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FOSSIL MARINE MOLLUSKS OF OAHU

BY

JENS MATHIAS OSTERGAARD

BERNICE P. BISHOP MUSEUM

BULLETIN 51

HONOLULU, HAWAII

PUBLISHED BY THE MUSEUM

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Fossil Marine Mollusks of Oahu

By JENS MATHIAS OSTERGAARD

INTRODUCTION

To even the casual observer it is apparent that the sea surrounding the Island of Oahu at some time in the past stood at a higher level than at present. Limestone formations in more or less continuous stretches fringe the shore line above the reach of tide and waves and extend for miles inland. No close scrutiny is required to recognize in these formations abundant fossilized remains of various marine organisms, particularly the shells of mollusks and sea urchins, the calcareous deposits of coralline algae, and the skeletons of stony corals. Here and there large coral heads also may be seen.

To throw light on the ecological conditions under which these emergent limestones of Oahu were built up, a comparison of the fossil animals and plants with those living in the surrounding water is being undertaken. Discussion is here confined to the phylum Mollusca, of which the two classes, Gastropoda (univalves) and Pelecypoda (bivalves), are abundantly represented.

Owing to the general fine state of preservation of the fossil mollusks of the limestone of Oahu, identification can usually be made with assurance. Doubt arises only with specimens represented by a small fragment and specimens worn by erosion previous to their preservation as fossils. Nearly all the fossils are preserved with the calcium carbonate of the shell intact, and many retain some of their color. Moulds without the shell are exceptional.

As the minute Hawaiian gastropods are very imperfectly known, I am reserving them for study at a later date, when literature may be available.

To Professor W. A. Setchell of the University of California I wish to express my sincere appreciation for aid and encouragement in this undertaking. To the late Dr. W. H. Dall I am indebted for verification or revision of determinations made for the greater part of the collection, and to Mr. David Thaanum of Honolulu for the determination of many species. For the photographic plates of fossils thanks are due Dr. C. H. Edmondson.

DISTRIBUTION OF SPECIES

The species of fossil marine mollusks described in this paper are listed in Table 1, where also is shown the localities from which they were obtained. The great difference in the number of species found at the different stations is due not so much to their actual relative abundance as to the accessibility of the limestones in which the fossils appear.

TABLE 1. DISTRIBUTION OF FOSSIL MARINE MOLLUSKS ON OAHU.

(A, abundant; M, medium; F, few. The numbers under the heading "Stations" refer to localities shown in figure 1.)

NAMES OF SPECIES	STATIONS																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Gastropoda																						
Cassid vibex var. erinaceus Linnaeus									F													F
Cerithium obeliscus Bruguière												F										
Cheilea dillwyni Gray				A																		
Columbella moleculina Duclos												F										
Conus abbreviatus Nuttall		F	M		F																F	
Conus auratus Hwass		F	F									F									M	
Conus catus Hwass					F																	
Conus flavidus Linnaeus																					F	
Conus hebraeus Linnaeus													F									
Conus hebraeus var. vermiculatus Lamarck																						F
Conus imperialis Linnaeus												F										
Conus literatus var. millepunctatus Lamarck					F						M											
Conus nanus Broderip		F		F																	F	
Conus nussatella Linnaeus				A								F						F				
Conus rattus var. tahitensis Hwass		M	A	A	M						F						M				A	
Conus tulipa Linnaeus		F		M					F								F					
Coralliophila bulbiformis Conrad												F										
Coralliophila neritoidea Lamarck						F																
Cymatium pileare Linnaeus				F																		
Cypraea caput-serpentis Linnaeus	A	A	A	A	A	A	A	A	A				M	M				F	A		A	A

NAMES OF SPECIES	STATIONS																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
<i>Neritina turrita</i> Chemnitz										M												
<i>Patella exarata</i> Nuttall			M			F															M	
<i>Patella melanostoma</i> Pilsbry					F												F					
<i>Pisania tritonoides</i> Reeve		F	F																			
<i>Pterocera chiragra</i> Linnaeus					F				F													
<i>Strombus auris-dianae</i> Linnaeus									F													
<i>Strombus floridus</i> Lamarck									F	F												
<i>Strombus gibberulus</i> Linnaeus									M													
<i>Strombus maculatus</i> Nuttall						M			M							F				F ^a	F	
<i>Strombus ostergaardi</i> Pilsbry ^b			F						M			F									F	
<i>Strombus samar</i> (Chemnitz) Dillwyn									F													
<i>Terebra maculata</i> Lamarck									F													
<i>Thais aperta</i> Blainville															F							
<i>Tonna perdx</i> Linnaeus				F																		
<i>Trochus intextus</i> Kiener				F						F												F
<i>Turbo intercostalis</i> Menke				A		M			A	M		M							F		F	F
<i>Turbo setosus</i> Gmelin									F													
<i>Vexillum multicostratum</i> var. <i>pyramidalis</i> Lamarck									F													

^a Species found in consolidated sand dune.^b Species believed universally extinct.

NAMES OF SPECIES	STATIONS																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Pelecypoda																						
<i>Antigona reticulata</i> Linnaeus	A	A	M	A		F	F		A	M								F			F	
<i>Arca hankeyana</i> Reeve									M		A											
<i>Arca hawaiiensis</i> Dall				F					M				F									
<i>Arca reticulata</i> Gmelin									F													
<i>Arca tenella</i> Reeve				F									F									
<i>Arca truncata</i> Reeve									M				F									
<i>Cardium orbiter</i> Reeve																						
<i>Codakia thaenami</i> Pilsbry					F								F									
<i>Jagonia bella</i> Conrad				F					M	A			M									
<i>Lithophaga obesa</i> Philippi	A																					
<i>Mytilus crebristriatus</i> Conrad										F												
<i>Ostrea bryani</i> Pilsbry ^b																F						
<i>Ostrea retusa</i> "Pease" Sowerby ^b												A										
<i>Ostrea sandwichensis</i> Sowerby														F		A						
<i>Pecten (Chlamys) albolineatus</i> Sowerby															F							
<i>Septifer kraussii</i> Kuster	M	F		A	A				A	A							M		F		M	A
<i>Spondylus tenebrosus</i> Reeve									M				M									
<i>Tellina (Arcopagia) elizabethae</i> Pilsbry				F									F									F
<i>Tellina rugosa</i> Born											M											
<i>Trapezium duperreyi</i> Deshayes				A																		
Totals of species	13	15	3	28	13	9	3	2	33	10	2	1	25	4	1	5	3	6	4	1	16	9

^b Species believed universally extinct.

LOCATION AND CONTENT OF LIMESTONE FORMATIONS

STATION 1, HAHAIONE VALLEY

Through the courtesy of Mr. Albert F. Judd I had the opportunity of examining several interesting limestone formations in Kamiloiki, Hahaione, and Kaalakei valleys in the Koko Crater region. (See fig. 1.)

FIGURE 1.—Map of Oahu showing stations at which fossil mollusks were collected: 1, Hahaione Valley; 2, Wailupe Point; 3, Hind-Clarke Dairy; 4, Wailupe Quarries; 5, Black Point (Kupikipikio); 6, Moiliili Sand Quarry; 7, Bingham and Farrington streets; 8, Honolulu plain; 9, Honolulu harbor; 10, Moanalua Quarry; 11, Railroad cut at Puuloa; 12, Railroad cut at Waipio; 13, Nanakuli sea cliffs; 14, Nanakuli shore line; 15, Maili Point; 16, Waianae Quarry; 17, Kaena Point; 18, promontory at Kawaihoa; 19, Kahuku Point; 20, Sand dunes at Laie; 21, Mokapu Peninsula; 22, Kailua and Waimanalo.

In Kamiloiki Valley close to the ridge dividing it from Kamilonui Valley, a few coral boulders with beach breccia are found in a small stream bed, not higher than 8 feet above sea level. In Hahaione Valley limestone of two distinct types were found. About two-thirds of a mile from the mouth of the valley is a large area of well-consolidated sand dunes at an elevation of 32 feet above sea level. The base of the formation consists of beach conglomerate containing numerous large rounded basaltic pebbles. Along the western side of the valley is a fossil coral reef consisting of many massive heads (*Porites lobata* ?), surrounded by the usual beach breccia, firmly cemented and rich in fossils. The fossil shells are identical with those

in the other limestones which contain open shore forms but particularly abundant is the rock-boring clam, *Lithophaga obesa*. No part of this formation is more than 25 feet above sea level. In the lower part of the valley a small section of the limestone is overlain by black ash and tuff, presumably derived from Koko Crater.

In the small Kaalakei Valley, next to and west of Hahaione, are limestones which closely resemble those of Hahaione Valley as to kinds and relative position, but because the valley is narrow and steep the uppermost limestones—the sand dunes—are only about one-half mile from the mouth of the valley. The material dug from a well $30 \pm$ feet deep and located $500 \pm$ feet nearer the mouth of the valley than are the consolidated dunes reveals a large amount of calcareous sand, a considerable number of coral and shell fragments, and some sea urchin spines. In the stream bed, a few hundred feet above the well, is a coral reef; and still farther up the stream are extensive beach breccias containing numerous fragments of corals and shells. The consolidated sand dunes reach the highest elevation. In some places they are continuous with the underlying beach breccia but on the western side of the stream are large isolated areas.

STATION 2, WAILUPE POINT

At the promontory between Niu and Wailupe valleys, here called Wailupe Point, the limestone reaches an elevation of $10 \pm$ feet above sea level immediately at the shore, where also lie several large blocks that have been torn from the main bluff. The limestone here is a typical marine breccia of well-consolidated fragments of coral and shells, numerous coralline algae of a globular type, and here and there coral formations apparently in place. No faunal changes from sea level to the highest point of the bluff are noticeable. The shells are mainly gastropods of the typical open shore forms that thrive in or near the surf, where fresh water influx with detritus is at a minimum. Among shell fragments at all levels are whole shells of several species of *Cypraea*, which are not wave worn; many of them retain their coloration to a considerable extent.

STATION 3, HIND-CLARKE DAIRY

At the Hind-Clarke Dairy, near the Wailupe Wireless Station and the western side of the mouth of Wailupe Valley, the emergent limestone forms an abrupt cliff, reaching 8 feet above the floor of the valley and extending for 100 yards at right angles to the shore line. It has the appearance in places of a coral reef, since large coral heads are visible in sections. The formation clearly marks a line of sea cliffs.

STATION 4, WAILUPE QUARRIES

From the Hind-Clarke Dairy, coral reef extends westward past the Wailupe Wireless Station, where the reef may be recognized readily by the widespread massive heads of the madreporarian corals, *Porites* and *Favia*. A small limestone quarry located at this point is here referred to as Wailupe Quarry No. 1. In its well consolidated state as well as in its fossil contents the rock closely resembles that of Wailupe Point. Its elevation above sea level is $12 \pm$ feet.

On the mountain side of the highway a few hundred feet west of Wailupe Quarry No. 1 is a deep excavation, Wailupe Quarry No. 2, from which a large amount of limestone has been obtained for road building. The quarry had not been worked for a long time previous to 1924 and 1925, when the collection of shells was made. It was then supporting a luxuriant growth of young algaroba trees and various shrubs. Notwithstanding, a considerable extent of limestone was exposed. The composition of the rock as well as its fossil contents are similar to rock at Wailupe Point and Wailupe Quarry No. 1, although the material here is in some places more loosely consolidated. More forms of mollusks were obtained here than at the other two stations, due perhaps to the greater area of exposed rock. Recently the quarry has been worked and a fresh surface exposed. This formation stands at an elevation of $15 \pm$ feet above sea level.

From Wailupe Quarry No. 2 westward limestone appears intermittently as patches of considerable size along the base of the broad dividing ridge between Wailupe and Waialae valleys. At the Waialae valleys limestone is lacking and does not reappear at the surface till Moiliili is reached.

The surface of the low, arid plain, comprising an area of about one square mile at the northeast side of Diamond Head, is a more or less continuous exposure of hard limestone. As this rock consists of calcareous sand showing the cross bedding commonly produced in sand transported by wind, it may be appropriately termed eolian limestone. Near the sea recent unconsolidated sand dunes take the place of the consolidated dunes. In a depression about a mile from the sea is a marine breccia with shells, coral, and sand firmly united.

STATION 5, BLACK POINT

Directly east of Kahala, where Kupikipikio crater, commonly known as Black Point, indents the shore line with its bold promontory of black basaltic rock, a sheer limestone cliff about 40 feet high and $250 \pm$ feet long forms a buttress against the sea. The upper 3 to 4 feet of the cliff contains a few large boulders and numerous basaltic rocks of various sizes, some rounded,

others angular.¹ The limestone seems to be of a beach rock throughout. Beach shells, chiefly worn and broken gastropods, coral pebbles, sand, and calcareous mud form a solidly united rock. The species of mollusks characteristic of the limestone in other places on the open shore stretches of Oahu include here as elsewhere some forms believed to be extinct in Hawaiian waters but living in other parts of the tropical Indo-Pacific.

The geological sequence at Kupikipikio appears to have been as follows:

The formation of the crater and the basaltic flows were followed by a long period of erosion, during which a prominent wave bench was excavated against a perpendicular cliff on the side of the crater facing the sea. A gradual subsidence of the region which then followed enabled the sea to accumulate a vast calcareous deposit on the wave bench against the cliff. Near the close of this period of subsidence, subaerial erosion caused the overhanging basaltic cliffs to fracture and tumble down into the sea, to become mixed with the calcareous debris transported by the surf. An upheaval followed, leaving the marine accumulation above the reach of the waves, where a consolidation of the material took place, binding it all together into a solid limestone. This limestone in turn has been subjected to the battering of the sea with consequent dislodgment of large sections from the main cliff. Probably during this last erosive period the limestone and the scattered basaltic blocks became deluged with tufaceous sand, as a result of the final volcanic activities of the region.

The basal rock along the beach at the base of Diamond Head crater is a brownish tuff, of which the whole or principal part of the crater appears to be made. A layer of more or less firmly united calcareous sand, 1 to 2 feet thick, overlies the tuff at an elevation of 4 to 5 feet above sea level. In a few places, and in scanty quantity, a solid beach breccia with shells and broken coral is found. Overlying this thin calcareous deposit is a vast accumulation of a loosely united talus-breccia, which running water during rain storms has sculptured into deep ravines. This talus consists of a mixture of a tuff detritus, rich in lime, with small angular fragments of tuff, which are usually coated with thin calcareous incrustations, giving them a whitish appearance. A number of small species of air-breathing snails, particularly of the genus *Auriculella*, are found as fossils in the talus. Further east, near Kupikipikio, the consolidated calcareous sand rises from below sea level to an elevation of 10 to 12 feet above and is overlain here as elsewhere by the talus.

Its almost horizontal stratification indicates that this talus-breccia was deposited by rain water upon wide ledges in water courses excavated in the

¹ For a discussion of the geology of Black Point see Wentworth, C. K., Pyroclastic geology of Oahu: B. P. Bishop Mus., Bull. 30, 1926.

tuff near the base of the crater. On the seaward face of the crater, near the lighthouse, it stands $200 \pm$ feet above sea level. The talus is almost entirely free from fossil marine organisms. The few that have been found presumably have been torn from an underlying limestone and ejected through the vent of the crater.

Contrary to the opinion of Dall,² the seaward face of Diamond Head, from the talus slopes at its base to its summit, plainly shows the usual brownish tuff without interstratified calcareous layers. Furthermore, Dall states that he found "near the eastern extreme of the island" (probably east of Diamond Head) shells of *Conus* and *Purpura*, which so far as his observations went are not now represented on the adjacent beaches. The few fossil marine mollusks I have seen from Diamond Head region, not including Kupikipikio, are of the species now living in Hawaii, and the same as have been collected from the limestone in other parts of Oahu.

The basal limestone of Diamond Head is more or less continuous along the shore westward, as far as Hale Kai on Kalakaua Avenue. It is well developed near the Elks Club, and west of the Marine Biological Laboratory it contains numerous small tuff fragments imbedded with shells and corals. It appears to be a continuation of the outer reef, which is here running 500 to 800 feet off shore, marking the line of breakers. In structure and composition the outer reef agrees, in a general way, with the limestone skirting the shore; it is a firmly consolidated heterogeneous mixture of calcareous material. There are probably also large coral heads concealed under a veneer of various calcareous deposits.

On Diamond Head Road, about one-half mile east of Kapiolani Park, calcareous sandstone stands about 50 feet above the sea. The large amounts quarried prove to be a loosely consolidated, uniformly grained calcareous sand, lacking in fossils of any kind. It shows the usual cross-bedding characteristic of wind-blown sand and is homogeneous in structure, except at its upper surface, where it is more or less mixed with the overlying talus.

STATION 6, MOILILI SAND QUARRY

The innermost limits—that is, the marine deposits farthest from the sea in this region—appear in a sand quarry about a quarter mile north of the old site of the Girls' Industrial School. In this quarry a stratum of loosely consolidated calcareous sand is overlain by about 15 feet of talus from a neighboring bluff which divides Manoa and Palolo valleys. This sand, which has an average thickness of $15 \pm$ feet and reaches $25 \pm$ feet above the sea, rests upon large basaltic boulders and contains near its base fragments of

² Dall, W. H., Quoted by Hitchcock, C. H., *Geology of Oahu: Geol. Soc. Am., Bull.*, vol. 11, pp. 57-60, 1900.

marine shells and corals, such as could have been washed up by the waves. But the formation in general is suggestive of sand dunes.

STATION 7, BINGHAM AND FARRINGTON STREETS

Northwest of Diamond Head at the base of Kaimuki slope along Kapa-hulu Road the limestone reappears. Toward the west it is interrupted by the streams from Palolo and Manoa valleys, beyond which it extends over the Moiliili district as far west as McCully Street as a firmly consolidated, hard limestone. On the plain at the mountain side of Moiliili, it is covered by 8 to 10 feet of alluvial soil, revealed by cesspool digging at Bingham and Farrington streets. Opposite the Stadium, over an area of about 150 by 300 feet between King and Young streets, coral reef in place is easily recognized; large coral heads of the genus *Porites*, showing the structures of their calices, are scattered about like huge boulders.

Seaward from Moiliili over the reclaimed swamps of Waikiki a recent marine deposit has been revealed by dredging. It differs from the emergent limestone in three respects: the lack of consolidation of the calcareous material, the excellent state in which shells of mollusks and coral are preserved, and most significant the absence of species characterizing the limestone formations throughout Oahu and which are now believed extinct or on the verge of extinction in Hawaii.

STATION 8, HONOLULU PLAIN

The plain occupied by the city of Honolulu consists of a firmly consolidated limestone overlain by several feet of black volcanic ash more or less disintegrated at the surface and generally covered with a few feet of soil. The numerous excavations for buildings have exposed from time to time the limestone in many places within both the business and the residential districts of the city. Inasmuch as the ash is found in direct contact with the underlying limestone it has been inferred by Wentworth³ that the site of Honolulu was an exposed coral plain previous to the deposit of ash from Punchbowl and Tantalus. The limestone underlying the city does not appear to be rich in fossils, but the mollusks so far found agree well with those found in other parts of the consolidated limestone of Oahu. From the excavation for the new Hawaiian Electric Building at King and Richards streets, L. A. Thurston and T. T. Dranga took from firmly consolidated limestone several specimens of *Cypraea erosa*.

³ Wentworth, C. K., Pyroclastic geology of Oahu: B. P. Bishop Mus., Bull. 30, 1926.

STATION 9, HONOLULU HARBOR

Dredgings in the Palama and Iwilei areas of Honolulu harbor have yielded several species of fossil gastropods which as yet have not been found living in Hawaii although they are living in other parts of the tropical Indo-Pacific. A few of these exotic species have been found in the limestone at numerous other places on Oahu. (See pages 26, 27.)

The material in which these unique gastropods were found is a rather firmly cemented limestone extending over a considerable area of the harbor and covered by only a few feet of water. It seems reasonable to infer that this material is part of the formation underlying the volcanic ash of the Honolulu plain and continuous with the vast limestone formations of the Palama and Kalihi plains, which are exposed at the surface uninterruptedly over large areas a few feet above sea level.

STATION 10, MOANALUA QUARRY

On the western side of Moanalua Valley, along Puuloa Road, a marine formation overlain by earth and fragments of volcanic tuff from Salt Lake crater attains an elevation of $20 \pm$ feet above present sea level. In the upper part of this marine formation are numerous blocks of volcanic tuff, embedded and underlain by what appears to be solidly cemented calcareous beach breccia, rich in univalves and bivalves, fragmented and whole. The species represented are chiefly those of pure marine habitat, but among them are forms which apparently are estuarine.

In a road cut on the eastern side of the valley, opposite the Moanalua limestone quarry, evidence of a reef in place is shown by the presence of a massive coral colony, *Porites compressa*, which has a horizontal diameter of $9 \pm$ feet with $3 \pm$ feet exposed in vertical section. It stands $15 \pm$ feet above the sea.

The Moanalua limestone quarry, located close to the coral colony, presents a good exposure of the marine formation which is a continuation of that in the road cut and, like it, stands $20 \pm$ feet above sea level. The bottom of the quarry is only $5 \pm$ feet above sea level. While the fossils here consist of the pure open shore species, there are in the uppermost part of the limestone formation representatives of the family Neritidae—gastropods inhabiting the shore rocks above the reach of the waves. One of these species, *Nerita neglecta* Pease, is at present abundantly represented on the adjacent shore rocks; another, *Neritina turrita* Chemnitz, has not been found in the fossil state elsewhere on Oahu and is not known to be living in Hawaii. It is, however, reported as living in other parts of the tropical Indo-Pacific. The limestone here is overlain by $5 \pm$ feet of soil and fragmented tuff.

These observations suggest a historical sequence similar to that at Kupiki-pikio. The seaward face of Salt Lake crater was cut into a prominent wave bench when the land stood at its present or higher level above the sea. With subsequent subsidence, marine debris with growing coral reef accumulated on this bench, against the excavated face of the tuff crater. Elevation to the present level and accompanying consolidation of the limestone followed. The limestone cliff appears to have been subjected to the destructive erosion of the waves before the sea finally receded to its present position.

About a quarter mile from the Moanalua limestone quarry, toward the sea, the limestone reappears at the surface over a small area and stands not more than 5 feet above the sea. To the west the limestone appears at the surface in interrupted patches along the shore to Fort Kamehameha at the entrance of Pearl Harbor.

STATION 11, RAILROAD CUT AT PUULOA

Exposed in a railroad cut about half a mile north of Puuloa Station is a marine formation $7 \pm$ feet thick with its surface $13 \pm$ feet above sea level. It is a typical estuarine deposit, consisting of a loosely united calcareous rock with a good amount of volcanic debris. Common here are shells of bivalves such as occur in estuaries or sheltered bays, where there are deep deposits of sand and mud. One of the commonest bivalves found here is *Arca hankeyana*, which is not known to live in Hawaii, but is found living in the China Sea and the Indian Ocean. The other species are now living in the adjacent inlets of Pearl Harbor.

STATION 12, RAILROAD CUT AT WAIPIO

From Puuloa for several miles north and northwest, through Pearl Harbor basin to Ewa plain, there is apparently no limestone. In its place is an estuarine formation characterized by the conspicuous fossil oyster, *Ostrea retusa*. This oyster, now believed universally extinct, occurs in greatest abundance in a railroad cut one-half mile east of Waipio Station, where a mass of shells attached to one another forms a bed of 1 to 2 feet in thickness.

Numerous nonfossil shells in the surface soil from Moanalua to Waipio cut and probably in several other localities should not be mistaken for those belonging to marine formations. They constitute in all probability only the edible species and are undoubtedly derived from Hawaiian kitchen middens, the shells having been distributed by heavy rains and mixed with the soil. The following forms occur: *Crepidula aculeata* Lamarck, *Cymatium tuberosum* Lamarck, *Lioconcha hieroglyphica* Conrad, *Littorina scabra* Linnaeus,

Mytilus crebristriatus Conrad, *Nerita picea* Recluz, *Pteria nebulosa* Conrad. These species are more or less common in the adjacent waters. Some of them probably are not now used by the Hawaiian people as food but likely were at earlier times.

In the region surrounding the three lochs of Pearl Harbor the limestone is absent, but farther out it is continuous with the formation extending from the Moanalua region along the seashore to Watertown, where it is terminated by the narrow entrance to Pearl Harbor. West of the harbor entrance it extends about 9 miles and attains a width of nearly 3 miles, forming the so-called Ewa Coral Plain, which constitutes by far the largest area of limestone on Oahu. The plain appears nowhere to be more than a few feet above sea level and is, on the whole, a firmly united limestone poor in fossils. Along the shore at Barbers Point it is eroded by the sea.

STATION 13, NANAKULI SEA CLIFFS

Westward from the Ewa Coral Plain along the shore at the base of the Waianae Mountains to Kaena Point the limestone forms a discontinuous narrow strip at a considerable elevation. At a point about one mile east of Nanakuli Railroad Station an interesting cliff of emergent reef limestone stands 15 feet above tide level. Erosion of this cliff by the sea has developed a perpendicular face against the base of which the waves are washing and from which large blocks have been dislocated and tumbled into the sea. The exposure is extremely rich in fossil shells and corals, and at a point near the base is a massive Madreporarian coral, *Porites compressa*, standing as it has grown. Sand, coral fragments, and shells now fill in the spaces between its long, slender processes, forming a loosely consolidated mass about them. At all levels of the formation are numerous bivalves with both valves intact. In places the limestone overlies basaltic lava.

STATION 14, NANAKULI SHORE LINE

On the shore one-half mile northwest of Nanakuli Railroad Station the limestone attains an elevation of $10 \pm$ feet above sea level and appears to be like that at Nanakuli sea cliffs, though more firmly united. Here, as well as in several other places on this shore line, the limestone includes large angular basaltic boulders and rests on a more or less dissected stratum of lava.

STATION 15, MAILI POINT

Between Nanakuli and Waianae, limestone intermittently fringes the shore line, attaining an elevation from 8 to 12 feet above sea level. At

Maili Point the limestone is very hard, apparently recrystallized, and contains few fossils. Only one specimen, a gastropod, was obtained.

STATION 16, WAIANAЕ QUARRY

About three quarters of a mile east of Waianae Station and a half mile from the sea is a limestone quarry at an altitude of not less than 60 feet above mean tide level. The rock in this quarry is a loosely cemented calcareous mud containing a few fossils, among them dislodged shells of *Ostrea sandwichensis* Sowerby and small fragments of *Strombus maculatus* Nuttall. The most remarkable fossil here is an oyster of massive size (*Ostrea bryani*) believed to be extinct. Of the two obtained, one constituting the type was found in a block brought down by a blast; the other was found *in situ* about 35 feet above sea level.

The emergent reef at Waianae is very conspicuous for the large coral heads found in place $6 \pm$ feet above tide. At the nearby Maili Point *Thais aperta* was collected.

STATION 17, KAENA POINT

At Kaena Point the limestone stands at about the same level as at Waianae, having been eroded to form a wave-cut bench, which extends 1 or 2 miles beyond the point. The rock is a beach breccia with fragments of coral and shells. It contains fossil mollusks of types common to other limestone areas where open-shore conditions prevail.

About one mile east of Kaena Point, along the Oahu Railroad leading to Waianae, several small, narrow patches of marine limestone lie in a horizontal line on the face of the mountain at an elevation of $110 \pm$ feet above sea level. They constitute a distinct beach breccia containing shells and coral fragments. Some individuals of *Porites lobata* measure as much as 6 inches in diameter. The altitude of this beach material agrees closely with that of the limestones at Heeia, Mokapu Peninsula (Station 21).

In a quarry between Waimea and Waialeale *Antigona reticulata* was collected.

STATION 18, PROMONTORY AT KAWAILOA

Between Kaena Point and Kahuku the limestone fringes the shore line intermittently. It is well developed at Waialua Bay, where it rises in extremely hard, jagged, wave-worn masses, and north of the mouth of Waimea River it extends as a surface sculptured by the sea into sharp, jagged processes.

At a small promontory about a half mile north of Kawailoa the limestone, here only a few feet above sea level, is a beach breccia with numerous shell and coral fragments.

STATION 19, KAHUKU POINT

At Kahuku Point, near the Marconi Wireless Station, the limestone forms a wide plain elevated only a few feet above the sea and consists of the usual firmly consolidated fragmented coral and shells, probably also with coral heads in place. This plain extends from Kahuku Point inland about $1\frac{1}{2}$ miles to the precipitous walls of a limestone bluff 100 feet high, evidently a former shore line. The rock forming the bluff is a firmly consolidated sandstone formed, no doubt, from sand dunes transported by wind. Further inland these consolidated sand dunes attain an elevation of $250 \pm$ feet.

Hitchcock⁴ expressed the opinion that the lower 60 feet of this bluff consists of coral rock. But this portion of the bluff, like that above it, shows nothing that is not characteristic of wind-blown sand. There are no coral fragments, and the very few small shells are such as are easily transported by wind and almost invariably associated with wind-blown sand. Mixed with the surface soil are many species belonging to genera of air-breathing snails.

STATION 20, SAND DUNES AT LAIE

From Kahuku Bluff, past Kahuku Mill and along the shore to a point about two miles beyond Laie (a stretch of about 6 miles), these consolidated dunes extend almost continuously. The prominent Laie Point and the several small islands and rocks that hem in Laie Bay are made of dunes. In this region some of the dunes attain an elevation of more than 100 feet and extend nearly a mile inland. Near Laie the rock is quarried for road material—a coarse-grained, well-consolidated calcareous sand, more or less recrystallized.

STATION 21, MOKAPU PENINSULA

From the Laie region to Mokapu Peninsula, a distance of about 20 miles, limestone is almost absent. But at Mokapu it is well developed in the form of a firmly cemented beach rock consisting of calcareous sand, coral fragments, and marine gastropods and pelecypods. It covers a low, flat area north of Nuupia Fishpond. In the western part of the peninsula, called Heeia, coral and marine shells are found at an elevation of 100 feet above

⁴ Hitchcock, C. H., *Geology of Oahu: Geol. Soc. Am., Bull.*, vol. 11, p. 30, pl. 4, 1900.

sea level. Local volcanic disturbances may be responsible for this exceptional altitude of a marine formation. Such fossil shells as have been collected on the Mokapu Peninsula are those characteristic of open-water marine conditions.

The two small islands, Kekepa and Kapapa, which lie at the entrance to Kaneohe Bay, consist, like those at Laie and adjacent regions, of firmly united wind-blown sand. Kekepa rises to 20 or 25 feet above the sea, while Kapapa is much lower and flatter. Both are much undercut by waves. Apparently these two islands are remnants of a series of limestone islands which formerly hemmed in Kaneohe Bay and extended parallel with the general shore line of windward Oahu. If this be so they would be marking an ancient shore line with extended beaches at a time, perhaps, when the greater part of the present Kaneohe Bay was a salt marsh.

Bordering the eastern shore of Mokapu Peninsula is a low-lying, wave-worn consolidated calcareous rock, rich in marine debris, such as coral and shells, more or less broken up.

STATION 22, KAILUA AND WAIMANALO

About one mile inland from the southeastern part of Kailua Bay a very conspicuous line of sea cliffs rises abruptly from the low, sandy plain to an altitude of $50 \pm$ feet. The rock constituting these cliffs is identical with that of the consolidated sand dunes elsewhere on the windward side of Oahu; but recrystallization has here been carried farther than elsewhere on Oahu. Along Waimanalo Bay a row of high sand dunes extends for about two miles. Back of these dunes and reaching one-half mile or more inland are a few scattered, low sand hills made of somewhat loosely united wind-blown sand. No beach rock or reef was seen. Skirting the shore line for several hundred yards southeast of Waimanalo Landing, limestone reappears similar in its component structure to that forming the shore line on the east side of Mokapu Peninsula and with nearly the same elevation above the sea ($5 \pm$ feet).

About three quarters of a mile west of Makapuu Lighthouse the lava rock of the Koolau Range reaches the sea in a series of step-like ledges. Here $10 \pm$ feet above the sea are thin patches of marine beach breccia rich in fossils, including shells of mollusks belonging to the open, exposed beaches. Because of its inaccessibility the shore toward Makapuu Point was not examined.

NUMBER AND CLASSES OF RECENT MOLLUSCA IN HAWAII

It has been estimated that the marine mollusks of the Hawaiian waters range in number of species between 1400 and 1500, not including the Nudi-branchiata—forms in which a shell is absent in the adult. The four classes of the phylum Mollusca represented are: Gastropoda, Pelecypoda, Amphineura, Cephalopoda.

The gastropods form by far the most important group in number of species as well as in number of individuals, being well represented in the shoal waters within the protecting reefs. Owing to these facts this group alone furnishes far more comparative data than all the other classes of mollusks combined—in fact, more than any other group of marine invertebrate animals inhabiting Hawaiian waters.

The Hawaiian marine molluscan fauna is strictly Indo-Pacific, and the Hawaiian species may readily be compared with those of the tropical Indian Ocean, the tropical South Pacific, and Micronesia. Owing largely, perhaps, to the isolation of the Hawaiian Archipelago, involving peculiar local conditions as well as increased difficulty of distribution from other regions, many of the Hawaiian marine gastropod mollusks exhibit racial peculiarities whereby they may be readily distinguished from exotic individuals of their own species. Indeed, many forms have been described as subspecies by the noted conchologists, Dr. Henry A. Pilsbry and Dr. William H. Dall; while a conservative estimate based on some of the genera of gastropods that are among those represented here by the largest number of species, fixes the number of well-defined endemic species at about 15 per cent. Of about thirty known Hawaiian species of the genus *Cypraea*, five are not known outside Hawaii. These are: *Cypraea semiplota* Mighels, *C. tessellata* Swainson, *C. sulcidentata* Gray, *C. madagascariensis* Gmelin, and *C. ostergaardi* Dall. Of the equally large locally represented genus *Mitra* at least four species are not known from foreign waters, while several well marked varieties of this group also have been described as endemic. The four species are: *Mitra kamehameha* Pilsbry, *M. emersoni* Pilsbry, *M. langfordi* Pilsbry, *M. ostergaardi* Pilsbry. Almost all of the species endemic to Hawaii have in other parts of the Indo-Pacific a closely related form, from which the endemic form may be safely derived. Some of these related forms appear also in Hawaii.

Owing to their paleontological significance and the light they throw on the early molluscan immigrants of the Hawaiian islands, each of the endemic species of the genus *Cypraea* is here discussed.

Cypraea tessellata Swainson and *C. sulcidentata* Gray are probably the most conspicuous of Hawaiian endemic forms of the genus. Although not

common, judging by shell fragments on beaches, the two species are distributed throughout the whole Hawaiian Archipelago. To the best of my knowledge, only two live specimens of *C. tessellata* have ever been collected and few live *C. sulcidentata* have been seen. These two species are very distinct from each other, both in form and markings. They show a close relationship to only one known recent species, *Cypraea arenosa* Gray, which stands as the connecting link between them. *Cypraea arenosa*, rare in Hawaii, is reported from Fanning Island, Samoa, Cook Islands, Society Islands, the Tuamotus, Australia, and Pelew Islands in Micronesia. The species *Cypraea arenosa* approaches *C. tessellata* in having shallow and narrow interstices between the teeth. In color pattern, *C. arenosa* closely resembles *C. sulcidentata*. The relationship to *C. sulcidentata* is represented by a specimen of uncertain locality; the resemblance to *C. tessellata* by an aberrant form recently dredged from Honolulu harbor.

Owing to the very general distribution of *C. arenosa* and the local distribution of the two other species, it seems safe to infer that *C. arenosa* is the oldest form and that *C. tessellata* and *C. sulcidentata* are its modified offshoots.

Parallel relations are recognized in the endemic *Cypraea semiplota* Mighels. Two of the several varieties of this species have been erroneously described as distinct species: *C. annae* Roberts and *C. polita* Roberts, both endemic. The only recent related species which is distinct from *C. semiplota* is *C. staphylaea* Linnaeus. This species, like *C. semiplota* known by several varieties, has an area of distribution that includes almost the entire tropical Indo-Pacific in one continuous sweep from the coast of Africa through Tonga, on the East Asiatic Coast extending to Japan, where three varieties are known. It is not known in Hawaii, neither living nor fossil. It again appears probable that a species so widely distributed and so well established as *C. staphylaea* is older than its locally distributed Hawaiian representative, *C. semiplota*.

Cypraea madagascariensis Gmelin (by some authors placed in the subgenus *Pustularia*, comprising three recent species) is the endemic form of the genus that can be traced with certainty to the modified descendant of *Cypraea nucleus* Linnaeus. Several fossils of this species from the limestone of Oahu show a marked approach to *C. nucleus*; although some recent specimens may also show its strong characters. Like *C. staphylaea*, *C. nucleus* has a wide continuous Indo-Pacific distribution. It is also reported from the Society and the Tuamotu islands, localities east of the known range of *C. staphylaea*. The third species of the subgenus, *Cypraea pustulata* Lamarck, is distributed along the American Coast from the Gulf of California to Peru. This species resembles *C. nucleus* and *C. madagascariensis*.

sis less than these two species resemble each other. There is no definite record of *C. nucleus* in Hawaiian waters.

The fifth endemic species of the genus is *Cypraea ostergaardi* Dall (equals *C. pacifica* Ostergaard⁵), six specimens of which have been dredged from Honolulu harbor—one in 1905, five in 1915. Though all of them were dead, the shells are well preserved, except for fading of color. This species approaches nearest to *C. helvola* Linnaeus, a common local species of a very general Indo-Pacific distribution. It seems logical to assume that this form is a recent offshoot of *C. helvola* that has not become established.

This history of *Cypraea* finds a counterpart in other genera of Hawaiian marine gastropods. Further enumeration of endemic forms and their close relationship seems unnecessary.

When geographic position is considered, it is not surprising to find that the Hawaiian molluscan fauna is tropical Indo-Pacific and strongly marked off from that of the American Coast. While most genera of the Indo-Pacific fauna are represented in Hawaii, it is important to note that some of the very large Indo-Pacific genera—*Marginella*, *Erato*, *Oliva*, and *Murex*—are represented by only one or two species and these conspicuous for their rarity. On the other hand, the Indo-Pacific genera—*Conus*, *Cypraea*, *Mitra*, and *Terebra*—are represented in Hawaii by numerous species. It is an interesting fact that many species abundant as individuals in most other parts of the tropical Indo-Pacific are rare in Hawaii and that some of these species continue to be abundant in individuals at islands south of the Equator which have the corresponding latitude and minimum water temperature of Oahu.

⁵ Ostergaard, J. M., A new *Cypraea* from Hawaii: *The Nautilus*, p. 92, pl. 2, Jan., 1920.

DESCRIPTION OF FOSSIL MOLLUSCA OF OAHU

LOCALLY AND UNIVERSALLY EXTINCT SPECIES

The unique fossil mollusks of the limestone of Oahu, forms that are probably extinct locally or universally, are as follows:

Gastropoda and Pelecypoda believed to be universally extinct are:

<i>Ostrea bryani</i> Pilsbry	<i>Strombus ostergaardi</i> Pilsbry
<i>Ostrea retusa</i> Pease	

Gastropoda and Pelecypoda not known to be living in Hawaii but living elsewhere are:

<i>Arca hankeyana</i> Reeve	<i>Strombus auris-dianae</i> Linnaeus
<i>Neritina turrita</i> Chemnitz	<i>Strombus floridus</i> Lamarck
<i>Pterocera chiragra</i> Linnaeus	<i>Strombus gibberulus</i> Linnaeus
<i>Septifer kraussii</i> Kuster	<i>Turbo setosus</i> Gmelin

Gastropoda in fossil state and as living forms apparently on the verge of extinction in Hawaii are:

<i>Conus tulipa</i> Linnaeus	<i>Cypraea erosa</i> Linnaeus
<i>Cypraea cruenta</i> Gmelin	

GASTROPODA AND PELECYPODA BELIEVED TO BE UNIVERSALLY EXTINCT

***Ostrea bryani* Pilsbry (Pl. II, *A, B, C, D*).**

Ostrea bryani Pilsbry: Acad. Nat. Sci. Philadelphia, Proc., vol. 69, p. 329, pl. 20, 1917.

Two specimens. Length of lower valve 245 mm., width 175 mm. Weight of both valves 4 pounds, 9 ounces. Shell very large, somewhat triangular in outline; lower valve concavo-convex, rather deeply excavated within; muscle impression large, oval, located near center; ventral region thrown into three large wave-like folds; beak short; outer surface roughly laminated concentrically near ventral margin; upper valve considerably smaller, nearly flat, except toward ventral border, where are large folds corresponding to those of upper valve.

Type, Waianae, in detached block of limestone, W. A. Bryan, collector, 1914; quarry three quarters mile east of Waianae Railroad Station. *In situ* 30 or 40 feet above sea level in mass of limestone which attains elevation 60 feet above the sea, Irwin Spalding, collector, 1920.

Only these two specimens known. The formation in which the oysters were found appears to be a loosely united calcareous mud containing a number of shells of the common recent *Ostrea sandwichensis* Sowerby. Through the courtesy of Mr. Spalding I have examined his specimen and find that it differs quite considerably from the type in having shells of a lesser thickness, a much shorter beak, and large wave-like folds instead of numerous

small radial ridges, and I therefore submit the above description for comparison with the type.

Ostrea retusa "Pease" Sowerby (Pl. I, F).

Ostrea retusa "Pease" Sowerby: Conch. icon., vol. 18, pl. 19, fig. 42, 1871.—Pilsbry: Acad. Nat. Sci. Philadelphia, Proc., vol. 69, p. 328, pl. 21, figs. 2, 3, 1917.—Bryan: Natural history of Hawaii, p. 115, Honolulu, 1915.

Fossils from railroad cut a quarter mile east of Waipio Station, abundant in bed of closely packed shells $1\frac{1}{2} \pm$ feet thick and at an elevation of $15 \pm$ feet above the sea; Waipio Peninsula, between Middle Loch and West Loch of Pearl Harbor, J. M. Ostergaard, collector; Waipahu, W. A. Bryan, collector; southern border of Ford Island, Langford, collector. Not known outside Oahu, where fossil only.

Strombus ostergaardi Pilsbry (Pl. I, B).

Strombus ostergaardi Pilsbry: Acad. Nat. Sci. Philadelphia, Proc., pts. 8-13, p. 320, pl. 12, figs. 27, 28, 1920.

Wailupe Quarry No. 2, vicinity of Nanakuli Station, consolidated limestone dredged from western section of Honolulu harbor, J. M. Ostergaard, collector; Mokapu Point, D. Thaanum, collector, 1924; Kailua Coast, W. A. Bryan, collector, between 1910 and 1920, fossil state only. Not known outside Oahu.

It appears most closely related to *Strombus maculatus* Nuttall, which is common among the shallow-water species of Hawaii, and occurs as fossil in the limestone of Oahu. *Strombus maculatus* is also known from Palmyra and Wake islands. It has allied exotic forms in *S. bulbulus* Sowerby and *S. floridus* Lamarck, both of wide Indo-Pacific distribution. The species *S. ostergaardi* appears to have been derived from *S. maculatus* and, judging by its general distribution, to have been once well established in the waters of Oahu, later becoming extinct.

GASTROPODA AND PELECYPODA NOT KNOWN TO BE LIVING IN HAWAII, BUT
LIVING ELSEWHERE

Arca hankeyana Reeve (Pl. I, E).

Arca hankeyana Reeve: Conch. icon., vol. 2, pl. 10, fig. 68, 1844.

In limestone at following places: western part of Honolulu harbor (in dredgings), western bank of Moanalua Valley, in abundance in railroad cut one-half mile north of Puuloa Station. All fossil.

Appears identical with *A. hankeyana* Reeve of the Indian Ocean and probably also of the China Seas.

Neritina turrita (Chemnitz) (Pl. I, A).

Nerita turrita Chemnitz: Conch. cab., vol. 9, pt. 2, p. 71, pl. 124, fig. 1085.—Reeve: Conch. icon., vol. 9, pl. 7, figs. 31 a, 31 b, 1855.—Tryon and Pilsbry: Man. conch., vol. 10, p. 37, pl. 11, figs. 1, 2, 1888.

Fossils from Oahu: Moanalua quarry, 1 collected by J. M. Ostergaard, 1924, 2 by Otto Degener, 1925 (from talus blocks), 1 *in situ* (in upper part of limestone) collected by J. M. Ostergaard, March, 1927. Reported living in Samoa, East Indies, the Philippines, and Australia.

The marine deposits in which the Oahu fossils were found are a loosely consolidated calcareous material made of coral fragments and of whole and fragmented univalve and bivalve shells—pure marine forms, not found in estuaries or in sheltered bays. The species is associated with *Nerita neglecta* Pease, a common recent species inhabiting the shore rocks of Oahu. Neither *Neritina turrita* nor any other species of the subgenus to which it belongs is known as living in Hawaii, the four specimens here listed are only ones known in fossil state, no living specimens have been found in Hawaii.

Pterocera chiragra (Linnaeus).

Strombus chiragra Linnaeus: Sowerby, Thes. Conch., fig. 12, 18.....—Tryon: Man. conch., vol. 7, p. 126, pl. 10, fig. 13, 1885.

From Oahu: small fragment from consolidated limestone (dredgings) from western section of Honolulu harbor, J. M. Ostergaard, collector; large, whole fossil from Honolulu harbor, about 1908; spire from Kupikupio, J. M. Ostergaard, collector. Not known to live in Hawaiian waters; reported alive from Zanzibar, Society Islands, and from regions between.

Septifer kraussii (Kuster) (Pl. I, C).

Tichogonia kraussii Kuster: Reeve, Conch. icon., vol. 10, pl. 9, fig. 40, 1857.

Extinct in Hawaii, so far as known, common and widely distributed in fossil form in limestone of Oahu. Reported living at Cape of Good Hope and Mauritius.

The species occurs with pure marine fossils, but is absent in estuarine formations. There is reason to consider it a good index fossil because it is found in the older consolidated rock and not in the newer loose material.

Turbo setosus Gmelin.

Turbo setosus Gmelin: Syst. nat. 13th ed., p. 3594.—Tryon and Pilsbry: Man. conch., vol. 10, p. 195, pl. 63, fig. 32, 1888.

In limestone from Honolulu harbor, 1 specimen, apparently in fossil

state, J. M. Ostergaard, collector. Reported not living in Hawaii, but with wide Indo-Pacific distribution.

***Strombus auris-dianae* Linnaeus.**

Strombus auris-dianae Linnaeus: Tryon and Pilsbry, Man. conch., vol. 7, p. 113, pl. 4, figs. 37, 38, 1885.

From limestone (dredgings) from Honolulu harbor, one entire fossil specimen, J. M. Ostergaard, collector. Extinct in Hawaii, reported as living in waters between Mauritius and Philippines to the Society Islands.

***Strombus floridus* Lamarck.**

Strombus floridus Lamarck: Animaux s. vert., vol. 9, p. 707, 1843.—Tryon: Man. conch., vol. 7, p. 119, pl. 7, figs. 73-76, 80, 83, 1885.

One entire fossil shell from limestone block dredged from western side of Honolulu harbor, July, 1927; entire fossil shell from Puuloa Road cut, close to Moanalua quarry, August, 1927; J. M. Ostergaard, collector. Extinct in Hawaii. Reported living in Zanzibar, Japan, Australia, Fiji, Tonga.

The living specimens are common in some places. The suggestion has been made that the closely related, almost endemic ally of this species, *S. maculatus* Nuttall, so common in Hawaii, has evolved from *S. floridus*.

***Strombus gibberulus* Linnaeus.**

Strombus gibberulus Linnaeus: Tryon and Pilsbry, Man. conch., vol. 7, p. 121, pl. 8, fig. 85, 1885.

In limestone dredged from Honolulu harbor, 10 specimens. No other fossils known, thought to be extinct in Hawaii. Reported from Mauritius, Natal, Zanzibar, Red Sea, Indian Ocean, Philippines, New Guinea, Fiji, Tonga, Samoa, Tuamotus. Widely distributed in Indo-Pacific.

In many localities this species is a very common shallow water form.

GASTROPODA IN FOSSIL STATE AND AS LIVING FORMS APPARENTLY ON THE
VERGE OF EXTINCTION IN HAWAII

***Conus tulipa* Linnaeus (Pl. I, D).**

Conus tulipa Linnaeus: Syst. nat., 10th ed., p. 717, 1758.—Tryon and Pilsbry: Man. conch., vol. 6, p. 87, pl. 28, figs. 80, 81, 1884.

From Wailupe Quarry No. 2, Honolulu harbor, and Kaena Point, several fossils collected, most of them large, mature forms. One live immature specimen, collected by C. H. Edmondson, 1922, is the only positive record of its present occurrence in Hawaii. Reported as living from East Africa, Red Sea, Ceylon, Philippines, New Caledonia, Fanning Island, Palmyra.

Cypraea cruenta Gmelin.

Cypraea cruenta Gmelin: Syst. nat., p. 3420, 1758.—Tryon and Pilsbry: Man. conch., vol. 7, p. 171, pl. 6, fig. 97, 1885.

From Honolulu harbor (dredgings) 7 specimens having more or less the appearance of fossils, about 1910; 1 specimen, thoroughly fossilized, from western section Honolulu harbor, J. M. Ostergaard, collector; 2 specimens washed up on beach on Coconut Island, near Hilo, Hawaii, T. T. Dranga, collector. Widely distributed in Indian Ocean and in Micronesia.

Cypraea erosa Linnaeus.

Cypraea erosa Linnaeus: Syst. nat., p. 3415, 1758.—Tryon and Pilsbry: Man. conch., vol. 7, p. 192, pt. 18, figs. 1, 90, 100, 1885.

Several fossils from each of the following localities: Hakaione Valley, Wailupe Point, Wailupe Quarry No. 1, Wailupe Quarry No. 2, Honolulu harbor, King and Richards streets, Honolulu; one fossil from Kupikipikio and one from Nanakuli. A live specimen from Kauai Coast, obtained by D. Thaanum from a reliable collector, about 1894, is only record of living form in Hawaii. Widely distributed from Port Elizabeth, South Africa, eastward through the Indian Ocean and its continental shores throughout Polynesia to S. Lat. 21° and throughout Micronesia.

This is one of the commonest Indo-Pacific species of the genus. Judging by its fairly frequent appearance in the fossil state, this species was perhaps formerly well established in Hawaiian waters. It now borders on extinction in Hawaii.

LIVING SPECIES DIFFERING FROM FOSSILS IN SIZE AND ABUNDANCE

The species *Cypraea carneola* Linnaeus, is conspicuous for its frequency as fossil in the limestone of Honolulu harbor, as well as for its consistent small size. The living forms are rare in Hawaii, but are large. The small fossils correspond in size to the living forms quite common in Samoa, Fiji, and Tonga. *Antigona reticulata* Linnaeus, is extremely common as fossil in the limestone, but comparatively scarce in the living state. It appears to be common in Samoa and other islands of warmer water, but absent or rare in the southern part of Tonga, in a latitude corresponding to that of Oahu.

The fossil mollusks described on pages 27, 28 constitute all of the known species that show a difference in one or more respects from living forms in Hawaii. While for many species it is difficult to judge how fossil forms compare in number of individuals with their living representatives in the surrounding waters, it seems obvious that some species have remained quite stable. The only abundant living Hawaiian species of *Cypraea*, *C. caput-*

serpentis Linnaeus, is also the most common fossil. Again, *Turbo intercostalis* Menke is conspicuous for its frequency in the fossil as well as in the living state. Many other species could likewise be enumerated to show a corresponding frequency or scarcity in the fossil and in the living condition.

THE NORMAL HABITAT OF SOME HAWAIIAN FOSSIL MOLLUSKS

In shallow water with rocky bottom and in tide pools are:

<i>Cerithium obeliscus</i>	<i>Conus imperialis</i>
<i>Conus abbreviatus</i>	<i>Conus nanus</i>
<i>Conus auratus</i>	<i>Conus ratus</i> var. <i>tahitensis</i>
<i>Conus hebraeus</i>	<i>Cypraea vitellus</i>
<i>Conus hebraeus</i> var. <i>vermiculatus</i>	<i>Turbo intercostalis</i>

In closed bays or inlets are:

<i>Cassis vibex</i> var. <i>erinaceus</i>	<i>Strombus maculatus</i>
<i>Cymatium pileare</i>	<i>Trochus intextus</i>

In cavities of living and dead coral in shallow water are:

<i>Coralliophila bulbiformis</i>	<i>Mitra astricta</i>
<i>Coralliophila neritoides</i>	<i>Morula nodus</i>
<i>Cypraea helvola</i>	<i>Pisania tritonoides</i>
<i>Cypraea isabella</i>	

On sandy and rocky bottom in water one to several fathoms deep are:

<i>Conus literatus</i> var. <i>millepunctatus</i>	<i>Cypraea scurra</i>
<i>Conus nussatella</i>	<i>Mitra ambigua</i>
<i>Cypraea peasei</i>	<i>Tanna perdix</i>

In strong surf on outer reef are:

Drupa horrida

In deep pools at outer reef are:

Spondylus tenebrosus

On lava rock on rough shores are:

<i>Cypraea mauritiana</i>	<i>Patella exarata</i>
<i>Cypraea reticulata</i>	<i>Thais aperta</i>

On shore rocks washed by surf are:

<i>Cypraea caput-serpentis</i>	<i>Mytilus crebristriatus</i>
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On shore rocks above high tide are:

<i>Littorina pintado</i>	<i>Nerita picea</i>
<i>Nerita neglecta</i>	

In shallow water, attached to rocks or other mollusks are:

Cheilea dillwyni

Hipponyx pilosus var. *imbricatus*

In estuaries or inlets are:

Arca hawaiiensis

Arca reticulata

Arca truncata

Ostrea retusa

Ostrea sandwichensis

Pteria nebulosa

SUMMARY

By various known means marine gastropods are distributed over a narrow expanse of water between adjacent shores or islands; but the method of distribution across a thousand miles or more of uninterrupted sea is not so easy to explain. An important factor of distribution should be kept in mind—the ability of the mollusk during its larval or immature or adult stage to establish itself in the new environment in which fate or its own aggressiveness might have placed it. A young mollusk may encounter not only climatic difficulties, but a chemical, physical, or symbiotic complex, any of which might be an effective deterrent to its successful establishment. A climatic barrier is recognized as the cause of the absence of tropical species in temperate zones; but when a form is absent in an easily accessible region within the climatic zone of its natural habitat, another explanation must be sought.

The comparatively rich Indo-Pacific molluscan population of Hawaiian waters and the great distance of Hawaii from other regions supporting a similar fauna call for a means of transport whereby the many forms may reach new regions beyond a wide expanse of water, far beyond their depth. It is not likely that land bridges of any kind have in recent geologic times existed between Hawaii and Micronesia or other parts of Polynesia.

There is reason to believe that the long free-swimming larval stage in the gastropod mollusk plays an important role in distribution. Of the 48 species, comprising 22 genera, of gastropods that have come under observation in the Marine Biological Laboratory at Waikiki, all but one were found to have a free-swimming larval stage. The larvae of *Tethys sandwichensis* Sowerby were kept for 21 days of their free-swimming period. At the end of the period their shells had increased but slightly in size and showed no sign of settling down. Only *Conus auratus* Hwass developed no free-swimming stage. This species is known in Hawaii under several distinct varietal forms. The absence in the islands of the Pacific of the conspicuous family Volutidae, of world-wide tropical and subtropical distribution, is believed by some conchologists to be due to absence of a free-swimming larval stage. There are, however, a few species of *voluta* reported from New Caledonia. An earlier land bridge may account for this distribution. The embryos of *voluta* before leaving their egg-capsule have formed a shell too large and heavy to be transported by swimming or by the action of currents.

In attempting to find an explanation for the scarcity in individuals of the many species of Hawaiian marine gastropods that are found thriving in the warmer waters of the Indo-Pacific, the climatic factor at once suggests itself, and this does appear to be the primary cause. So far as investigations in spawning habits of the Hawaiian marine gastropods have been carried,

the evidence shows that the species which are rare in Hawaii and common in warmer regions spawn during the warmer months of the year—June and July—while those abundant in individuals spawn either throughout the year or at certain seasons other than the warmest.

It has been experimentally determined that certain marine organisms will discontinue feeding when the water temperature falls below a given point owing to a paralyzing effect produced on the organism. Should the temperature remain long enough below this feeding point, the organism dies for want of food. On the other hand, it has been shown that tropical and subtropical species reproduce only in water of favorable temperature and that in the Northern Hemisphere the limits of their range is controlled by this factor.

These facts afford an explanation for the scarcity of individuals in Hawaii and their abundance in the warmer waters of the Indo-Pacific. Considering the northerly latitude of the Hawaiian islands and the cold westward sweeping current in which they lie, it seems justifiable to recognize Hawaii as the northern limit of a large number of Indo-Pacific species of mollusks.

In view of the fact that many species now found thriving best in the warmer Indo-Pacific are represented in Hawaii by fossils only and others by species on the border of extinction, it is reasonable to assume that at the time the limestone of Oahu was formed Hawaii had a higher ocean temperature. A more prolific representation of fossil than of living Madreporarian coral on the reefs of Oahu supports this conclusion. Worthy of note also is the presence of well-developed coralline algae, which form compact encrusting layers over dead coral boulders and substantially aid in reef building by preventing a breaking up or dissolution of these coral boulders. The efficiency of these corallines in reef building is well exemplified in the reef at Apia, Samoa, where these algae are seen to encrust and cement together coral masses into a firm compact reef, forming a barrier about a mile from shore.

In the collections so far studied are 3 presumably extinct species of a total number of 82 fossils. Of the 3 fossils, *Strombus ostergaardi* may yet be found living, though *Ostrea bryani* and *O. retusa* because of peculiar local habitats are more liable to extermination than are such open-shore and reef forms as *Conus*, *Mitra*, *Cypraea*, and *Strombus*.

On the basis of percentage of extinct forms a geological age greater than the Pleistocene should not be assigned to the emergent limestones of Oahu. Supporting this conclusion is the comparatively small amount of subaerial erosion at the contact of limestones with the lavas of the Waianae Mountains and the Koolau Range.

A

B

C

D

E

F

HAWAIIAN FOSSIL MOLLUSKS; A, *NERITINA TURRITA*, VENTRAL AND DORSAL ASPECTS; B, *STROMBUS OSTERGAARDI*, VENTRAL AND DORSAL ASPECTS; C, *SEPTIFER KRAUSSII*, OUTER AND INNER SURFACE OF RIGHT VALVE; D, *CONUS TULIPA*, VENTRAL ASPECT; E, *ARCA HANKEYANA*, INNER AND OUTER SURFACE OF RIGHT VALVE; F, *OSTREA RETUSA*, INNER SURFACE OF LOWER AND UPPER VALVE. PHOTOGRAPHS BY C. H. EDMONDSON.

A

B

C

D

OSTREA BRYANI; A, B, INNER SURFACE LOWER AND UPPER VALVE; C, D, OUTER SURFACE LOWER AND UPPER VALVE. PHOTOGRAPHS BY C. H. EDMONDSON.

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