14. TEPHROCHRONOLOGY AT SITES 502 AND 503[1]

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ABSTRACT

Four hydraulic piston cores at Site 502 and two at Site 503 were analyzed for dispersed tephra. Peaks in dispersed tephra abundance were combined with megascopic ash layers to produce a tephrochronology based on the magnetostratigraphy and biostratigraphy for the section at each site. The frequency of tephra deposition at Site 502 increased in the late Miocene and Quaternary and may be related to the subduction rates of the Cocos Plate under Central America or major changes in wind direction over Central America. The much-less-complete section at Site 503 yielded only a few dispersed tephra layers for the same time interval, because the site was far from sources of ash until the middle Pliocene—when the movement of the plate brought the site into the dispersed ash-fall zone surrounding Central America.

INTRODUCTION

Central America is characterized by a bimodal volcanic suite consisting of basaltic andesite volcanics and rhyolitic ignimbrite and air-fall deposits. The widespread air-fall ashes on land have equivalent marine tephra in the three ocean basins surrounding Central America (Hahn et al., 1979; Drexler et al., 1980). The discovery of widespread marine tephra in the equatorial Pacific was accomplished using seismic reflectors identified as white ash (Worzel, 1959). More than a dozen discrete ashes within the Worzel ash were geochemically fingerprinted, and source areas for the largest volume tephra were suggested (Bowles et al., 1973). Of these, the Worzel Layer D is one of the largest in volume (Rose et al., 1979) and may be correlated with the Los Chocoyos Ash, which has its source in the Lake Atitlán Caldera in Guatemala (Hahn et al., 1979).

The recent use of marine tephra has enhanced terrestrial volcanic studies by providing information on the areal distribution of air-fall ashes (e.g., Watkins et al., 1978; Ninkovich et al., 1978), the eruption mechanics (e.g., Wilson et al., 1978; Huang et al., 1979; Ledbetter and Sparks, 1979), and the frequency of explosive eruptions (Kennett and Thunell, 1975). Additionally, we can readily determine the age of major volcanic eruptions by tracing an ash layer into well-dated marine cores (e.g., Ninkovich and Shackleton, 1975; Drexler et al., 1980).

The recovery of nearly complete stratigraphic sections at Sites 502 and 503—very near many of the major volcanic centers in Central America and northern South America (Fig. 1)—provides an opportunity to establish a tephrochronology at an important convergent plate boundary. The frequency of explosive eruptions may be established by determining the presence of dispersed and megascopic tephra within a closely sampled section. Fluctuations in the eruption frequency may be compared to spreading-rate changes on the East Pacific Rise, thereby testing the hypothesis that eruption frequency reflects changes in the subduction rate of the Cocos Plate under the Caribbean Plate.

[1] Prell, W. L., Gardner, J. V., et al., *Init. Repts. DSDP*, 68: Washington (U.S. Govt. Printing Office).

METHODS

To sample a complete stratigraphic section at each site, a composite section was selected from four holes at Site 502 and two holes at Site 503. At both sites, a 20-cm sampling interval was employed in the Quaternary section, and a 50-cm interval was used in the older section. The sample spacing in years ($1/10\text{–}15 \times 10^3$yr.) is approximately the same throughout the composite section.

Samples weighing approximately 1 g were sieved through a 62-μm screen and treated with HCl. A qualitative compositional analysis of the dispersed tephra abundance was preformed, and the relative amount of tephra was classified as follows: "absent," "trace," "common," "abundant," or "layer" ("very abundant" was used at Site 503). The compositional data were plotted against depth in the composite section at each site (Figs. 2, 3).

Each peak in dispersed tephra abundance and each magascopic ash was numbered and resampled with a larger (approximately 9-g) sample. After sieving with a 38-μm screen, the percentage of tephra in the coarse fraction was determined, and the weight of tephra (in mg/gm of total sample) was plotted with age in the section at both sites (Figs. 4, 5).

DISCUSSION

Thirteen megascopic and at least 63 dispersed tephra were identified in the composite section at Site 502 (Fig. 2). Twenty-five dispersed tephra were identified in the composite section at Site 503 (Fig. 3). The tephra abundance (mg $>$ 38-μm/g total sample) for each ash is shown with assigned age (Figs. 4, 5) based on magnetostratigraphy and biostratigraphy (site chapters 502, 503, this volume). The relative magnitude of peaks in tephra abundance is a function of distance to source, wind direction, eruptive column height, and total volume of eruptive products. Relative tephra abundance at a site, therefore, cannot be the only measure of eruption magnitude.

The eruption frequency record at Site 502 shows that the late Miocene and Pleistocene were characterized by increased volcanic eruptions (Fig. 4). These two periods of increased volcanism correspond to the global pattern of increased volcanic activity proposed by Kennett and Thunell (1975) and Kennett et al. (1977) but disputed by Ninkovich and Donn (1976), who attribute the Quaternary increase to the movement of the site into the ash-

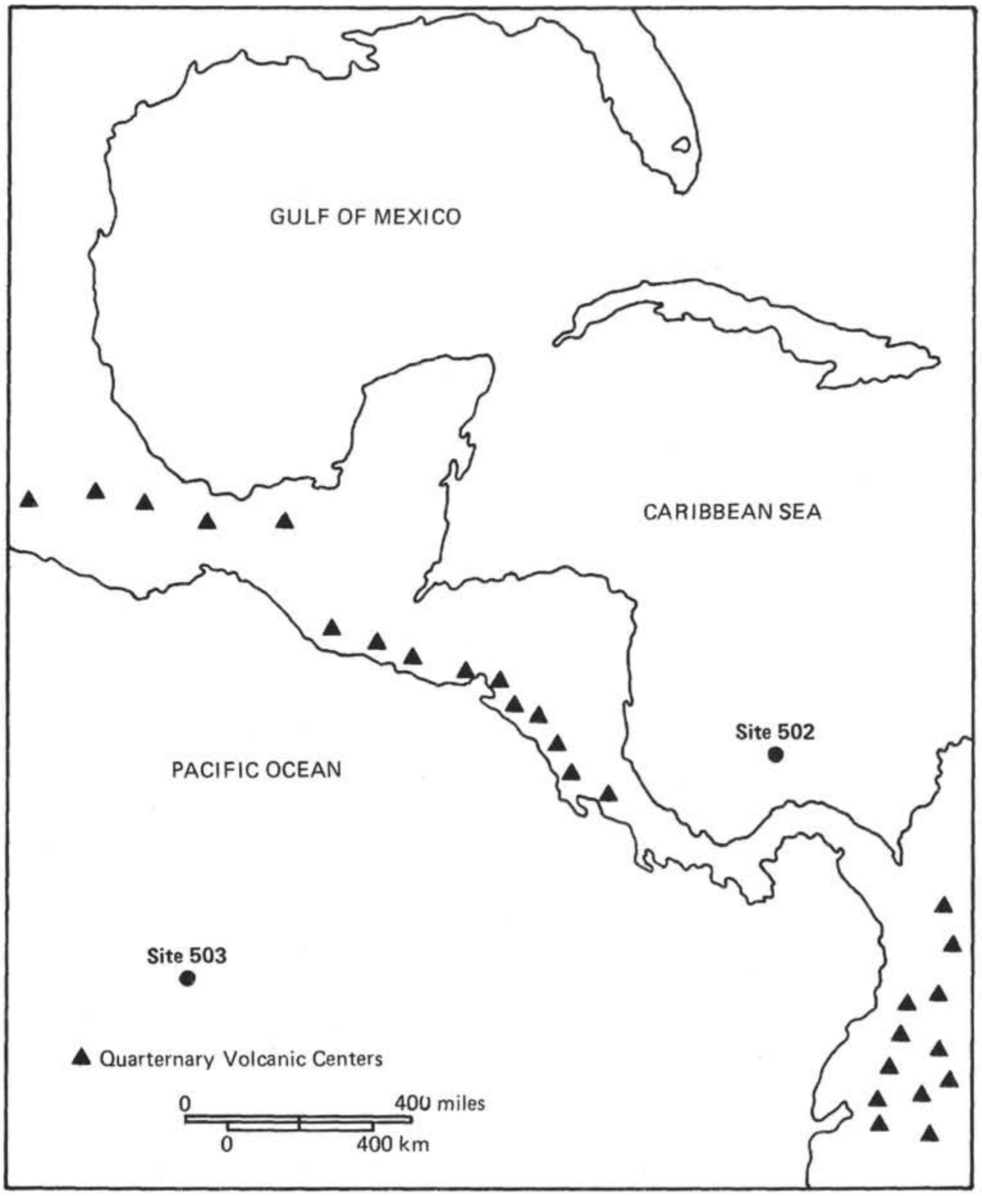

Figure 1. Sites 502 and 503. (Explosive volcanic centers of Central America and northern South America shown for reference [from Ninkovich and Shackleton, 1975].)

fall zone adjacent to the convergent margin. Site 502 is on the Caribbean Plate, however, which has not moved with respect to the Central American volcanic centers (Fig. 1). Therefore, the increased tephra frequency during the Quaternary at Site 502 may represent a true increase in eruption frequency and not simply a movement of the site into the ash-fall zone surrounding the source region.

The increased eruption frequency of Central American volcanoes in the late Miocene and Quaternary may represent an increase in subduction rates during those periods (Kennett and Thunell, 1975). This hypothesis is consistent with the increased spreading rates on the East Pacific Rise during the Quaternary (Rea and Scheidegger, 1979). If the subduction rate is equivalent to the spreading rate on a rigid plate, then the increase in volcanism during the Quaternary may have been caused by an increased subduction rate under Central America.

The episodic nature of the volcanism that provided the ash layers at Site 502 has been observed throughout the circum-Pacific region (Nobel et al., 1974; McBirney et al., 1974; Hein et al., 1978). The late Miocene and Quaternary increases in volcanism may represent increased spreading rates and a concomitant increase in subduction rates in the Pacific basin. The increased subduction rates may also play a role in the evolution of calc-alkaline magmas at convergent plate boundaries (Scheidegger and Kulm, 1975). The episodic nature of the spreading/subduction in the Paleogene (Kennett and Thunell, 1975) cannot be determined at Site 502 but could be tested with additional sites that penetrate older sediment on the western Caribbean Plate.

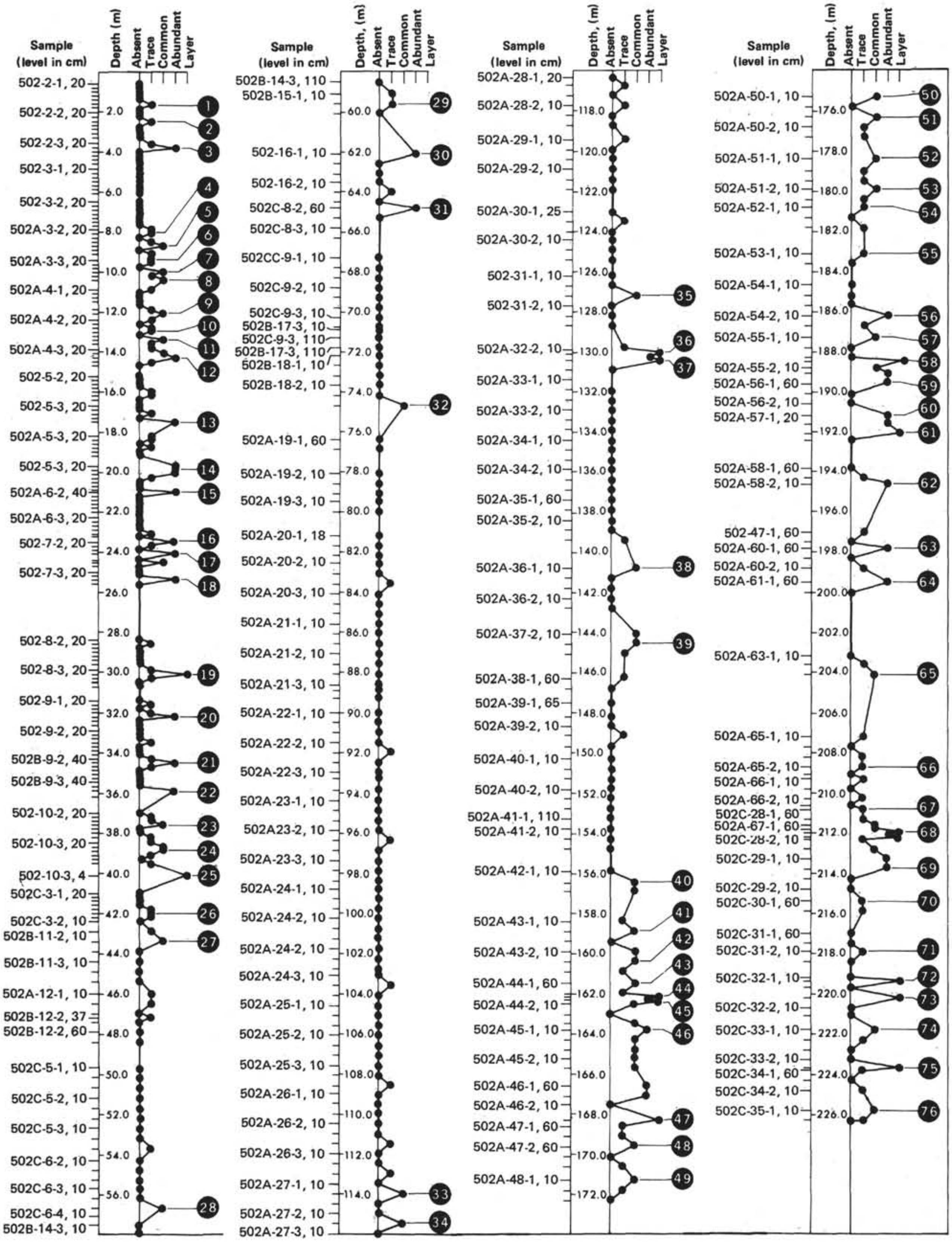

Figure 2. Tephra abundance versus corrected depth in a composite Site 502 made up from four hydraulic piston cored holes. (Concentration of tephra in the > 38-μm noncarbonate fraction is qualitatively divided into four categories for dispersed tephra and megascopic layer. Each peak in abundance is numbered for reference to Fig. 4.)

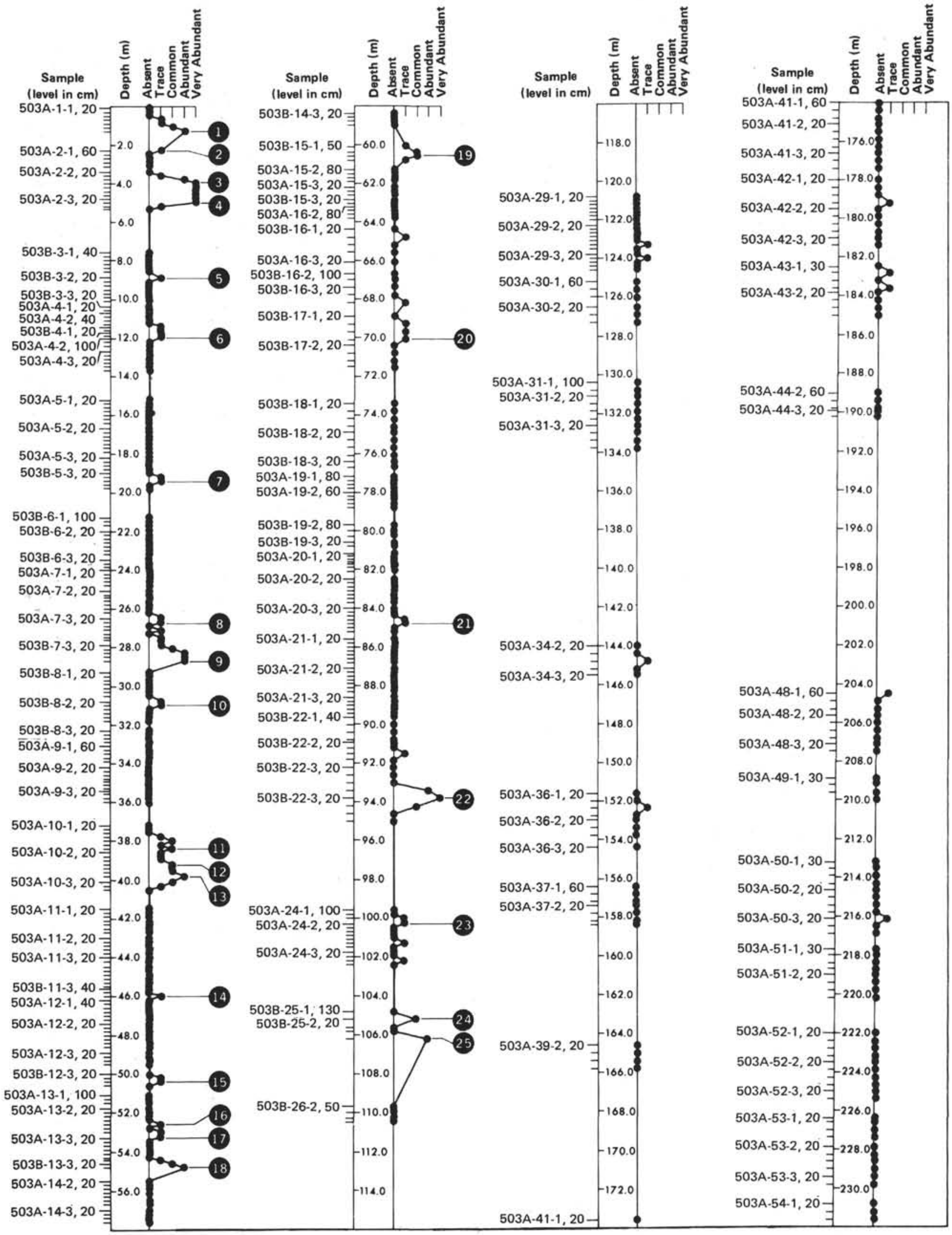

Figure 3. Tephra abundance versus corrected depth in composite Site 503 made up from two hydraulic piston cored holes. (Concentration of tephra in the > 38-μm noncarbonate fraction is qualitatively divided into five categories for dispersed tephra. No megascopic tephra layers were identified. Each peak in abundance is numbered for reference to Fig. 5.)

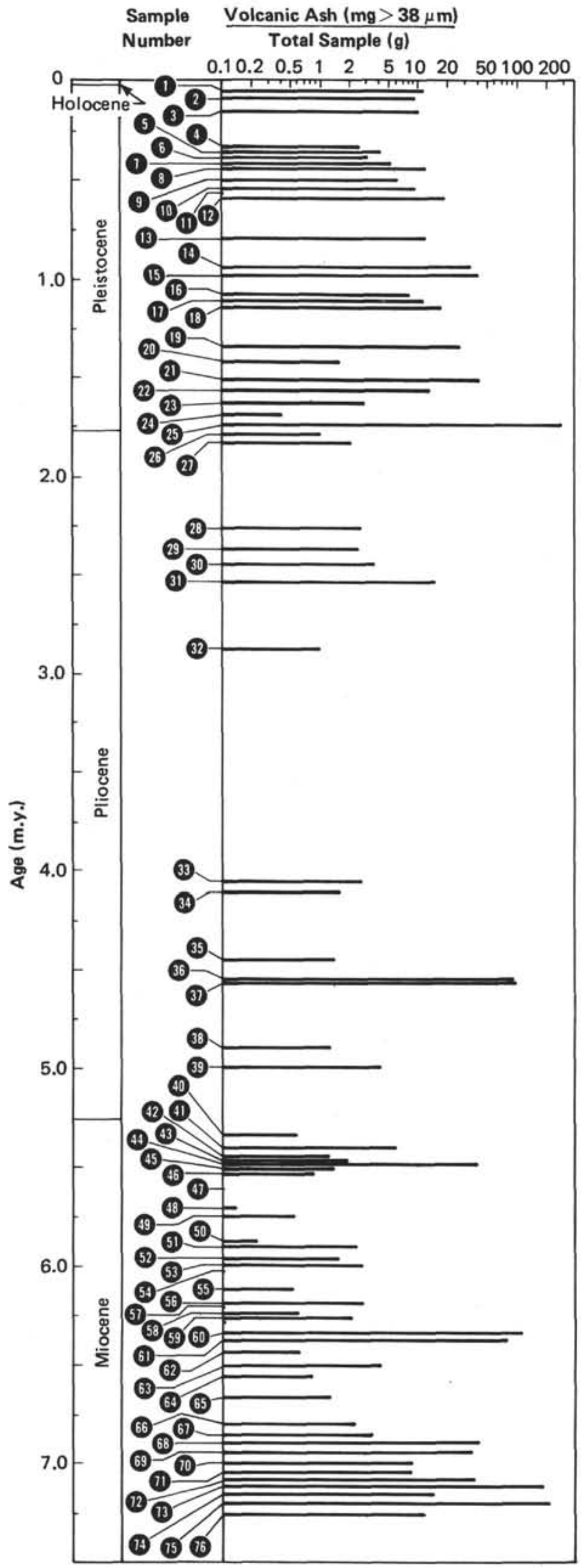

Figure 4. Quantitative measurements of tephra concentration for larger samples at each horizon in Figure 2 plotted with age, Site 502. (Increased frequency of ash fall from explosive eruptions in the Central American region [Fig. 1] occurred in the late Miocene and Pleistocene.)

Another explanation for the Quaternary and late Miocene peaks in tephra abundance at Site 502 may be a shift in wind direction. If winds changed direction in the Pliocene, so that volcanic ash was carried to the west instead of east into the Caribbean, then the low in the Pliocene could be explained by this change in wind direction rather than by a low in eruption frequency. The change-in-wind-direction hypothesis may be tested using ash frequency data from Site 503. If wind directions changed in the Pliocene, then the periods of ash-fall abundance should be out of phase between Sites 502 and 503, with highest abundances at Site 503 occurring during periods of low abundances at Site 502.

The frequency of dispersed tephra in the composite section at Site 503 (Fig. 5) is quite different from the pattern at Site 502 (Fig. 4). The late Miocene peak in abundance is not observed, and the first tephra occurs in the middle Pliocene with increasing frequency thereafter (Fig. 5). Since Site 503 did not receive tephra during the late Miocene, when peak abundances occurred at Site 502, the winds were either not strong enough or in the right direction to deliver ash to Site 503. The increasing tephra frequency at Site 502 during the Quaternary also occurs at Site 503 but with fewer layers (none megascopic) on the Pacific side. If a change in wind direction from east in the late Miocene and Quaternary to west in the Pliocene accounts for the near absence of tephra on the Caribbean (Fig. 4) and its initial occurrence in the Pacific (Fig. 5), then the change back to east during the Quaternary, which produced ash again at Site 502, should have been accompanied by a decrease in abundance at Site 503. Instead, the high tephra abundance in the Quaternary occurs at both sites. Since Site 503 moved no more than 100 miles (8 cm/y.) during the period (2.5–4.5 m.y.) of low tephra abundance at Site 502, a Quaternary change back to an easterly distribution pattern would have eliminated the ash-fall at the still-too-distant Site 503. Therefore, a change in wind direction alone cannot explain the low tephra abundance at Site 502 during the Pliocene.

Since Site 503 is on the Cocos Plate, it is approaching the convergent boundary at Central America. A zone of megascopic ash layers exists in the ocean basins adjacent to the subduction zone (Ninkovich and Donn, 1976). A region of dispersed ash surrounds the zone of megascopic layers, where original ash thickness was so small that bioturbation has dispersed the ash. Therefore, the increased frequency of dispersed tephra in the middle Pliocene at Site 503 (Fig. 5) occurred because of the arrival of the site within the zone of dispersed ash. The site is still within that zone, which extends far out into the Pacific and is only found in the westernmost Caribbean (Drexler et al., 1980).

SUMMARY

The tephra frequency at Site 502 indicates that an increase in subduction rates occurred under Central America in the late Miocene and Quaternary. Site 503 has approached the subduction zone for millions of years but reached the outer limits of the ash-fall zone only since the early to middle Pliocene.

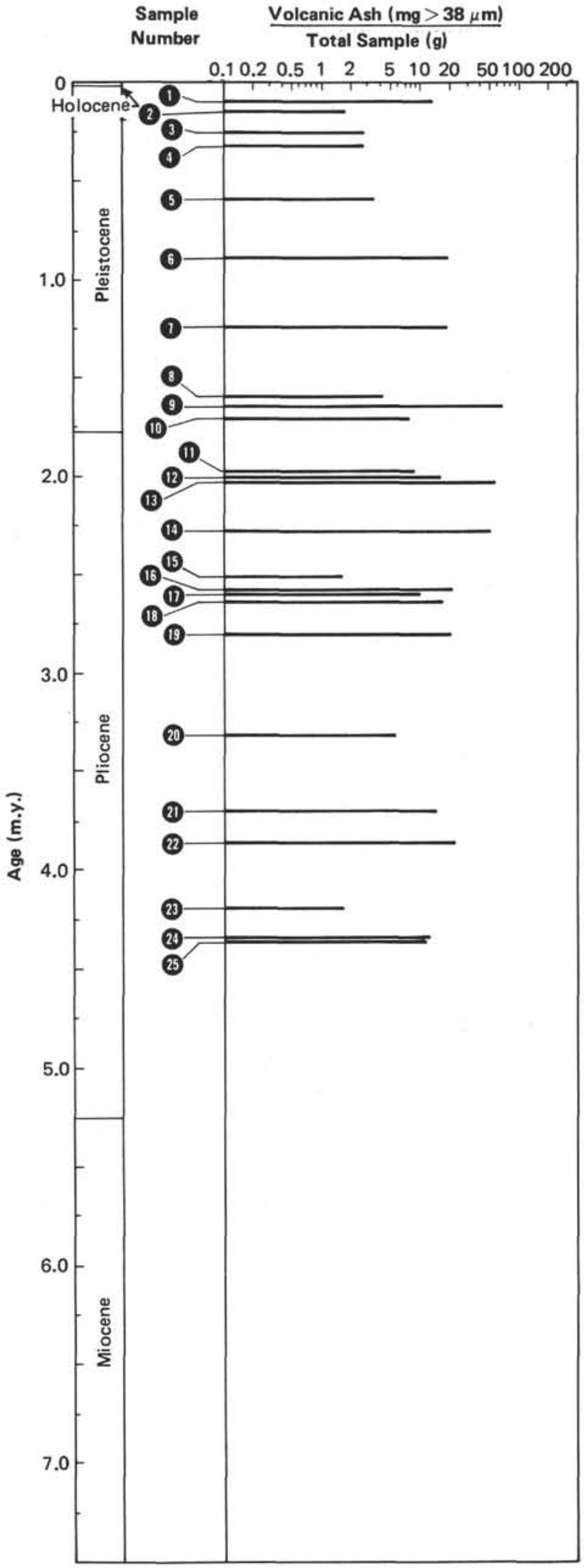

Figure 5. Quantitative measurements of tephra concentration for larger samples at each horizon in Figure 4 plotted with age, Site 503. (The first occurrence of tephra in the middle Pliocene represents the arrival of the site within the ash-fall zone surrounding Central American volcanic centers.)

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