QUATERNARY SHORELINES IN THE HAWAIIAN ISLANDS

HAROLD T. STEARNS

BERNICE P. BISHOP MUSEUM BULLETIN 237

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INTRODUCTION

ALL OF THE IMPORTANT DATA to date on Quaternary shorelines are widely scattered, and this volume will serve to make them more readily available. It also includes some new observations. Much progress has been made deciphering the shorelines since the writer started studying the geology of the Hawaiian Islands more than fifty years ago, but much more remains to be done.

It was thought that many of the younger shorelines would be dated correctly with the discovery of the C^{14} method for dating shells, but this method has been shown to be greatly in error by the uranium-series method (Stearns, 1972, p. 242). We do not yet have a reliable dating method for coral reefs more than 300,000 years old. Some geologists mistakenly believe that the volcanic islands of Hawaii are unstable, but concordant glacioeustatic shorelines indicate that they have been stable during at least the last 500,000 years. Early in the Pleistocene the islands were sinking steadily, as shown by cores from test holes at Ewa, Oahu (Stearns and Chamberlain, 1967). Oahu probably is the best gauge or "dip stick" in the Pacific for determining glacioeustatic movements since the middle Pleistocene, in spite of Ward's article (1973) to the contrary (see reply by Stearns, 1974b). The graph in Figure 1 shows the Pleistocene Hawaiian shorelines in relation to glacioeustatic fluctuations of sea level.

One of the best proofs of stability in the late Pleistocene is the similarity of elevations of submerged notches off the coast of Kauai to those elsewhere in Hawaii, as measured by Dr. Richard Grigg in 1974 and 1975. He states that the notches are continuous for miles and are cut 6 to 8 feet deep in the cliff faces of older submerged reefs. Those at −60 and −190 feet are the largest. All measurements were made by a fathometer worn on his wrist. A comparison of the previously known submerged notches with those on Kauai is given in Table 1.

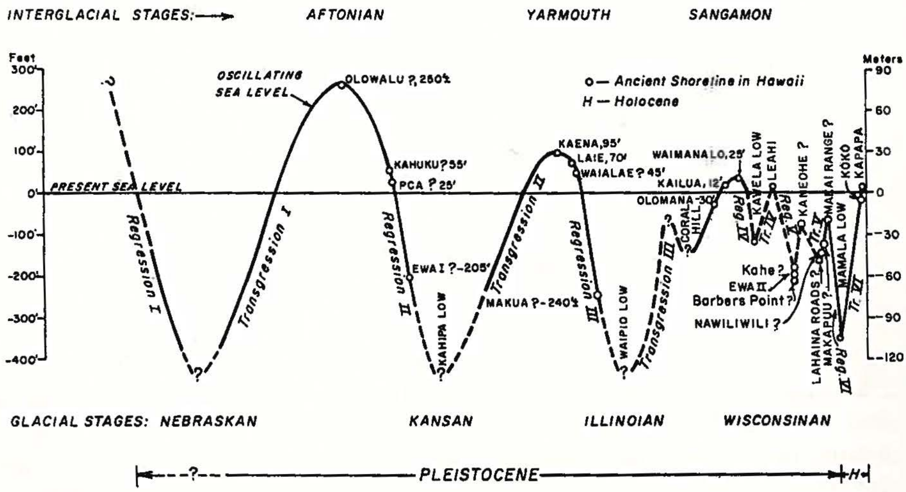

FIGURE 1.—Graph showing glacioeustatic fluctuations of sea level and Hawaiian Pleistocene shorelines.

ACKNOWLEDGMENTS

Dr. Richard Grigg, Associate Marine Biologist, University of Hawaii, is a specialist in deep water corals. He has made dozens of SCUBA dives along the coasts of the Hawaiian Islands and had a grant for studying black, pink, and gold corals, using a submersible. Grigg furnished most of the data and photographs of the submarine shorelines. Grigg, W.E. Easton, J.H. Beard and R.M. Jeffords kindly criticized the manuscript.

HOW LONG WAS THE PLEISTOCENE?

THE LENGTH OF THE PLEISTOCENE has been argued in many scientific papers which need not be reviewed here, because the problem revolves chiefly around whether the Pleistocene started with the onset of cooling temperatures, the beginning of glaciation, or the extinction of certain marine organisms. Absolute age of the Pleistocene epochs has been approached by several methods synthesized by Beard (1969). He places the beginning of the Pleistocene at 2.8 million years ago. Others have placed it at about 1.8 million years ago. Cooke (1973) has synthesized the data and arrived at the results given in Table 2. The dates are taken from the graph in Cooke (1973, Table 3).

It will be shown in this paper that the Sangamon was only about 125,000 years ago, but Cooke's dates for the Illinoian and the Yarmouth coincide well with the radiogenic data herein.

The lengthening of the Pleistocene from 1 million years to 2.3 m.y. would shift the position of the Hawaiian Island chain in the geologic time scale. Of the main islands only Kauai, Niihau, and Oahu were above the ocean at the beginning of the Pleistocene. The rest of the main Hawaiian Islands are younger than 2.3 m.y., as indicated in Table 3.

There is a question as to the reliability of K-Ar ages for some of the Hawaiian lavas. The results are mostly consistent, as shown by dates obtained independently in separate laboratories, and have been widely accepted. They are supported also by the ages of geomagnetic reversals. Gramlich and others (1971) have dated, by the K-Ar method, lavas of the Honolulu Volcanic Series which are interstratified with limestones on Oahu. A few of these limestones have been dated by the uranium-series method, making a cross-correlation possible, as described below.

The Salt Lake volcanics have a K-Ar age of about 430,000 years. The 25-foot (7.5 m) Waimanalo shoreline has a uranium-series age of about 125,000 years (Stearns, 1974a, p. 800). It is cut into the Salt Lake tuff (Stearns and Vaksvik, 1935, Pl. 12). The Salt Lake tuff lies on a dissected

TABLE 1
LIST OF SUBMERGED SHORELINE NOTCHES PREVIOUSLY REPORTED COMPARED WITH THOSE ON KAUAI

Depth Below Mean Sea Level (Feet)	(Meters)	Name of Shoreline	Island (Stearns, 1974a)	Kauai (By R. Grigg) (Feet)
−60	−18	Makai Range	Oahu	−60
−80	−24	Kaneohe	Oahu	−85
−120	−36	Makapuu	Oahu	−120
−135	−41	Nawiliwili*	Kauai	−135
−155†	−47	Lahaina Roads	Maui	−155
−190	−58	Kahe**	Oahu	−190
−205	−62	Ewa II	Oahu	−205

*Named from Nawiliwili Harbor, Kauai, where it was discovered by Grigg in 1974.

**Named from Kahe Point, Oahu, where it was first found by Grigg. This is the same notch previously described as at −185 feet.

†Grigg states that the notch is more nearly −155 feet instead of −150 feet, as formerly listed.

terrace of the Kaena 95-foot stand of the sea and extends below sea level as a subaerial deposit laid down during the Waipio low (Stearns and Vaksvik, 1935, p. 127); hence is Illinoian in age. Thus the K-Ar age for the Salt Lake tuff falls close to the date shown for the peak of the Illinoian glacial epoch in Table 1.

The Punchbowl volcanics have a K-Ar age of about 530,000 years (unpublished K-Ar date furnished by G. B. Dalrymple). The tuff is overlain by limestone of the Waimanalo stand of the sea and has been correlated tentatively with the Waipio stand of the sea (Stearns and Vaksvik, 1935, p. 148). A lava flow from Punchbowl at a depth of 80 feet lies below the Waimanalo reef in borings at the new Kuhio Federal Building in Honolulu. The age of the tuff fits into the Illinoian (Table 2).

TABLE 2
AGE OF GLACIAL AND INTERGLACIAL PERIODS BEFORE PRESENT

Name	Years
Wisconsinan	70,000
Sangamon	250,000
Illinoian	500,000
Yarmouth	650,000
Kansan	800,000
Aftonian	1,150,000
Nebraskan	1,400,000
? Early Nebraskan	1,700,000
Sierran	2,300,000

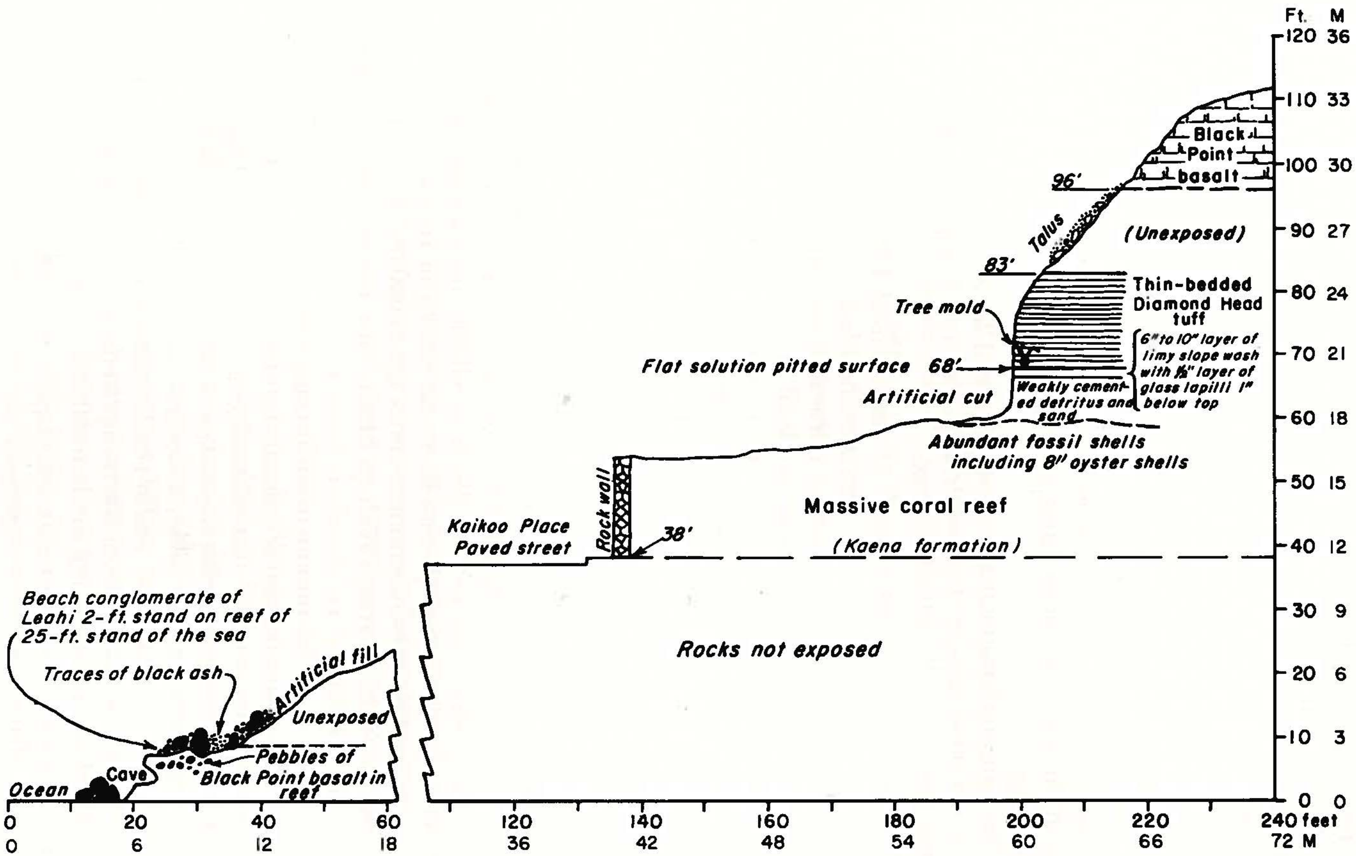

FIGURE 2.—Section of Kaikoo Place, Honolulu, showing relation of Diamond Head tuff and Black Point basalt to the Kaena reef.

The Nuuanu basalt has a K-Ar age of about 420,000 years. It lies between two layers of marine limestone in wells in Honolulu (Stearns and Vaksvik, 1935, p. 113) and is at least as old as Illinoian.

Sugar Loaf basalt has a K-Ar age of about 67,000 years. The basalt lies unconformably on Waimanalo limestone about 125,000 years old; hence the Sugar Loaf basalt is Wisconsinan in age.

Kaau basalt has a K-Ar age of 650,000 years. The stratigraphy of the lava indicates only that it is pre-Kaimuki volcanics in age and erupted during a high stand of the sea prior to the Waipio low, which was the Kaena 95-foot stand of the sea. The Kaena stand, of Yarmouth age (Table 1) fits the Kaau K-Ar dates.

The Kaimuki basalt has a K-Ar age of about 283,000 years. It is overlain by the 125,000-year-old Waimanalo reef and dunes laid down during the Waipio low; hence is Illinoian in age.

The Black Point basalt has a K-Ar age of about 480,000 years (Stearns and Dalrymple, in preparation). Because the Black Point and the Kaimuki basalts are both nepheline-basanites (Gramlich and others, 1971, p. 1401) and lie unconformably on Diamond Head tuff, it is likely that they were erupted simultaneously. The stratigraphic position of the Black Point basalt is well exposed in relation to the underlying and overlying limestones. The upper limestone is definitely Waimanalo in age and has been dated carefully by Ku and others (1974) as about 120,000 years old. Black Point basalt at Kaikoo Place in Honolulu rests unconformably on Diamond Head tuff which rests, in turn, upon fossil trees that grew on the weathered surface of the emerged limestone of Kaena or Yarmouth age, as shown in Figure 2.

The Diamond Head tuff and Black Point basalt are post-Kaena and are overlain by dunes of the Waipio low stand of the sea; hence these volcanics are Illinoian in age. They provide the most reliable cross-correlation we now have between uranium-series and K-Ar age dating in Hawaii. The Kaena reef of Yarmouth age has a uranium-series age of 600,000 ± 100,000 years, according to Veeh (Stearns, 1973b, p. 3483). This date is at the peak of the Yarmouth in Table 2.

A comparison of the amount of weathering and erosion between the end of the Yarmouth and the end of volcanism of the Koolau Volcano is instructive. For example, only two feet of weathered and partly weathered basalt formed in a dry climate on the Kaimuki and Black Point basalts during the 480,000 years since they erupted, in contrast to the 10 feet or more of soil formed on the Koolau basalt under similar climatic conditions. The basalt cobbles in the beach deposits of Kaena age in the dry Waianae Range show only slight weathering during the last 500,000 years.

The sequence of sediments encountered in the core borings at Waimanalo, Oahu, seems to represent the entire Pleistocene (Lum and

TABLE 3
AGE IN MILLIONS OF YEARS OF HAWAIIAN VOLCANOES

Island	Island Volcano	Range of K-Ar Ages (Million Years)*
Midway Atoll		17.9[a]
La Perouse Pinnacle	(French Frigate Shoals)	11.7[a]
Necker Island		10.0[a]
Nihoa Island		7.0[a]
Kauai Island		5.6-3.8[b]
Niihau Island	Paniau	3.0[c]
West Oahu	Waianae Range	3.4-2.7[b]
East Oahu	Koolau Range	2.5-2.2[b]
West Molokai		1.8[b]
East Molokai		1.5-1.3[b]
Lanai Island		1.25[d]
West Maui	Wailuku Mts.	1.3-1.15[b]
East Maui	Haleakala	0.8[b]
Hawaii	Kohala Mt.	0.68[e]
	Pololu V. Series	0.4[f]
	Hawi V. Series	0.25-0.06[f]
Hawaii	Puu Waawaa	0.4[h]
Hawaii	Ninole V. Series, Mauna Loa	<0.5[g]
Hawaii	Laupahoehoe, Mauna Kea	0.6[h]

*Dates determined by the following:
[a]Dalrymple and others (1974)
[b]McDougall (1964)
[c]Jackson and others (1972)
[d]Bonhommet and others (1977)
[e]Dalrymple (1971)
[f]McDougall and Swanson (1972)
[g]Two tests made by Everndon and others (1964)
[h]Funkhouser and others (1968)

Stearns, 1970). They were laid down at the foot of the great *pali* (cliff) eroded in the Koolau basalts, a feature which required a long erosional epoch. The presence of high marine shorelines and terraces including the Waimanalo, Kaena, and Olowalu on Mt. Kohala in Hawaii are in conflict with the K-Ar ages of the lavas there (Stearns, 1973b).

No doubt exists that the Hawaiian Islands have subsided, probably chiefly isostatically, since they were formed. Much of the subsidence has occurred since the deep valleys were cut, as shown by the fact that the valleys on Oahu have been traced to more than 5,000 feet under sea (Shepard and Dill, 1966; Andrews and Bainbridge, 1972). Borings at Ewa, Oahu, indicate that, during the early Pleistocene, barrier reefs existed off the south coast of Oahu and have subsided more than 1,000 feet (Stearns and Chamberlain, 1967; Stearns and Vaksvik, 1935, Pl. 20). Resig (1969) who studied the fossils in the Ewa test holes, thinks the 1,072 feet of sediment above the eroded and weathered Koolau basalts in these holes was all laid down during the Pleistocene. A radiometric date from a sample at 898 feet in Hole 1 is older than 700,000 years (Veeh, quoted in Hammond, 1970, p. 33). Hammond (1970, p. VII), who studied the same cores by magnetic methods, thinks the sediments have a minimum age of 1.62 million years and a maximum of 3.92 million years. The lavas under the sediments are definitely Koolau basalt, which have a K-Ar age of 3.5 to 4 m.y. (Funkhouser and others, 1968). But these dates are much older than the 2.2 to 2.5 m.y. usually accepted for the age of the Koolau basalts; hence the 3.5 to 4 m.y. dates are in question. It seems likely that the deep sediments in the Ewa holes were laid down during Nebraskan time.

The sea halted for long periods during subsidence, as evidenced by the broad submerged coral reefs. The most common are at −145, −180, −250, and −330 feet (Coulbourn and others, 1974), but these could have formed during eustatic lowering of the sea during the Pleistocene ice ages.

Another submerged reef off Kauai at a depth of −450 feet (137 m) is 4 miles (5.7 km) wide (Inman and others, 1963). Shelves at −450 feet are common worldwide and, for this reason are believed to represent the lowest and longest eustatic low stand of the sea during the Pleistocene. Grigg observed, from a submersible, a line of sea caves at this depth located at the base of fringing reef cliff at Kawaihae on the Island of Hawaii which probably indicates a brief halt at this level. A notch at −430 feet off Penguin Bank has been noted also by Grigg (Fig. 13). However, the notches represent only brief halts of too short a time for a coral reef to have grown to the size of the one off Kauai.

The average increment rate of Holocene reefs in the Pacific based on C^{14} dates is about 2 meters or 6.5 feet per 1,000 years (Stoddard, 1973, p. 320). Most of the drowned reefs exceed 100 feet in thickness requiring minimum halts of 15,000 years or more. Much additional time would be required to develop reefs 1 to 4 miles wide. Thus minimum halt time would be about 100,000 years for development of the drowned reefs. The growth of so many reefs during the low stands of the Pleistocene indicates that Hawaiian waters were not chilled significantly by glacial epochs.

The great subsidence continued during the early Pleistocene until the islands were submerged much more than they are today. Lanai was submerged by about 1,200 feet (365 m), but it is not certain that all the islands were submerged by this amount. We know that the ocean moved upward rapidly onto the land and retreated rapidly because no reefs were left at the maximum level and only one small patch of reef at the 560-foot level. Also, only soil was washed away, and then only in areas exposed to strong wave action. Bonhommet and others (1977) have found the average K-Ar age of

Lanai basalts to be 1.25 million years. Based on Table 2, extinction of Lanai occurred during the Aftonian interglacial.

Rapid emergence to the Manele shoreline at 560 feet (170 m) followed the great subsidence, and finally an additional emergence to somewhere near the present shoreline or lower. The 1,200 feet of rapid submergence and emergence requires some catastrophic event to explain its occurrence. Possibly a tremendous body of magma was intruded rapidly into the shallow crust driving the islands upward en masse 1,200 feet. However, the lavas erupted since the hypothetical uplift are so diverse chemically that this theory is not satisfactory. Or a great sinking of the ocean floors may have withdrawn vast quantities of water, causing a tectonic eustatic shift in sea level. Both processes could have worked together, resulting in the rapid rise and fall of sea level too great to be glacioeustatic in origin. A sufficient number of glacioeustatic shorelines are superimposed on the islands and are sufficiently concordant to indicate that the islands ceased movement at least since Yarmouth time about 600,000 years ago.

Lanai has marine deposits of the Waimanalo, Kaena, and Olowalu glacioeustatic stands of the sea similar in their heights to the deposits on the other islands and dunes of Waipio (Illinoian) age; hence Lanai has been stable for more than 650,000 years, if the dates in Table 2 are accepted. Sufficient time elapsed between the extinction of the Lanai volcano and the Mahana stand of the sea for deep canyons to be cut and for the basalts to weather to soil 10 to 50 feet thick (Stearns, 1940), thus indicating a much longer lapse of time before than after the Mahana stand.

The well-developed emerged reefs of the Waimanalo (Sangamon) and the Kaena (Yarmouth) stands of the sea are in sharp contrast to the absence of emerged reefs during the Olowalu stand, which is shown in Figure 1 as correlative with the Aftonian interglacial. The contrast could mean either that reefs did not thrive in Hawaiian waters during the Aftonian interglacial, or that the Olowalu shoreline was a short halt during the withdrawal of the sea from the Mahana shoreline and so is not correlative with the Aftonian interglacial.

DESCRIPTION OF SHORELINES

THE SHORELINES will be described from the oldest to the youngest. A list of those so far identified in the Hawaiian Islands is given in Table 4.

MAHANA 1,200 ± FOOT SHORELINE

Evidence for the Mahana shoreline on Lanai at 1,200 ± feet (365 m) was discovered and described by Stearns (1938), as follows. Five miles southwest of Lanai City, in the head of a small swale, 3,200 feet due south of Puu Mahanalua and 5,700 feet north of Manele Landing, are several veinlike fillings of fossiliferous marine limestone in crevices in basalt (Fig. 3). As determined by a transit level line, the altitude of the highest outcrop is 1,069 feet. This is the highest outcrop of marine limestone so far discovered in the Hawaiian Islands and in the central Pacific. A stone monument was built around this outcrop, to prevent its being destroyed by cattle. It is 80 feet S 43°30″ W from the mark "L1" chiseled in a 3-foot boulder on the east side of the swale. Evidently considerably more limestone formerly cropped out at this place, but weathering and livestock have nearly destroyed the exposure, leaving only the veinlike deposits. These outcrops are only ¼ to ½ an inch wide and 2 to 3 feet long. They contain, however, distinctly recognizable coralline algae, corals, and shells. Paul Bartsch and H. A. Rehder, of the United States National Museum, found one pelecypod—*Pinctada* sp.—and three gastropods—*Modulus tectum* Gmelin, *Triforis* sp., and *Strombus hellii* Rousseau— in fragments of limestone from this locality. All these forms are now living in Hawaiian waters, which fact indicates that the deposit is probably not older than Pleistocene. Its preservation is accounted for by the lack of drainage at this point.

Around the entire island of Lanai, but more particularly in areas where marine erosion would naturally take place, are numerous boulders and cobbles which owe their shape to wave action. Here and there are piles of large subangular rocks, which resemble partly destroyed marine stacks. A

TABLE 4
ANCIENT SHORELINES AND SHELVES IN THE HAWAIIAN ISLANDS†

Approximate Altitude (Feet)	(Meters)	Shelf or Terrace (Name)	Age B. P.	Type Locality (Island)
0	0	Present	Present	—
5	1.5	Kapapa	4,000±	Oahu
−15	−4.5	Koko	Late Holocene	do
−350±	−106±	Mamala	12,000±	do
−60	−18	Makai Range	Late Wisconsinan	do
−120*	−36.5	Makapuu	do	do
−135*	−41	Nawiliwili	do	Kauai
−155	−47	Lahaina Roads	Wisconsinan	Maui
−80*	−24	Kaneohe	do	Oahu
−190*	−58	Kahe	do	do
−205*	−62	Ewa II	do	do
−220*	−67	Barbers Point	do	do
2±	0.6	Leahi	115,000±	do
Low	Low	Kawela	Early Wisconsinan	do
25**	7.5	Waimanalo	Sangamon, 125,000±	do
12	3.6	Kailua	Sangamon	do
−30	−9	Olomanu	do	do
Low	Low	Coral Hill	Illinoian	do
High	High	Unnamed	do	do
−350 (?)	−106±	Waipio	do	do
−240±*	−75±	Makua	do (?)	do
45	12	Waialae	Early Illinoian (?)	do
70	21.5	Laie	do	do
95-100	29-30	Kaena	Yarmouth, 650,000±	do
−350 (?)	−106 (?)	Kahipa	Kansan	do
−205*	−62	Ewa I	do	do
25*	7.5	PCA	do	do
55*	17	Kahuku Point	do	do
250±*	75±	Olowalu	Aftonian (?)	Maui
325±	100±	—	—	Lanai
375±	114±	—	—	do
560	170	Manele	Pleistocene	do
625	190	Kaluakapo	do	do
1,200±	365±	Mahana	do	do
−1,200 to −1,800	−365 to −550	Lualualei	Late Pliocene (?)	Oahu
−3,000 to −3,600	−915 to −1,100	Waho	Tertiary	do

†The Penguin Bank at −185 ft. is present but has a complex history; hence is not a single halt.

*Position in sequence uncertain.

**Two shorelines 22 and 27 feet above mean sea level.

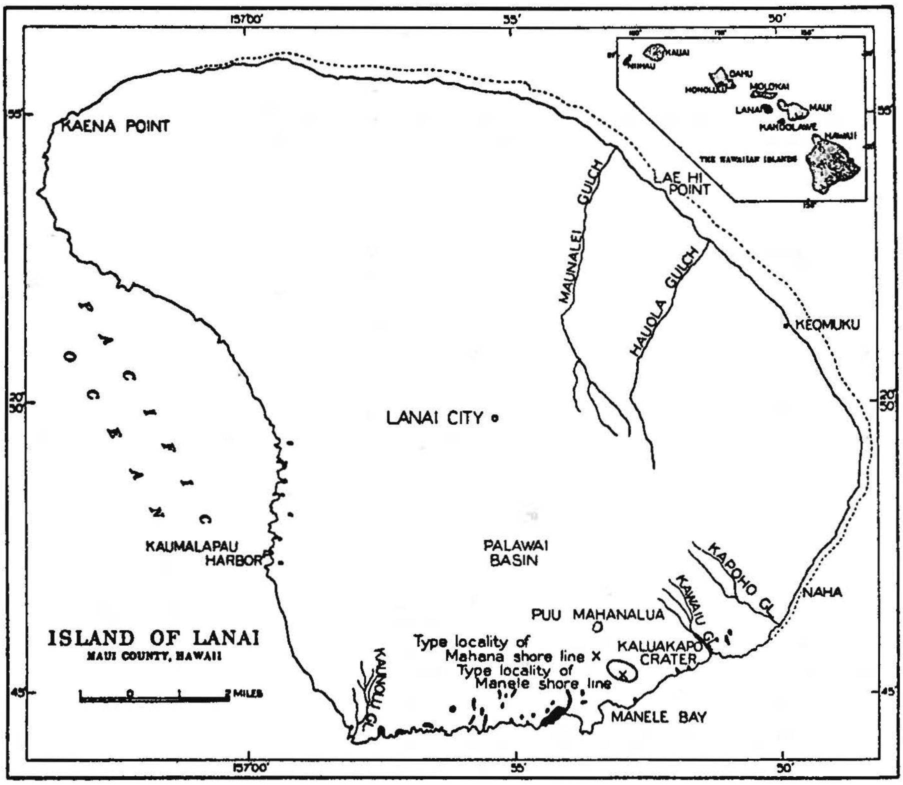

FIGURE 3.—Map of the island of Lanai showing location of type localities of Mahana, Kaluakapo, and Manele shorelines.

suggestion of a cliff about 25 feet high, its base at approximately 1,070 feet above sea level, was observed in several places. However, the evidence is not conclusive that a shoreline or halt in the emergence of Lanai occurred at this altitude. The summit and basin area on Lanai are covered with lateritic soil, from a few feet to about 50 feet deep. When the Mahana limestone was laid down, the shoreline may have been higher, because this soil has been eroded below an altitude of about 1,200 feet (aneroid); such a condition strongly suggests marine erosion up to this level. When viewed from high points, there is a distinct line of demarcation around the island, at about the 1,200-foot level, separating the wave-eroded scabland from the tillable soil above. At many places in this once sea-covered area, brown-black soils stand in strong contrast to the red lateritic soils on the summit area.

The rounded boulders and shingle left by this sea show slight spheroidal weathering. The bedrock beneath the shingle is decidedly weathered and shows definite spheroidal weathering in places, but most of this occurred prior to the Mahana stand. It is obvious that the present drainage pattern developed during the period when the deep lateritic soil was forming; and that the valleys were eroded to essentially their present form prior to the Mahana submergence, for the small amount of weathering of the Mahana gravel indicates that only a relatively short time has elapsed since the Mahana waters withdrew.

Macdonald and Abbott (1970, p. 208), without examination of the outcrop, suggested incorrectly that possibly "the sand was blown inland from a beach at a lower level." Such a suggestion casts doubt upon the validity of the Mahana shoreline. The present writer has examined hundreds of outcrops of lithified dunes in the Hawaiian Islands and has never seen a marine shell or coral fragment in windblown dune sand above the high water mark. Dunes blown inland two miles on Lanai to an altitude of 950 feet (Stearns, 1940, p. 13) have been described, but in no place do they contain fossil mollusks. No doubt exists that the fossiliferous deposit at 1,069 feet (326 m) elevation was left at that place by the sea.

On Oahu, West Maui, and Molokai, shingle and a surface swept free of soil up to levels comparable with the Mahana stand may indicate that these adjacent islands also have emerged about 1,200 feet.

The only other high-level marine deposit described to date on a central Pacific island was found on Upolu island at an altitude of more than 650 feet (198+ m) (Stearns, 1955). A large problem exists as to what caused the sea to rise to an elevation of 1,200 feet in early Pleistocene time and to stay at that elevation only long enough to remove soil and to recede to or below present sea level, with only brief halts on the way down. The rise and fall cannot have been caused by glacioeustatism because calculations indicate that ocean levels did not rise above an altitude of about 350 feet while the earth was ice-free.

KALUAKAPO 625 ± FOOT SHORELINE

Blocks of marine conglomerate were noted at an altitude of about 625 feet (190 m) in the swale on the southwest side of Kaluakapo Crater, a mile northwest of Manele Bay, Lanai (Stearns, 1938, p. 620). This limestone and the presence of rock platforms suggest a halt at the 625-foot level as the sea receded from the Manele stand. Easton (1965, p. 21), who later visited the locality, was impressed with the deposit as an ancient strand and named it the Kaluakapo shoreline.

MANELE 560-FOOT (170 M) SHORELINE

The Manele, or 560-foot (170 m) stand of the sea is another shoreline found on Lanai. Its type locality is 5,100 feet (1,555 m) south-southeast of Puu Mahanalua, 2,600 feet (792 m) southeast of the type locality of the Mahana stand of the sea, and 4,500 feet (1,372 m) northeast of Manele Landing in the crater of Kaluakapo (Fig. 3). This crater is about 4,000 feet (1,220 m) across. The floor is level and is composed of gravel of two distinct ages. The top gravel is unconsolidated and unconformable on a lower, partly consolidated one, which in places contains much fine silt. Recent stream erosion has cut through the top gravel into the older gravel, exposing in each of the channels draining the crater a fossiliferous limestone conglomerate consisting of large heads of waterworn coral, waterworn boulders of reef rock, and other calcareous debris such as is common on the shores of Hawaii. The highest fossiliferous limestone in place, as determined by a transit level line, is in the southwesternmost stream bed crossing the crater floor, at an altitude of 561.5 feet (171 m). Approximately 25 feet south of this outcrop is a large algaroba tree; midway between this tree and the limestone is a large flat boulder on which was cut a 5-inch cross as a reference bench mark.

Fossiliferous marine conglomerate of this shoreline crops out at an altitude of 550 feet (167.6 m) as determined by a barometer, in Kawaiu Canyon, in the unnamed gulches to the east of this canyon, in the gulches draining into Huawai and Poopoo bays, 2 miles (2.8 km) west of Manele Landing, and in Kaunolu Gulch (Fig. 3). No evidence of tilting was found, even though these outcrops stretch along the south coast for 7½ miles (10.7 km). All these Manele deposits lie in the bottom of gulches, indicating beyond question that the present canyons were cut prior to the Manele stand of the sea.

In Kawaiu Gulch the marine conglomerate left by this sea reaches 150 feet in thickness and, in one place, reef rock, rich in fossils, crops out. Nine species of Pelecypoda and 47 species of Gastropoda were identified from this locality. They are listed elsewhere (Stearns, 1938, p. 621). All are Pleistocene to Recent in age but a few are not now living in Hawaiian waters.

The Manele shoreline is indicated around most of Lanai by the sharp line of demarcation between the bare surfaces strewn with fresh waterworn cobbles and boulders, below an altitude of 560 feet, and the older and more weathered surfaces left by the Mahana sea above it. One gains the impression of a much longer time interval between the Mahana and the Manele stands of the sea than between the Manele and the present stand. It may be that the ocean receded lower than the 560-foot level after the Mahana, and then, during the Manele stand, Lanai was again partly submerged.

Above the site of the abandoned Hawaiian village of Naha, where the Manele sea eroded weak spatter cones, broad platforms and definite cliffs were cut. The land below the 560-foot level in this area is so barren that it supports scarcely any vegetation except the recently introduced algaroba trees. Above the old shoreline, where weathering has been greater, the land is covered with grass. This sharp break in the vegetation makes the shoreline obvious. Examples of broad platforms cut by the Manele sea may be seen 2½ miles southeast of Kaena Point, a mile southwest of Keomuku, and 2 miles north-northeast, a mile north, and ¾ of a mile east of Naha.

The Manele 560-foot shoreline is traceable on the south slope of West Molokai by the upward termination of black gypsiferous muds and a heavy cover of lag boulders (Stearns and Macdonald, 1947, p. 14). No high marine deposits were found on Kahoolawe, which has been stripped of soil by wave action up to 860 feet (262 m) elevation (Stearns, 1940, p. 126).

SHORELINES BETWEEN 250 AND 560 FEET

On most of the slopes of Lanai, especially on the northeast side, several definite wave-cut, gently seaward-sloping platforms, 1 to 20 acres in area, lie at altitudes between 250 and 560 feet. These benches are strewn with round boulders and cobbles and in places are obviously caused by more rapid yielding to wave erosion by weaker beds than by the underlying stronger rocks. There can be little doubt that stripping has occurred.

The wave-cut platforms are so discontinuous that, without numerous precise profiles, it is not feasible to determine which ones represent shorelines. In one place a narrow rock bench, several feet high and 10 to 30 feet wide, similar to the fringing bench along the present-day coast, was observed.

Because the field work was done with a barometer, and readings were subject to a change of 50 to 100 feet during the day, owing to atmospheric changes, only a general idea was gained of the short halts in the recession of the sea from the 560-foot Manele level. Halts, assumed from the position of platforms, possibly occurred at about 325 to 375 feet. Some of the marine fossiliferous conglomerates on the south slope are correlative with these halts (Fig. 3).

OLOWALU 250 ± FOOT SHORELINE

Well-cemented marine fossiliferous conglomerate is exposed in a gulch near Olowalu, West Maui. The gulch was used formerly as a target range, which was later moved into the next gulch to the west. The outcrop is in the bottom of a 6-foot gully and is overlain by talus from a trachyte cliff which forms a box head to the gulch about 75 feet (23 m) inland from the conglomerate. A level line was run to the outcrop 240 feet (73 m) above mean sea level and marked with an iron stake and a pile of rocks. The Olowalu shoreline was named from this locality near the village of Olowalu. The location of the Olowalu and other nearby marine limestone outcrops is shown elsewhere (Stearns and Macdonald, 1942, Pl. 1).

The road from the north tip of West Maui to Kahakuloa Valley traverses an area of severe marine erosion from the shore to more than 200 feet altitude. Huge waterworn boulders, former marine stacks, and the stripping away of more than 30 feet of soil indicate that this area, which faces the roughest seas, was likewise swept by rough seas during the Olowalu stand.

Conglomerates of the Olowalu shoreline are present also in the unnamed gulch a mile west of Kaunakakai, Molokai (Stearns and Macdonald, 1947, p. 14). Fossiliferous marine conglomerates are exposed at an altitude of 189 feet (57.6 m), by level line, in a gulch east of Puu Maniniholo near Kaunakakai (Stearns, 1935b, p. 1953).

Lum (1972, p. 192) has described a shoreline about 208 feet (63.4 m) above sea level in the bank of a small unnamed gully located half a mile southeast of Manawainui Gulch on the western slope of East Molokai near the main road to the airport. The elevation was determined by a level line. Lum showed the locality to the writer who made the section in Figure 4. The caves at 208 feet are stream-made and not wave-cut; hence the caves do not

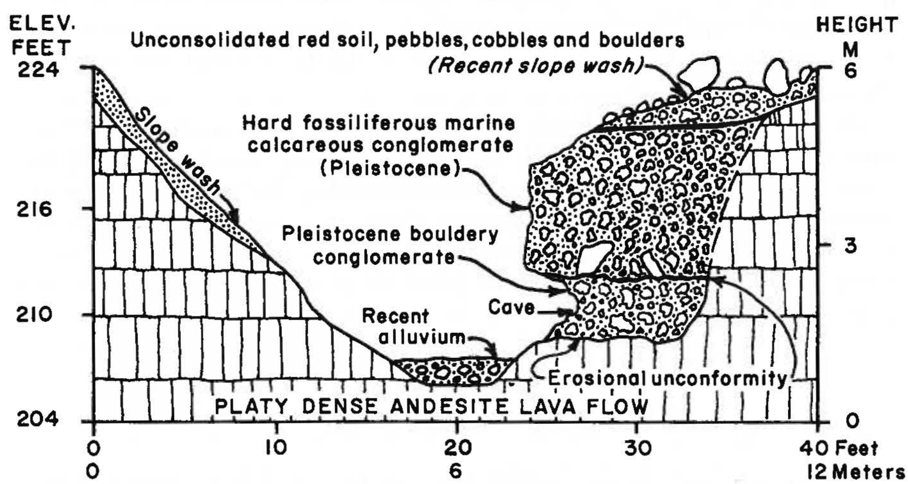

FIGURE 4.—Geologic section of marine conglomerate on Molokai island.

TABLE 5
STRATIGRAPHIC SECTION OF BLUFF AT KAHUKU QUARRY, OAHU

	Thickness (Feet)	Altitude of Top (Feet)
1. Cross-bedded lithified calcareous dune rock pitted by weathering (Waipio dunes)	11	91.0
2. Massive reef limestone (Kaena reef)	20.5	80.5
3. Erosional unconformity, in one place a lens of dirty friable stream-laid boulder conglomerate containing angular blocks torn from the underlying beach and boulders of Koolau basalt, 4 feet in diameter (Kahipa gravels)	variable	65
4. Lithified fossiliferous calcareous beach sediments showing usual cross-bedding (Kahuku Point beach conglomerate)	9.5	60.0
5. Reef limestone with bottom unexposed (Kahuku Point reef)	. . .	50.0
Total	41	

indicate a shoreline at 208 feet. The fossiliferous conglomerate indicates the sea has been there in the past. The highest point of the marine conglomerate is 213 feet (65 m). Samples of coral from the deposit were too altered to be dated by the uranium-series method. The marine conglomerate lacks sand and bedding typical of a beach deposit; hence the deposit probably was laid down below sea level during the Olowalu stand of the sea.

A few deposits of marine fossiliferous conglomerate, forming terraces along the south coast, and several wave-cut platforms along the northeast slope of Lanai are sufficiently concordant to indicate a shoreline on the island at an altitude between 250 and 270 feet, correlative with the Olowalu shoreline. Three fossil Pelecypoda and five Gastropoda were collected from what appeared to be a beach deposit of this shoreline in an unnamed valley, 2 miles (2.86 km) east of Manele Bay, Lanai. Considerable limestone, apparently before consolidation a typical calcareous beach sand, crops out at this place. The altitude was determined by a barometer that had been checked against a bench mark one hour earlier (Stearns, 1938, p. 624).

Only in very dry areas, and where streams do not head into wet upland areas, are high-level marine deposits preserved in Hawaii. It appears that the sea halted at the 250-foot level for only a short time because no reefs were built at this level. Large loose blocks of limestone were found among the talus during a highway excavation on the east end of Oahu which might have come from the Olowalu shoreline (Stearns, 1935b, p. 1933). An outcrop of

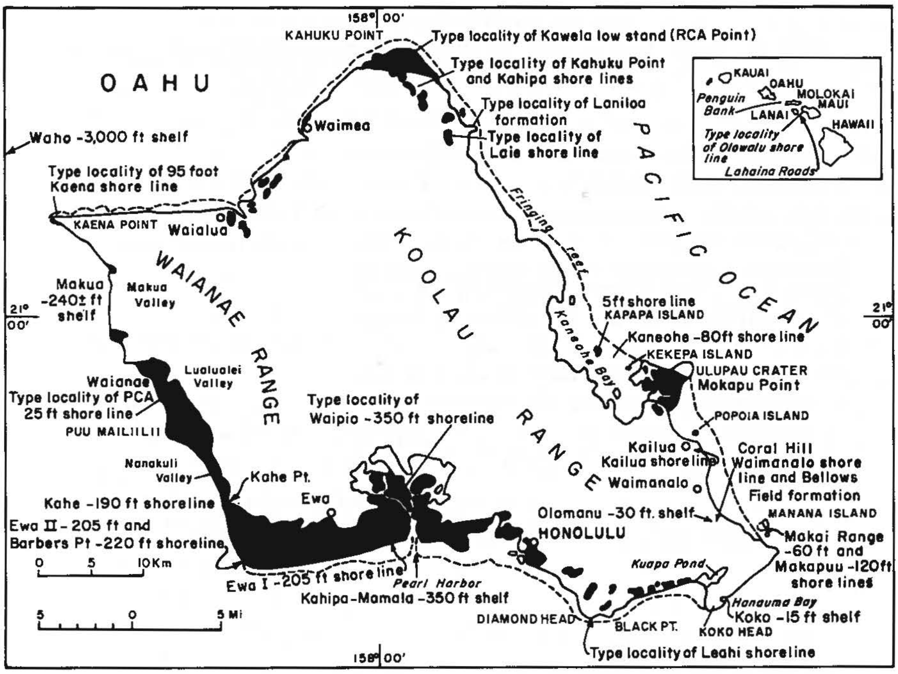

FIGURE 5.—Map of Oahu showing areas of emerged reefs (solid black), fringing reef (dashed line) and type localities of emerged and submerged shorelines and shelves.

eolianite on a saddle at the top of a basalt cliff 330 feet above sea level about 1,000 feet south of Mahie Point at Kahana Bay, Oahu, may be sand blown there from the Olowalu shoreline (Pottratz, 1968). Fossiliferous marine conglomerate in a gully two and a half miles south of Mahukona, Hawaii, apparently indicating the Olowalu shoreline, lies on Mt. Kohala at an elevation of 260 feet as determined by a barometer (Stearns and Macdonald, 1946, p. 55). The new road to Hawi crosses the gulch on a high bridge near the deposit. The older alluvium on Kauai was graded to a sea more than 200 feet (61 m) above sea level, doubtless the Olowalu stand of the sea (Macdonald and others, 1960, p. 84).

The age of the Olowalu shoreline is unknown except that it preceded the 95-foot Kaena shoreline and was separated from it by several shorelines described below. It may represent the maximum high stand of the sea during the Aftonian interglacial, as shown in Figure 1, because similar shorelines are worldwide at the 250 foot level.

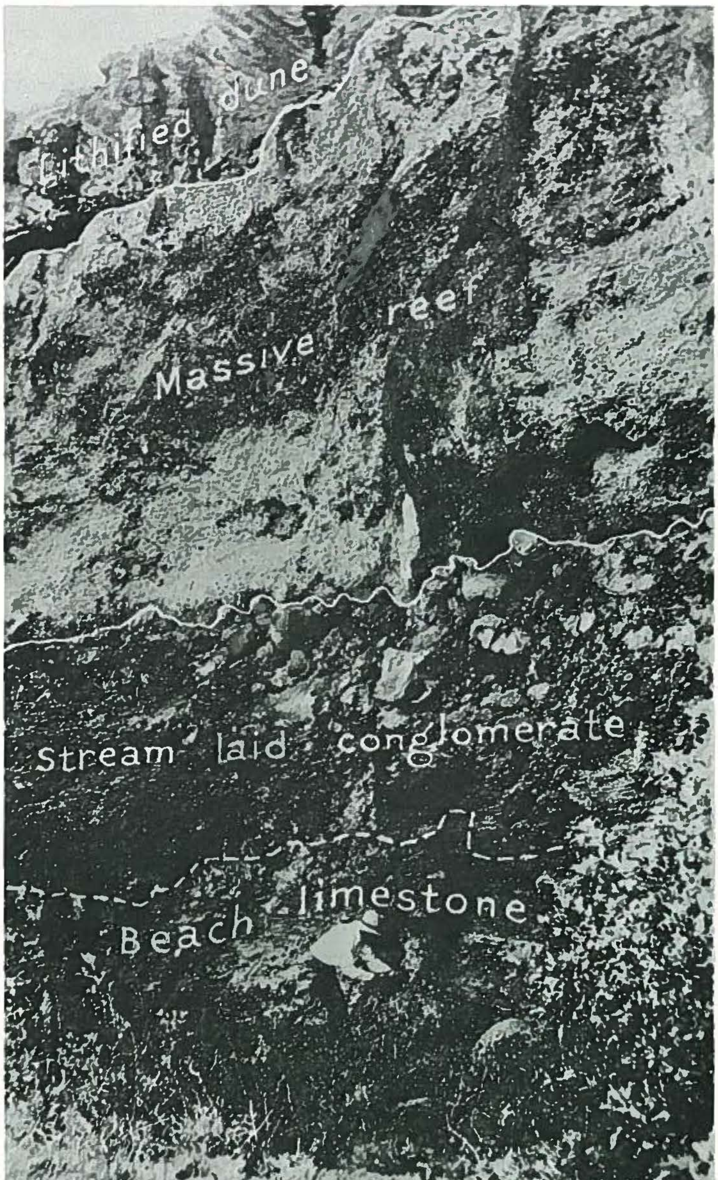

FIGURE 6.—Cliff near Kahuku, Oahu, showing the beach limestone of the Kahuku Point 55-foot shoreline separated by an erosional unconformity from the stream-laid conglomerate of Kahipa age. Another unconformity separates the conglomerate from the massive reef of Kaena age and it is, in turn, separated by soil and a solution unconformity from lithified dunes laid down during the Waipio low stand. Photo by H. T. Stearns.

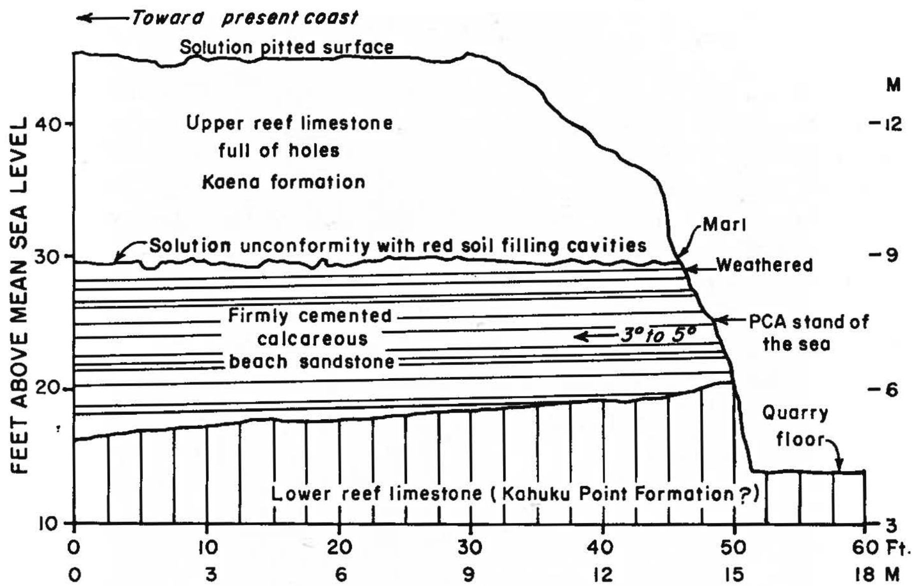

FIGURE 7.—Geologic section of the PCA Quarry, Oahu, showing the beach sandstone of the PCA 25-foot shoreline.

KAHUKU POINT OR 55-FOOT SHORELINE

The following section was formerly exposed in a bluff, 1½ miles (2.1 km) northwest of Kahuku, Oahu, 600 feet (183 m) south of the point where the highway rounds the northernmost point of Oahu (Fig. 5). The altitudes were determined by a Wye level. The rock units are shown in Figures 6 and 10.

It is assumed that the middle part of the beach sediments was approximately at mean sea level when the basal reef was laid down, or approximately 55 feet above present sea level. It is believed that this stand, named Kahuku Point from a nearby point, was a short halt in the recession of the sea from the Olowalu stage (Stearns, 1935b). The location of the type locality is shown in Figure 5. A view of the Kahuku Quarry taken when in operation has been published (Stearns, 1974c, Fig. 7). The quarry is now overgrown with brush. Because the beach rock is overlain by terrestrial conglomerate and the Kaena reef of Yarmouth age, the sea must have halted at the 55-foot (17 m) level in Kansan time. A limestone in the PCA Quarry in Lualualei Valley, Oahu, shown in Figure 7, has been assigned tentatively to the Kahuku Point formation. The name Kahuku has been pre-empted for the Kahuku Volcanic Series on Hawaii; hence the deposits of the Kahuku shoreline are renamed the Kahuku Point formation.

PCA 25-FOOT SHORELINE

Beach sandstone indicative of a former shoreline 25 feet (7.5 m) above mean sea level was formerly well exposed in the PCA Quarry in Lualualei Valley, Oahu (Stearns, 1975). It is separated from the overlying Kaena reef limestone by a solution unconformity and underlain by a reef limestone tentatively assigned to the Kahuku Point formation, as shown in Figure 7. In 1974 the quarry was filled for a housing development. An unconformity at the 25-foot level is exposed in the Barbers Point and Hawaiian Cement quarries on the Ewa plain. The PCA shoreline is tentatively assigned to the Kansan glacial epoch because it preceded the Kaena shoreline of Yarmouth age. The unconformity indicates that it was a halt of the sea on the way down to the Kahipa low (Fig. 1).

EWA I −205-FOOT SHORELINE

Hard, sandy beach rock, which indicated a stillstand, was cored between −203 and −209 feet in Ewa Test Hole 1 (Stearns and Chamberlain, 1967, p. 158). It was named the Ewa shoreline (Stearns, 1974a) and its location is shown in Figure 5. It is hereby renamed Ewa I because a later shoreline exists at the same elevation. A deposit consisting of basaltic pebbles and sand was cored between −204 and −208 feet in Ewa Test Hole 2, doubtless indicating the same stillstand. A beach conglomerate was found at this depth in Holes 1 and 8 at Waimanalo, and there it appears to be pre-Yarmouth in age (Lum and Stearns, 1970, Fig. 6). A pronounced solution unconformity was found in the Midway cores at −200 feet, indicating a long exposure of Midway Island above sea level (Ladd and others, 1967, p. 1094).

A hole drilled at Waialua, Oahu, penetrated a peaty layer at −204 feet below sea level, apparently indicating a swamp at sea level during the Ewa I stand of the sea (Stearns, 1974a, p. 802). It is certain that the Ewa I shoreline is pre-Yarmouth in age, but it is not certain whether it was a halt in Regression II or in Transgression II (Fig. 1).

KAHIPA OR −350-FOOT STAND OF THE SEA

The angular blocks of lithified beach sediments in the conglomerate overlying the Kahuku beach deposit indicate that these sands hardened before the stream eroded them. It would have been possible for this beach to lithify and the stream to cut the beach rock without a change in sea level. However, there is a fine interstitial silt in the conglomerate, which would have been washed away by waves breaking on this beach if the sea had not been lower when the conglomerate was laid down. Farther north in the same cliff, several inches of soil and decomposed limestone separate the 55-foot beach limestone from the overlying reef, which further indicates that the sea stood lower after the Kahuku stage. This low stand is called the Kahipa stage, after the Hawaiian name for this locality.

A remarkably level and extensive submarine shelf, 300 to 360 feet (480 m) below sea level, surrounds Oahu, Maui, and other islands of the group, as shown by the United States Coast and Geodetic charts. Although it cannot be shown positively that this shelf was formed concurrently with the Kahipa low stand of the sea, the Kahipa shore is correlated tentatively with this shelf. The Kahipa low is defined as the low stand of the sea reached during Kansan glaciation (Fig. 1). The location of the type locality is shown in Figure 5.

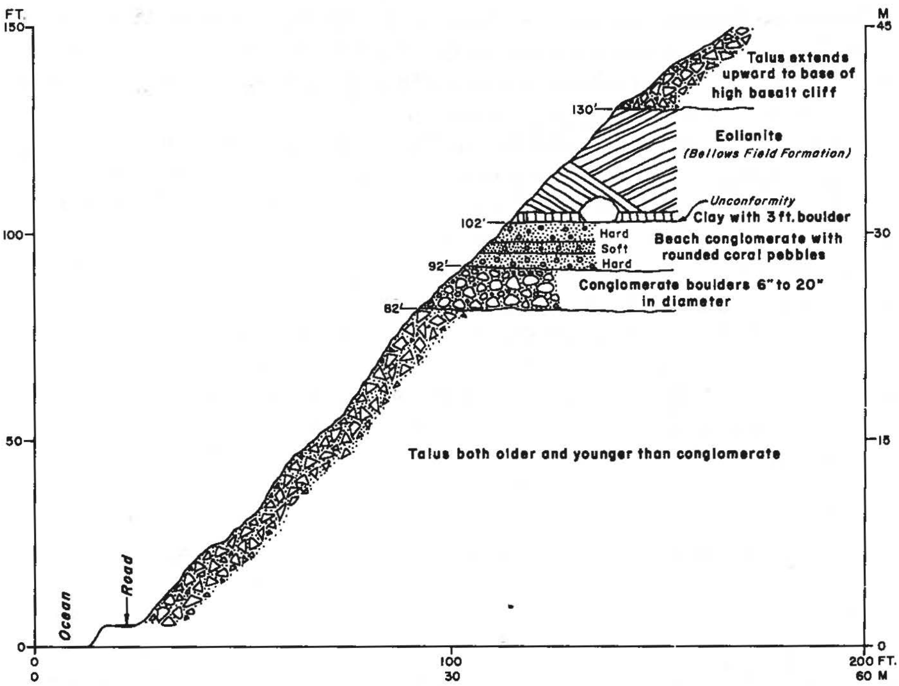

FIGURE 8.—Geologic section of Kaena beach deposits 1¼ miles southeast of Kaena Point, Oahu.

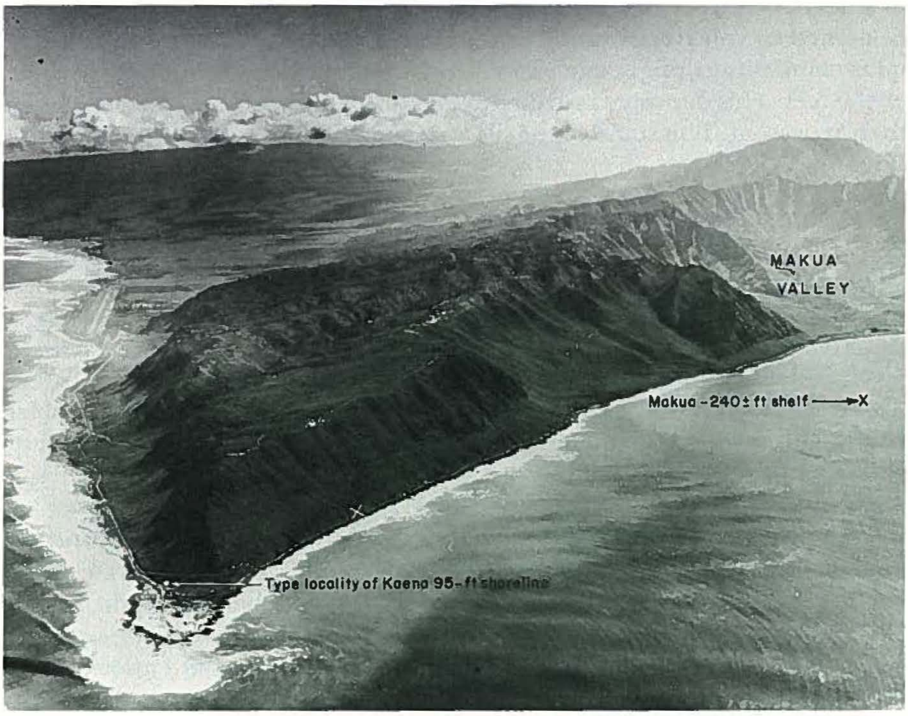

FIGURE 9.—Air view of Kaena Point and western end of the Waianae Range showing the type localities of the Kaena 95-foot shoreline and the Makua -240— foot shelf. Also shown, at the place marked X, is the location of the geologic section shown in Figure 8. Photo by Agatin C. Abbott, Hawaii Institute of Geophysics.

KAENA OR 95-FOOT SHORELINE

EVIDENCE ON OAHU

Bryan (1916, p. 121) described calcareous beach conglomerates along the Kaena trail between Makua and Kaena Point, and estimated them to be between 60 and 80 feet above sea level. For several hundred feet along this trail, 1¼ miles southeast of Kaena Point, excellent exposures of coarse, lithified, calcareous beach sand containing well-rounded lava boulders up to 3 feet in diameter occur. A geologic section of this outcrop is shown in Figure 8 and its location in Figure 9. The top of the marine deposit is at 102 feet. At Kaena Point there are several ledges of marine fossiliferous conglomerate projecting through the talus. The highest point of these deposits is directly above the former Kaena railroad station. This outcrop, as determined by a

Wye level, is 89 feet above mean sea level. It consists of a lava boulder beach, cemented by calcareous sand containing coral pebbles and fossils. A heavy talus mantles the upper edge, but a 4-inch coral cobble was found in the talus at 100 feet. This deposit was evidently laid down in a sea 90 to 100 feet higher than at present. This stand of the sea was named the Kaena, from this locality (Fig. 5).

On the south side of Puu Mailiili, at the Waianae Health Center, occurs a conspicuous white terrace of fossiliferous limestone, 100 yards wide and 130 yards long, at an altitude of nearly 90 feet. Back of the terrace is what appears to be a marine cliff from which a little talus has fallen. The highest outcrop of reef limestone, as determined by a Wye level, is 88 feet above sea level, and the highest outcrop of fossiliferous beach conglomerate is 97 feet above sea level. About half of the latter outcrop is made up of lava cobbles reaching one foot in diameter. This deposit definitely establishes a stand of the sea at least 95 feet (29 m) higher than the present.

It is evident that this terrace is an emerged fringing reef that grew in a sea at least 88 feet above the present. The ten feet of beach conglomerate above this reef is more or less continuous for ¼ of a mile to the east, on the side of this hill, and indicates a sea level about 95 to 100 feet above the present. Hitchcock (1900, p. 30) was apparently the first to call attention to this locality. Later, Bryan (1916, p. 119) estimated its height to be about 120 feet, which led him to believe there had been a 120-foot (36.5 m) stand of the sea.

An excellent exposure of Kaena reef can be seen along the highway around Oahu at its northernmost place two and a quarter miles northwest of Kahuku. A map of the area is shown in Figure 10 and a geologic section in Figure 11.

The Kaena 95-foot stand of the sea existed for a long time and led to the growth of the most extensive emerged coral reefs on Oahu now used for the manufacture of cement. Most of the stream-laid terraces are graded to this stand (Stearns, 1935b, Fig. 4). Ruhe and others (1965, p. 490) did much test drilling and other work supportive of the Kaena shoreline. The shoreline could have been as high as 100 feet (30 m). The writer collected a specimen of coral from the Kaena beach deposits at the upper end of Kawili Street subdivision in Lualualei Valley. Veeh dated it as >200,000 years old. He noted: "Some recrystallization (4% calcite) U^{234}/U^{238} ratio of 1.03 suggests 600,000 ± 100,000 years" (Stearns, 1973b, p. 3483). A basaltic dike cutting Kaena limestone at Black Point, Oahu, has a K-Ar age of about 410,000 years which also supports the age of the Kaena reef as being 500,000 ± years old (Stearns and Dalrymple, In press).

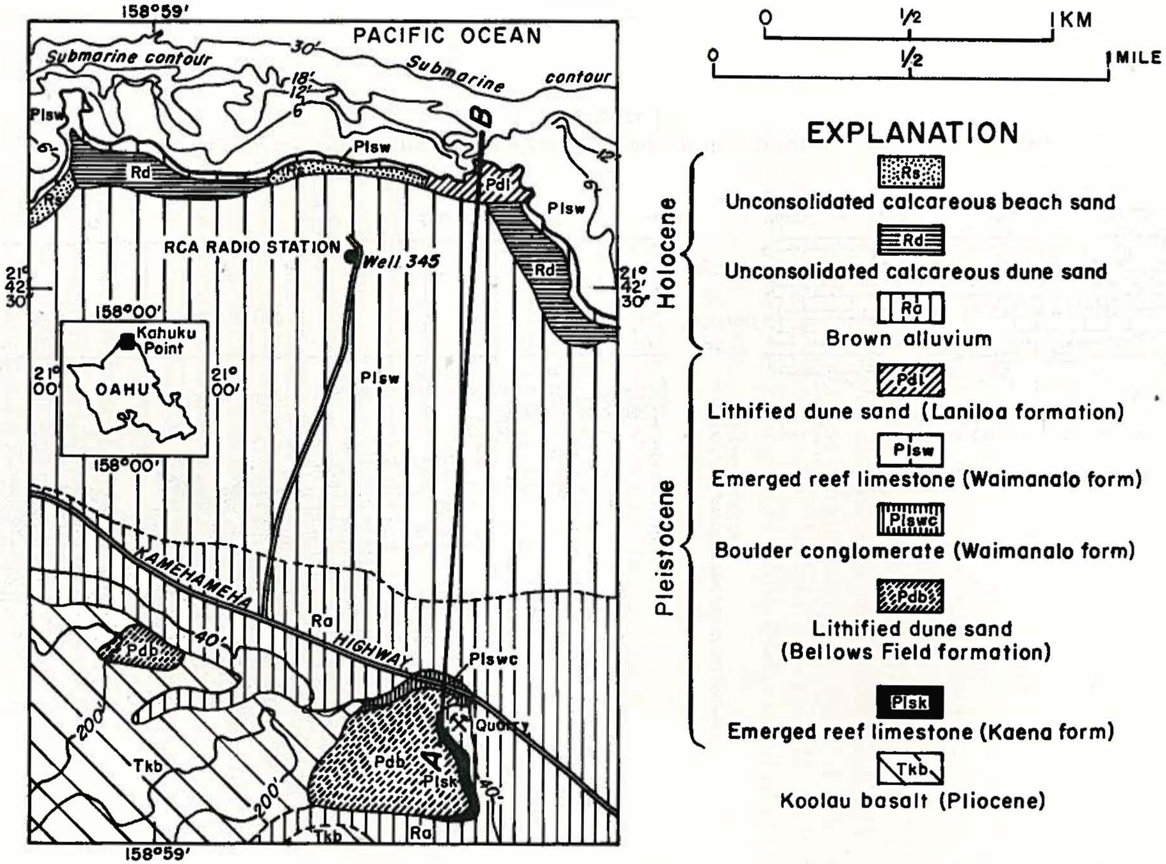

FIGURE 10.—Geologic map of Kahuku Point, Oahu.

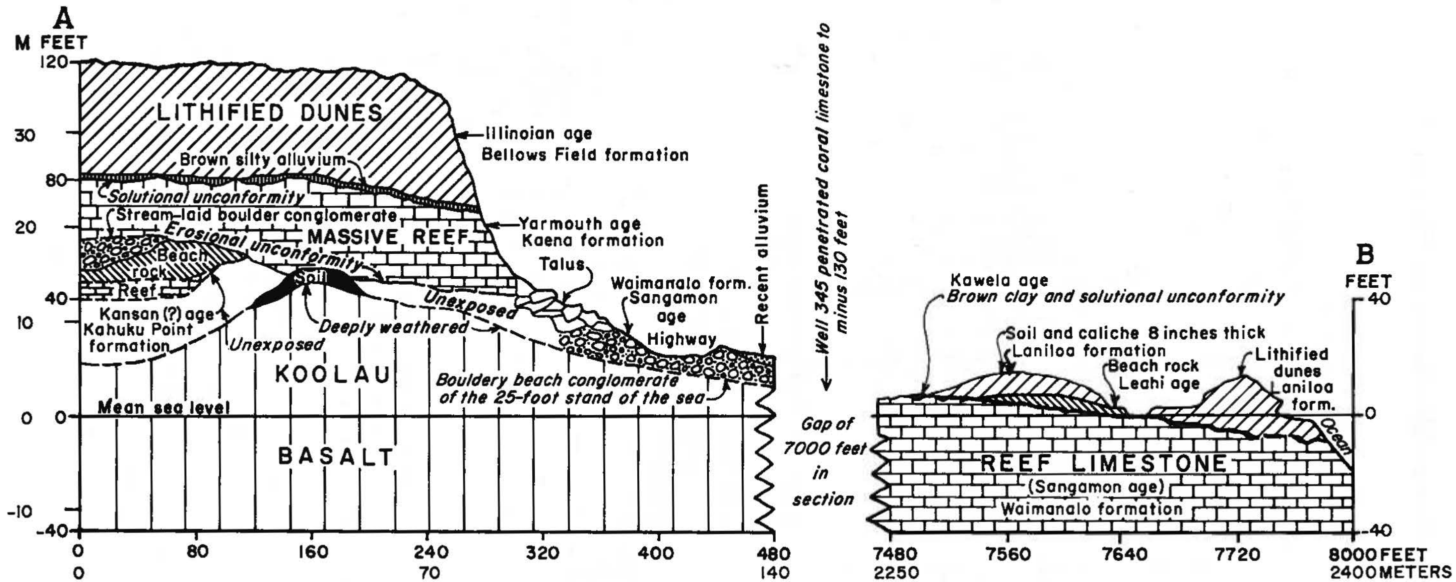

FIGURE 11.—Geologic section from Kahuku Quarry to the coast along a north-south line AB in Figure 10.

Evidence on Other Islands

A ledge of reef rock containing coral heads and other marine fossils lies unconformably on tuff in a small ravine on the northwestern side of Kawaihoa cone at an altitude of 100 feet, as determined by a barometer, on the island of Niihau (Stearns, 1947, p. 13). Other wave-cut features at this level also occur on the island. The gravel terrace at the mouth of Kalalau Stream on Kauai is graded to the Kaena shoreline (Macdonald and others, 1960, p. 84). An emerged reef crops out in an unnamed gulch a mile west of Kaunakakai, Molokai, at an altitude of 100 feet as determined by barometer (Stearns and Macdonald, 1942, p. 14). No marine deposits have yet been found of the Kaena stand of the sea on Maui, but many gravel fans at the mouths of valleys are graded to this sea (Stearns and Macdonald, 1942, p. 182). Numerous benches of marine conglomerate indicate the Kaena shoreline on Lanai (Stearns, 1940, p. 20). Waipio Valley on Mt. Kohala, Hawaii, contains terraces of alluvium graded to the Kaena stand of the sea (Stearns and Macdonald, 1946, p. 55).

LAIE OR 70-FOOT STAND OF THE SEA

Evidence on Oahu

About 1,000 feet southwest of the Mormon Temple at Laie (Fig. 5) is a hill of marine limestone capped by lithified dunes. Wye levels show that the contact of this lithified dune sand on the underlying lithified pebbly fossiliferous beach sand is 71 feet above sea level. About 50 feet west of this outcrop, beach limestone reaches a height of 76 feet. About 50 feet of reef limestone is exposed below, and east of, these beach sediments. Since some of these shore deposits were doubtless several feet above sea level, mean sea level of that period was probably 70 feet (21.5 m) above the present. The Laie stand of the sea is named from this locality.

Reef rock, overlain by lithified coarse beach sand containing pebbles of lava 3 inches across, crops out ½ mile west of Kahuku at an altitude of 65 feet, according to the topographic map. This reef is referred to the Laie sea.

At Ewa Plantation Reservoir No. 10, ¾ of a mile northwest of Gilbert, on the southeast slope of the Waianae Range, lithified fossiliferous bedded sand is exposed with its top 67 feet above sea level, as determined by a Wye level. An indeterminate amount of sand has been eroded away, but it is probable that this deposit was laid down near the shore of a 70-foot sea. At Kahe Point, which is between Reservoir No. 10 and Nanakuli Valley, a fossiliferous marine beach conglomerate clings to a lava bluff. A Wye level shows its highest point to be 75 feet above sea level; hence, it was probably laid down by the Laie sea. This locality was discovered by W. D. Alexander many years ago, while land surveying.

A practically continuous reef, 4 miles (5.7 km) long and 0.5 mile (.7 km) wide, extends across the mouth of Lualualei Valley and is now quarried for lime near Waianae. Bryan (1916) thought that this reef was laid down by an 80-foot sea, but a Wye level line to the highest exposed shore deposits at the inland edge of this reef gives a height of only 72 feet; hence, it is correlated with the Laie sea. Poor estimates of the height of this particular reef have led various writers to postulate 40-, 50-, and 60-foot seas. It is evident that much of the confusion about high stands of the seas on Oahu results from different estimates of the height of one and the same reef.

The poor development of terraces in the noncalcareous sediments at the mouths of Oahu streams points to the Laie stand as being only a temporary halt in the recession of the sea to lower levels. Consequently, the extensive reef in Lualualei Valley, with its top 65 feet above sea level, may have accumulated largely during the Kaena stand of the sea, and simply failed to grow to the ocean surface during that epoch. Then, during the subsequent Laie stage, this reef would have been practically at sea level, and any higher portions would have been planed off, so that it now looks as though it were entirely the product of the Laie sea. The extensive high reefs on the Ewa coral plain may have had a similar history.

The reef in Lualualei Valley has been incised by streams so that it now forms distinct terraces along them. Behind the reef are extensive deposits of older alluvium, graded to the Laie sea and forming stream terraces. The seaward front of the reef terminates in most places in a steep bluff with its base about 25 feet above sea level. This escarpment was cut by waves of a sea about 25 feet higher than the present, because beach deposits lie at the base of the cliff. Thus, the 70-foot sea is older than the 25-foot sea.

Beach conglomerate, unconformable on Waianae basalt, was exposed in 1970 at the south end of Puu Heleakala in Lualualei Valley where Helelua Street terminates at an altitude of 70 feet, according to construction drawings. Marine limestone could be traced in a ditch to an altitude of 85 feet indicating the 70-foot stand was only a brief halt in the regression of the sea from the Kaena stand. Ruhe and others (1965, p. 490) questioned whether the Laie stand was distinct from the Kaena stand. The writer agrees with them that the Laie stand was not a long stand, but only a short halt in the regression from the Kaena level.

When Farrington Highway to Waianae, Oahu, was widened, it exposed 10 feet of emerged, weakly consolidated calcareous beach conglomerate resting unconformably on basalt of the upper Waianae Volcanic Series on the north side 1.05 miles (1.5 km) east of the Hawaiian Electric Co. plant in Kahe Valley (Fig. 12). The deposit is well bedded and consists of numerous

FIGURE 12.—Bedded beach conglomerate 10 feet thick on the north side of Farrington Highway, 1.1 miles east of the Kahe Hawaiian Electric Co. plant. The top of the beach is 62 feet above mean sea level.

coral pebbles and cobbles in an abundant matrix of "coral" sand dipping about 3° seaward. The deposit is overlain with 1 foot of black clay containing numerous blocks of basalt. The base of the deposit is 52 feet and the top of the deposit is 62 feet above mean sea level as determined from the highway profile. A pebble of coral was sent to T. L. Ku of the University of Southern California who found that it had "an age of $\geqslant$350,000 years, i.e., beyond the range of the U-Th method" (personal communication, Dec. 13, 1974). It appears to have been deposited during a brief halt of the sea as it receded from the Kaena 95-foot stand.

Drilling and geologic mapping by Dames and Moore Consultants for foundations at the Kahe electric plant in nearby Kahe Valley revealed marine beach deposits of the Kaena stand of the sea and numerous beach deposits left as the sea receded during the Illinoian glacial epoch.

WAIALAE 40-FOOT SHORELINE

The 40-foot (12 m) Waialae shoreline was named by Wentworth (1926, p. 66) from cliffs in the Waialae area of Oahu which he thought were cut by a sea 40 feet higher than today. However, these cliffs extend far below sea level and were cut by a sea lower than today. Many terraces along the coast of Oahu are graded to a sea about 40 feet above present level (Stearns, 1935b, p. 1941), but marine deposits at this level are scarce. A small patch of fossiliferous marine conglomerate was exposed at 37.5 feet above sea level (Stearns, 1939, p. 21) on Hawaiiloa Ridge on the north side of Kalanianaole Highway. Easton has provided the best evidence of the Waialae stand by his discovery of marine caves and fossiliferous conglomerate at about 40 feet in Mauna O Ahi Ridge in the Hawaii Kai area of eastern Oahu (Easton, 1963). The scarcity of deposits makes it seem likely that the Waialae stand was only a brief halt during the regression of the Kaena sea to the Waipio low during the early Illinoian glacial epoch.

Marine fossils were found approximately 40 feet above sea level, in a hole drilled 1,800 feet west of Well 7 of the Hawaiian Commercial and Sugar Company, near Puunene, Maui, on the isthmus connecting Haleakala and West Maui. These may belong to the Waialae stand or to some higher sea.

A small outcrop of fossiliferous marine conglomerate lies at an altitude of 40 feet half a mile south of Mahukona on Mt. Kohala, Hawaii, that may have been deposited by the Waialae stand of the sea (Stearns and Macdonald, 1946, p. 55). No deposits of the Waialae stand have been found on Kauai, Niihau, Molokai, or Lanai.

MAKUA −240 ± 10-FOOT SHELF

The −240 ± 10-foot (75 m) shelf is ubiquitous in Hawaii and was first seen by Chamberlain (quoted in Stearns, 1966a, p. 257) from a submersible along the Waianae coast between Kaena and Kepuhi Points, Oahu. It was named the Makua shelf from Makua Valley (Fig. 9), which discharges in this area (Stearns, 1974a, p. 802). The shelf was found, by seismic reflection profiling, to be present under marine sediments all around Oahu (Campbell and others, 1972, p. 135). The major stream valleys had cut across it before burial by sediments. Soundings on U.S. Coast and Geodetic Survey Chart No. 4139 indicate it is three miles across in Lahaina Roads between Maui and Lanai and between Molokai and Lanai. Grigg reports that it is the shelf below the −190-foot (58 m) shoreline. The extensiveness of the shelf indicates that it was a reef which grew during a long halt in the Pleistocene. It may have been the level reached during the Waipio low. The shelf is assumed to be later than the Kaena stand because the reefs of that stand are so extensive they should have buried the −240 ± 10-foot shelf. The sonar profile made by Robert Kinzie off Pokai Bay at Waianae, Oahu, shows this shelf.

WAIPIO −350 ± FOOT (?) LOW STAND OF THE SEA AND THE BELLOWS FIELD EOLIANITE

Evidence on Oahu

At a tuff locality near the south end of Waipio Peninsula in the Pearl Harbor area, 4 feet of laminated Salt Lake tuff, full of molds of stems and branches of small trees, can be seen resting on 4 inches to a foot of red-brown soil underlying reef limestone. The soil contains numerous fragments of partly rotted limestone, showing that subaerial weathering of limestone occurred prior to the deposition of the tuff. This soil horizon and overlying tuff containing upright tree molds passes beneath sea level, 100 feet south. The tree casts in the tuff indicate that the tuff was deposited subaerially upon the soil. Where it passes beneath sea level this tuff is overlain by 6 feet of emerged reef; hence, the sea must have stood lower than at present at the time the tuff was deposited, and then higher at a later date. A view of this locality has been published (Ruhe and others, 1965, Pl. 10). According to Pollock (1928), tree molds were found in similar tuff below sea level at the Pearl Harbor Navy Yard, in the course of excavations for a pipe line.

The Salt Lake tuff, with its submerged tree molds, is cliffed in many places by the 25-foot sea, and is overlain by reef of the same sea. The reef underlying this tuff has been traced into noncalcareous sediments forming a marine terrace 100 feet above sea level. Thus, this low stand, called the Waipio after the localities on Waipio Peninsula, took place prior to the 25-foot stand and after the 95-foot stand (Fig. 5).

The Waipio low stand exposed broad marine flats on which sand was abundant in many places. It was also a time of strong trade winds, and great volumes of sand were blown inland, in places to great heights. All dunes of this epoch are firmly cemented and hard enough to be used for concrete aggregate. Large crystals of calcite line cavities in the eolianite. The drop in sea level lasted long enough for all major streams to cut their channels to levels well below present sea level along the coasts. Considerable erosion of the sedimentary caprock of the Honolulu artesian basin took place, resulting in numerous leaks, now the site of artesian springs.

Dunes reached a height of 160 feet (49 m) at Waimanalo, Oahu, and they were found by drilling to extend 160 feet below sea level (Lum and Stearns, 1970, p. 14). They extend a horizontal distance of 3 miles. Dunes formed during the Waipio low comprise the Bellows Field eolianite (Fig. 5). This formation covers a large area on the east side of Diamond Head (See *Geologic Map of Oahu,* Stearns, 1939). The dune surfaces are covered with solution pits, crusts of caliche, and patches of reddish brown soil. It is obvious that the dunes have been long exposed to weathering. The Waipio low represents the long period of low sea level reached during the Illinoian glacial epoch (Fig. 1). It is presumed to have dropped to about −350 feet (107 m), but it may have dropped only to −240 feet when the Makua shelf reef was formed. The drilled holes at Waimanalo show the sea dropped more than 160 feet below present level. Dunes formed during the Waipio low commonly cover Kaena reef limestone and are always separated from it by a layer of soil (Figs. 6, 8, 10, and 11).

Evidence on Other Islands

Lithified dunes of Waipio age are extensive on Niihau and reach an altitude of 45 m (Stearns, 1947, p. 25); on Kauai of 500 feet (150 m) (Macdonald and others, 1960, p. 85); on Molokai of 600 feet (180 m) (Stearns and Macdonald, 1947, p. 28); on Lanai of 950 feet (290 m) (Stearns, 1940, p. 13); and on Maui of 200 feet (60 m) (Stearns and Macdonald, 1942, p. 109). More sand blew inland during the Waipio low than in all other low stands put together. All deposits indicate strong trade winds. A time interval occurred long enough after they cemented for 6 inches of brown soil and solution pits a foot or more deep to form on the Bellows Field eolianite at the Waimanalo Quarry. The soil is overlain there by 5 feet of eolianite (Fig. 13).

UNNAMED POST-WAIPIO STAND OF THE SEA

The discovery in 1974 of a solution unconformity and soil bed between two eolianites in the Coral Hill Quarry 1¼ miles southeast of Waimanalo (Fig. 13) requires a rise in sea level from the Waipio low to stop the wind having access to sand. The sea did not rise above present sea level or some records should have been left. The sea remained at the high level long enough for the formation of solution-made pits 2 feet deep in top of the Bellows Field eolianite, and for 6 inches of soil to form. The top of the outcrop is about 50 feet (15 m) above sea level.

CORAL HILL LOW STAND OF THE SEA

The 5 feet of hard dune limestone above the soil and Bellows Field formation (Fig. 13) requires a drop in sea level so that the wind could again have access to a sand supply. It is hereby named the Coral Hill low from the place where it was discovered and the deposits the Coral Hill eolianite. Coral Hill is notched by the Waimanalo 25-foot sea; hence, the eolianite cannot be

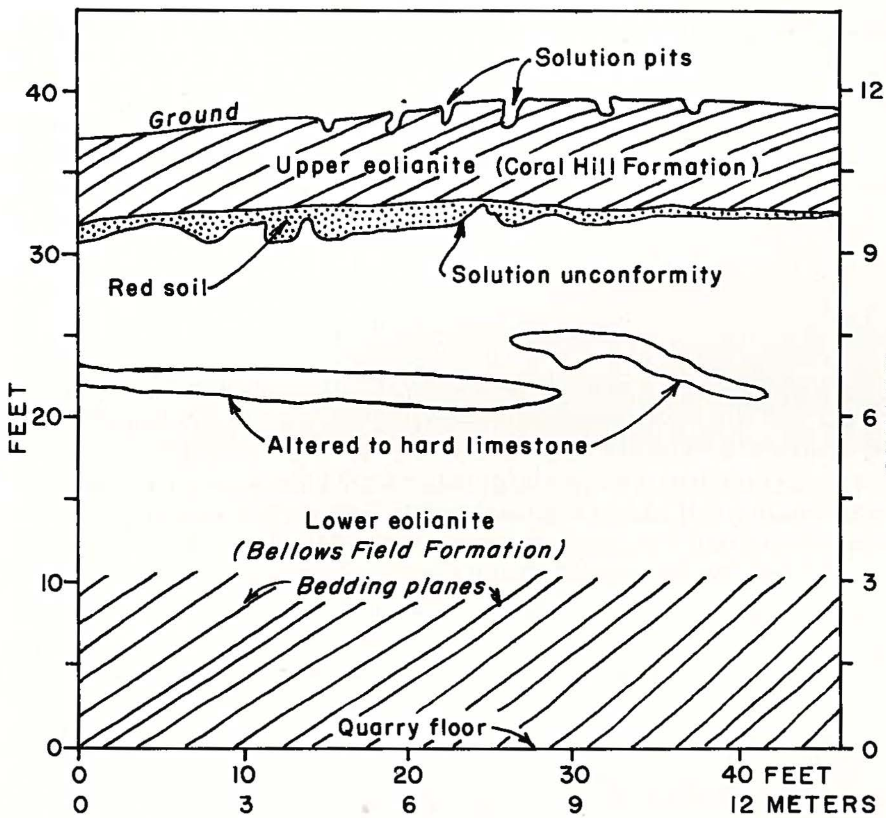

FIGURE 13.—Uncomformity between dunes of two ages at Coral Hill Quarry near Waimanalo Quarry, Oahu.

the Laniloa eolianite deposited during the Mamala low, which was later than the 25-foot stand. The low did not last long compared with the Waipio low when dunes 160 feet high accumulated. The presence of two eolianites separated by soil has been noted once before on Oahu at the Artex Quarry near Laie (Stearns, 1970, p. 56). The upper eolianite at that quarry was thought to be too well cemented to belong to the Laniloa formation; hence, it probably is correlative with the Coral Hill eolianite.

OLOMANA −30-FOOT SHELF

The Olomana −30-foot (9 m) shelf truncates Bellows Field dune limestone of Illinoian age for a horizontal distance of 650 feet. It is overlain by five feet of Waimanalo reef limestone of Sangamon age, as found in cores from holes drilled at Waimanalo, Oahu. The Olomana −30-foot shelf probably was cut by the sea on the rise from the Waipio low. If so, it is early Sangamon in age. It is named from Olomana Peak near Waimanalo (Lum and Stearns, 1970, p. 13). It is doubtful whether evidence of this shelf can be found elsewhere except in drilled holes.

KAILUA 12-FOOT SHORELINE

The type locality of the Kailua 12-foot (3.6 m) shoreline is in the former Costa Dairy pasture cut into lithified dunes of Waipio age near Kailua, Oahu (Fig. 5). The dunes have been quarried away and the area is now covered with apartments. The sea rose from the Waipio low to 12 feet and stayed there long enough to remove a large mass of eolianite, make many large sea caves, and cut a cliff 35 feet high as shown in Figure 14. This stand occurred during the rise of the sea in late Sangamon time. After this halt the sea rose to 22 and 27 feet (Waimanalo stand) and a few corals grew on the eolianite at an altitude of 14 feet (4.25 m) (Stearns, 1935b, p. 1945). Most of the emerged and extensive reefs of the Waimanalo 25-foot sea do not rise above an altitude of 12 feet, indicating that the time interval between the end of the Kailua halt and the 22 and 27 foot halts was relatively short. Ruhe and others (1965, p. 495) found much evidence from a study of topographic maps on Oahu of a 10- to 15-foot terrace. The writer believes they compiled elevations of terraces of the Kailua stand of the sea, and not a post-Waimanalo 12-foot stand.

WAIMANALO 25-FOOT SHORELINE

The Waimanalo shoreline is the best documented in Hawaii, and has been the most extensively studied. It consists of two shorelines 22 and 27 feet above sea level, but 25 feet (7.5 m) is used because in most places the two levels cannot be distinguished. Their altitudes were determined by a level line to the apex of the notches cut into eolianite at the former Costa Dairy near Kailua shown in Figure 14. They extend for 4,000 feet along the shoreward face of Coral Hill, the large deposit of lithified dunes at Waimanalo, and the shoreline was named from this locality (Fig. 5; a view is shown in Lum and Stearns, 1970, Fig. 3). It was named by Stearns (1935b, p. 1944). The shoreline represents the long halt during the Sangamon interglacial and more reef grew at this time than at any time since the Kaena 95-foot stand, probably because the water was warmer than today (Oster-

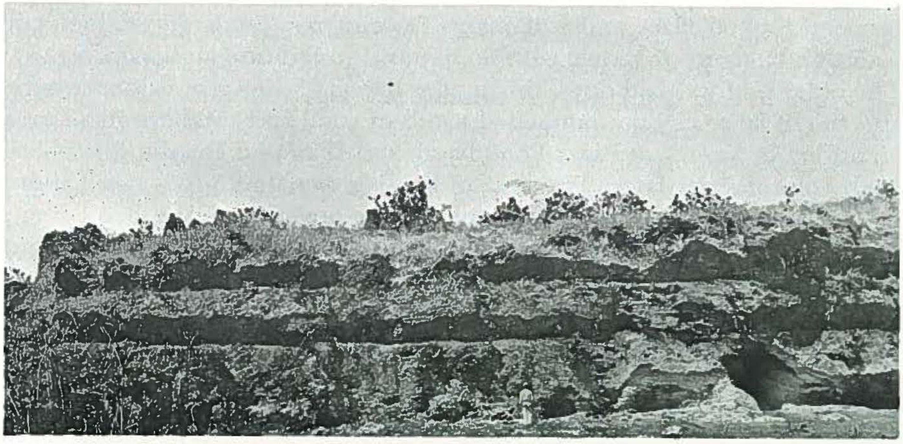

FIGURE 14.—View of double notches 22 and 27 feet above sea level cut into eolianite at the former Costa Dairy near Kailua, Oahu. The man stands on the bench of the Kailua 12-foot stand of the sea. Photo by H. T. Stearns.

gaard, 1928, p. 32). The reef is characterized by dense limestone filled with large laminated heads of coral and coralline algae and is readily distinguishable in most places from other reefs. The top of the emerged reef lies usually not more than 10 feet above sea level. But outcrops of fossiliferous beach conglomerate are ubiquitous and, along exposed coasts, reach 35 feet above sea level, as at Black Point, Oahu. Beach conglomerates of the Waimanalo stand and terraces graded to this level are found on all of the islands in Hawaii but are most abundant on Oahu. All marine deposits of this stand are included in the Waimanalo formation. In most places the beach conglomerates of the 25-foot stand are hard rock, but in other places they are only weakly cemented and easily confused with later deposits.

Much effort has been spent on determining the absolute age of the Waimanalo formation. The C^{14} dates range from 18,000 to > 38,000 years (Ruhe and others, 1965, p. 494), whereas the uranium series dates range from 120,000 to 125,000 years (Ku and others, 1974; Stearns, 1974a, p. 800). The C^{14} dates are in error (Stearns, 1972) because there was no main interglacial high sea level corresponding with these dates.

A re-examination of the limestone along the shore at Kaikoo Place, Oahu, revealed that the shore notch is cut into reef limestone of the Waimanalo 25-foot sea rather than reef of the 5-foot sea. This correction is shown in Figure 2, as compared to its first printing (Stearns, 1966a, Fig. V.5). No stands of the sea later than the 25-foot stand left reefs, an important criterion for separation of deposits. Much of the shore of Black Point between Kaikoo Place and Kulamanu Place carries two reefs of different ages tightly grown together with no deposits to indicate an unconformity. The older reef was laid down during the Kaena 95-foot sea. It is very hard and full of large circular laminated heads of coral and coralline algae. It is identified by its lack of Black Point basalt and Diamond Head tuff cobbles. Both volcanics are later. The reef of the Waimanalo 25-foot stand there always contains cobbles and commonly huge boulders of the Black Point basalt. Blocks of Diamond Head tuff occur also. Superimposed and cemented to both of the older reefs are the conglomerates of the Leahi stand of the sea. No reef limestone of this stand is known to exist. The conglomerates consist of pebbles and cobbles of coral and Black Point basalt in a limestone matrix. They commonly are cemented to the interstices between the boulders in the Waimanalo reef. They form fairly continuous deposits with their top 5 feet above sea level along the shore, but they never reach the level of the beach deposits of the 25-foot sea. The deposits on this coast are so tightly cemented together with very irregular contacts that they are distinguished with great difficulty.

KAWELA LOW STAND OF THE SEA

The sea fell an unknown distance below present sea level after the Sangamon interglacial as a result of the growth of glaciers again. The Waimanalo limestone was exposed to subaerial weathering. It became extensively pitted and near Laie, Oahu, developed deep sink holes. At RCA Point near Kahuku the pits were filled with clay which became lithified. The clay was first studied by Chapman (1946). It contains fossil land snails and extends below sea level indicating the ocean was lower when it was deposited (Fig. 11). This low stand of the sea (Figs. 1 and 5) was named Kawela from a nearby village (Stearns, 1970, p. 67).

A red soil is exposed on the east side of Mokuauia Island near Laie at tide level. At this place it is so hard that it caps small pedestal rocks of limestone along the shore. It is suspected that the soil is windborne. A brown clay six inches thick caps emerged reef and is overlain by Laniloa eolianite at the former sink hole near Laie (Stearns, 1966b, p. 18).

LEAHI 2 ± FOOT SHORELINE

The type locality of the Leahi shoreline is at the foot of Beach Road on the south shore of Diamond Head (Fig. 5). It was first described as the Leahi I shoreline by Stearns (1970, p. 57). It derives its name from the Hawaiian name for Diamond Head. A Leahi II shoreline at the same place was also described (Stearns, 1970, p. 71), but C^{14} dating of a sample from the conglomerate indicates that the deposit is only 2,340 ± 110 years old (Stearns, 1972, p. 242); hence, it does not represent a new shoreline. Thus, Leahi II is abandoned. The conglomerate may be an erosional remnant of the Kapapa stand described later. A geologic section of the type locality is given in Figure 15. A color photograph of Leahi beach conglomerate at Diamond Head has been published (Stearns, 1970, Fig. 7). It was from this outcrop that a uranium series date was obtained of 121,000 ± 4,000 years (Ku and others, sample C16, 1974, p. 959). Another coral sample from Leahi conglomerate 5 feet above sea level on Black Point gave a date of 125,000 ± 10,000 years (date by Veeh in Stearns, 1974a, p. 797).

For years the Leahi shoreline was not recognized because its deposits lie along the present shore at and a few feet above tide level. Now that the shoreline has been recognized, it has been found in a number of places. Commonly, dunes associated with the shoreline are overlain by talus or alluvium (Stearns, 1974a, Fig. 5). The consolidated beach deposits of this stand also fill solution cavities in the older Waimanalo limestone. A specimen from such a filling from Mokapu Point has been dated as 118,000 ± 9,000 years (Spec C13 in Ku and others, 1974, p. 959). The deposits on this point were thought to represent a 12-foot stand of the sea (Wentworth and Hoffmeister, 1939, p. 1571) but Stearns (1974a, p. 797) has shown the deposits were laid down by the Leahi stand. An easily accessible deposit lies adjacent to Makai Range Pier near Sea Life Park, Oahu (Fig. 16). A sample from this deposit has a C^{14} date of 23,200 ± years, but this date is probably not reliable in view of the fact that most Pleistocene C^{14} dates are unreliable in Hawaii (Stearns, 1972, p. 242). The deposit was probably left by the Leahi stand of the sea (see also Stearns, 1974a, Fig. 8).

The relation of the Leahi stand to the Kawela soil is best seen at RCA Point near Kahuku. There the beach rock of the Leahi stand lies as slabs on the Kawela soil at high tide level, making one wonder if the Leahi stand was any higher than the present sea. Its relation to several formations is shown in Figure 11. It was at this place Ku and the writer collected corals lying on the Kawela soil that had a uranium series date of 115,000 ± 6,000 years (Sample C18, Ku and others, 1974, p. 959). No doubt exists that the sea dropped to the Kawela low and returned to present sea level following the 25-foot stand, as shown in Figure 1. Unfortunately, the uranium series method does not have sufficient accuracy to determine reliably the number of years between the 25-foot stand and the Leahi stand, but it had to be at least 5,000 years to account for the solution pitting of the Waimanalo reef prior to the deposition of the Kawela soil and the Leahi beach rock. Leahi conglomerate overlies Kawela soil on the east side of Mokuauia Island off Laie (Fig. 17).

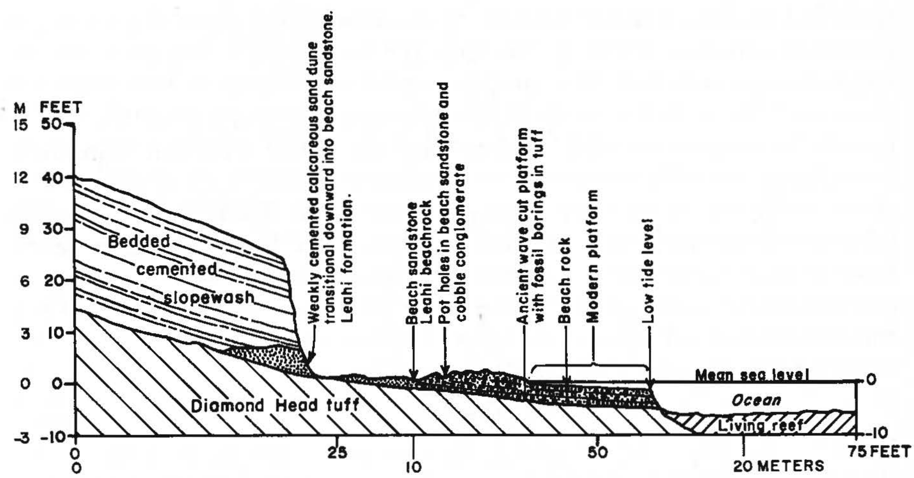

FIGURE 15.—Geologic section at the foot of Beach Road at Diamond Head, the type locality of the Leahi shoreline.

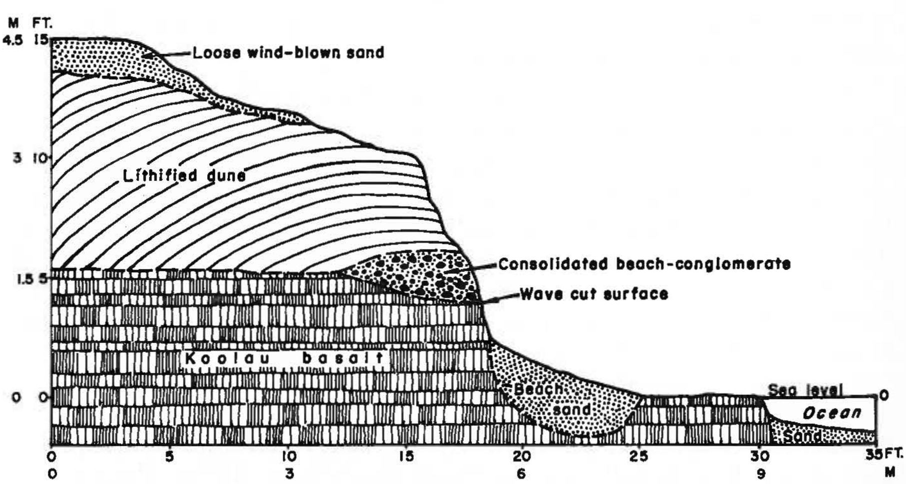

FIGURE 16.—Geologic section of emerged Leahi deposit at Makai Range Pier, Oahu.

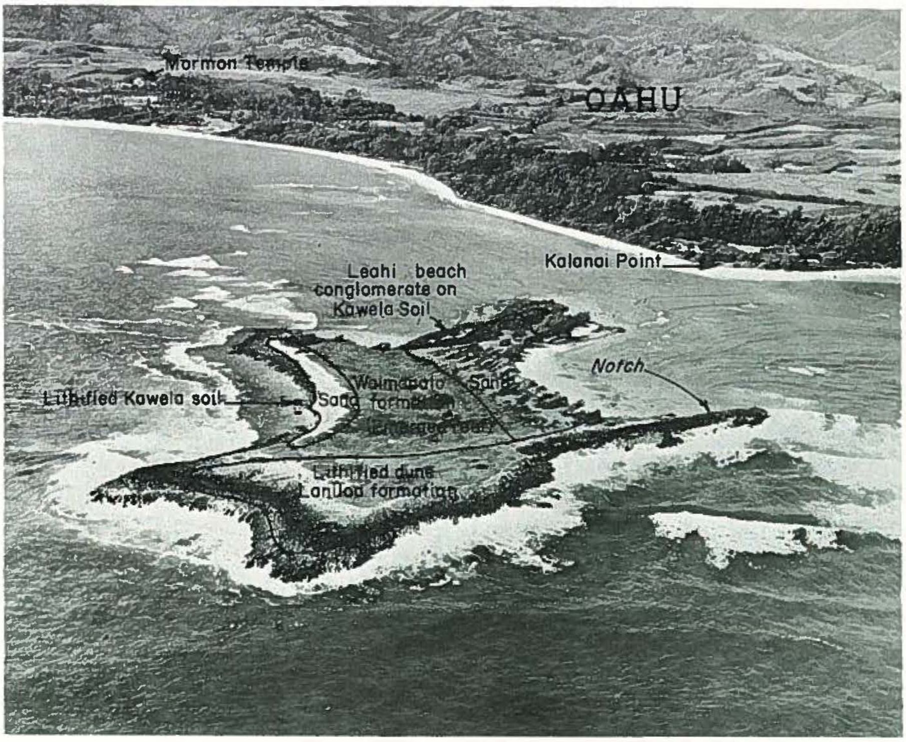

Figure 17.—Air view looking southwest to Mokuauia Island and the coast of Oahu geology. March 21, 1974. Photo by Warren R. Roll.

The antiquity and multiplicity of the shorelines of Oahu have been proven by uranium-series dating and overlapping unconformities. All consolidated beach deposits need dating before the history of our shorelines will be untangled. Long stretches of so-called modern beach rock are now suspect as not being modern. C^{14} studies of the elevation of the ocean during the last 12,000 years have shown that the sea returned to its present level only a few thousand years ago (Milliman and Emery, 1968, p. 1121). Beaches cut in durable rocks, sea cliffs, stacks, and many other marine features of the present coast must have been formed thousands of years ago before the Wisconsinan Mamala low.

PENGUIN BANK −185-FOOT SHELF

The −185-foot (56 m) shelf was named from Penguin Bank 27 miles across off the west end of Molokai (Stearns and Macdonald, 1947, p. 14).

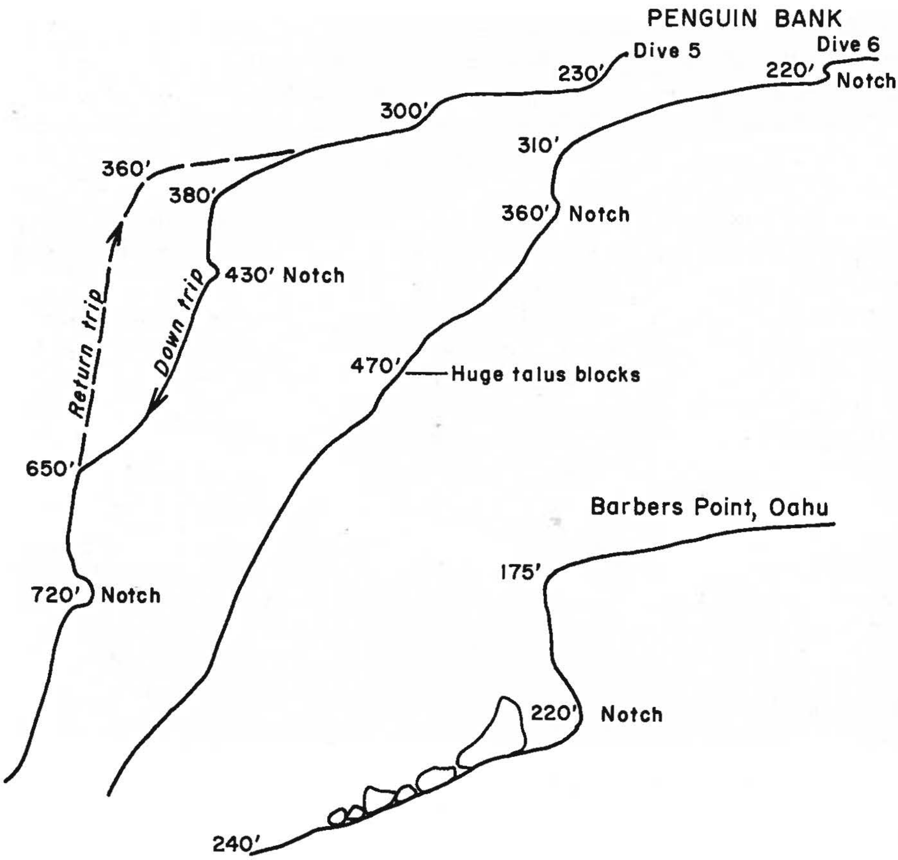

FIGURE 18.—Submarine profiles of Penguin Bank and Barbers Point, Oahu.

The bank has an area of 115 square nautical miles, far too great to be the result of a halt in the Wisconsinan fluctuating sea levels. The Penguin Bank has less than 100 feet of reef and sediments, according to a reflection survey (Kroenke and Woollard, 1966, p. 13). The sediments veneer a very flat bench consisting of basalt. How such a flat bench was cut in hard basalt at that depth is unknown. The −185-foot shelf is very flat off Makua Valley, Oahu, as seen from a submersible (Brock and Chamberlain, 1968, p. 382). It is not shown on the graph (Fig. 1) because it has a complex history and its age is unknown. It was obviously exposed to subaerial erosion during the various glacial epochs and veneered by corals during interglacial epochs.

Grigg made two submersible dives 25 miles apart off the northwest side of Penguin Bank in 1974 and found notches at −220, −360 (Mamala level),

−430, and −720 feet on the face of limestone cliff, made by halts of sea (Fig. 18). He found the −220-foot (67 m) notch in the limestone cliff off Barbers Point, Oahu, also (Fig. 18). A break in slope occurs at −470 feet (143 m) and −650 feet (198 m) in addition to the notch at −720 feet (220 m). Pratt and Dill (1974) report terraces at −480, −660, and −790 feet in the Bering Sea and off the coast of southern Australia. Grigg found a terrace at −460 feet (140 m) off Kaena Point and a notch at this depth between Lanai and Maui. These similar elevations at such widely spaced places point to eustatic halts of the sea during the early Pleistocene. If 790 feet (240 m) of water had been removed from the oceans and stored as ice on the poles, the early glaciers would have had to be double their Wisconsinan thickness, for which no evidence exists. Pratt and Dill (1974) think the deep shelves might be glacioeustatic, whereas the present writer thinks the oceans have been moving rapidly up and down due to tectonoeustacy in addition to glacioeustacy.

Grigg reports strong currents on the ocean floor 300 yards off Penguin Bank. They are indicated by the large ripple marks 2 feet high and 50 feet from crest to crest at a depth of 950 feet (290 m). In the same Molokai Channel, but near Sandy Beach at the east end of Oahu, he found huge ripple marks 2 to 8 feet high and 8 to 30 feet across normal to the 40° slope on which they occur.

BARBERS POINT −220-FOOT SHORELINE

A shoreline notch at −220 feet (67 m) has been discovered by Grigg off Barbers Point, Oahu, cut into a submerged cliff (Fig. 18). It is herein named the Barbers Point shoreline, from nearby Barbers Point (Fig. 5). He also found the shoreline notched into the Penguin Bank reef (Fig. 18). Its position in the sea level graph (Fig. 1) is unknown, but it is probably a halt in Regression or Transgression VI. A bank 220 feet below sea level lies 5 miles off Niihau, but it is too extensive to have been built during this halt.

EWA II −205-FOOT SHORELINE

Grigg states that he found a notch cut in limestone cliffs at −205 feet (62.5 m) during his dives near Ewa and Sandy Beach, Oahu, and also off Kauai. It is hereby named the Ewa II shoreline from the type locality at Ewa, Oahu (Fig. 5). Notches made by this stand must be Wisconsinan in age; hence much younger than Ewa I, which is pre-Yarmouth in age. The notch is shown tentatively as formed during Regression V, in Figure 1, but it may have formed any time during the Wisconsinan.

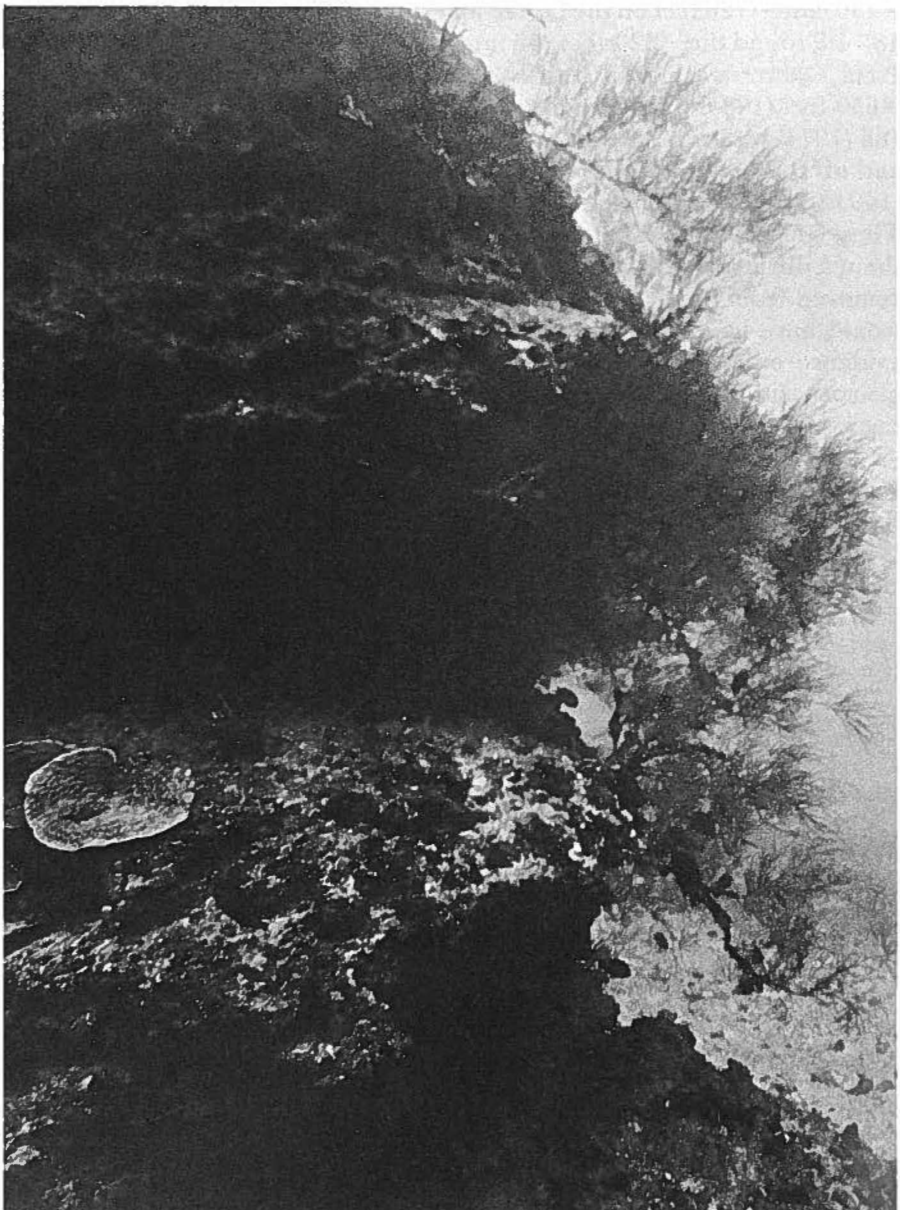

FIGURE 19.—Two notches in limestone cliff 2.16 miles off Kaanapali, Maui. The upper one is about −180 feet and the lower one about −190 feet (Kahe stand). Black coral "trees" grow in the notches. Photo by Richard Grigg.

KAHE −190-FOOT SHORELINE

A shoreline notch has also been discovered by Grigg off Kahe Point, Oahu, at −190 feet (58 m) (Figs. 1 and 5). It is cut into a submerged reef cliff for 8 miles between Barbers Point and Nanakuli. It is herein named the Kahe shoreline, from nearby Kahe Point. It is the most persistent and largest notch in the face of a reef cliff along the southeast coast of Kauai, according to Grigg, who dove for black coral growing in the notch. It is also extensive off the coast of Lahaina, Maui, where it is nearer −185 than −190 feet. Off Maui, it consists of a double notch, one at −180 feet and the lower one at −190 feet, as shown in Figure 19. It is an ecological niche for black coral, which can anchor on the bare rock in the notch.

Similar notches are cut at present sea level in limestone everywhere in the tropical Pacific. Since the sea has been at its present level for only 3,000 years or less, such nips indicate only short halts during regressions and transgressions. The position of the −190-foot notch in the Wisconsinan curve is unknown (Fig. 1).

Grigg recovered a well waterworn basalt cobble 4 inches in diameter from the base of a black coral tree 2.8 miles off Lahaina, just below the −190-foot notch. The encrusting corals conceal beach deposits and cement them together. Reef-type corals are flourishing on the drowned reef 130 feet below sea level in Lahaina Roads because of the clarity of the water. The water off Oahu is too turbid for reef corals to grow at this depth. Thus, before man caused so much erosion on Oahu reef, corals probably grew at a similar depth. In 1932 the writer spent many hours studying the living corals in Kaneohe Bay, Oahu, where now many have been killed off by sediments from the adjacent hills owing to bulldozing for housing. Many of the older shelves in the Hawaiian Islands may have had appreciable additions of coral and sediment as they subsided, thus their elevation may not now be indicative of the sea level when they started to subside.

KANEOHE −80-FOOT SHORELINE

The −80-foot (24 m) shoreline was first noted during dives by Robert Dill in 1969 in Kaneohe Bay, from which it was named (Fig. 5). Grigg observed the −80-foot shoreline all around Oahu during his many dives. In Kaneohe Bay, the sea made a notch 8 feet high and 8 feet deep, with a prominent overhanging visor (Fig. 20) typical of the submarine notches described herein. It appears to have been made during a short halt in the late

FIGURE 20.—View of notch of the −80-foot shoreline with overhanging visor in dead coral reef in Kaneohe Bay, Oahu. Photo by Robert Dill. Published by permission of the U.S. Navy.

Pleistocene reefs in many places. A break in slope was found in 5 of the 24 sonar profiles made by Dr. Robert Kinzie along the Waianae Coast of Oahu. More details are given elsewhere (Stearns, 1974a, p. 799). Its position in the sea level curve (Fig. 1) is unknown, except that it is older than the Manana Island eruption.

LAHAINA ROADS −155-FOOT SHORELINE

A well-developed notch cut into dead reef in the face of a vertical cliff 30 feet high was found by Grigg to be 155 feet (47 m) below mean sea level off Lahaina, Maui (Fig. 5). It is named the Lahaina Roads shoreline. The notch varies from 3 to 15 feet in depth and from 6 to 8 feet in height.

The notch lies 30 feet above the base of the cliff that forms the edge of a submerged reef. The top of the cliff is the edge of an extensive shelf that lies 120 feet below sea level, possibly indicative of the −120-foot stillstand.

Grigg has found it a prominent notch in the submerged reef along the south coast of Kauai. Its position on the eustatic curve is not known, but it is probably Wisconsinan (Fig. 1).

NAWILIWILI −135-FOOT SHORELINE

Grigg, while diving in Nawiliwili Harbor on Kauai, found a well-developed notch in the face of the reef limestone cliff at an elevation of −135 feet (41 m). This notch has not been reported previously and is hereby named the Nawiliwili shoreline. It extends for a considerable distance and represents a stillstand during the Wisconsinan, but its position in the chronological sequence of shorelines is unknown.

MAKAI RANGE −60-FOOT SHORELINE

The type locality of the −60-foot (18 m) shoreline is a notch cut into a cliff of Kaohikaipu basalt near Sea Life Park, Oahu (Fig. 5). It is named after Makai Range Pier near by (Stearns, 1974a, p. 799). The Kaohikaipu basalt appears to have erupted simultaneously with the Kaupo basalt under Sea Life Park, which would place the eruption about 33,000 years ago (Gramlich and others, 1971, p. 1401). Thus the notch and cliff were cut some time in the late Wisconsinan as shown in Figure 1. Grigg reports the −60-foot notch cut into reef limestone off Sunset Beach, Oahu. He says the −60-foot notch is the deepest, largest, and most continuous along the coast of Kauai. The writer found a break in slope at −60 feet in 7 of the 24 sonar profiles made along the Waianae coast, Oahu, by Robert Kinzie.

Ruhe and others (1965, p. 485), from many profiles of the bathymetric map of Oahu, came to the conclusion that the −60-foot level was incorrect and was −40 feet (12 m) instead. SCUBA dives by many have shown that the −60-foot shoreline is correct and that the notch would not be found by soundings used for making the United States Coast and Geodetic bathymetric map. In fact, all of the notches indicating shorelines described in this paper would not be recorded by soundings, because they are in vertical cliff faces.

MAKAPUU −120-FOOT SHORELINE

An extensive notch 6 feet high and 6 to 10 feet deep and 120 feet (36.5 m) below sea level is cut into the base of a cliff of horizontally bedded Manana Island tuff off Sea Life Park, Oahu (Fig. 21). It is named from nearby Makapuu Point on the east end of the island (Fig. 5). It is fronted by a cobble beach. Many of the blocks of tuff are not rounded and potholes 3 feet across and 10 inches deep are common. The Manana Island tuff overlies a soil and formerly tree-covered emerged Waimanalo reef on the adjacent shore; hence, the shoreline must be Wisconsinan in age, as shown in Figure 1. (Also see Fig. 7 in Stearns, 1974a). A submerged coral reef lies at this depth off Lahaina. The shoreline is notched into the face of a submerged reef for many miles off the south coast of Kauai, according to Grigg.

KAHIPA-MAMALA −350-FOOT SHELF AND LANILOA EOLIANITE

The −350-foot (106± m) shelf is one of the most extensive undersea shelves in Hawaii. This low stand of the sea was named the Kahipa of pre-Kaena or pre-Yarmouth age (Stearns, 1935b, p. 1933). Later, the writer pointed out that the same shelf was occupied by the sea during the Tazewell glacial substage of the Wisconsinan, but no new name was assigned to it for the substage occupancy (Stearns, 1961, p. 8). Much later, the same shelf was named the Mamala, from Mamala Bay (Fig. 5) near Pearl Harbor (Ruhe and others, 1965, p. 486). Ruhe and others assumed it was cut by the sea during the last Wisconsinan low (Fig. 1). They showed, by the study of 187 profiles of the sea bottom around Oahu, that the shelf is not tilted. There is not much doubt that the sea fell to that level during the Wisconsinan, but to avoid confusion, it was renamed the Kahipa-Mamala shelf (Stearns, 1966a,

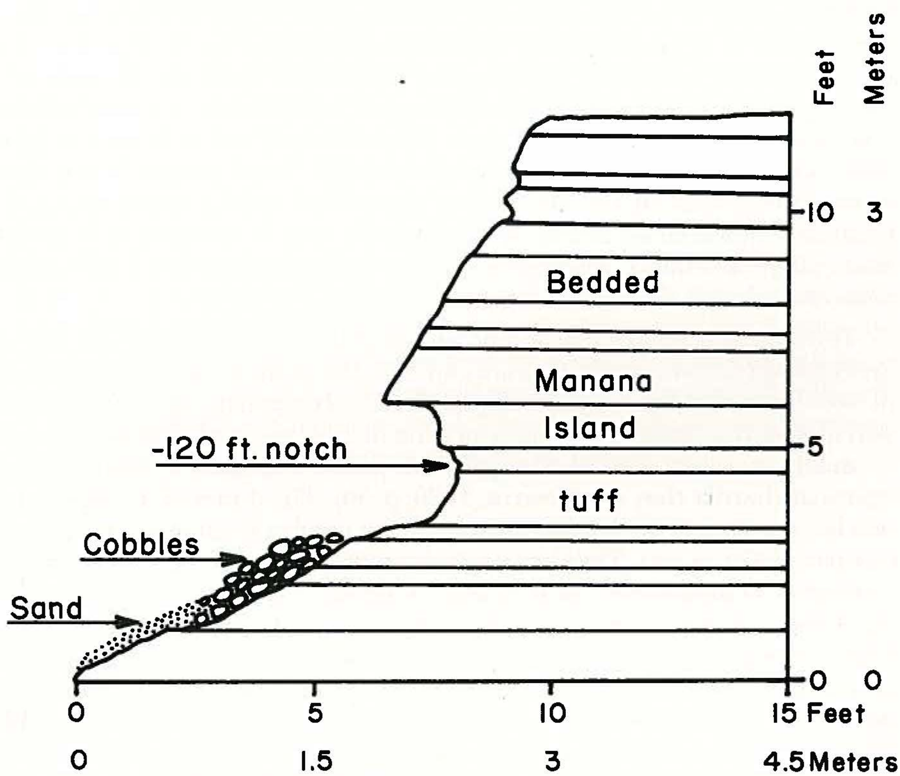

FIGURE 21.—Section of submerged bench and notch at — 120-feet cut into Manana Island tuff, Waimanalo Bay, Oahu.

p. 23). Actually, the shelf has a complex history and may have been at or above sea level during all the glacial epochs.

The writer examined the Kahipa-Mamala shelf from a submersible off Manana Island and found that it is a drowned reef at that place, and not a wave-cut feature. The submersible traversed the outer edge of the platform for 0.5 mile. It was remarkably uniform in depth and very rocky. Shell fragments and pebbles up to 2 inches across filled low places. No live coralpolyps were seen. The edge of this drowned reef has an overhang of 8 to 10 feet; it then drops off to −450 feet with a slope of 20° to 60°. The base elevation at −450 feet has been assumed by some scientists as the maximum drop of sea level during the Pleistocene (Donn and others, 1962). The face is rough limestone and very cavernous. In one place, a narrow, deep crevice cuts the cliff. The shelf surface changes to a 10° slope below the cliff, flattens to 5° above the rim, and becomes covered with sediment inland. No evidence of wave-cutting, potholes, beach cobbles, or other features typical of the −60- and the −120-foot shorelines was seen. The reef may have died during each of the glacial highs, become re-colonized with coralpolyps, and grown again during each of the glacial lows, in spite of cooler temperatures. A notch at −360 feet was found by Grigg on the cliff at the edge of Penguin Bank (Fig. 18), but it represents only a brief halt; hence, it is probably coincidental with the Kahipa-Mamala shelf.

During each of the low stands of the glacial epochs when the sea is lowered and broad coastal areas are exposed, the winds blow great quantities of sand inland to form dunes. These become cemented into limestone by percolating rainwater. The degree of cementation, except in the spray zone, is usually in direct ratio to the age. With minor exceptions, the older the dunes the harder they are (Stearns, 1970, p. 50). The dunes of the Wisconsinan low are named the Laniloa eolianite from Laniloa Point near Laie, Oahu (Stearns, 1970, p. 55). They are next in volume and extent to those formed during the Illinoian low. Many islands in the sea between Laie and Kahuku are Laniloa eolianite (See *Geologic Map of Oahu,* Stearns, 1939, Pl. 2). In places, Laniloa dunes lie unconformably on the Bellows Field eolianite, indicating that the wind blew from the same direction in the Wisconsinan, as well as in the Illinoian, as it does today. The Laniloa dunes are weakly lithified and, in a few places near the bottom of dunes, are unconsolidated. Easton reports that land snails in the dunes at RCA Point have a C^{14} age greater than 34,000 years (Stearns, 1970, p. 67). The relation of the Laniloa dunes to other geologic formations at RCA Point is shown in Figure 11.

A large area of weakly cemented dunes reaching a height of about 90 feet above sea level crops out on the southwest side of Diamond Head. The writer tentatively assigned them to the Leahi 2-foot stand of the sea (Stearns, 1970, p. 60), but is now inclined to believe they are Laniloa eolianite. This change in assignment of age is based on the fact that high, extensive dunes were formed during a low stand of the sea when reef flats were bare, and not when they were covered with water.

The Laniloa dunes are extensive near Koloa, Kauai (Stearns, 1935b, p. 1954) and extend across the isthmus of Maui (Stearns and Macdonald, 1942, Pl. 1). Considerable work has been done on the dating of the dunes on West Molokai (Stearns, 1973a). The lower, partly submerged eolianite is very well cemented, like the Bellows Field formation on Oahu, and is also very extensive. A red transported soil bed up to 3 feet in thickness lies on the lower eolianite and is covered by a weakly cemented upper eolianite correlated with the Laniloa dunes on Oahu that accumulated during the Mamala low.

C^{14} and ionium dates indicate an age of about 27,000 years for the soil and upper dune, which fits the time of the Wisconsinan low. The soil, however, is too young to be correlative with Kawela soil on Oahu, which is more than 105,000 years old and younger than 125,000 years old at the type locality at RCA Point near Kahuku. The dunes on West Molokai form the Dune Strip mapped by Stearns and Macdonald (1947, Pl. 1).

Two lithified dunes of different ages, with a steeply dipping soil between them, crop out near Hole 5 of the Waiehu Golf Course near the beach on West Maui. The upper dune is weakly cemented. The reddish brown soil layer is 2 to 4 feet thick and appears to be wind-blown. It lies on an older, more firmly cemented dune which has fossil solution pits 1 to 2 feet across and 2 feet deep. Caliche crusts indicate a long period of weathering before burial by the soil. The whole deposit has been cliffed by a sea higher than the present, possibly the Waimanalo stand. The stratigraphy is much like that on West Molokai. The lower dune is possibly of Waipio age.

KOKO −15-FOOT SHELF

The Koko −15-foot (4.5 m) shelf was first described and named by Easton (1965, p. 21). The type locality is in Hanauma Bay in the Koko Crater area on eastern Oahu (Fig. 5). The Koko Volcanics in this area have a K-Ar age of ±40,000 years B.P. (Gramlich and others, 1971). The tuffs are subaerial and rest on soil-covered emerged reef of the Waimanalo 25-foot stand in an adjacent valley and in the sea cliff near Hanauma Bay (Stearns, 1935a, p. 1477). They were assigned to the very late Pleistocene (Stearns and Vaksvik, 1935, p. 150). The −15-foot shoreline probably was cut during a halt by the sea on the way up from the Mamala low. A detailed description of the −15-foot shelf has been published (Easton, 1965). C^{14} dates of coral obtained in bore holes indicate the bench is at least 5,800 years old (Easton and Olson, 1976).

KAPAPA 5-FOOT SHORELINE

The Kapapa 5-foot (1.5 m) shoreline was named from a bench at this level cut into eolianite on the island of this name in Kaneohe Bay, Oahu (Fig. 5; Stearns, 1939, p. 10; 1940, p. 54). A cross section and description of the island has been published (Stearns, 1935a, p. 1470). Two benches occur at Kapapa Island. The lower one about low tide level is smooth and covered with living algae and was made by the present sea. It is similar to the benches everywhere present on limestone coasts in the islands and owes its origin to multiple causes. The upper bench is pitted by solution and is inundated only by storm waves. This bench was made when the sea was five feet higher than at present and originated in the same way as the modern bench. It is now being destroyed. Beach rock of unknown age fills many of the solution pits.

The age of the eolianite making up the island is unknown, but it resembles the eolianite islands near Laie and it probably belongs to the Laniloa formation. Its position in the sequence of shorelines was shifted from Holocene (Stearns, 1939, p. 10) to late Wisconsinan (Stearns, 1966a, p. 23) because much evidence was published indicating that the sea at no time during the Holocene stood higher than today. The evidence from the North Atlantic coasts supports this view, but in the last decade evidence has been accumulating for a 5-foot stand at the climatic optimum about 4,000 years ago. The writer's decision to return it to the Holocene in Figure 1 was based on the dating of corals 5 to 7 feet above sea level from small remnants of bedded beach rock 8 to 20 cm thick cemented to lava rock in Hanauma Bay. Easton (1977) incorrectly stated they were only a few millimeters thick. The shells have a C^{14} date of 3,485 ± 160 years (Stearns, 1974a, p. 795). Thus, the bench at Hanauma Bay was made by the 5-foot Kapapa stand of the sea and not by storm waves or biological processes. Easton has recently argued that the deposit was formed at present sea level by waves rushing up a narrow surge channel. Also that the bedding planes are solution ridges (Easton, 1977). He does not explain the 2-meter bench continuous with the deposit (Stearns, 1977). The bench was certainly not cut by the present sea. Also some of the deposits lie away from the surge channel.

Evidence continues to accumulate for a 5-foot Holocene stand in the Pacific. An emerged reef, whose top is nearly 5 feet above mean sea level on Midway Island, has a C^{14} age of 2,420 to 1,230 years B.P. (Gross and others, 1969). A view of this emerged reef has been published (Stearns, 1941, Fig. 2). A similar emerged reef on Guam has a C^{14} age of 3,400 ± 250 years (Tracey and others, 1964). Guilcher (1969) reports that corals 1 meter above sea level in the Society Islands have a C^{14} age of 3,450 years, exactly the same age as those in Hanauma Bay. In Japan, Fujii and Fuji (1967) found that the sea stood several meters above present level from 6,000 to 3,000 years B.P. Most five-foot benches, especially if cut in lava rock, have a composite origin and were made by earlier stands at this height because the last 5-foot stand did not endure long enough to make benches in durable nonsoluble rocks.

CONCLUSIONS

It is axiomatic that if Hawaii has not moved in the latter part of the Pleistocene, its shoreline should be found at the same elevations as those found elsewhere in the world on stable coasts. Hundreds of papers have been published on eustacy in the Pleistocene. The subject has been reviewed by Guilcher (1969) and many of the papers are listed in his bibliography. The island of Mallorca has a very complete record of the changes in sea level. It is similar to Hawaii because it has marine carbonate deposits, eolianites, and interbedded stream deposits. Terraces similar in height to Hawaiian shorelines extend undisturbed along 250 miles of the Chilean coast. No eolianites occur; hence, the low stands of the sea could not be deciphered. The same condition occurs along the South Carolina coast of the United States. The similarity in elevation of Hawaii and South Carolina terraces is striking. This was pointed out years ago for Georgia terraces (Stearns, 1935b, p. 1952). Only the Hawaiian shorelines at the peak of each interglacial and glacial epoch have been listed in Table 6. Many halts intervene and their preservation is fortuitous, depending on the character of the rocks and the shape of the coastline. Comparisons in elevation are given in Table 6. The depth of the low sea levels in Hawaii is imprecise, but their order in the sequence is certain.

The Waimanalo 7.5 meter shoreline is an excellent datum to prove that Oahu has been stable since the Sangamon. Gill (1968) states that the 7.5 meters level is worldwide and serves as a reliable datum. It has the identical height in Chile and South Carolina as it does in Hawaii; hence, Mallorca appears to have been uplifted several meters. The other Mallorca shorelines are consistently higher by several meters, also. Seven of the submerged shorelines in Hawaii correspond in elevation to shorelines in the Mediterranean (Flemming, 1972).

The well-developed Waimanalo emerged reef at 25 feet (7.5 m), and the dating of its corals by radiogenic methods, establish the Sangamon, or last interglacial eustatic high sea level, as having occurred 120,000 years ago. It was preceded by the glacial Illinoian (Waipio) low stand during which

TABLE 6
COMPARISON OF TERRACE HEIGHTS IN METERS: HAWAII, MALLORCA, CHILE, AND SOUTH CAROLINA

Epoch	Name	Hawaii	Mallorca*	Chile**	Name	So. Carolina***
Holocene	Kapapa	1.5	4	1.5/2	Silver Bluff	1.5
Wisconsinan	Mamala low	−106±	−100±	—	—	—
Interstadial	Leahi	.6±	2/3	—	—	—
Stadial	Kawela low	?	?	—	—	—
Sangamon	Waimanalo	7.5	9/15	5/7	Pamlico	7.5
Illinoian	Waipio low	−106±	−100±	—	—	—
Yarmouth	Kaena	29/30	30/35	35/40	Wicomico	32
Kansan	Kahipa low	?	?	—	—	—
Aftonian?	Olowalu	75±	—	75/80	Hazelhurst	75

*Butzer and Isaac (1975).
**Paskoff (1967).
***Ward and others (1971).

widespread dunes, now lithified, formed. The eolianite has been cored to a depth of 160 feet (48 m) below sea level and doubtless goes much deeper. The dunes are unconformable on the very extensive emerged Kaena reef whose shoreline stood at 95 to 100 feet (30 m) above present sea level. The reef was formed during the long Yarmouth interglacial and is dated by radiogenic measurements as having occurred about 600,000 years ago.

Some time prior to the Yarmouth the islands were deeply submerged by amounts too great to have been caused by glacioeustatic changes in sea level. As measured on Lanai, the submergence reached 1,200 feet (365 m) above present sea level and then the island re-emerged to present sea level, or lower. Lanai ceased erupting 1,250,000 years ago so the great submergence and re-emergence had to occur in a relatively short time because the deep weathering on Lanai occurred prior to the submergence.

The cause of such rapid changes in the elevations of the islands during the Pleistocene is a great scientific mystery. Some of the change in sea level may have resulted from worldwide tectonoeustacy.

LITERATURE CITED

ANDREWS, J. E., and C. BAINBRIDGE
1972. "Submarine Canyons off Eastern Oahu." *Pacific Science* **26:** 108-113.

BEARD, J. H.
1969. "Pleistocene Paleotemperature Record Based on Planktonic Foraminifers, Gulf of Mexico." *Trans. Gulf Coast Assoc. Geological Socs.* **19:** 535-553.

BONHOMMET, N., M. H. BEESON, and G. B. DALRYMPLE
1977. "A Contribution to the Geochronology and Petrology of the Island of Lanai, Hawaii." *Geological Soc. America Bull.* **88:** 1282-1286.

BROCK, V. L., and T. C. CHAMBERLAIN
1968. "A Geological and Ecological Reconnaissance off Western Oahu, Hawaii." *Pacific Science* **22:** 373-394.

BRYAN, W. A.
1916. "Evidence of Deep Subsidence of the Waianae Mountains, Oahu." *Thrum's Annual,* pp. 95-125.

BUTZER, K. W., and G. L. ISAAC, Editors
1975. "Pleistocene Littoral: Sedimentary Cycles of the Mediterranean Basin: A Mallorquin View." In *After the Australopithecines: Stratigraphy, Ecology, and Culture Change in the Middle Pleistocene,* pp. 26-71. The Hague: Aldine.

CAMPBELL, J. F., W. T. COULBOURN, and R. MOBERLY
1972. "Pleistocene Drainage Patterns in Hawaii as Revealed by Seismic Reflection Profiling." *Geological Soc. America Abstracts with Programs* (Cordilleran Sec.) **4**(3): 135-136.

CHAPMAN, R. W.
1946. "Lithification of Pleistocene Clay at Kahuku Point, Oahu." *Geological Soc. America Bull.* **57:** 985-996.

COOKE, H. B. S.
1973. "Pleistocene Chronology: Long or Short?" *J. Quaternary Res.* **3:** 206-220.

COULBOURN, W. T., J. F. CAMPBELL, and R. MOBERLY
1974. "Hawaiian Submarine Terraces, Canyons, and Quaternary History Evaluated by Seismic-Reflection Profiling." *Marine Geology* **17:** 215-234.

DALRYMPLE, G. B.
1971. "Potassium-Argon Ages from the Pololu Volcanic Series, Kohala Volcano, Hawaii." *Geological Soc. America Bull.* **82:** 1997-2000.

DALRYMPLE, G. B., M. A. LANPHERE, and E. D. JACKSON
1974. "Contributions to the Petrography and Geochronology of Volcanic Rocks from the Leeward Hawaiian Islands." *Geological Soc. America Bull.* **85:** 727-738.

DONN, W. L., W. R. FARRAND, and M. EWING
1962. "Pleistocene Ice Volumes and Sea-Level Lowering." *J. Geology* **70:** 880-882.

EASTON, W. H.
1963. "New Evidence for a 40-Foot Shoreline on Oahu." In *Essays in Marine Geology,* pp. 51-68.
1965. (Abstract) "New Pleistocene Shorelines in Hawaii." *Geological Soc. America, 61st Annual Meeting,* p. 21.
1977. "Radiocarbon Profile of Hanauma Reef, Oahu, Hawaii: Reply." *Geological Soc. America Bull.* **88:** 1535.

EASTON, W. H., and E. A. OLSON
1976. "Radiocarbon Profile of Hanauma Reef, Oahu, Hawaii." *Geological Soc. America Bull.* **87:** 711-719.

EVERNDON, J. F., D. E. SAVAGE, G. H. CURTIS, and G. T. JAMES
1964. "Potassium Argon Dates and the Cenozoic Mammalian Chronology of North America." *American J. Science* **262:** 145-198.

FLEMMING, N. C.
1972. "Relative Chronology of Submerged Pleistocene Marine Erosion Features in the Western Mediterranean." *J. Geology* **80:** 633-662.

FUJII, S., and N. FUJI
1967. "Postglacial Sea Level in Japanese Islands." *J. Geosciences, Osaka City Univ.* **10:** 43-51.

FUNKHOUSER, J. G., I. L. BARNES, and J. G. NAUGHTON
1968. "The Determination of a Series of Ages of Hawaiian Volcanoes by the Potassium Argon Method." *Pacific Science* **22:** 369-372.

GILL, E. E.
1968. "Eustacy." In *Enclopedia of Geomorphology,* p. 333. New York: Reinhold.

GRAMLICH, J. W., V. A. LEWIS, and J. J. NAUGHTON
1971. "Potassium-Argon Dating of Holocene Basalts of the Honolulu Volcanic Series." *Geological Soc. America Bull.* **82:** 1399-1404.

GROSS, M. G., T. D. MILLIMAN, J. T. TRACEY, JR., and H. S. LADD
1969. "Marine Geology of Kure and Midway Atolls, Hawaii: A Preliminary Report." *Pacific Science* **23**: 17-25.

GUILCHER, A.
1969. "Pleistocene and Holocene Sea Level Changes." *Earth-Science Reviews* **5:** 69-97.

HAMMOND, S. R.
1970. "Paleomagnetic Investigations of Deep Borings on the Ewa Plain, Oahu, Hawaii." *Hawaii Inst. Geophysics Rep.* HIG-70-10. 60 pp.

HITCHCOCK, C. H.
1900. "Geology of Oahu." *Geological Soc. America* **2:** 15-60.

INMAN, D. L., W. R. GAYMAN, and D. C. COX
1963. "Littoral Sedimentary Processes on Kauai." *Pacific Science* **17:** 106-130.

JACKSON, E. D., E. A. SILVER, and G. B. DALRYMPLE
1972. "The Hawaiian Emperor Chain and Its Relation to Cenozoic Circumpacific Tectonics." *Geological Soc. America Bull.* **83:** 601-618.

KROENKE, L. W., and G. P. WOOLLARD
1966. "Seismic Reflection Investigations in the Vicinity of the Hawaiian Ridge." *Hawaii Inst. Geophysics Rep.* HIG-66-14, p. 11.

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.

LADD, H. S., J. L. TRACEY, and M. G. GROSS
1967. "Drilling on Midway Atoll, Hawaii." *Science* **156:** 1088-1094.

LUM, D.
1972. "Pleistocene (?) 208-Foot Emerged Shoreline on Molokai, Hawaii." *Geological Soc. America Abstracts with Programs* (Cordilleran Sec.) **4:** 192.

LUM, D., and H. T. STEARNS
1970. "Pleistocene Stratigraphy and Eustatic History Based on Cores at Waimanalo, Oahu, Hawaii." *Geological Soc. America Bull.* **81:** 1-16.

MACDONALD, G. A., and A. T. ABBOTT
1970. *Volcanoes in the Sea.* Honolulu: Univ. Hawaii Press. 441 pp.

MACDONALD, G. A., D. A. DAVIS, and D. C. COX
1960. *Geology and Ground Water Resources of the Island of Kauai, Hawaii.* Hawaii Div. Hydrography Bull. 13. 207 pp.

McDOUGALL, IAN
1964. "Potassium-Argon Ages from Lavas of the Hawaiian Islands." *Geological Soc. America Bull.* **75:** 107-128.

McDOUGALL, I., and J. A. SWANSON
1972. "Potassium-Argon Ages of Lavas from the Hawi and Pololu Volcanic Series, Kohala Volcano, Hawaii." *Geological Soc. America Bull.* **83:** 3731-3738.

MILLIMAN, J. D., and K. O. EMERY
1968. "Sea Levels During the Past 35,000 Years." *Science* **162:** 1121-1123.

OSTERGAARD, J. M.
1928. *Fossil Marine Mollusks of Oahu.* B. P. Bishop Mus. Bull. 51. 32 pp.

PASKOFF, ROLAND
1967. "Recent State of Investigations on Quaternary Sea Levels along the Chilean Coast between Lat. 30° and 33° S." *J. Geosciences, Osaka City Univ.* **10:** 107-113.

POLLOCK, J. B.
1928. "The Origin of Pearl Harbor, Island of Oahu." *Pap. Michigan Acad. Sciences, Arts and Letters* **10:** 217-250.

POTTRATZ, S. W.
1968. Lithified Carbonate Dunes of Oahu, Hawaii. M. A. Thesis, Univ. Hawaii, Honolulu. 49 pp.

PRATT, R. M., and R. F. DILL
1974. "Deep Eustatic Terrace Levels: Further Speculations." *Geology* **2:** 155-159.

RESIG, J. M.
1969. "Paleontological Investigations of Deep Borings on the Ewa Plain, Oahu, Hawaii." *Hawaii Inst. Geophysics Rep.* HIG-69-2.

RUHE, R. V., J. M. WILLIAMS, and E. L. HILL
1965. "Shorelines and Submarine Shelves, Oahu, Hawaii." *J. Geology* **73:** 485-497.

SHEPARD, F. P., and R. F. DILL
1966. *Submarine Canyons and Other Sea Valleys.* Chicago: Rand McNally.

STEARNS, H. T.
1935a. "Shore Benches on the Island of Oahu, Hawaii." *Geological Soc. America Bull.* **46:** 1467-1482.
1935b. "Pleistocene Shorelines on the Islands of Oahu and Maui, Hawaii." *Geological Soc. America Bull.* **46:** 1927-1956.
1938. "Ancient Shorelines on the Island of Lanai, Hawaii." *Geological Soc. America Bull.* **49:** 615-628.
1939. *Geologic Map and Guide of the Island of Oahu, Hawaii.* Hawaii Div. Hydrography Bull. 2. 75 pp.
1940. *Geology and Water Resources of the Islands of Lanai and Kahoolawe, Hawaii.* Hawaii Div. Hydrography Bull. 6. 177 pp.
1941. "Shore Benches on North Pacific Islands." *Geological Soc. America Bull.* **52:** 773-780.
1947. *Geology and Ground Water Resources of the Island of Niihau, Hawaii.* Hawaii Div. Hydrography Bull. 12. 51 pp.
1955. (Abstract) "High Level Fossiliferous Limestone on Upolu Island, Samoan Archipelago." *Geological Soc. America Bull.* **66:** 1681.
1961. "Eustatic Shorelines on Pacific Islands." *Z. Geomorphologie* **3**(suppl.): 1-16.
1966a. *Geology of the State of Hawaii.* Palo Alto, California: Pacific Books. 266 pp.
1966b. *Road Guide to Points of Geologic Interest in the Hawaiian Islands.* Palo Alto, California: Pacific Books. 68 pp.
1970. "Ages of Dunes on Oahu, Hawaii." *B. P. Bishop Mus. Occ. Pap.* **24**(4): 49-72.
1972. "C^{14} vs. Uranium-Series Dating of Late Pleistocene Shore Deposits, Oahu, Hawaii." *Geological Soc. America Abstracts with Programs* (Cordilleran Sec.) **4**(3): 242.
1973a. "Geologic Setting of the Fossil Goose Bones Found on Molokai Island, Hawaii." *B. P. Bishop Mus. Occ. Pap.* **24**(10): 155-163.
1973b. "Potassium-Argon Ages of Lavas from the Hawi and Pololu Volcanic Series, Kohala Volcano, Hawaii: Discussion." *Geological Soc. America Bull.* **84:** 3483-3484.
1974a. "Submerged Shorelines and Shelves in the Hawaiian Islands and a Revision of Some of the Eustatic Emerged Shorelines." *Geological Soc. America Bull.* **85:** 795-804.
1974b. "Correlation of Pleistocene Shorelines in Gippsland, Australia, and Oahu, Hawaii: Discussion." *Geological Soc. America Bull.* **85:** 1189.
1974c. "Geologic Description of Quarries on Oahu, Hawaii." *Hawaii Div. Water and Land Development, Dept. Land and Natural Resources,* Circ. C67. 25 pp.
1975. "The PCA 25-Foot Stand of the Sea on Oahu, Hawaii." *Geological Soc. America Bull.* **86:** 1279-1280.
1977. "Radiocarbon Profile of Hanauma Reef, Oahu, Hawaii: Discussion." *Geological Soc. America Bull.* **88:** 1535.

STEARNS, H. T., and T. K. CHAMBERLAIN
1967. "Deep Cores of Oahu, Hawaii, and Their Bearing on the Geologic History of the Central Pacific Basin." *Pacific Science* **21:** 153-165.

STEARNS, H. T., and G. B. DALRYMPLE
In press. The K-Ar Age of the Black Point Dike on Oahu, Hawaii, and Its Relation to the Yarmouth Intergracial. *Bishop Mus. Occ. Pap.*

STEARNS, H. T., and G. A. MACDONALD
1942. *Geology and Ground Water Resources of the Island of Maui, Hawaii.* Hawaii Div. Hydrography Bull 7. 344 pp.
1946. *Geology and Ground Water Resources of the Island of Hawaii.* Hawaii Div. Hydrography Bull. 9. 363 pp.
1947. *Geology and Ground Water Resources of the Island of Molokai.* Hawaii Div. Hydrography Bull. 11. 113 pp.

STEARNS, H. T., and K. N. VAKSVIK
1935. *Geology and Ground Water Resources of the Island of Oahu, Hawaii.* Hawaii Div. Hydrography Bull. 1. 479 pp.

STODDARD, D. R.
1973. "Coral Reefs: The Last Two Million Years." *Geography* **58:** 313-323.

TRACEY, J. I., JR., S. O. SCHLANGER, J. T. STARK, D. B. DOAN, and H. G. MAY
1964. "General Geology of Guam, Mariana Islands." *U.S. Geological Survey Prof. Pap.* 403A, pp. A1-A104.

WARD, W. T.
1973. "Correlation of Pleistocene Shorelines in Gippsland, Australia, and Oahu, Hawaii." *Geological Soc. America Bull.* **84:** 3087-3092.

WARD, W. T., P. J. ROSS, and D. J. COLQUHOUN
1971. "Interglacial High Sea Levels: An Absolute Chronology Derived from Shoreline Elevations." *Palaeogeography, Palaeoclimatology, and Palaeoecology* **9:** 77-99.

WENTWORTH, C. K.
1926. *Pyroclastic Geology of Oahu.* B. P. Bishop Mus. Bull. **30:** 121 pp.

WENTWORTH, C. K., and J. E. HOFFMEISTER
1939. "Geology of Ulupau Head, Oahu. *Geological Soc. America Bull.* **50:** 1553-1572.