Recent Reefs and Shore Lines of Guam[1]

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Abstract.—The Merizo Limestone has been traced around most of the shore line of Guam, ranging up to 1.8 m above sea level. Radiocarbon ages of the formation range between 2880 years and 5115 years, with an average of about 3600 years. The Merizo Limestone is a coral deposit requiring a rise of sea level of about 3 m. Subsequently Guam has been uplifted about 2 m due to a combination of tectonic events and possibly postglacial rebound and elastic deformation. Deposits of sand and gravel extending up to 5.3 m at Ylig Bay resemble the Waimanalo shoreline (~120,000 years old) on Oahu, but the Guamanian deposit is only 900 years old and seems to be a storm deposit.

Introduction

The raised reefs and shore line deposits on the island of Guam were studied and collected in 1974, 1975, and 1976. Part of this work was in conjunction with the International Symposium on Indo-Pacific Tropical Reef Biology. The purposes of the study were to date relative changes of sea level on Guam and to correlate them with those identified in Hawaii so that some of the tectonic movements and eustatic changes in sea level recorded by the island's shoreline deposits can be differentiated. The data gathered should further help to elucidate the Pleistocene and Holocene geological history of Guam.

Extent of the Merizo Limestone

The Merizo Limestone was named by Tayama (1936) for outcrops of coral reef elevated as much as 5 m above sea level on the island of Guam (Fig. 1). Subsequently he extended his views on the formation under the name "Younger Raised Coral Reef Limestone" (Tayama, 1952: 211–219). In 1964, Tracey et al. (page 51, Pls. I, II), restricted the Merizo Limestone to exposures equivalent to those near Merizo, all of which are less than 2 m above the reef flat, and mapped exposures along the southwest coast of Guam from about 0.6 km northeast of Facpi Point to Ajayan Bay east of Merizo. They obtained a radiocarbon age of 3,400±250

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years on a *Tridacna* shell from the Merizo Limestone northeast of Facpi Point (locality 6; see Fig. 1 and Locality List).

Curray, Shepard, and Veeh (1970: Fig. 2B not 2C) traced the Merizo Limestone several kilometers farther north along the east coast of Guam to the north shore of Talofofo Bay near Asanite Point. They reported a radiocarbon age of 2,880±110 years for a coral from the Merizo Limestone at Toguan Bay (locality 7) on the southwest coast (Curry et al., 1970: 1870, Table 2). The locality is at or near the raised reef they illustrated (Curry et al., 1970: Fig. 2C, cf. Franz J. Emmel and Francis P. Shepard, March, 1975). They (Curry et al., 1970: 1867) concluded that the emerged reef 1.4 to 1.8 m above present sea level comprising the Merizo Limestone "probably represents uplift of the island of Guam rather than a higher than present Holocene stand of sea level".

Additional outcrops of elevated coral reef were recognized in 1974 by us on the south side of Ylig Bay on the seaward side of Togcha Cemetery just east of the coast road at a point 0.8 km south of the bridge over the Ylig River. Coral

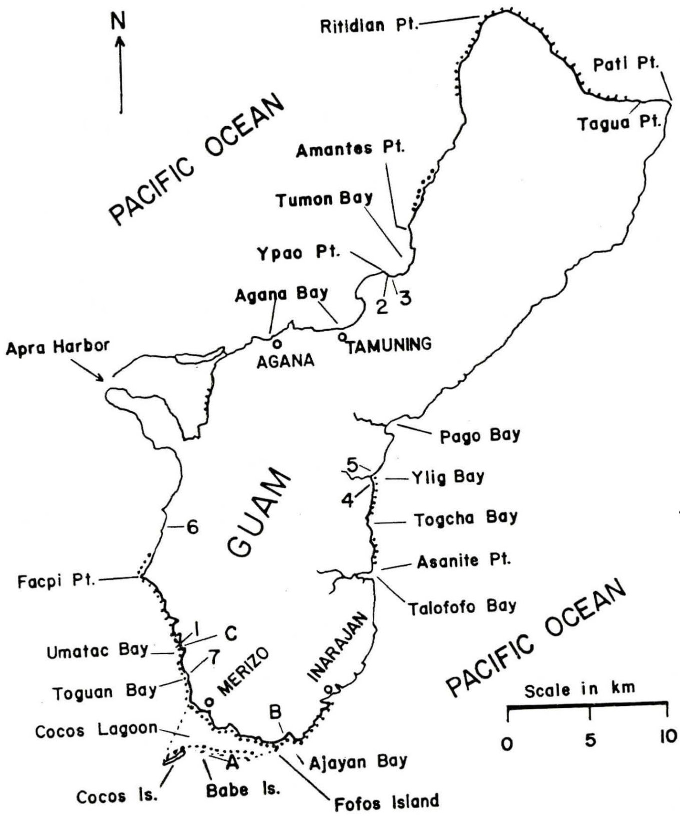

Fig. 1. Locality map of Guam. The localities discussed in the text are either numbered or lettered. Outcrops of the Merizo Limestone are indicated along the shoreline by a series of dots.

reef similar in faunal content, preservation, and elevation to the Merizo Limestone extends for several hundred meters along the shore and forms the surface of the promontory about 0.3 m above mean low tide and the recent shore bench. A coral from locality 5 has been dated at 3,655±150 radiocarbon years (Table 1).

We also found outcrops of elevated coral reef apparently referable to the Merizo Limestone on the recent broad shore bench east of Ypao Point. A patch of coral pinnacles extends for 75 m along the shore bench. The pinnacles rise about 1 m above the shore bench and their summits are essentially concordant in elevation. They consist of a profusion of coral colonies, mostly in growth position, although some had been dislodged (but not waterworn) before becoming incorporated in the reef. The former reef has been deeply dissected since the ensuing drop in sea level, thus leaving pinnacles as remnants of the reef. A coral from one of the pinnacles at locality 3 has an age of 4,115±195 radiocarbon years (Table 1). Additional remnants of limestone probably referable to the Merizo Limestone were noted in 1976 around the north half of Guam, except along the shore between Togua Point and Pago Bay on the northeast side of the island (Fig. 1).

Cocos Island and Babe Island are remnants of Merizo Limestone on the southern margin of Cocos Lagon (Tracey et al., 1964: 51, Pl. I). Other, mostly submerged, remnants occur on both sides of Babe Island between Cocos Island and Fofos Island. This alignment of reefoid limestone presumably indicates a former barrier ridge defining the windward side of the lagoon.

Different outcrops of the Merizo Limestone have been subjected to various degrees of alteration. The alteration appears to result from recent geochemical action rather than to indicate different ages for the deposits. In general, corals in the outcrops along the shore on both sides of Facpi Point (as at locality 6, cf. Fig. 1), Umatac (locality C), Ylig Bay (locality 4), and Ypao Beach (locality 3) are altered only slightly as detected by x-ray studies. Likewise, aragonitic corals are found on Babe Island (locality A). This small island is only a meter above sea level and is on the edge of Cocos lagoon where it is exposed to the full force of waves near the edge of the reef and is frequently splashed with spray.

Corals at locality B in the recreation park southwest of Inarajan are completely replaced and infiltrated by calcite. They occupy a thin veneer over basalt just above the high tide level. Water in the shallow inlets and tidal pools is warmed by the sun, hastening the precipitation of $CaCO_3$ and presumably contributing to the ex-

Table 1. Radiocarbon ages of samples from Merizo Limestone.

Locality	Sample No. Source	Aragonite, %	Age, yrs.	Analysis by	
1	74–6–23–2	83%	2,975±150	Geochron	(GX3848)
3	74–6–27–3	100%	4,115±195	Geochron	(GX3849)
5	74–7–10–2	100%	3,665±150	Geochron	(GX3850)
4	74–7–10–1	n/a	900± 80	Isotopes	(I–8415)
A	74–6–25–2	100%	5,115±100	U. Miami	(UM937)
6	Tracey et al., 1964	100%	3,400±250	U.S.G.S.	(W–370)
7	Curray et al., 1970	n/a	2,880±110	Isotopes	(I–2812)

tensive replacement of corals in the intertidal and splash zone.

North of Umatac Bay (locality C) a shore bench is cut in pillow basalt at the level of mean low tide. The pillow basalt extends up to 30 cm above the shore bench and its upper surface is somewhat undulatory. A veneer of Merizo Limestone extends less than 50 cm above the shore bench. A narrow fringe of reef is growing vigorously seaward along the outer part of the basalt bench. The raised reef of Merizo Limestone is remarkably similar in appearance and faunal composition to the modern reef. One of us (RHR) has identified 107 species of corals representing 37 genera on the growing reef, denoting it as one of the more diverse coral populations encountered so far along the southwest coast of Guam. A narrow abrasion channel has cut through the reef and 10 cm into the underlying basalt on a narrow terrace on the reef front. At a depth of 7 m on the side of the channel, a coral embedded in the base of the reef (locality 1) was collected. Although the coral has been partially (17%) altered to calcite, it provides concordant ages of about 3,000 years, based on uranium disequilibrium studies (3,200±100 years) and radiocarbon analysis (2,975±150 years, cf. Table 1). This coral, therefore, grew at the same time that the Merizo Limestone was being deposited, as indicated by the radiocarbon dates mentioned above for nearby localities at Facpi Point and Toguan Bay. It is possible that the alteration took place near the shore line, after which the coral was transported into the channel and overgrown by the reef.

4-Meter Deposits at Ylig Bay

Tracey et al. (1964: Pl. I), mapped "beach deposits" as a mixture of beach sand and gravel, beach rock, and recently emerged detrital limestone; sand is generally less than 5 m above sea level and seldom as high as 10 m. They recognized beach deposits at Togcha cemetery on the east coast of Guam, but did not describe that particular locality.

Recently a sand pit has been operated on the east and south sides of Togcha Cemetery, thus exposing a profile of the deposit. The ground surface is 5.3 m above mean low water. The main part of the sand pit consists of about 2 m of cream-colored, medium- to coarse-grained, bioclastic sand and gravel in beds approximately 20 cm thick. The upper one meter of the exposure consists of land fill graded smooth. Beneath the land fill is a prominent grey zone 10 cm thick consisting of two soil layers separated by cream-colored bioclastic sand. Two faint grey zones lower down in the sequence indicate other soil zones. The lowest meter of the deposits is poorly exposed sand. At the base of the pit large coral heads 0.3 to 0.5 m in diameter lie at about the level of the surface of the pitted, raised reef of Merizo Limestone along the shore.

Waterworn coral cobbles were collected from the sand pit 1.5 m below the surface of the terrace and 40 cm beneath the prominent grey soil zone. A specimen of *Porites* sp. from this site (locality 4) was radiocarbon dated to be 900±80 years old (Table 1).

On the west side of the shore road 140 m south of the Y in the sandy roads east of the cemetery is a 0.6 m thick bed of coral gravel with a sand matrix. Its base lies 0.5 m above the Merizo Limestone. Intervening sediments are not exposed. The bed is much more indurated than any of the other detrital beach deposits and would seem at first impression to represent a basal conglomerate of the beach deposits, including those of the sand pit. However, the conglomerate also contains fragments of bottles, hence it is a recent storm deposit abutting against beds cropping out in the sand pit. This outcrop is proof that degree of lithification can be misleading in estimating relative ages of shore deposits.

The terrace on which Togcha Cemetery lies presumably consists of a continuous deposit of bioclastic sand as exposed in the sand pit. The horizontal torrential bedding, poor sorting, and intercalated soil zones suggest a sequence of storm deposits with intervening quiet periods when vegetation was able to become established. This sequence is expectable, for Guam lies in the path of typhoons in the western Pacific ocean. Tracey et al. (1964: 71) infer a similar source for the sand flats inland from Tumon Bay and Tarague Beach. Randall has first hand knowledge of fresh material being deposited 10 m above sea level on Pati Point in northeast and southeast Guam during a storm. In August, 1974, during a rather severe tropical storm, waves 7 to 8 m high carried fresh sediment back inland to the base of cliffs at that height. Although the shores bordering Yling Bay are not now lined with either dunes or broad sandy beaches, a large amount of sand and gravel must have been present 900 years ago to provide a source for the terrace deposits.

After we collected and measured the section in the sand pit at Togcha Bay, Typhoon Pamela, in 1976, washed much new debris from the shore bench and reef flat into the pit. In attendant erosion, many graves were exhumed on the north side of the sand pit and the broad sand terrace surmounting the shore line was extensively excavated by storm waves between Ylig Bay and the mouth of Togcha River. Furthermore, limestone benches previously covered by beach deposits were uncovered. Rubble from the shore bench and living corals broken off the marginal fringe of reef were transported over 100 m beyond the shore line at some places.

Sea Caves at Ypao Point

Rocks making up the limestone cliff at Ypao Point in western Guam have been mapped (Tracey et al., 1964: Pl. I) as a detrital facies of the Mariana Limestone of Pliocene and Pleistocene age. These workers also indicate that a reefoid facies crops out on higher parts of the headland. The detrital facies as they mapped it consists of bioclastic limestone that is cream to white, fine- to coarse-grained, friable to well-cemented, and generally not distinctly bedded. They interpreted it as a lagoonal deposit near coral reefs. The formation is generally quite porous and is traversed by innumerable caverns (Tracey et al., 1959: Pl. II, p. 221–225, 230, 234–240). The Mariana Limestone is the principal formation cropping out on the north half of Guam where it forms the rolling upland and stands as towering cliffs along much of the sea shore.

A flat shore bench lies at the foot of the cliff east of Ypao Point. The bench is about 50 m wide at its eastern end but narrows to the southwest and pinches out against the cliffs at Ypao Point. The seaward edge of the shore bench consists of spurs and channels where the narrow fringing reef joins it at the level of mean low tide. Pinnacles of Merizo Limestone described above stand on the bench. The shore bench is cut in Mariana Limestone.

Two prominent caves penetrate the face of the cliff. The larger cave (Fig. 2) is 8 m high and 50 m wide. Its floor is about 2.6 m above the shore bench. The cross section of the cave is semicircular. It is not known how far back the cave originally extended into the cliff of Mariana Limestone because it is filled from floor to ceiling with stratified calcarenite and coral conglomerate. Beds range from about 1 cm to 20 cm in thickness, with materials mostly 1 to 10 mm in grain size. A few beds of rounded coral boulders occur near the base of the sequence. In one of the lowest layers, about 30 cm above the floor, a fragment of a stalactite was collected (74–6–27–1).

The horizontally stratified cave filling abuts cleanly against the side walls of Mariana Limestone. Although the Mariana Limestone also is generally stratified horizontally, the beds forming the cave roof and walls form an anticlinal-like arch as if they were draped over a preexisting mound. Beds of Mariana Limestone both overlying the arcuate strata and extending away from them laterally become progressively more nearly horizontal.

The second cave is 50 m east of the large cave. It is about 10 m wide and its

Fig. 2. Sea cave at Ypao Point. The shore bench cut in Mariana Limestone is exposed at low tides. The drape effect over the cave is also developed in Mariana Limestone. Horizontally stratified beachrock of sand and coral conglomerate fills the cave. The cave is 50 m wide and 8 m high and its floor is 2.6 m above the shore bench.

ceiling is not as high as that of the first cave. Its floor also is about 2.6 m above the shore bench. As in the case of the larger cave, this one is filled with stratified bioclastic deposits. Some of the lower beds are coral conglomerates; the higher beds consist of coarse-grained bioclastic sands and pebbles.

Examination of the caves adds new details to the geological history of Guam. It is desirable to know the age of the cave fill for that would establish the most recent time for the development of the cave and a time after which sea level stood at least as high as the roof of the cave. Unfortunately, the corals in the cave fill have been completely calcified so that any radiometric date derived from them probably would be erroneous.

We have attempted to date the fragment of stalactite near the base of the cave fill (locality 2) and obtained a Th^{230}/U^{234} age of 210,000 years (Table 2). This specimen is compact and shows no apparent signs of alteration. But in view of the alteration of the corals associated with it, it may be suspected that the specimen might have also been affected by post-depositional mineralization. This process likely involved addition of new calcite in which case the age cannot be younger than 210,000 years. Therefore, this vadose or dripstone cycle of the cave at the time of formation of the stalactite, when sea level was as low as or lower than the floor of the cave, was no more recent than 210,000 years ago.

We suggest the following sequence of events for these caves in the past:

(1) Deposition of the Mariana Limestone took place during Pliocene and Pleistocene time. It is likely that the present sites of the caves were once occupied by small coral bioherms growing in a lagoon. As the lagoon was filled with detritus from the reefs nearby, these small bioherms were overwhelmed and buried by sediment that was distinctly draped over the bioherms.

(2) Uplift of the Mariana Limestone occurred, probably alternating with periods of submergence, based on present knowledge of sea level changes in Hawaii (Stearns, 1966).

(3) Formation of the caves took place by preferential removal of the loose framework of corals in small bioherms. The relative importance of solution by groundwater and quarrying by wave action, if any, cannot be evaluated with the cave in its state of expression. Relative sea level was 2.6 m higher than at present for a considerable time during the development of the caves. The cave formation ended more than 210,000 years ago.

(4) Culmination of the cave-forming cycle took place in a period of vadose circulation in which cave travertine was precipitated. This stage was operational about 210,000 years ago when the stalactites were growing.

Table 2. Results of U-series isotopic analyses of two samples.

Sample No.	Material	U (ppm)	U^{234}/U^{238}	Th^{230}/Th^{234}	Th^{230}/U^{234}	Age (10^3 yrs)
74–6–23–2	Coral	$3.57\pm.09$	$1.13\pm.01$	43.1 ± 6.0	$0.030\pm.001$	3.2 ± 0.1
74–6–27–1	Stalactite	$0.188\pm.005$	$1.01\pm.04$	37.7 ± 19.1	$0.86\pm.08$	$210\pm^{90}_{50}$

(5) Sea level stood at least once thereafter, at a level at least as high as the roof of the larger cave. As sea level rose, the cave was back-filled with carbonate debris from contemporaneous reefs and possibly with some detritus from erosion or collapse of the Mariana Limestone. Shortly after the beginning of this cycle, the fragment of dated stalactite fell from the roof of the cave. The stratified cave fill might have been deposited about 120,000 years ago, during which time the Waimanalo shore lines in the Hawaiian Islands were formed (Ku et al., 1974), for there is no other sea stand significantly higher than the present level since 200,000 years ago (Stearns, 1966). The Waimanalo stand in Hawaii is about 8 m above the present shore bench, and this is the height of the roof of the cave and the depth of the cave fill at Ypao Point. However, sea level may have been higher than the depth of the cave fill, in which case either the deposits could be older than 200,000 years, or the island of Guam was uplifted after the Waimanalo high stand.

(6) Relative lowering of sea level occurred, exposing the stratified cave fill. Sea level at some stage, including the present one, stood long enough at about the level it now occupies for a wide shore bench to be cut in the Mariana Limestone. Contemporaneous lithification of the beachrock occurred. It is widely recognized that sea level stood much lower than at present before it rose for the last time to its present position.

(7) Relative rise of the sea level about 1 m occurred and growth of the shore line reefs about 3,000 to 4,000 years ago forming the Merizo Limestone on the shore bench cut during event 6.

(8) Lowering of the sea level took place for 1 m to the present level—about the same level as in event 6. The Merizo Limestone has been dissected into pinnacles standing on the Holocene shore bench at Ypao Point. This means that the present shore bench is the result of two stages of erosion at approximately this level. Slight warping or faulting may have caused some variation of about 30 cm in the elevation of the two erosional levels, as at Umatac Point.

Other Localities

Among the many islands in the Pacific, Guam has an unusually persistent and wide Holocene shore bench. The widest, at Achang Reef on the east side of Cocos Lagoon, extends 850 m from shore. The Guamanian shore bench is a scoured surface eroded into Mariana Limestone in many places, and resembles superficially the flat constructional surface of typical fringing reefs around many Pacific islands. Locally, it is overlain by Merizo Limestone. It commonly bears a fringe of living corals along its outer slope and both Merizo Limestone and living corals occur on the narrow bench at Ypao Point. The bench underlying Pago Bay extends as much as 200 m seaward. A trench cut across the north portion of the bench in 1975 for a sea water intake at the Guam Marine Laboratory shows that the bench is entirely Mariana Limestone. Small, scattered colonies of corals are attached to the upper surface and the margin is encrusted with a dense growth of reef organisms

(Emery, 1962: Figs. 30, 43). Inner portions of much of the shore bench are mantled with patches of sand composed of coral and shell fragments and foraminifers (Emery, 1962: Figs. 41, 43). Other benches or reef flats such as that at Togcha Bay bear much wider and more luxuriant growths of organisms on the frontal slope, with attendant surge channels (Emery, 1962: Fig. 31). No datable material that would help elucidate former changes in relative sea level is available from these erosional benches.

We did not find any marine deposit associated with the alluvial terraces at 40 feet mentioned by Tracey et al. (1964: 99, 100). Nor have we succeeded as yet in obtaining marine material in place from any of the five terraces that formerly were so well exposed at Ritidian Point (Tracey et al., 1964: 50).

Finally, we have not been able to correlate laterally the prominent nips at Amantes Point and some nips and sea caves at other localities with marine deposits. Some benches that once bore marine deposits might have been stripped by erosion. Others are heavily overgrown with jungle or have been disturbed and obscured by earth moving equipment.

Tectonic Versus Eustatic Changes of Sea Level on Guam

Guam has been a dominantly emergent structural element since the close of deposition of Mariana Limestone during the Pleistocene. The northern half, for instance, is a flat constructional plateau dipping southwestward about 25 feet per mile, (Tracey et al., 1964: 61, 62). The uplift need not have been continuous or even persistently in one direction, for there may have been times of subsidence in consequence of the position of Guam on the tectonically active Mariana Arc (Tracey et al., 1964: 99). At the same time when tectonic movements took place there have been eustatic changes in sea level during the Pleistocene. The problem is to differentiate between tectonic and eustatic changes in relative sea level.

Some of the benches, such as those at about 30 m on northern Guam, may be due to stillstands during uplift, or to eustatic changes. But datable material is not available so that correlation with dated benches in Hawaii and elsewhere cannot be made at this time.

Although the Waimanalo stand may be represented in the caves at Ypao Point, there is no clearly defined upper surface to the deposits. Therefore, it is not possible to evaluate either the potential amount of uplift or the level at which the sea stood during filling of these caves on Guam.

On the other hand, the upper and lower surfaces of the Merizo Limestone offer an opportunity to correlate elevation and age of these deposits with sea level changes from eustatic causes as interpreted elsewhere.

Several workers have published convincing evidence that sea level was at −1 m approximately 3,000 years ago when the Merizo Limestone was being deposited (Curray et al., 1970: Fig. 6; Easton and Olson, 1976: Fig. 4 and Table 2). Our work shows that patches of Merizo Limestone crop out from 0.3 m to 1.8 m above sea level on the east and west sides of Guam. The island therefore has been elevated approximately 3 m during the past 3,000 to 4,000 years. Some of the elevation may have been caused by postglacial rebound and elastic deformation of the globe (Walcott, 1972). Minor variability in elevation indicates that Guam has been affected by minor faulting or has been warped slightly during the recent uplift. Finally, it also appears that the fringing reef at Umatac has prograded from shore since the recent uplift of Guam began.

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Locality List

Elevations refer to mean low water.

1. (WHE–74–6–23–2). Coral in contact with basalt in eroded channel at base of fringing reef. Point 300 m north of Umatac Bay. Elevation: minus 7 m. Collected by RHR.
2. (WHE 74–6–27–1). Fragment of stalactite in beachrock 0.3 m above the floor of the large cave about 300 m east of Ypao Point and 700 m west of the south end of Tumon Bay. Elevation: 2.9 m.
3. (WHE 74–6–27–3). Corals mostly in growth position from pinnacles on the shore bench 150 m west of the west end of Ypao Beach and the south end of Tumon Bay. Elevation: 1 m or less.
4. (WHE 74–7–10–1). Waterworn cobble from 1.5 m below top of sand pit in Togcha Cemetery, 0.8 km south of bridge over Ylig River. Elevation: 3.8 m.
5. (WHE 74–7–10–2). Corals from pitted surface of reef flat on the shore east of Togcha Cemetery, 0.8 km south of bridge over Ylig River. Elevation: 0.5 m.

A. (WHE 74–6–25–2). Corals from Babe Island, east of Cocos Island on the south edge of Cocos Lagoon. Elevation: 1 m or less.
B. (WHE 74–6–26–1). Corals from veneer of reef deposits overlying basalt in small embayment 30 m west of swimming pool on beach on south side of Inarajan. Elevation: 1 m.
C. (WHE 74–6–23–1). *Tridacna* shell in Merizo Limestone. Point 300 m north of Umatac Bay. Elevation: 50 cm.

References Cited

Curray, J. R., F. P. Shepard, and H. H. Veeh. 1970. Late Quaternary sea-level studies in Micronesia: CARMARSEL Expedition. Geol. Soc. America Bull. 81: 1865–1880.

Easton, W. H., E. A. Olson. 1976. Radiocarbon profile of Hanauma reef, Oahu, Hawaii. Geol. Soc. America Bull. 87: 711–719.

Emery, K. O. 1962. Marine geology of Guam. U. S. Geological Survey Prof. Paper 403–B, v+ 76 p.

Ku, T. L., M. A. Kimmel, W. H. Easton, and T. J. O'Neil. 1974. Eustatic sea level 120,000 years ago on Oahu, Hawaii. Science 183: 959–962.

Strearns, H. T. 1966. Geology of Hawaii. The State of Hawaii Pacific Books, Palo Alto. 266 p.

Tayama, R. 1936. Geomorphology, geology, and coral reefs of Tinian Island together with Aguijon and Naftan Islands. Tohoku Univ. Inst. Geology and Paleontology, Contr. 21: 26, 27, 31. (In Japanese. English translation in U. S. Geological Survey Library).

Tayama, R. 1952. Coral reefs in the south seas. Bull. Hydrographic Off., No. 11 (Pub. 941): (English text, p. 183–292).

Tracey, J. I., Jr., C. H. Stensland, O. B. Doan, H. G. May, S. O. Schlanger, and J. T. Stark. 1959. Military Geology of Guam, Mariana Islands. Pt. I, II: U. S. Army, Chief of Engineers, Intelligence Div., Headquarters U. S. Army Pacific (Tokyo). 282 p.

Tracey, J. I., Jr., S. O. Schlanger, J. T. Stark, D. B. Doan, and H. G. May. 1964. General geology of Guam. U. S. Geological Survey Prof. Paper 403–A, iv+104 p.

Walcott, R. I. 1972. Past sea levels, eustacy and deformation of the earth. Quaternary Research 2: 1–14.