times as rapidly as do clays not bearing fossils, and calcareous-siliceous oozes probably accumulate about five times as rapidly as siliceous oozes. If mid- and late-Cenozoic sediments became progressively more calcareous, or even more siliceous, eastward, the older sediments might be so deeply buried as to be beyond the reach of erosional processes (as is apparently the case at the equator).

The information that is available on the nature of Tertiary sediments of various ages (Fig. 2) is insufficient to provide a conclusive answer to this question, but these data give no reason to suspect a pronounced thickening of the sediment column eastward. And even in the vicinity of 5° to 10°N, 145° to 150°W, where all post-Eocene sediments are apparently siliceous and calcareous-siliceous oozes, the resulting sediment column is not sufficiently thick to prevent the occurrence of Eocene microfossils at the sediment surface.

These considerations seem to justify interpretation of the micropaleontological evidence in relation to the hypothesis of spreading of the sea floor. If the easternmost observed occurrence of Eocene microfossils is taken to represent the part of the sea floor formed at the crest of the East Pacific Rise at the end of the Eocene, an average rate of spreading (from the ridge crest at about 105°W) of approximately 8 cm/year is indicated between the Eocene and Recent time—about twice the spreading rate calculated for the late Cenozoic far to the south on this rise (see *8*).

Rates for Oligocene and Miocene spreading also may be deduced from the evidence presented, but the data may be less satisfactory—partly because uncertainties in long-range correlation of the Oligocene-Miocene boundary (*9*) affect the necessary time-distance calculation, and partly because sampling localities are sparse east of 125°W.

Possible stumbling blocks to explanation of this micropaleontological evidence in terms of spreading of the sea floor are the occurrences of calcareous oozes lacking siliceous microfossils at 15°54′N, 133°57′W (late Eocene) and 15°34′N, 127°11′W (early Miocene) (*10*). These occurrences are readily explicable if their localities of deposition are assumed to be within the area covered by the Tertiary equivalent of the North Pacific Central Water, which is now underlaid by sediments containing little or no biogenous silica (*4*). However, the crest of the East Pacific Rise in these latitudes was probably within an area in which the accumulating sediments contained siliceous microfossils throughout the Tertiary; therefore the only explanation (consistent with spreading of the sea floor) of the absence of siliceous microfossils from these two calcareous oozes is that they were deposited well west of the crest of the rise, where sediments might be expected to contain few or no siliceous microfossils. Sediments deposited farther east during the portions of the Eocene and Miocene that are represented by these two cores presumably contain siliceous microfossils.

In other parts of the Pacific, available samples bearing Tertiary microfossils are still too few for attempts to relate them to spreading of the sea floor. Occurrences between 0° and 10°S in the eastern Pacific are sparse but not inconsistent with the pattern in the northern latitudes that I have considered.

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Holocene Changes in Sea Level: Evidence in Micronesia

Abstract. *Investigation of 33 islands, scattered widely across the Caroline and Marshall Island groups in the Central Pacific revealed no emerged reefs in which corals had unquestionably formed* in situ, *or other direct evidence of postglacial high stands of sea level. Low unconsolidated rock terraces and ridges of reef-flat islands, mostly lying between tide levels, were composed of rubble conglomerates; carbon-14 dating of 11 samples from the conglomerates so far may suggest a former slightly higher sea level (nine samples range between 1890 and 3450 and one approaches 4500 years ago). However, recent hurricanes have produced ridges of comparable height and material, and in the same areas relics from World War II have been found cemented in place. Thus these datings do not in themselves necessarily indicate formerly higher sea levels. Rubble tracts are produced by storms under present conditions without any change in datum, and there seems to be no compelling evidence that they were not so developed during various periods in the past.*

Daly's (*1*) time-honored hypothesis of a postglacial stand of sea level higher than that of the present has had little support from many recent investigations made along many of the supposedly relatively stable coasts of the world (*2*). Most of these painstaking studies show the sea rising rapidly until 6000 or 7000 years ago, then rising at a decreasing rate, and possibly reaching a relatively steady state during the last 2 or 3 millennia. However, evidence of recent stands of the sea higher than today's has been reported from the Mediterranean Sea and South America (*3*), and many scientists have reported evidence of postglacial stands as much as 3 m higher than today's (*4*) in the Pacific islands. The best way to test the two hypotheses for a portion of the Pacific area seemed to be for advocates of both ideas to make a joint visit to the Marshall and Caroline islands, center of the disputed area; this we did, spending 2 months (*5*) visiting 33 islands between Guam and Kwajalein (Fig. 1). We worked on 22 atoll islands, including four on a partially "drowned atoll," and on 11 high volcanic islands in the Truk, Ponape, and Kusaie groups.

Our return was so recent that our observations and samples need more processing before they can be offered as evidence. Only a few of many samples to be processed have been dated by the radiocarbon method. The samples come from both above and below sea level, but additional dates should not appreciably change the principal field results of our study, which are acceptable to all of us.

On Guam we saw the slightly emerged coral reefs (*6*) on the southeast and southwest coasts; there is no reasonable doubt that these represent corals that grew in place about 3000 years ago at a level that is now 1.5 m above the living reef flats of the area. Such reefs have been reported from Okinawa (*7*) and other islands that are related to tectonic areas. Very small reef remnants containing corals in position of growth have been reported from Funafuti (*8*), Onotoa (*9*), and Bikini (*10*), but these examples lie between tides and therefore could have developed in tide pools that subsequently have been drained. This explanation applies particularly to *Heliopora*, the coral commonly reported from these emerged reef remnants.

If the easily detected emerged reefs of Guam result from a postglacial high stand of sea level rather than from tectonic uplift, the same high stand should have left many counterparts in the neighboring islands of Micronesia. Guam, however, forms part of the tectonically active Mariana Arc and is therefore unstable, whereas the Caroline and Marshall groups of islands are in a tectonically quiet area having no earthquakes or volcanism. On all 33 islands of the stable area we looked in vain for emerged reefs that contained corals grown *in situ* like those of Guam.

We had countless opportunities to see myriads of living microatolls and other corals that generally mark the low-tide level and grow outward rapidly from a center to form flat-topped coalescing groups. These formations would be easily recognized as elevated reef flats if the sea should sink below the present level, giving them an emerged status like those of Guam. Aside from somewhat greater rainfall in parts of Micronesia, there is no more reason why solution during the past few thousand years should have eliminated emerged reefs in the area of Micronesia visited by us than in Guam or Okinawa (*7*).

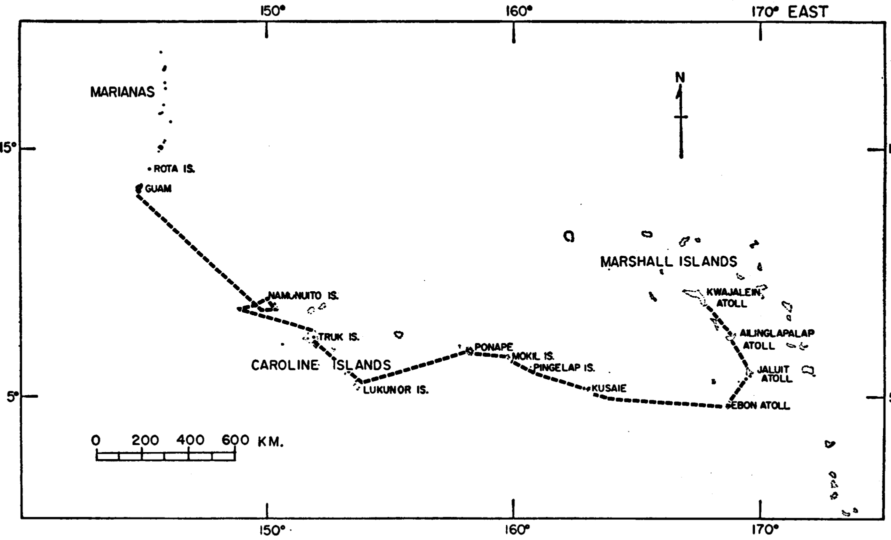

Fig. 1. General track of R.V. *Horizon* during study of changes in sea level in the Caroline and Marshall islands.

Another line of evidence indicating higher stands of the sea is the presence of wave-cut notches along the coast that are too high for present-day waves. Such notches are common along the world's coasts, but are usually difficult to date. Notches and encrusting organisms proved to be virtually absent from the many islands visited, even a few decimeters above high tide. We found one notch that could be interpreted as wave-cut, about 1.5 m above high tide on Udot Island in the Truk area, and another on Param Island, Ponape, but both are in volcanic rock and cannot be dated, nor are they clearly above action by storm waves. All other breaks in slope appeared to be adequately explained by salt-spray weathering of rocks differing in hardness.

Many interpretations by others have been based on extensive rubble platforms or groins (partly flat-topped) that rise 1 or 2 m above the reef level: some can be shown to be remnants of former beaches; some are broad, solidly cemented throughout, flat-topped, and as much as 2 m above the reef flat, but rarely above the high level of spring tide. Although unquestionably these could have been piled by storms to this or greater height, one

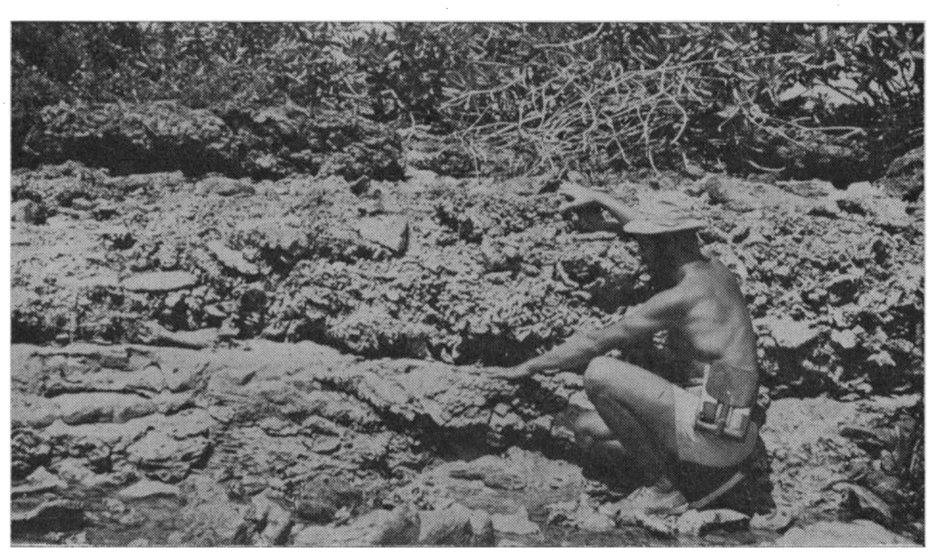

Fig. 2. Section exposed on the wall of a trench on Jabor Island, Jaluit Lagoon. Three layers of rubble rock are shown, with flat, somewhat oxidized, boundaries. These layers represent deposits by two storms, and the graded nature of the rubble is shown in the middle layer. A fourth layer, representing the 1958 hurricane is just beyond the right of the photograph.

is puzzled by the solid cementing. Many of the islands we visited have terraces and flat tops of solid rock, but none of the rock formations proved to represent coral reefs grown in place; all corals appeared to have been thrown up by waves during violent storms and later incorporated into various types of beach rock. The same interpretation had been made for other islands (*11*). This type of beach rock or rubble rock forms very rapidly in the tropics; we found many relics of World War II incorporated in some outcrops. On Jaluit Atoll we counted as many as four layers, at least three representing deposits during great storms, lying one atop the other, each grading from coarse rubble below to somewhat finer above, with weathered zones between (Fig. 2). The size of some of the corals in these rubble rocks is amazingly large, and one can easily see why they have been mistaken for growing reefs—especially when some of the blocks have landed right-side-up after transportation by the waves.

Indications of beveling by erosion of some of the beach rock, up to about the high level of spring tide, may possibly indicate slightly higher stands. Moreover, the preliminary carbon-14 dates from this rubble range only from 1890 to 4500 years ago. Some flat-topped ridges of beach rock were rather hard to equate with present reef flats, but none carry atop them corals in position of growth; furthermore, the flat tops may reflect firm cementation up to the level of high tide and erosion by storm waves above that level.

The dates of 1890 to 4500 years ago, with something of a cluster around 2500 to 3000 years, indicate a period when the sea, according to most recent investigators (*2*), stood quite close to the present level. The fact that these preliminary dates include none younger than 1890 years ago may have some significance, but deposits by older storms have had more time to be firmly cemented. Reasons for our failure to find younger firmly cemented terraces (apart from the contemporary reef flats) are not clear. Relative subsidence causes coral growth to flourish. If the rate of rise of sea level slowed or if the level dropped slightly between 2000 and 3000 years ago, before the final rise to the present level, more coral material then became available for erosion and incorporation into storm beaches. Alternatively, storms may have been more intense during the period that includes the cluster of dates.

We do not wish to imply that our investigation has solved for the Pacific the problem of sea level. Admittedly our evidence is only negative, and there are vast tracts of relatively stable island archipelagoes where our results should be checked. Particularly valuable would be probes of the estuaries on the high islands of these groups, searching for peat deposits below sea level that may provide more positive evidence of the history of sea level. Results of our studies of this sort are not yet ready, partly because we are waiting for this material to be dated. Major unsolved problems emphasized by our investigations include the cluster of dates, from flat-topped cemented rubble terraces, between 2500 and 3000 years ago, and the firm cementation of this rubble up to approximately the present level of high tide.

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Emission-Line Variability and Distance of Quasars

Abstract. *The radius of the line-emitting region in quasars is larger than 1 parsec for the cosmological hypothesis and smaller than 1 parsec for the local hypothesis. Variability in emission lines has been reported but not proved beyond doubt. Its time scale would be a direct observational indicator of this radius and would add an important element to the discussion of the origin of quasars. Objects that are variable in their optical continuum seem to be the most promising ones to look at for line variations, and they should be observed spectroscopically at regular intervals.*

Greenstein and Schmidt (*1*) have estimated the radius of the line-emitting regions in quasars under the assumption that the cosmological hypothesis holds, that is, that the red shifts are caused by the expansion of the universe. They found a few tens of light-years for the radius of 3C 48 and a few light-years for 3C 273. Oke (*2*), however, has argued that the radius of 3C 273 might be larger. In the present report we want to estimate a minimum radius by a somewhat simpler method, and to point out implications of this determination for the question of local (*3*) or cosmological origin of quasars.

Two conditions must hold if forbidden lines are emitted by a gas (*4*). First, the electron density must be so low that there occurs no appreciable depopulation, by electron collisions, of a metastable state which has been filled up from the ground state by electron collisions or from higher states by allowed transitions. This condition was used by Greenstein and Schmidt to calculate the number of forbidden transitions per cubic centimeter per second, and, from the observed luminosity, the radius of the emitting region. Second,