetric information from the drill sites. For the younger maps, the present bathymetry was used as a guide, but increasing age necessitated greater generalization.

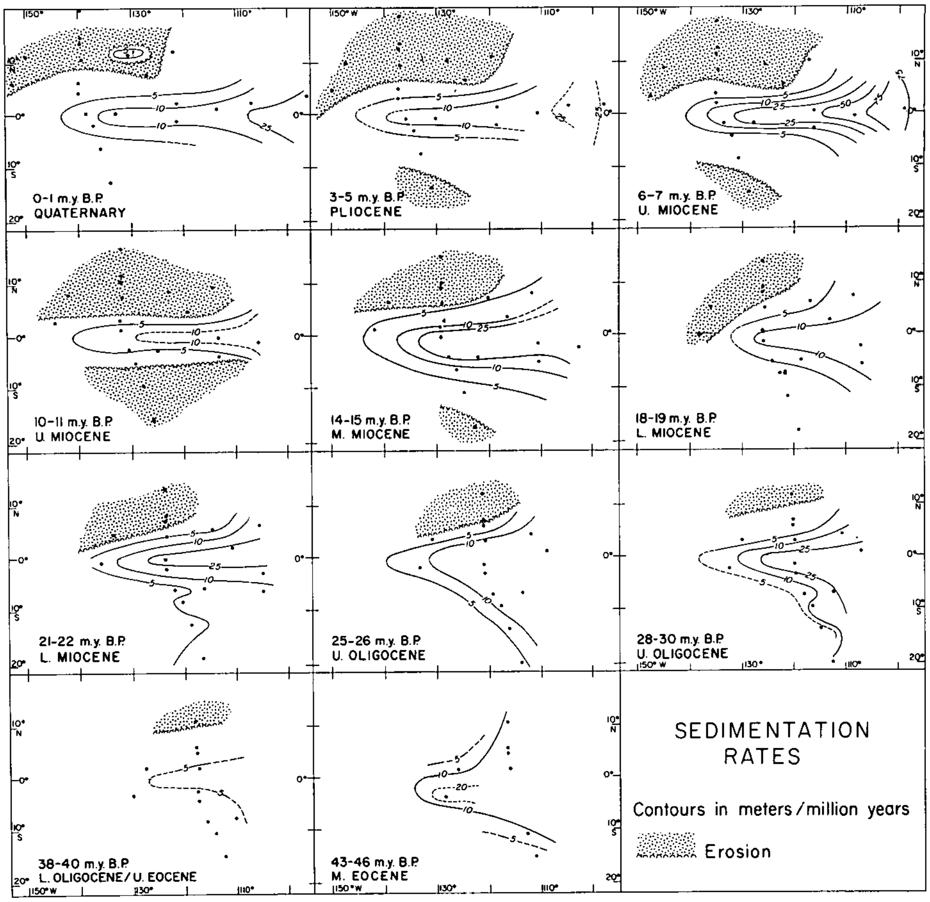

Figure 4. Sedimentation rate maps for 11 intervals of Cenozoic time in proper paleoposition according to rotation scheme of Figure 3. From this set of maps, but before rotation to paleopositions, axes of Figures 1 through 3 were obtained. Dots indicate control points.

In general, the change in topography with time is not great, and mainly reflects a gradual change in orientation, but there are some interesting exceptions. Between 50 m.y. and 20 to 30 m.y. B.P., the eastern edge of the Pacific plate migrated rapidly eastward from lat 115° W. to 105° W.—probably in consequence of an excessive spreading rate over the small westward component of the early rotation. When the rate of plate migration increased, it approximately balanced the spreading rate, and since about 25 m.y. B.P., the plate edge has maintained a stationary position near lat 105° W. This position was not permanently affected by the jump from the earlier Clipperton-Mathematicians Ridge system to the present East Pacific Rise around 10 m.y. B.P. (Sclater and others, 1971; Herron, 1972), which formed part of a major reorganization of the eastern edge of the Pacific plate and also involved the extinction of the Galapagos Rise.

At the present time, a broad shallow zone above 4,000 m lies south of lat 10° S. and west of the East Pacific Rise crest. The middle Cenozoic position of this shallow zone was considerably farther north (Fig. 5), and its persistence in time since the Eocene series is supported by a broad nonequatorial zone of calcareous deposits (van Andel and Moore, 1974). The origin of this shoal, which has an anomalously low heat flow, is unknown; it could be crust riding over an asthenospheric bulge (Menard, 1973), but gravity data do not support this explanation (Mammerickx and others, 1975).

Another aspect of Figure 5 is the progressive widening of the west flank of the East Pacific Rise from a rather narrow and steep feature, especially in its upper part, to the broad and gentle slope of today. The present East Pacific Rise south of the equator is markedly asymmetric, with a broad and gentle west flank and a steeper and narrower east flank (Mammerickx and others, 1975). Apparently, this asymmetry did not exist in the Eocene and Oligocene but developed between 20 and 30 m.y. ago.

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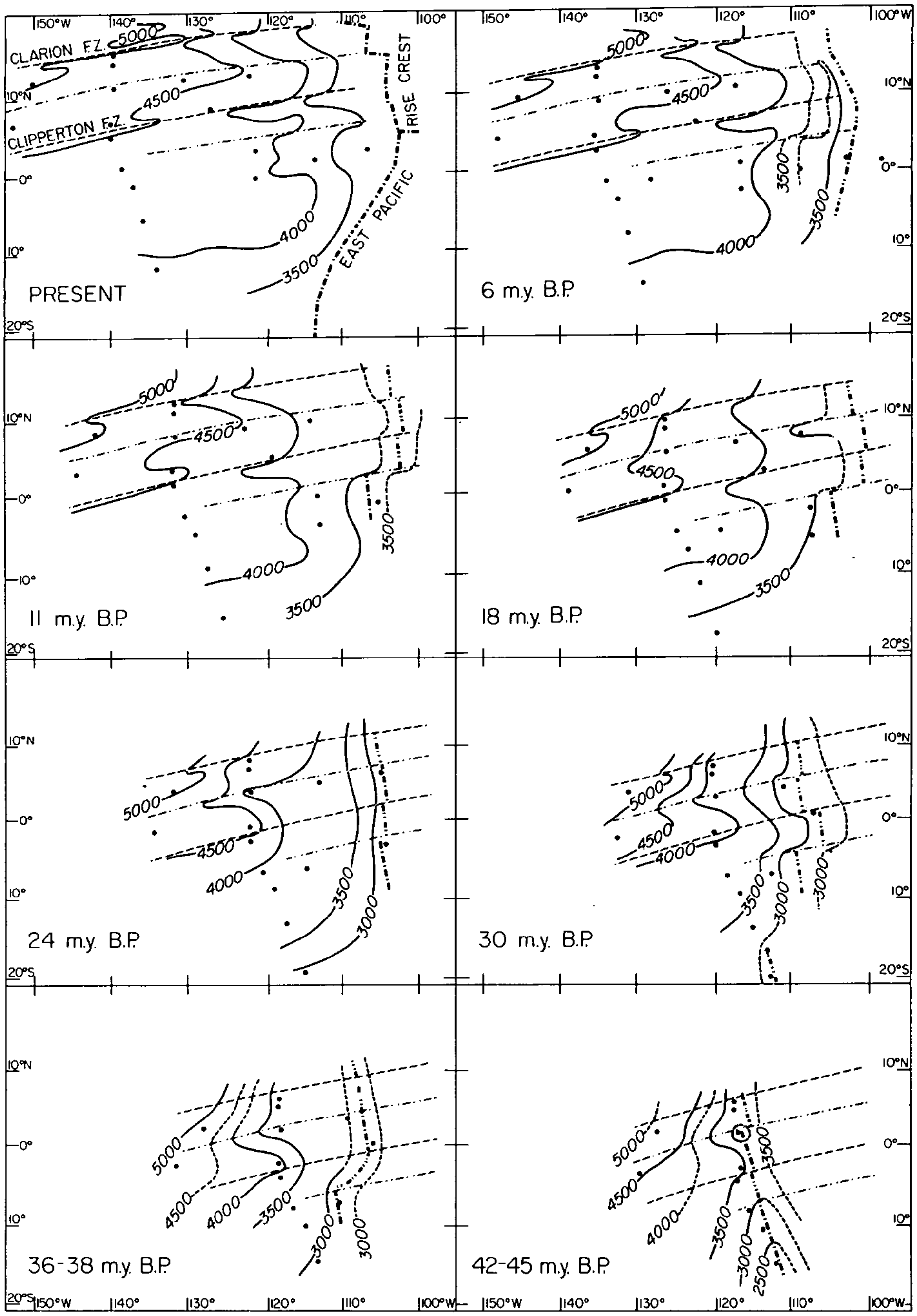

Figure 5. Paleobathymetry of central equatorial Pacific based on rotation of fracture zones and drill sites according to Figure 3, obtained by contouring of drill-site paleobathymetries (van Andel and others, in prep.). Dots, control points.

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