nating from the inner side of the upper edge of the cup; no appearance of reticulation under the base; disc of column convex, processes on surface eleven, one of which is in the centre, the rest arranged around it, their summits entire and hispid; lower part of tube of perianth studded with thick glandular hairs; anthers ten, with cells and pores, as in the other species; no moniliform cord at base of column; sporiferous cavities not apparent, flowers examined probably male; interior of perianth covered with various formed tubercles.

Art. IX.—REMARKS UPON CORAL FORMATIONS IN THE PACIFIC; WITH SUGGESTIONS AS TO THE CAUSES OF THEIR ABSENCE IN THE SAME PARALLELS OF LATITUDE ON THE COAST OF SOUTH AMERICA.

By Joseph P. Couthouy. (Read December 15, 1841.)

Among the various geological phenomena which at once bear record of the past changes in the structure, conditions and climate of our planet, and indicate the alterations at this moment slowly and silently, but effectually going forward; few have given rise to more speculation, than the countless coral isles and reefs, which stud the equatorial seas, especially in the Pacific and Indian Oceans.

It is my intention, in this communication to, throw together a few observations upon this class of rocks, and such correlative topics as may present themselves as I proceed. With regard to the latter, no fixed system or order of introduction will be pursued, but they will be taken up at random, as suggested by the main subject.

The vastness of the region over which these singular formations are scattered; the evidence they afford, by analogy, of the existence, in former epochs, of a more uniformly warm temperature of the earth than has prevailed since its present organization — in the fact that such rocks now form only in the more heated parts of the ocean, while their fossil types and analogues extend even into the arctic regions — the great density of the beds of coral, exhibited in some of the uplifted islands — the light thrown by an examination of them, on the

origin of the wide tracts of chalk and limestone found in various parts of the globe — the apparent insignificance and insufficiency of the tiny architects that construct these singular edifices when compared with the stupendous results of their labor — all these are points which have long directed to them the researches of the geologist, and given rise to a variety of theories upon the mode in which such innumerable masses of coral have risen from the bottom of "the vasty deep."

The inaccurate statements of early voyagers, relative to the rapidity with which coral rose to the surface, seemed to be in a measure corroborated by the accounts brought home by almost every vessel trading to these regions, of new reefs springing up as by magic, in the most frequented tracks.

Many were in consequence, induced to regard the coral seas as containing the rudiments of a new continent, which, silently but rapidly, rearing itself above the waste of waters, was destined, at no very remote period, geologically speaking, to equal in magnitude either of those now existing.

Later, and more systematic examination, however, has shown that such an inference was deduced from very erroneous premises. By observations upon the depths of channels in well known harbors, and the level of reefs in their vicinity; by the fact that not the slightest increase of the coral is perceptible on or around anchors and guns cast upon a reef from a stranded vessel, and known to have remained undisturbed for more than half a century — and by similar means of arriving at an approximation to the truth; it is now ascertained that the growth of coral is exceedingly slow.* The lapse of many

* I am inclined to believe that the increment of the branching corals, or at least of certain species, is much more rapid than that of the sessile or encrusting genera; having observed such shells as Pecten, Lima, Plicatula and Pedum, of an inch and a half in length, completely overgrown by the Polyparia, while their colors and internal polish were scarcely impaired. These were not lodged as we frequently see Arcæ and Mytili, in accidental cavities, but for the most part imbedded at the divergence of the branches. There are specimens exemplifying this, now in my possession, and also in the Society's collection, in which the branches are enlarged, and sometimes deflected by their envelopment of these foreign bodies. The rate of increase in such cases, might be approximately ascertained, by experiments upon the time requisite for shells of this kind to attain a size equal to the imbedded specimens, which it is very likely were lodged upon the corals soon after their expulsion from the parent shell.

centuries would be requisite for the construction of a solitary reef, and myriads of ages must pass before the lateral growth of the thousands of scattered islets and shoals could extend itself so widely as to unite them all in one continuous body.

That so many new islands in those seas, were and are still discovered by almost every navigator, need not excite our surprise if we consider their small extent, in general rendering them mere specks in the ocean, which, together with their slight elevation, prevents their being visible more than a few miles under the most favorable circumstances. By day they are often concealed by a veil of mist and cloud, and I have myself passed within three miles of one, whose existence, owing to this cause, would never have been suspected had we not previously been well assured of it. During the night especially, in consequence of their being surrounded by deep, blue water, vessels may, and do, frequently pass within a very small distance of such perilous spots without receiving the slightest warning of such proximity.

On this subject the *facts* stated by intelligent, though unscientific observers, are entitled to our respect and consideration, whatever may be our opinion of the *inferences* they draw from them.

The Rev. John Williams,* late missionary from England to the South Seas, had bestowed much attention upon the subject of coral formations, among which he spent about sixteen years of his valuable life. In his "Narrative of Missionary Enterprise in the South Seas," p. 49, (1st Am. Ed.) he observes, "the rapidity of the coral growth has been egregiously over-rated and over-stated." "You seldom find a piece of branching madrepore, of brain, or of any other coral, however deep in the water, above two or three feet in height."

And again on p. 50, alluding to the formation of new islands, he remarks, "I have traditions of the natives on almost every subject, especially of their former navigators, wherein every island which has subsequently been discovered within

* Mr W. was barbarously murdered in November, 1839, by the cannibals at Errumanga, one of the New Hebrides, while endeavoring to open a communication with them, for the object of introducing some native teachers from Samoa.

a thousand miles, is named; but in no one of them is there any mention of, or reference to, a newly formed island. I am familiar with one tradition in which there is a genealogical account of the reigning family for thirty generations, which is equally silent upon the subject of new formations."

In conversation with Mr W. at Upolu, one of the Samoan or Navigator Group, but a few days prior to his death, he stated that on the reef bordering that island, there were particular clumps of coral, known to the fishermen by names derived from either some particular configuration, or tradition attached to them, and handed down from generation to generation from time immemorial. By careful inquiry among the natives, he had satisfied himself that these had undergone no perceptible alteration since the earliest mention of them. The testimony of the missionaries, and other foreigners, at the Tahitian and Hawaiian Islands, some of whom had resided during nearly forty years within sight of the reefs, confirmed, as far as it went, the remarks of Mr Williams. Did the limits of this communication permit, many other facts might be adduced, corroborative of the evidence given by these persons of the extremely slow increase of the living corals; but the point is perhaps now too generally conceded, to render farther details necessary in an article like the present. In connection with this subject of growth, a few remarks, however, upon some of the theories respecting recent coral formations, which have found supporters among men of science, may not be misplaced.

It was at one time a very generally received opinion, founded chiefly upon the circumstance that a fathomless ocean laved the very margin of the reefs; that the coral animals commenced their labors at an illimitable depth, and, governed by a certain instinct or impulse, toiled upward to the light, giving to their sub-marine structures the peculiar form they exhibit, through the same instinct teaching them that it was the best adapted to afford shelter from the violence of wave and tempest.

Thus, the windward portion of the reef was supposed to be that first elevated, presenting a perpendicular face to the

breakers, and shelving away on the opposite side. Protected by this wall, it was thought the polypes next constructed their edifices at some distance to leeward, which at first rose in a series of detached masses arranged in a somewhat circular form. But gradually the intermediate spaces were filled up and a continuous chain was thus formed, enclosing a deep, bowl-shaped lagoon, which, in process of time was also filled up by the stony dwellings of the polypes.

Fragments of coral, heaped up by wind and sea, and cemented together, formed a ridge of two or three feet elevation above the level of the surrounding ocean. Multitudes of marine birds frequenting the rock to deposit their eggs — the exuvia of crabs and shell-fish on which they fed, the sediments left in hollows by the heavy and frequent rains ; gradually prepared a light soil for the reception of the few seeds wafted thither by favoring currents, or brought by stray land birds — these sprang up, and by their subsequent decay added continually to the depth of soil, — a single cocoa-nut perhaps, cast upon the beach, germinated, and arriving at maturity, its seeds in a few years were scattered over the island, which was then fitted for the abode of man.

That this is the manner in which the once sterile and weather-beaten ledge of rocks has been here gradually covered with the most luxuriant vegetation, there can be no question.* Perhaps no more striking proof of it can be adduced,

* An instance of the rapidity with which even the largest plants multiply and spread themselves over the soil in these regions, is afforded in Christmas Island, an extensive lagoon island, situated between about 1° 40′ and 2° 10′ North lat. and 157° 10′ and 157° 50′ West long. By the statement of Capt. Cook, who discovered it in 1777, "on the cocoa-nut trees upon the island, (the number of which did not exceed thirty,) very little fruit was found ; and in general, what was found was either not fully grown, or had the juice salt or brackish ; so that a ship touching there must expect nothing but birds, fish and turtle, and of these an abundant supply may be depended upon."

In 1837, the English whale ship Briton was wrecked on this reef, and her Captain, George Benson, with his crew of twentythree persons, remained upwards of seven months on the island, from which they were finally taken by an American whaler. According to Capt. Benson, there were several large groves of cocoa-nut trees, one of them containing between six and seven hundred, and the whole number exceeded two thousand, bearing excellent fruit, although many trees had been cut down by the whalers occasionally touching

than the fact that the small number of species of plants found on these islands previous to the visits of man, are all those whose seeds would bear this mode of transportation, without injury to the germinating principle, and belong to an almost equal number of orders, and sometimes of classes, whose primeval soils were widely remote from each other.

But there is nothing whatever in the appearance of the reefs, confirmatory of the supposition that the windward portion was constructed anteriorly to the opposite one. They have both precisely the same level, present similar inequalities of surface, and an equally perpendicular wall facing the sea. The only material difference is, that the elevated fragmentary beach is in general, as might be expected, first formed and highest on the windward side.

But even this is not invariably the case. At Minerva or Clermont Tonnerre Island, which is situated on the southeastern skirts of the Dangerous Archipelago, in about 18° 26′ South lat. and 136° 30′ West long., and whose greatest extent is from E. S. E. to W. N. W., or nearly in the direction of the S. E. trade wind; the northern shore is the more elevated one. The southern or windward side of the lagoon is here bounded by a low, naked line of reef rock, and several small, detached islets. At Ocean Island, in lat. 28° 22′ North, long. 178° 30′ West, near the limits of the N. E. trade wind in the Pacific, the highest points, and the only ones in fact above water, are a ridge some three miles long and no where above ten feet high, at the S. E. extremity of the reef; and two knolls about a mile and a quarter in circuit, on the South skirt of the lagoon. The reef extends from the S. E. ridge, about eight and a half miles to the N. W. in form of an oval, whose shorter diameter is six miles from N. E. to S. W.

On no part of this extensive reef, is there any thing to show that one portion of it is of higher antiquity than the rest, and it is on all sides washed by an unfathomable ocean. It cannot surprise us that while so little was known of the habits

there for supplies. The turtles, however, appear to have been driven away by the intruders, as he caught but about twenty, of small size, during his long stay; whereas Capt. Cook procured three hundred during his brief visit.

of the saxigenous polypes, reefs of this nature were supposed to be raised by them from a depth like that found outside. But later and more careful investigations of their habits, have undeniably proved the incorrectness of this opinion. By the concurrent testimony of all recent observers, it is now shown, that instead of inhabiting such profound depths, the reef-building polypes require for their development and support, a certain degree of light and heat, not penetrating lower than one hundred and twenty, or at the utmost, one hundred and thirty feet in any part of the ocean. Some indeed have asserted less than half that depth to be the limit of growth, but this can only be true of particular tracts, as I shall have occasion to show in another place.

Another theory, and one obtaining the sanction of some distinguished names among the geologists of Europe, was suggested by the circumstance of nearly all the coral islands having a lagoon of variable depth in their centre. From this peculiarity it was conjectured that the reefs rested upon the summit of extinct sub-marine volcanoes, whose craters were represented by the lagoon.

It cannot be denied that this hypothesis presents many plausible features, but still there are some knotty and stubborn facts for which it fails satisfactorily to account. It is true, that a knowledge of such enormous craters as those on the summit of Mauna Loa in Hawaii, and Haleakala in Maui,* which are estimated at twentyfour and twentyseven miles in circuit, might in a measure quiet the doubts of those to whom the great extent of some of these lagoons, appeared the chief obstacle in the way of assuming their crateric basis. Yet although it may be possible that some of the lagoon islands

* Hawaii and Maui are the two principal islands of the Hawaiian Group. The great crater on Mauna Loa, here spoken of, is on the very summit of the mountain, which is little less than fourteen thousand feet high. It must not be confounded with that of Ka lua Pele, or Kilauea, spoken of by Lord Byron, Ellis, Stewart, and others. This latter is on the S. E. flank of the mountain, about four thousand feet above sea level, and is at present in full activity. No signs of action, other than a faint smoke, have been perceived in the terminal crater for about fifteen years. The great crater of Haleakala, or "The House of the Sun," also a terminal one, at an elevation of nearly eleven thousand feet, has been extinct from a period beyond that reached by the traditions of the islanders.

having a circuit of twenty, forty, or even eighty miles, are thus based ; it is rather startling to assert that such a multitude of submarine craters, and of such varied and anomalous configuration, were grouped together in so small a space as the coral archipelago of Polynesia ; not to mention the still greater number that, if this theory is correct, must have existed in other parts of the Pacific, and in the Indian Ocean, where similar formations prevail to a great extent. There is, I believe, nothing analogous to this hypothetical huddling together of craters in any of the present volcanic regions of the globe. It is true, that the Galapagos have been estimated to contain from fifteen to eighteen hundred craters, of various magnitude, but nine-tenths perhaps of these, are rather to be regarded as funnels, or chimnies, composed of scoria, or gravel and ashes, which are constantly crumbling in and becoming obliterated merely through the action of the weather ; and could not have been formed under water at all. It is indeed very probable that at some remote period of the past, the agency of internal fires may have been much more powerfully manifested than at a later day, and the vents therefore much more numerous then than since the earth received its present form. But admitting that submarine volcanoes once existed in the number and limited space required by this theory ; there are still one or two points that would seem to be fatal to it, though they appear to have been overlooked by its advocates.

From the peculiar adaptation of structure in every other class of animated beings to certain habits and conditions, analogy would certainly lead us to the conclusion, that the organization of creatures flourishing so luxuriantly near the surface, could hardly be capable of supporting the great pressure resulting from such a column of water as would rest upon them at profound depths. But besides this objection, there was the improbability that beings so frail could exist equally well, amid temperatures so widely different as those of the surface of the ocean and its bed or any considerable depth. In the parallel of 16° South, where the surface temperature was 82° Fahr., that of six hundred feet below it

was shown by a registering thermometer to be but 56°, and at nine hundred feet but 48°. This experiment was made by myself, in the open ocean. At the same depths upon soundings, the difference would, I doubt not, have been still greater, but not having actually ascertained this by experiment, I cannot speak positively on this point.

According to the statements of those zealous naturalists, MM. Quoy and Gaimard, the result of their observations during the first voyage of the Astrolabe, was, that the growth of the more solid corals was limited to a depth of five or six fathoms.* In fixing this limit, however, I think they have not sufficiently taken into consideration the variations of temperature at small depths, produced by accidental causes, and that in the tropics, where the sea is warmed to a considerable depth by the presence of large bodies of land, these corals may flourish considerably lower.

In approaching the island of Tutuila, one of the Samoan group, I remember suddenly coming from deep water upon a shelf, upon which there were but thirteen fathoms. This ledge, distant about two and a half miles from the coast, which was very steep, was profusely covered with coral. The surface temperature was here 81°, and that of the bottom 76°,

* The work of Q. and G. not being accessible here, I trust of necessity to memory, in quoting the depth assigned by them, as the lowest limit for the growth of the coral in any considerable quantity.

It is well perhaps to notice here, that wherever, in this communication, certain depths and temperatures are spoken of, as essential to the growth of the polypes, I refer only to the reef-constructing genera, and more particularly to those whose Polyparia form hemispheral masses, broad, lamellar incrustations, or solid palmate clusters. Some of the arborescent corals have been found in extra-tropical seas, in very low temperatures, and depths far exceeding those here assigned as the limits of the saxigenous polypes. There is now, or should be, in the collection at Washington, a small species of Madrepora, dredged on the coast of Patagonia, from a depth of eighty fathoms; and Dr. Gould has lately received specimens of another from our coast, in the vicinity of Portland, Maine. I have also picked up specimens on the New Jersey shore. But these have all a shrunken, dull, and if I may so call it, starved appearance, and are of insignificant size. Such species may, and I doubt not do, exist at depths of corresponding temperature, in the tropics, but they bear the same affinity to those constituting the coral reefs, that our humble bracken does to the magnificent and stately palm-tree-like Ferns of Polynesia.

Fahr. Throughout the coral archipelago to the eastward of Tahiti, the surface temperature ranges from 78 to 81°. The same may be said of that in the neighborhood of the detached islets, between Tahiti and Samoa to the west. Throughout this region, I observed all kinds of coral flourishing in perfection on the outer plateau of the reefs, at a depth of seven, eight, and in some cases, as that just cited, twelve or thirteen fathoms.

In our own hemisphere, in the vicinity of Eleuthera and Abaco, and also of the Stirrup Keys on the N. E. edge of the great Bahama Bank; I have dredged up considerable masses of Meandrina from a depth of sixteen fathoms, and in sailing over Salt Key Bank, have seen them, on a calm day, in twenty fathoms. This is probably attributable to the increased temperature caused by the proximity of the Gulf Stream which has here a heat of 85° Fahr. The most compact and vigorous growth, may, I think, however, be considered as prevailing, in general, at a depth of from three to eight fathoms.

To assume, therefore, that the lagoon islands are based upon extinct submarine volcanoes, we must also suppose that these all had their summits raised to nearly an uniform level, and that, the one best adapted to the habits and development of the coral animal, an arrangement scarcely within the bounds of probability. It is difficult to believe that some two hundred or more craters, if they ever existed in so narrow a space as that occupied by some groups containing that number of lagoon islands, nowhere presented more than one hundred or one hundred and twenty feet difference of level.

But granting that all these requisites for the establishment of this theory existed; it offers no explanation of the circumstance that some of the reefs have, as ascertained by sounding, a thickness of several hundred feet, and of their fossil representatives in the chalk and marine limestone being found in strata of still greater density. Neither does it in any way account for the existence of extensive shore reefs like those of Samoa, Hawaii and Tahiti; or of encircling reefs with lagoons between them and the shore, as at Vanikoro and several of the New Hebrides and Friendly Islands; or for the im-

mense barrier reefs of New Caledonia and Australia, the latter of which, at a distance of thirty or forty miles from the coast, extends in an unbroken chain nearly one thousand miles from north to south. It affords at best, but a very questionable explanation, of a single variety of structure in these wonderful edifices, than which nothing more forcibly illustrates the immense results that may ensue from the operation of apparently trifling causes, when continued unremittingly throughout a long series of ages.

It is my belief that, to a certain extent, the corals are limited in their range of growth by temperature rather than depth, and that wherever this is not below 76° Fahr. there, *cæteris paribus*, they will be found to flourish as in the Polynesian seas; accordingly we find that their principal formations are placed within the tropics, and though I have no means of ascertaining at this moment the fact, I apprehend that in the Indian Ocean, as in the Pacific, the saxigenous polypes will be found most abundant and at their greatest depths, in a belt comprising about twenty degrees on each side of the equator.

But even allowing that they invariably commenced their structures at the extreme depth of twenty fathoms, it is obvious that no reef would attain a thickness of much more than a hundred feet, before the labors of the polypes must cease and themselves perish, in consequence of their exposure to the sun's rays. The question then naturally arises, how are we to account for the existence of coral banks, so greatly exceeding this thickness as some are known to do; if it is thus disproved that their polypes build at corresponding depths?

Mr. Charles Darwin, who accompanied King and Fitzroy, as Naturalist, in their late survey of the southern extremity of our continent, was led by his examination of a lagoon island, (the only one I believe on which he landed,) and a comparison of the observations of his predecessors on this subject, to frame an hypothesis, which appears to offer us a solution of this problem, at once satisfactory, simple and rational.

According to the statements lately given by Prof. Lyell, in his lectures before the Lowell Institute, Mr. D supposes the

great thickness of the reefs, to have been formed by a gradual and long continued subsidence of the original shelf of coral, while the surface was maintained at the same level as at first, by the unceasing additions made by the polypes. Carrying out this principle, he attributes the peculiar conformation of lagoon islands to the operation of similar causes. That is to say, he considers that the site of those islands of such a character, now sprinkled over the whole vast coralliferous belt of ocean, was once occupied by islands of various elevation, surrounded as many of the same class now are, by a fringing or shore reef; that as these have slowly sunk, the reef has gradually receded from the shore, and on their total disappearance left the lagoon only to mark the place of their existence. Thus the coral islands instead of being looked upon as the germs of a new continent, should be contemplated as the wrecks, or rather as beacons, pointing out where lie the wrecks of one, long since

"In the deep bosom of the ocean buried."

Having personally examined a large number of these islands, and also resided eight months among the volcanic class having shore and partially encircling reefs, I may be permitted to state that my own observations have impressed a conviction of the correctness of the theory here advanced by Mr. Darwin. Indeed without being aware at the time that such views were entertained by any one else, but failing to discover in any author a satisfactory elucidation of the apparent anomalies they exhibited, I was led, more than two years ago, by a comparison of the features presented by the reefs of Tahiti with those of the Dangerous Archipelago and Paumotu Group, (of which I had just enjoyed an opportunity of examining a very considerable number,) to similar conclusions as to their origin, with those recently published by that gentleman; though not to entertain his opinions respecting limited and definite areas of subsidence and elevation.

My observations in MS. on this subject are now in the possession of the Navy Department at Washington; but not being permitted to have access to them, I am compelled, in

all the statements made in this communication, to rely upon memory alone. I shall in another place, briefly give my reasons for believing that the whole of Polynesia is at present slowly rising, and proceed, here, with a few remarks suggesting themselves at the moment, relative to its former subsidence.

It is not denied that some portions of this region may exhibit certain peculiarities of structure, which, in the present state of our information we may find some difficulty in reconciling with this theory.

But I feel persuaded, that as this is enlarged, as a greater number of facts bearing on the question are brought together, and we are enabled to fix with more certainty than can now be done, the causes of such variations from a general character, these will nearly if not quite all be found consistent with the admission of a principle, which holds out a rational explanation of phenomena, inexplicable upon any previous hypothesis.

The immensity of the tract, throughout which it is assumed this subsidence or submergence of land has prevailed, will appear less astonishing, when we reflect that nearly the whole of that now elevated above the level of the ocean bears upon its surface incontestable evidence of having been slowly uplifted from its depths, and that in some regions, as on the Baltic coast, the process is still going on under our own observation. On the loftiest heights to which man has ascended, as in the lowest vallies, the presence of beds of marine shells and other fossils, attest that there once were the "foundations of the great deep." Even in New Holland, whose animal and vegetable productions differ so singularly from those of all the world beside, as to leave conjecture itself at fault, in attempting to account for the fact; and which a learned German author, once gravely endeavored to show was the nucleus of some comet that had come in collision with our planet—even there, beds of marine limestone, and marine fossils of the same genera, and evidently belonging to the same era as those found in some of the Silurian rocks of Great Britain, have lately been found in large numbers far inland and on the

highest mountains. On the lower grounds of the coast, in the vicinity of Newcastle, New South Wales, there are strata of clay from sixty to one hundred feet thick, abounding in marine shells, many of them analogous to, and some of them identical with, species at this moment living in the adjacent seas.

It is not unreasonable to conjecture, that when the existing lands constituted the bed of an ocean, teeming, as evinced by their fossil remains, even in regions now condemned to the regions of perpetual winter, with forms of animal life peculiar to our tropical seas; then the balance of land and water was preserved by the existence of a broad equatorial continent, or it may have been a number of large islands, whose structure was chiefly, if not entirely volcanic. We can then conceive, how by one of those stupendous oscillations, which an examination of its various strata, shows the earth's crust to have experienced at different epochs; as the Alps, the Andes, and the Himalayas uprose from the abyss, and age after age continued to raise their aspiring summits to the skies; the pre-existing lands gradually sank and finally disappeared; even the elder mountain ranges, hiding "their diminished heads" beneath the waters; a few only of the loftiest remaining, like scattered monuments, in those ancient

> "Titan peaks that overtop the waves,
> Beaconing a sunken world." *

* It is a curious coincidence, if nothing more, and even to those who are not in the habit of attaching much importance to the signification of names, may seem worthy of this passing notice, that the appellation of "Paumotu," bestowed by the natives upon the extensive group of lagoon islands to the eastward of Tahiti, is compounded of "*Pau*," lost or passed away, and "*Motu*," an island. They have also an ancient tradition that all this region was once high land; but the gods being angered by the inhabitants, caused the sea to rise up and overflow it, when all perished but one chief and his family, who were saved by escaping to the top of Raiatea, an island a few leagues to the northwest of Tahiti. From these, when the waters partially subsided, the islands were repeopled. Similar traditions are extant in Samoa and Hawaii. In one of these the story is precisely that of Deucalion and Pyrrha, excepting that the rescued pair raised up a new race by scattering cocoa-nuts instead of stones behind them. I mention this only as one more instance, in addition to those already well known, of the widely spread if not universal belief, in the occurrence of a deluge by which nearly the whole of mankind were once destroyed.

Such we may consider the Tahitian, Samoan and other groups of elevated volcanic islands in Southern Polynesia, interspersed among which are occasionally found lagoon islands also. The rocks of the former class, from New Zealand to Tahiti, (and I might include most of the Hawaiian islands, two thousand four hundred miles farther north,) are so nearly alike in all respects, that on seeing a series of specimens from each group placed together, any mineralogist ignorant of the fact would in all probability decide that the whole were collected within a short distance of each other. Indeed, it was necessary in packing specimens collected by myself of the deeper seated rocks of South New Zealand, Tahiti and Kauai, for me to use great precaution in keeping them separate; as if once mingled it would have been impossible from any difference of character to identify their several localities again.* May we not be justified then, in assuming this common character to be some proof of a common age as well as origin for those islands, and an indication at least, that though now so widely separated, there was a period when they were connected together in a grand whole?

It may perhaps be asked, if this theory of subsidence be well founded; why is it that the original shore reef does not, instead of forming a lagoon, present a flat surface, on the total submergence of the land, extending over the whole area once occupied by this latter? But this could not possibly occur unless the submerged island had been of very small extent, and rose almost perpendicularly from the sea. In all the shore reefs that I have seen, there is a narrow interval of shallow water between them and the shore, which the wash of the beach renders too impure and turbid for the growth of the coral in any quantity. This space would be continually widening during the subsidence, (even were the lateral increase of the coral equal to that upwards, which is doubtful,) by reason of the recession of the mountain side from the reef being greater than its perpendicular descent. Thus if we

* These specimens are now deposited in the new Patent Office at Washington, and, as I learn, are open to public inspection; so that any one may there easily convince himself of the truth of these remarks.

suppose the face of the mountain to have presented an angle with the horizon of say 30°, it is evident that for every foot of subsidence there would have happened three feet of recession from the reef's original limit. By the time it had sunk two thousand feet, allowing as above, the lateral and upward growth of the reef to be equal in rate, and that rate sufficient to maintain it at its primary level, a channel would thus be formed four thousand feet in width, between reef and shore. The steeper the mountain, the narrower would be the lagoon formed by the same amount of subsidence ; and the reverse.

Now this difference is precisely that which is really exhibited by the encircling and barrier reefs, according to the nature of their coasts. In the abrupt and lofty volcanic islands of Polynesia, the lagoons seldom exceed three fourths of a mile or a mile in breadth, while on the gently ascending coast of New Holland, the reef is in some places fifty miles from shore.

I shall notice at present but one more feature in these lagoons, which is their small depth, in comparison with what the assumed subsidence would at the first glance lead us to expect. But the wash from the beach, which in every instance under my observation, spite of the protection afforded by an outlying reef, was very considerable ; and the detritrus of the reef itself, together with the alluvium deposited by streams, would be sufficient to raise the bed of the lagoon very materially. If in addition to this we suppose, what may well have been the case, that there were intervals of time during which the land was stationary, while these causes continued in full operation, or that any considerable time has elapsed since a cessation of the subsidence, there is no longer any difficulty in accounting for this comparative shallowness of the lagoons.

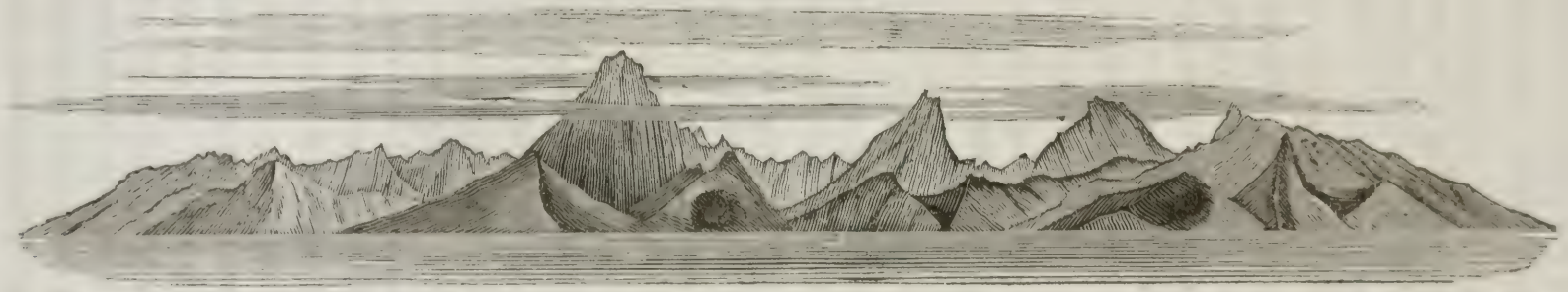
As the general character and aspect of the low coral islands is not very clearly understood by some of our number, I may be pardoned for venturing to occupy a few moments in a hasty sketch of their structure. This seems the more called for, because in the recent course of Lectures delivered for the

Lowell Institute, in this city, by that eminent Geologist, Prof. Charles Lyell, a part of his language, while describing these Paumotus or Attols, was calculated to mislead many of his audience as to their general configuration. He invariably spoke of them as "circular," "annular," or "ring-shaped," and they were so represented in the drawings illustrative of his remarks. Indeed, the question has since been more than once put to me, how was this uniformity of outline to be accounted for, unless the reefs really were based on submarine craters?

But so far from this particular shape being the constant or even most frequent one, it is of comparatively rare occurrence, at least in the Polynesian seas. The most ordinary form is that of a short bow, crescent, or horseshoe; the convex side facing different points of the compass in different islands. In those of the Dangerous Archipelago, a very common figure is a long, narrow, sinuous ellipsis. This, indeed, is the configuration one might expect a group of these Paumotus to assume, following that of the pre-existent ridges whose site they occupy.

Unassisted by plans or sections, it is not easy for the mind to follow out the appearances that would be presented by a mountainous tract surrounded by a shore reef, during its transition to the lagoon formation. Nevertheless some notion of this may be formed, if we imagine to ourselves an island like Tahiti or Eimeo, or some of those in Samoa, consisting of a number of central conical peaks, (some of them crateriferous,) from which diverge in all directions, sharp ridges having upon them, here and there, hills sometimes several hundred feet high — these ridges intersected by profound ravines, whose walls frequently present a precipice of fifteen hundred or two thousand feet elevation—and the ravines sometimes barred by a transverse ridge, perhaps a portion of the mountain, which has fallen down, so as to give the space between the barrier and the head of the chasm the appearance of a long, narrow, and deep pit or trench.

The stupendous ravines which separate the lateral ridges of the central chains, form such a remarkable feature in all the volcanic islands of Polynesia, that they seem to me entitled



Island of Eimeo, as it Appears from the Harbor of Pappeiti, in Tahiti. Principal Peak W. N. W., Dist. 18 Miles.

to something more than a mere passing notice of their existence. They may be divided into three classes. The most common and extensive is that descending from the base of the central ridge, where it is often so narrow that a person may spring across with ease, to the sea shore, where it gradually widens into a plain of a mile or more in breadth, and constitutes the most fertile and valuable portion of the soil. The ravines of this character are in general the bed of streams, fed by mountain torrents and cascades, of which I have counted eleven from one point of view, having a fall of from two hundred to twelve hundred feet, and glittering like so many veins of burnished silver, on the black face of the volcanic rock. They are bounded on each side by steep and frequently inaccessible walls, every crevice and ledge of which is clothed with the most luxuriant vegetation, and are generally terminated at their upper extremity by the central mountain, which rises in a perpendicular barrier of occasionally two thousand feet elevation. The only way in which these central peaks can be reached, is by following up the securiform lateral ridges, and even this method is not always practicable, on account of the steep and lofty cliffs that rise from their summits, and frown a stern denial to all further progress.

It is on the plains at the termination of these ravines, that the villages of the natives are usually situated, and the voyager who has coasted the shores of Tahiti, can never forget the Eden beauty of some of these spots. The groves of orange, whose golden fruitage and snowy blossoms gleam star-like from a mass of dark verdure ; the intermingling of the tall cocoa's graceful, plumelike crest of drooping foliage ; the lofty and wide spreading Vi, (*Spondias dulcis*,) and Barringtonia, (*B. speciosa*,) the rich hues of the bread fruit tree ; the deep shining green of the broad, bannery leaves of the plantain ; the Hibiscus, with its large, gay blossoms of orange and crimson ; the coral tree, (*Erythrina corallodendron*,) one dazzling mass of scarlet flowers ; with a little wilderness of limes, guavas, and other trees peculiar to these climes—the picturesque cabins, peering out here and there from the dense

vegetation—the wild and gloomy ravines in the rear, lighted up in spots by sparkling waterfalls; and in the remote background, the fantastic pinnacles of the grandly broken mountains, towering up in clear relief against the soft blue tropical sky—all these combine to form a picture of such transcendant loveliness as can be scarcely equalled in any other part of the world.

The second class of ravines is often not to be distinguished from the first, where it opens on the coast, but at some distance inland it contracts to a very narrow gorge, of varying extent, which again opens suddenly into a sort of circus, occasionally eight or ten miles in compass, but usually from an eighth to three-fourths of a mile in diameter, surrounded, except at the outlet, by a lofty and precipitous escarpment, so as to present exactly the aspect of a crater whose walls have been riven asunder by some violent convulsion. This structure of the ravines is of more common occurrence in the Samoan and Hawaiian Islands, than at Tahiti. They are sometimes dry at bottom, but more frequently form the basins of streams, which, flowing through a tract of table land above, throw themselves over a precipice of from one to five hundred feet in height, and pass out through the narrow gorge to the sea. At Upolu there is a fine instance of this, in the cataract of Vaisafa, or "the broken water." The river, about seventy feet wide, and four deep just above the pitch, falls in three sheets about two hundred feet, into an oval basin, about three-fourths of a mile in circuit, from which it escapes between two high cliffs, not above twenty yards asunder.

In the following cut it is attempted by different lines, to exhibit at one view four distinct sections of this class of ravine, to show the character of its terminating circus.

a. Natural section presented at the falls.

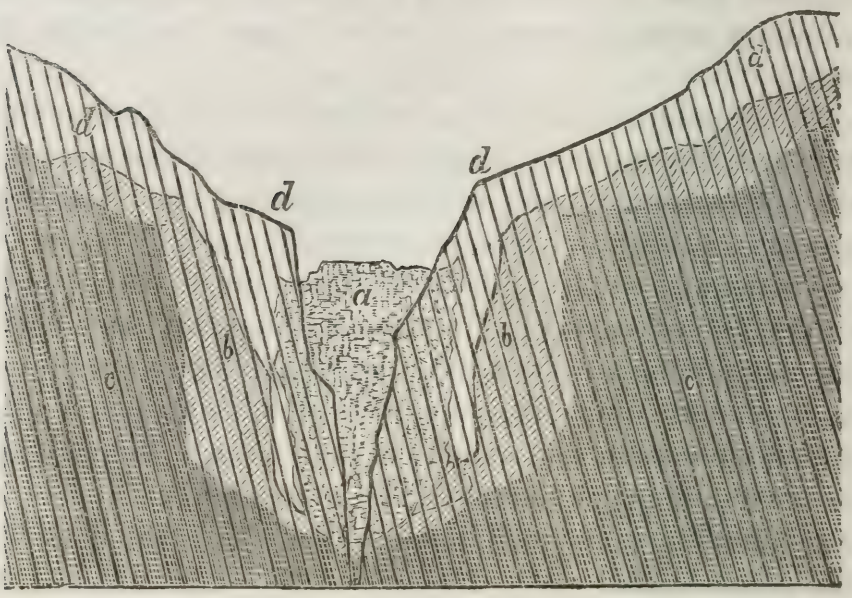
b. b. Imaginary transverse section at forty yards below them. The dotted curve line crossing *b* near the bottom, represents a large excavation, worn by the spray at the foot of the falls.

c. c. Similar section at widest part of circus, about one hundred and fifty yards below the falls.

d. d. d. d. Do. at the gorge where the river enters it from the basin.

The gorge, which in this instance may possibly have been formed by the recession of the falls, extends almost three-fourths of a mile, and then gradually widens into a common valley, terminating seaward in a broad plain.

SECTIONS OF THE RAVINE AT THE FALL OF VAINAFA.



At Hilo, on the Island of Hawaii, there is a very beautiful miniature ravine of this class, at the cascade of Waianuenue, ("the water of the rainbow,") and there are grand examples of it in the falls of Wailua and Hanapépé in the island of Kauai, especially in the latter, which pitch down full five hundred feet, into a circular basin about one thousand feet round, hemmed in by walls of alternately columnar and stratified lava, the only break in which is the narrow outlet for the stream. If we imagine the rapids of Lake Erie to be a plain, girt with lofty mountains, with the Niagara flowing through it, and this latter narrowed below the falls to one-fourth its present width, we shall have a very good idea of the ravine under consideration. Of those similar in form, but having no stream of water, there is a fine exemplification in the great amphitheatre at the head of the Nuuanu valley, in Oahu. They are also to be seen in full perfection, on the north side of the ridge of Konahuanui, between the Pali, or precipice of Nuuanu, and Kualoa. There is one near Waiahole, described by the late Meredith Gairdner, M. D. (in a "Sketch of Oahu,"

published in the Hawaiian Spectator,) as "very remarkable for its great depth and narrowness; resembling exactly the section of an immense chimney, rising from the heart of the mountain; an effect which is heightened by the black color of the rocks."

If we picture in our minds a ravine of this description, having a barrier across the narrow gorge or outlet, we shall then have an accurate conception of the structure of the third class. Although this doubtless exists in the other islands, I only met with it at Tahiti. There is one example of it in the mountain lake of Waihiria, at the head of the Waihara valley, North of Mairapehi. This lake is about fifteen hundred feet above sea level, three-fourths of a mile in circuit, and ninety feet deep, bounded on all sides except the southern by a wall of rock from one thousand to fifteen hundred feet high. To the South it is dammed up by a barrier of inconsiderable height on the lake side, but on the other descending several hundred feet to the valley, and apparently formed by the crumbling down of a large body of rock from the Western ridge. This is the same lake referred to by Beechy, Tyerman and Bennet, and others, and prior to our visit was believed by the natives to be unfathomable. There is a similar pit, except that it has only a small stream at the bottom, discharging itself by some crevice, between two of the lateral ridges of Waritiva. With great difficulty and some risk, I descended perhaps twelve hundred feet into this ravine, near its commencement, thinking to find an easier path to the shore; but after scrambling and wading, for nearly a couple of miles, was to my vexation arrested by a naked wall of lava, several hundred feet high, which nothing but a bird or a lizard could scale. I was thus compelled to retrace my steps, and toil up once more to the crest of the ridge. My guide informed me that in the upper portion of the valley of Atehuru, leading from Matavai to the foot of Orohena, there were several of these barred ravines of less extent.

SECTION OF A RAVINE CLOSED AT BOTH EXTREMITIES, IN ONE OF THE VALLIES RUNNING FROM THE COAST TO THE BASE OF WARITIVA, IN TAHITI.

a. a. a. Longitudinal section of the ravine.

b. b. Steep lateral ridge, rising to a height of two thousand feet.

The mountains in outline, are from five to eight thousand feet high.

It is difficult, satisfactorily, to account for these singular chasms. That at Waihiria may indeed have been produced by a landslip blocking up the valley, but the one last mentioned would rather appear, were it not for the perpendicularity of its terminal walls, to have arisen from a confluence of the two great lava streams forming the lateral ridges, as the rocks are on all sides in a normal position and of uniform structure. Or they may be owing to a sudden sinking in of the crust at the time when the subterranean fires were in activity. Pits, very similar to them, but of less extent, are of quite frequent occurrence on the black ledge of lava surrounding the crater of Kilauea. The second class of ravines may, I think, generally be referred to ancient craters, one side of which has been rent apart by earthquakes. In their situations and outline, in the uniform perpendicularity of their parietes, and the sub-columnar structure of the lava composing them, they correspond exactly to the craters of the table land of Mauna Loa. In fact, not many years ago, during a sharp earthquake, a similar outlet, since filled up near its commencement by subsequent overflowings of the lava, was produced on the S. W. side of the great crater of Kilauea or

Ka lua Pele, and extended if I remember aright, some seven or eight leagues to the coast.

But to return from this long digression, to the subject more immediately under consideration.

It is obvious that as the land sinks, and the water reaches the base of any ridge, barrier, or mount, a shore reef may be formed upon or around it, which, if the subsidence continues, will, from the operation of causes already explained, be gradually converted into an encircling or outlying one. There will naturally be intervening channels, in place of some of the ravines, while on those of a trench-like character and upon the ruins of ancient craters, will form lagoon reefs, and on the whole being overflown, there will thus be formed a group of lagoons varying in size and configuration, according as they rest upon a sunken crater, a ridge, or one of the trench-like ravines, and surrounded by a common reef, which is traversed at intervals, as in its primary state, by passages of various breadth and depth. And such, on a large scale, as I have before observed, is the appearance presented by the Paumotu groups and dangerous archipelagos of Polynesia.

Although the seaward side of the reefs encircling these, has been described as rising in a perpendicular wall, yet it must not be understood, that by this it is meant, that we literally step from an unfathomable ocean, upon the upper surface of a reef. They present a succession of terraces or plateaus, the outer having sometimes twelve or fifteen fathoms ; and in one instance, that of Bellinghausen's Island, twentyeight fathoms of water was found upon it. This lowest plateau is of variable breadth, but I think seldom exceeds one hundred and fifty feet ; declines somewhat rapidly seaward, and apparently projects beyond the wall like a shelf, as I have known the lead to fall from twelve fathoms on it, to two hundred and no bottom, within a distance of about ten yards.

These terraces become, as they recede from the sea, narrower and shoaler, presenting a like declination with the lowest, and having at their extremity an abrupt descent of several feet. The highest, or last formed, differs in its margin forming

a sort of steep talus extending to the next below it; and allowing for inequalities in the growth of the corals, offers a dead level of from twenty to one hundred and fifty yards broad, terminating for the most part at the fragmentary beach, and often having less than a foot of water upon it at low tide, except in the numerous hollows and gullies.

It has been suggested that this succession of terraces was owing to the action of the surf, which breaks heaviest, and of course tears off the largest masses, upon the extreme edge of the plateau; that when this has proceeded so far as to weaken in a measure the force of the rollers, a less powerful surf breaking against the inner wall thus formed, will in time form a second terrace, and then a third, or even a fourth, though this is perhaps rare, before it spreads harmlessly over the broad upper shelf. Yet although the sea acts with great force in abrading the reef, I doubt much whether it can have produced such results as these. It would be more likely to cause a long uniform slope, from the farthest limit of the breakers, to their origin at the margin of the reef.

It is more in accordance with appearances to suppose that such a slope once really existed, and that the reef subsequently sunk so low as to prevent the growth of the coral on this inclined plane beyond a certain line. There may then have ensued an interval during which the reef was stationary, when the polypes would naturally build upwards from the depth suited to their habits, and in time raise it to its former level, thus forming the lowest wall, while the dead reef beyond constituted the lowest terrace. A second inclined plane would be produced by the abrasive action of the surf, and a second or third period of sinking, followed by one of rest and re-elevation, would give the outer portion of the reefs that peculiar conformation which they at present exhibit.

It is upon the lower terraces and margin of the upper one, that the corals are found in their greatest variety, and exhibit the richest hues. Clusters of orange, violet, crimson, green of every shade, purple, blue and yellow, are intermingled in gay confusion, and with a brilliance yet softness of coloration of which pen or pencil can give but a faint idea. When first

passing over them, I could compare their appearance to nothing but a pavement thickly strewn with bouquets of beautiful flowers.

At a depth of three or four fathoms, the forms were as manifold as their coloration, some branching like beautiful shrubbery, others spreading out like the most delicate mosses, and others again resembling beds of saffron, or daisies and amaranths, while in and out of, above and between the thickets of these Neptunian gardens, sported thousands of splendidly colored fishes, from not more than an inch to two or three feet in length. A large bright scarlet Diacope (*D. Tiea*, Lesson) a Julis about a foot long, of a rich bluish green, marked with blood red bands crossing the back to the lateral line, and intersected by others extending from the opercles to the tail, (*J. quadricolor*, Less.) Serrani, Scari, Glyphisodons, Chætodons, Balistes and Holocentri, all richly adorned, were some of the most conspicuous in the bright array. The water was so transparent that the smallest object on the bottom could be seen as distinctly as if it were not three feet from the surface; and gazing down upon the beautiful creatures that tenanted these coral groves, like Coleridge's "Ancient Marinere," "I blessed them unawares" — although the next moment I could not avoid wishing to coax them into my net. As a drawback however, upon all this beauty, silently but swiftly, near the surface, glided in shoals, the spectral and malignant, "ravening salt sea shark," reminding one of satan's intrusion of his hateful presence amid the bowers of Paradise. So fierce were these tigers of the deep, that they repeatedly seized hold of the oars as we pulled toward the reef; rendering the attempt to reach by swimming (often the only chance) a coast thus sentinelled, rather a hazardous affair.

The solid, massive and encrusting genera of corals which enter most largely into the composition of the reefs, appear to flourish best in exposed situations and violently agitated waters. On the upper plateau the coral has generally a stunted, dwarfish appearance, and the branching genera predominate over the more showy Astræas. Near its edge, and lining the crevices, certain Goniopores, Porites and Pavonias, spread

themselves in thin lamellæ; but these gradually disappear as we recede from the surf, and finally abandon the field almost entirely to the Madrepores. Ill calculated, however, by reason of their fragility, to withstand the force of the breakers that occasionally roll over the whole ledge, even these latter are only found in small detached clusters, principally in the little sandy pools and cavities which are scattered over the surface, their greatest luxuriance being displayed in the clear, tranquil waters of the lagoon, where they form submarine thickets of great beauty, many yards in extent.

The major portion of the plateau is encrusted by Nulliporæ and a laminar deposition of carbonate of lime. In this are imbedded multitudes of Tridacnæ, the edges of whose mantles, as shown by the gaping of the shell, are so gorgeously colored, that a correct representation of them would certainly be thought exaggerated by one who had not seen the originals. The varieties in this respect are very numerous, but the most common are a deep vivid ultramarine blue or green, with dark orange, purple or golden ocellations and wavy lines interspersed. The marginal papillæ are similarly ornamented.

The Tridacnæ appear like the Pholades, Lithodomi, &c., to secrete a peculiar acid, enabling them to perforate calcareous rocks, since, differing altogether in this from the shells imbedded in branching corals, the situation in which they were generally found, was not caused by the growth around them of the polyparia, nor by the deposition of calcareous matter. This was evident at once, from their being in some cases imbedded in small clusters or masses of coral, which were cut through by them in such a manner that the parietes of the cavity exhibited sections of the polyparia, transverse, vertical or oblique, just as the Tridacna chanced to have worn its hole. I have seen the base of large Madrepores, cut in this way, at the origin of the branches, so that the upper portion of a branch was on one side of the shell and the lower on the other. The cavity is usually worn quite smooth, and fits closely to the shell, there being often but just space left at the surface for the valves to open about half an inch. They bury themselves, beaks downward, and the basal margins of the

valves parallel with the surface — adhering very strongly by a coarse corneo-fibrous prolongation of muscle. It differs somewhat from the byssus, properly so called, of the Mytilacea, which is produced at pleasure by the animal, may be torn away without injury to it, and terminates in a sort of receptacle at the base of the foot. Here the fibres proceed from a thick, conical, tendinous mass, and though I have reason to believe the animal has the power of detaching itself, yet when it was attempted to pull one away from the rock, in almost every case, the whole muscle was torn from the body, inflicting a fatal wound. I have often pulled them off in this way and left them on the reef, to see if they would re-produce the byssus, but always found them dead the next day. It is a little singular that the Tridacna, when immoveably imbedded, should continue to moor by as strong a cable, as when free upon the surface it is exposed to the rude assaults of the breakers. The manner in which they become thus buried, seemed to require a word of explanation, because this condition has been considered a proof of the rapid increase of the coral, which it was imagined had thus covered the shell subsequent to its attainment of full size, yet during the animal's life.

On all parts of the reef, Crustacea and Echinodermata are met with in astonishing numbers and variety. The Mollusca generally speaking, are less abundant as a whole. The pools and gullies literally seem alive with beautifully painted fishes, a bare enumeration of whose genera would almost fill a page. Among these a large spotted Muræna was conspicuous for its fierceness not less than size. It lurked under stones or in crevices, and when molested, instead of retreating, darted directly at the intruder, and unless promptly avoided, inflicted a most formidable bite. It moved with exceeding rapidity, sometimes scuttling over the coral, sometimes making a succession of horizontal leaps from the water, of a couple of yards' length. I have seen, at the attack of one, a whole boat's crew flying in terror, who would fearlessly chase the numerous sharks infesting the edges of the reefs and lagoons, till up to their breast in the water.

Scattered along the plateau are fragments of greatly varying size, thrown up by the surf, some loose, and affording shelter to a multitude of small fish, crustacea, &c.; others forming tabular masses of such magnitude as to render it almost incredible that any wave could be sufficiently powerful to tear them off and transport them to their present locality. They constitute one of the most remarkable features of the surface reef at several islands. I have seen it for miles lined with these nuclei of future ridges, from a yard square, to thirty or forty feet long by four or five broad, and averaging three and a half in height. Their lower portion is worn by the water so as to cause the smaller blocks to assume a variety of fantastic shapes. By the percolation and infiltration of water charged with carbonate of lime, these masses are in general firmly cemented to the subjacent coral, and converted into a very solid limestone, called by seamen, "reef-rock," in which the original cellular structure is sometimes almost obliterated. This reef-rock appeared to be the basis of the elevated belt between the lagoon and sea, in almost every Paumotu that I examined. I shall refer to these erratic blocks again, under the head of re-elevation.

It sometimes occurs that the plateau or surface reef, instead of extending quite to the beach of coral sand, is separated from it by a strip of smooth coralline limestone, apparently formed by cementation of the finer detritus, dipping from 5° to 7° seaward, and from ten to fifty or sixty yards wide. A peculiar character in these belts, is the fissures, which from one-eighth to three-fourths of an inch wide, run nearly parallel with the beach for one hundred rods together, and sometimes cross them at very large angles with it. There are similar formations along the North coast of Tutuila, one of the Samoan Group, and in its harbor, Pangopango. They also occur, but of coarser texture, on the East coast of Kauai, near Wailua, where they are from eight inches to two feet in thickness, and are frequently quarried for building materials, such as foundations, door-stones, &c.

To this limestone shelf, or the surface reef, as the case may be, succeeds a narrow and rather steep coral sand beach, be-

yond which rises the fragmentary ridge, composed of large blocks of reef-rock, having their interstices filled with a rubble consisting of small fragments of coral, shells, and Echini, cemented together so firmly as to require a smart hammer-stroke for their separation. It has an elevation of from three to ten feet, and varies in width, even on the same island, from one hundred and twenty feet to one thousand yards. It is highest on its seaward side, where it rises somewhat abruptly, but shelves very gradually towards the low, sandy shores of the lagoon. There is rarely much vegetation till the summit is crossed, but thence inland it frequently flourishes luxuriantly to the very brink of the water. This elevated tract seldom if ever entirely surrounds the lagoon. I do not remember having seen a single Paumotu, which had not, on one side, a considerable space of low, naked reef, or detached masses of rock, over and between which, the sea at high water broke into the lagoon. At Raraka, on the southern side, to the westward of the passage between this and the sea, where the upper plateau is rather narrower than common, the ridge was of a character entirely different from what was observed at any other island, being mostly a heap of loose rubble, eight or ten feet high, and perhaps a hundred yards in breadth at the base, nearly as steep on the inland as on the seaward side, and destitute of any trace of vegetation. Just inside of this ridge, were numerous shallow pools of salt water, ebbing and flowing with the tide, and abounding in Ophiuræ, Cidarites, Fistulariæ and Actiniæ. A large species of Melampus was so plentiful among the fragments at the base of the ridge, that it could be collected by handfuls. Beyond the pools was a plain of coral, which I estimated to be a large mile across to the lagoon, but had no opportunity of ascertaining it by actual measurement. It appeared to have a very slight ascent from the sea, and was tolerably well clothed with trees and shrubs, though the species were few in number. A few cocoa-trees only were seen, and those had, as the inhabitants (about thirty Chain Islanders, engaged in collecting pearl shells,) stated, been introduced recently by themselves.

Crossing the plain, which is overrun with a variety of burrowing Crustacea, terrestrial Paguri, and on some islands a species of Birgus, as often found on trees as among stones; we emerge from a tangled thicket upon the light green waters of the tranquil lagoon. This of course, varies greatly in extent and depth, and not less in the character of its bed. Some have the appearance of being very shallow throughout, the water being, except where darkened by occasional gullies, of an uniform pale, yet brilliant green hue. In others, there are large strips and patches toward the centre, where it is nearly as blue as the surrounding ocean. At Aitoho, one of the Disappointment Islands, the whole central portion of the lagoon is of this latter color, as if it were very deep, although less in circuit than many others. From the beach of some, I have waded out for a couple of hundred yards, with the water deepening almost imperceptibly, over a bottom of fine sand, with only a few scattered bunches of coral; while in others, their bed is very unequal, full of large and deep pits, and traversed by gullies several fathoms deep and from ten to three hundred yards wide, occasioned probably by like irregularities in the submerged land.

At Serle Island, and several other Paumotus, I observed at a couple of miles or so from shore, several small islets and clumps of rock, rising above the surface of the lagoon, nearly as much as its bordering ridge, and apparently encircled by water much deeper than the average.

It would have been exceedingly interesting, and was certainly of importance in arriving at a correct idea of the structure of these islands, to have ascertained the composition of such islets; but the circumstances in which I was placed, entirely dependent on the pleasure of those in whose opinion such objects were of merely secondary consequence, and by whom my every movement was limited and controlled, rendered it impossible for me to make an examination so desirable. Should they hereafter be found to consist of volcanic rock, they would establish beyond all question the theory of subsidence first advanced by Mr. Darwin. Should they, on the contrary, be as I suspect, of coralline formation, this would

not by any means, as I conceive, disprove it, but rather afford us the means of determining with some degree of exactitude the amount of re-elevation that has taken place at such islands.

I was informed by Mr. Samuel Wilson, of Tahiti, who had long resided among the Hervey Islands, that at Mangaia, which is an ancient reef elevated nearly three hundred feet, there are in the central hollow formerly the bed of the lagoon, many scattered patches of coral rock, some of them raised to a height of forty feet. At a certain stage of the elevatory process, it is evident that these patches must have presented an appearance very similar to the lagoon islets to which I have referred.

So far from the beach as examined, the bottom in some lagoons I have found to be a clean coral sand, composed of a detritus of coral and shells, but in most instances this was covered to the depth of a foot by an exceedingly fine white sedimentary paste or ooze, which on desiccation had every character of common chalk, except in being much more friable. I think it is principally formed by the decomposition of flexible corallines and alcyonia, and the softer Echinodermata, such as Fistularia and its congeners, all of which abound in the lagoons, rather than from that of corals proper. It may also partly arise from the excretions of certain fishes, which feed occasionally on the tender extremities of Madrepores, as readily as on Crustacea, Echini, &c. I once collected a quantity of these corallines and kept them in a jar of water till the muscular and fibrous portions were entirely decomposed, when an impalpable sediment was deposited, in all particulars answering to that obtained from the lagoons.

Not least among the phenomena attracting our attention in these Paumotus, are the channels which in the majority of them afford a passage from the sea into the lagoon. There is usually but one of any consequence at each island, though there are rare instances of the occurrence of three or even four at different points of the reef. They are almost invariably situated in the leeward reef, but there are occasional exceptions and deviations from this general rule, some of which will be specified presently.

These outlets are by some persons supposed to designate fissures in the walls of submerged craters, represented by the lagoons. If we admit, however, that these islands have been formed by the process which it has been attempted to describe in this communication, such an explanation is rather unsatisfactory, since if the coral began to grow in the fissure immediately upon the water covering it, there is no reason why the reef should not reach the surface there, as early as at any other point, and the rent thus be filled up.

In his lectures for the Lowell Institute, Prof. Lyell expressed an opinion, that these channels were formed at a period when the encircling reef was nearly on a level with the surface of the ocean, by the rapid rush of the ebb over the leeward side of the lagoon, whose waters at high tide were raised considerably above sea level by the breakers bursting into it from the windward quarter. The passage, he argued, once thus opened by the water forcing its way out, would ever after be maintained by the same power.

Now this might possibly have occurred, provided the rush of waters had ever been directed for a length of time to one particular point. But if the surface of the reef was in times past, as it now is, nearly of one level throughout, which there seems no reason for doubting, it is evident that the ebb would, at the period alluded to by Prof. Lyell, set equally over the whole leeward portion, till uniformity of level between the lagoon and sea, was restored at low tide. As he had no reference either in his descriptions or diagrams, to the plateau which I have described as extending from the beach to some distance seaward; but rather spoke as though he supposed the whole space between the lagoon and surf to be a fragmentary ridge; I have sometimes thought that when he spoke of the reef, as nearly on a level with the surface of the ocean at the period when the passages were formed, he meant that this ridge was much lower then than at present, yet sufficiently high to oppose a considerable obstacle to the efflux of the surplus waters of the lagoon; or in other words, that the difference of level between the sea and reef, consisted in the latter being a little the higher, instead of as it really is, the lower of the two. If it was in fact his idea, that the lagoon

had once been girt by such a wall, the conclusion was not unreasonable that the constant pressure of the water, poured over from the windward side of the reef, would eventually form a breach in the weakest portion of its leeward side. But in truth such a condition of things never existed, there being in most Paumotus to the present day, on one side or other, a considerable portion of the reef where there is no ridge to bar the escape of the water from the lagoon, and yet a passage is found. Nor, as I have said, is this always on the leeward side. At Raraka, which is situated in the full strength of the south-east trades, it is on the southern, or windward side. At Clermont Tonnerre, and Tooa, the westernmost of the Disappointment Islands, the entrance, if any exists, must be to windward, as the coast in that direction is very low and broken, and none was discovered in running down the lee shore. At Waterland Island the opening is in the eastern or weather reef.

Moreover, there are reefs, like that of Ocean Island, as yet wholly submerged, save in two or three small spots, which are intersected by no less than four canals. At this island, there is one entrance on the south-east side, and three about half a mile apart in the south-west portion of the reef. In these last, it is worthy of notice that the depth is eight or ten feet greater than that of the lagoon, and therefore could not have been excavated by the outward rush of its waters, as this at most could have worn a passage in the reef to the level of their bed.

On the other hand, at Aitóho, the eastern Disappointment Island, no passage was met with, in pulling all round the island, although portions of it are so low, that the surf at high water must break heavily into the lagoon.*

At Rose Island, where, judging from the drift line on the beach, there is a rise and fall of about five feet, the entrance is to leeward, and the same at Christmas Island. Through all these channels, the ebb pours out with great velocity,

* This peculiarity, with the apparent great depth of its waters, and its circular outline, render it possible that this lagoon is one of those occupying the site of a submerged crater.

whether they are on the windward or leeward side, the water falling into them from the lagoon and fringing plateau, so as to resemble a mill race.* At Raraka, six stout oarsmen, in a swift whale-boat, were a full quarter of an hour, vainly attempting to enter the lagoon, though the passage was not above seventy or eighty yards in length; and finally succeeded only by taking an eddy pointed out by the natives. The velocity of the current here could not have been less than six or seven miles an hour, and it was not greater at Rose Island, where the entrance is on the opposite side. The lagoon of this latter is however of comparatively small extent.

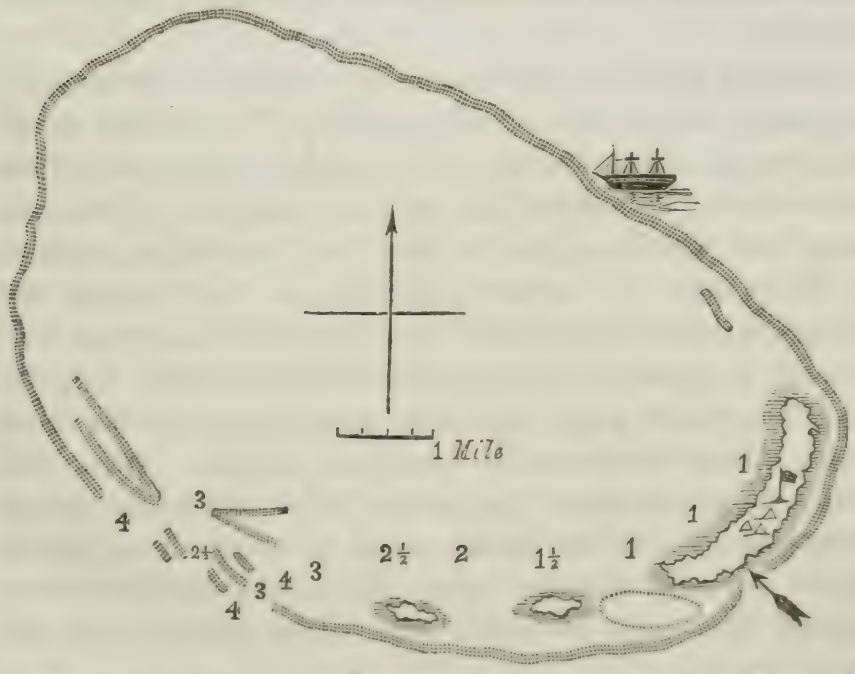
But rapid as it is, this current alone does not account for the existence of such channels. It is difficult to believe that the attrition of the passing water would suffice to prevent their being closed or filled up by the labors of the polypes, when we see these flourishing in the greatest perfection on the margin of the reef, exposed to the unceasing and far more violent action of the surf, which is continually tearing off large masses of rock, and driving them toward the beach. And were we at first sight disposed to consider their formation the result of the powerful tides, a closer examination would convince us of error, by showing that in no portion of the reef is the growth of the encrusting and lamellar corals more profuse than upon the sides (and in some instances the bottom also,) of these very channels. Even the more fragile Madrepores are to be seen there, though less in size and number than inside.

The tides on the weather side of Christmas Island, whirl round it with frightful rapidity, so that it is highly dangerous to venture into them with a boat. The surf also, on this side, runs to an amazing height, especially during the spring tides, rising sometimes, like that of Guam, to the altitude of twenty feet, before it bursts upon the reef. Yet though the extreme edge of the plateau has been greatly shattered by these tremendous rollers, the polypes are no where more industrious or numerous than just inside the breakers.

* Christmas Island is an exception to this rule, the ebb current setting out moderately, owing probably to the shallowness of the lagoon, and unusual width of the passages.

It is another argument against the probability of the reef passages being produced by the tides, that they are generally deepest toward the outer margin of the reef, where the current is weakest, and shoal gradually as we approach the lagoon, near whose entrance it is most rapid. Moreover, no accumulation of water would be likely to force a passage either into or from the lagoon, *through* the reef, against wind and sea, or even aided by them, when it could without difficulty flow *over* it on the leeward side, till the waters of the lagoon were on a level with those of the ocean. Much less should we expect it to scoop out several channels, and that too on both sides of the reef, as we see them in some Paumotus. At Ocean Island, whose lagoon of twentyfour miles in circuit, has no less than four entrances, situated as shown in the accompanying sketch; seven-eighths of the reef are, even at low water, overflowed to the depth of two feet or more.

SKETCH OF OCEAN ISLAND AND REEF.*



The figures represent the depth of water in fathoms. The dotted lines inside of the reef indicate coral patches nearly bare at low tide. The arrow denotes a passage through the reef to the main island. The other figures explain themselves. The centre of the island is in 28° 22′ N. lat., and 178° 30′ W. long.

* The British whale ship Gledstanes, Capt. J. R. Brown, was wrecked on the reef at midnight of July 9th, 1837. The cut here given is reduced from a

The lagoon is everywhere full of sand-banks and patches of coral, having only a few inches of water upon them, and as will be seen by reference to the figures, is not so deep by from ten to eighteen feet as the channels in the reef. Whatever may be thought of the other passages, it is clear that the one leading to the island is not owing to the action of currents, as from its sheltered situation, and the shallowness of the water between the beach and margin of the reef, they are scarcely felt.

I cannot, therefore, in view of these facts, coincide with those who entertain the opinion that the lagoon entrances were primarily hollowed in the reef by the rush of surplus waters from the enclosed basin, and have been kept open ever since by the tides. If we adopt the doctrine of a general subsidence of the land, with its attached shore reef, during which the latter has been maintained at its original level by the polypes; it appears to me that the facts admit of an explanation more probable, though not covering perhaps every difficulty.

I believe that these reef channels, in almost every instance, originated during the primal condition of the islands, in the influence of fresh water streams preventing the growth of the coral where they emptied themselves. Instances of the same thing now happening, are frequent in all the volcanic islands of Polynesia. I observed especially at the Samoan and Hawaiian islands, that there were openings in the shore reefs opposite the mouths of streams, and sometimes very insignificant ones, which I am convinced were caused by the fresh water acting detrimentally upon the polypes. While the island remained above the sea, or rather while the stream continued to flow, the same causes in which it originated would keep the channel open. When the subsidence had reached that point at which these causes ceased to operate,

chart engraved for the third number of the Hawaiian Spectator, by a native scholar of the Mission Seminary at Lahainaluna, Maui, from surveys by Capt. Brown, who remained upwards of five months on the island, with his crew. "The only fresh water is what drains through the sand, after the heavy rains." —[Haw. Spec. July, 1838.]

provided the depth was not too great, the polypes would soon by the diffusion of their gemmules, extend themselves over this portion of the reef, the same as elsewhere. Assuming the depth of the channel at that period to have been from twenty to forty feet, and the upward increase of the coral therein, to have been ever since equally rapid with that on the reef, it is clear that the original difference of level, between this latter and the bed of the channel would remain unchanged to this hour, were there no tide whatever setting in or out. Even supposing that before the action of the fresh water ceased, the subsidence had been so great that this difference of level amounted to between two and three hundred feet, (though it is very doubtful whether such could ever have been the case, since the amount of elevation from the deposition of alluvial matter, would in all probability be sufficient to counterbalance the depression by subsidence,) this would not invalidate the explanation here suggested.

In all the Paumotus that I have seen, these channels are very narrow, often but a few feet, and rarely exceeding forty or fifty yards in width. Even in the semi-encircling reefs of Tahiti, Samoa and Hawaii, they are seldom more than a few rods across. Supposing then the bed of a channel to have been at any period so far below the surface as to preclude the formation of coral upon it ; still, in process of time, the lateral increment would form a bridge across, at the depth best adapted to the requirements of the zoophytes. During the same period its width would be considerably contracted at the surface, and except in large openings, might be wholly closed up. Instances of these bridged channels are numerous throughout the coral islands of Polynesia. It frequently happens that the approaching shelves have not yet come in contact, and a crevice from only a few inches to a yard in breadth, is left. On looking down this, the bottom and sides of the ancient channel, are seen as distinctly through the transparent water, as if within reach of the hand. Such crevices are unusually frequent at Rose Island. An examination of these has led me to conclude that the existing entrances into lagoons, are attributable only to their original magnitude having been such

as to prevent their being, as yet, obliterated as others have been, by the extremely slow growth of the coral; and that in the lapse of future ages, they too will disappear, when the lagoons will gradually dry and be partially filled up with detritus from the neighboring beaches. Possibly, the level between the sea and the lagoon of Aitóho, to which I have stated no entrance was seen, may be restored by the water accumulated during floodtide passing out by subterranean canals, such as are described above.

It is not improbable that some channels were produced by other causes than that here mentioned, such as original inequalities in the submerged land, or fissures made in the reef by earthquakes, which we may presume to have been, at a former period, as frequent in this region as they now are in those where volcanic fires are still raging; but I am convinced that instances where a passage has been cut through a reef by the action of tides are of exceeding rarity, if indeed they occur at all. So long as it is the tendency of water to seek an uniform level, I cannot conceive how that accumulated in the lagoon during the flood tide, or from the rolling in of the surf, should in flowing out over a reef covered even at low water to a depth of from one foot to ten fathoms, excavate a narrow canal, occasionally (as at Christmas and Ocean Islands,) deeper than the lagoon itself.

It is my impression that Prof. Lyell described these channels as invariably situated on the leeward reef; yet suggested no cause for their assumed absence on the windward side, except the inference that as the water was forced into the lagoon from that direction, it would naturally seek to escape in an opposite one; and at a late meeting of this Society it was asked why, if his reasoning was not just, such should be the case.

But they are, as I have endeavored to show, confined to no particular portion of the reef, though they certainly do occur most frequently to leeward. Nor will this, upon reflection, appear so singular as it may at first be considered. Admitting that there were originally as many in the weather as in the leeward reef, by far the greater number would long since

have been filled up by fragments broken from the outer margin of the plateau and carried landward by the surf, together with the drift and wash from the beach of loose coral sand and shingle. Others we may suppose have been obliterated by the natural increase of the coral, till, from both causes, only one remains here and there. Still there are sufficient to show us that the formation of these channels cannot with propriety be attributed to causes that would operate but in a certain direction, such as we must regard the tide, which can scarcely be supposed to seek an egress against the continual rushing in of a powerful surf.

Much light would no doubt be cast upon this and many other peculiarities in the coral formations we have been considering, by an examination and comparison of the phenomena presented by those of the Antilles, the Caribbean Sea, and along our southern coasts. In fact, I believe that without such comparison, it is impossible for a person to arrive at a full knowledge of the structure of these rocks. Those especially, bordering the South coasts of Cuba and Florida, deserve particular attention, on account of the numerous canals intersecting the extensive reefs, the varied nature of their lagoons, and the opposite character of their neighboring lands, which, broken and mountainous in the one case, are in the other low, sandy, and level. I trust that at some future period it will be in my power to examine these interesting formations, with more time and opportunity for their study at command, than were enjoyed in my brief and restricted visit to those in the great coral region of the Pacific.

(To be continued.)

ART. XI. — REMARKS UPON CORAL FORMATIONS IN THE PACIFIC; WITH SUGGESTIONS AS TO THE CAUSES OF THEIR ABSENCE IN THE SAME PARALLELS OF LATITUDE ON THE COAST OF SOUTH AMERICA. BY JOSEPH P. COUTHOUY. Read December 15, 1841.

[Continued from page 105.]

The conclusions to which I have been led by all the observations made among the coral islands of Polynesia, may be summed up as follows :—firstly, that the subsidence was not continuous, but interrupted by long periods during which the land, and after its disappearance, the reef, remained stationary, and the successive terraces were formed; secondly, that it continued, at least in certain places, up to a comparatively recent day, and ceased not long after the total submergence of the pre-existing land; thirdly, that there followed an indefinite interval of repose, with the reef at a sufficient depth below the surface of the ocean, to enable the polypes to construct the overhanging shelf whose fragments now strew the upper plateau; fourthly, that to this quiescent state ensued one of re-elevation,* at a period of which, when the shelf was considerably lower than the plateau now is, yet exposed to the full violence of the surf, it was torn off and the fragments carried to their present locality; and lastly, that this re-elevatory process is still going forward, not only in the coral groups, but also in most of the volcanic ones of Polynesia.

After what has been said, it is perhaps unnecessary to remark further upon the first of these conclusions. As regards the second, I will here briefly notice one of the facts on which it rests. At Rose Island, a chain of coral reefs mostly covered only at high tide, and small islets but a few feet

* There is one peculiarity in the sea or barrier reefs of all the volcanic islands, for which, unless it is to be attributed to the recentness of their elevation, I can at present suggest no explanation. I refer to the entire absence upon them, no matter how exposed may be their situation, of any fragmentary ridges, such as are found at every Paumotu, even where the distance from the outer plateau to the lagoon is much less than the breadth of some barrier reefs.

above water, principally loose rubble and sand, the whole about a league in circuit, and situated twentyfive or thirty leagues east of the Samoas—so recent was the formation that besides the main entrance into the lagoon on the leeward side, there were several small channels, others partially bridged over, and some closed only at one extremity. Not a particle of vegetation had yet made its appearance, elsewhere than on the most elevated portion of one sandy knoll, which a solitary shrub (a Pisonia, if I recollect right,) had begun to clothe with verdure. In the shallow lagoon, it would seem as if there had not elapsed since its formation a period sufficient for the coral to have grown in any quantity, as only a few small clusters were seen here and there, the bottom being almost entirely a fine white coral sand, such as is common on the beaches of those islands having shore reefs, and quite destitute of the smooth, calcareous paste, deposited in most lagoons. Scattered over this sand, were a number of boulders of volcanic rock, some of them so heavy that two men could not raise them from the bottom, and precisely similar in appearance and mineral structure to that constituting the mass of the neighboring groups of Samoa and Tahiti. A specimen weighing about twenty pounds was picked up in four feet of water, among small rolled blocks of coral conglomerate. This circumstance appears to afford conclusive evidence that the main rock of the submerged island must be at no great depth below the sandy bottom of the lagoon, since it was evidently not long since acted upon by the surf, the only imaginable power which could have placed these boulders in their present situation. At the same time, that the islets are now slowly emerging, is indicated by the whole surface of the reef, which is so for elevated, that the corals have nearly ceased to flourish, and are for the most part covered with an incrustation of lime, which promises ere long to unite the whole into an uniform consolidated mass.

That there was an interval of quiescence between the last epoch of subsidence and that of re-elevation, is, I think, proved not only by the construction of the marginal projecting shelf, which has evidently once existed on the upper

plateau, but by these elevated islands, like Tahiti and others, having both shore and barrier reefs, which are raised to the same level, and where a shore reef does not exist, by the detached masses and clusters of living coral that are found at those islands in only three or four feet of water, and within a few yards of the beach, quite equalling in size any that are found upon the sea reefs, which clusters must both have grown at a considerably greater depth, and required a long time to attain their present magnitude.

In the lectures to which allusion has been made, the island of Tahiti was incorrectly represented in ground plans of it exhibited by Prof. Lyell, and also described by him, as surrounded by a reef enclosing a continuous lagoon of nearly uniform width between it and the shore. Of a fact so important in its geological bearings as the co-existence of a fringing and lagoon-enclosing reef at this island, the distinguished lecturer was, I presume, not aware, inasmuch as it was in no manner alluded to by him. There is scarcely any portion of the reef which I have not visited, and so far from encircling the island, the lagoon only exists at intervals, and in many of these a shore reef runs out so far as to leave but a narrow boat channel between it and the outer one. Sometimes it terminates in a cul de sac; in other places it communicates with the sea by two passages near its extremities, thus isolating a portion of the outer reef, and there are parts of the coast where for miles the two reefs appear to have united, and there is no intervening canal; so that the natives wade from the beach to the breakers. It would be nearer the truth, to state that instead of a continuous lagoon, there is a nearly continuous fringing reef, surrounding the island and varying from a few yards to more than a mile in width, and that the lagoons merely form canals between this and the sea reef. Like the latter, these shore reefs are in general very steep. There is one in Pappeiti, the principal harbor, forming a sort of natural pier, alongside of which a vessel can lie in thirty or forty feet of water, so close that a person may step from her channels, upon the reef, where it is not more than eighteen inches or two feet deep.

The island of Eimeo, lofty and broken like that of Tahiti, from which it is distant between four and five leagues, is almost entirely surrounded by a fringing reef, containing occasional small lagoons inaccessible to any thing but a canoe, and often having no entrance whatever. The same may be said of several other islands in the Tahitian group. For these reefs to have formed upon the shore and extended so far as in some instances to be blended with the outer ones, there must as it seems to me, have been a long period of rest between the cessation of subsidence and the re-elevatory process, which it is my belief has been for some time and is still going forward. For this belief I now proceed to submit some of the reasons.

At almost every Paumotu visited, I found the shore of the lagoon raised from eighteen to thirty inches, containing imbedded shells, and corals standing as they grew.

At Clermont Tonnerre Island, on the North shore of the lagoon, there is a reef two feet above sea level, literally paved with the shells of Tridacnæ, imbedded precisely as in the adjacent submerged plateau, and in a state of perfect preservation, even as to color. At Honden Island, some two hundred and twenty miles north-west of this, a similar raised ledge borders the lagoon. At Raraka, three hundred miles further west, on the plain between the windward ridge and lagoon, which had a very slight ascent inland, corals both sessile and arborescent, were met with in a normal position, half a mile from the sea, and at about the same height above it as the shells at Clermont Tonnerre. At King's Island, in crossing from the leeward beach to the lagoon, several large tracts of reef-rock were observed, full of imbedded Tridacnæ, and corals occupying their original locality. Similar appearances were presented by several other islands, to which I cannot refer at present.

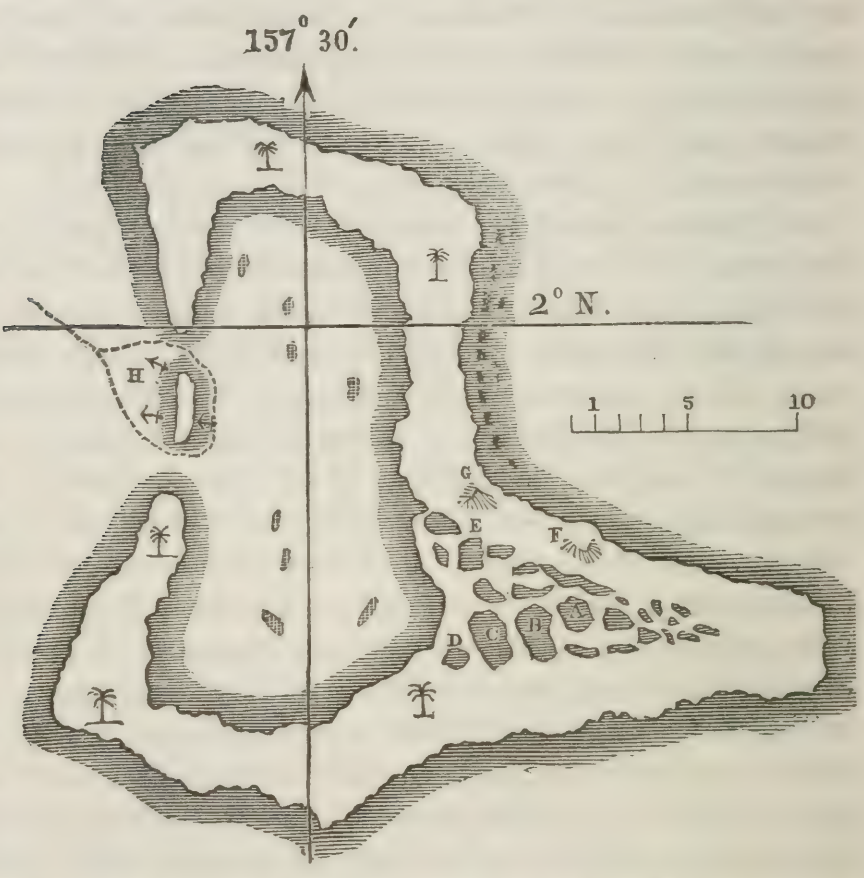
The surface reef or upper terrace, every where bears evidence of having been elevated higher than the natural growth of the corals would raise it, in their scanty number and diminished size, and the calcareous incrustations now covering the larger portion of the reef, to the extinction of the polypes. At Waterland Island, the leeward reef is quite bare at low

water, and so bold that one may spring upon it from a boat without wetting his feet. So trifling is the depth of water on other reefs, that many arborescent and some even of the sessile corals, have their superior portions so constantly exposed that the polypes are all dead, while below a certain line they still continue to flourish. In the lagoons, also, are frequently seen clusters of Madrepore, whose extremities are from an inch to a foot above water, which like those on the terraces could have been constructed by the polypes, only when continually covered by it.

At Christmas Island, the re-elevation has been so great, that the lagoon, of sixty miles in circuit, is in no part, at half a mile from shore, more than three feet deep, has hardly any where over ten feet of water at high tide and is full of still shallower patches, raised reef-rock, and corals. On the south-east side, numerous lagoons from a quarter of a mile to a couple of leagues in compass, originally no doubt deep hollows in the principal one, have been formed by the elevation of their surrounding bed above water. In some of these, though they have no outlet, the tide continues to rise and fall regularly, the water passing readily through the porous sand, but the evaporation is such as to render them exceedingly salt. In others, the water is entirely dried up, and the bottom covered with a thick saline incrustation. The intervals between these small lagoons and hollows, is sometimes the bare coral rock, but more commonly coral sand and shells, containing an infinite number of Echini, Spatangi, &c. imbedded. Near the centre of the island are plains of perfectly level coral rock, some of them a mile long by half a mile broad, raised eight or ten feet above sea level, and covered with about a foot of black porous earth. The magnitude of these rocks precludes all idea of their having been torn from the reef like the large blocks of similar composition that line the eastern coast. A very remarkable character in the structure of this island is the unusually great width of the two entrances, it being full two miles, as will be seen by the accompanying sketch. The fringing reef runs out about half a cable's length all round the island, except on the south-west side, where the surf rolls

in directly upon the beach. There is anchorage for ships in from ten to thirty fathoms water on either side of the low, sandy islet by which the entrances are separated.*

SKETCH OF CHRISTMAS ISLAND.



The letters A. B. C. D. E., and the adjoining dark spots, indicate the position of the smaller lagoons and dry hollows.

F. and G. are two hills of coral sand, about ten feet higher than the rest of the island.

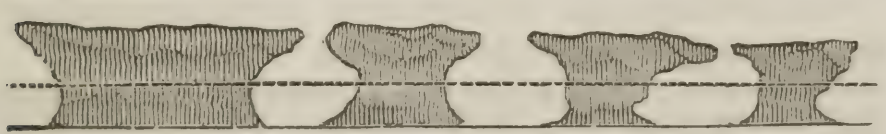
*For the sketch of Christmas Island, and also many of the facts in connexion, I am indebted to the Hawaiian Spectator, for July, 1838. This publication, which was issued quarterly, in a very handsome octavo form, at Honolulu, in Oahu, and conducted with much ability by an association of the foreign residents, was discontinued at the close of the second year, for lack of patronage. This is much to be regretted, as it promised to be the vehicle of much important information, both of a scientific and general character, relative to Polynesia. Its place is in a measure supplied by a weekly paper entitled "The Polynesian," established in June, 1840, and ably edited by our townsman and former associate, J. J. Jarves, Esq., but the size of this renders it less valuable than the Spectator, as a work of reference.

H. the low, sandy island between the entrances, which are marked by the dotted line.

The four trees represent the situation of as many groves of cocoa-nut. The dark dotted patches in the lagoon, which should be much more numerous, are sand banks and coral shallows; and the black spots on the eastern shore, denote large fragments of reef-rock thrown up by the breakers.

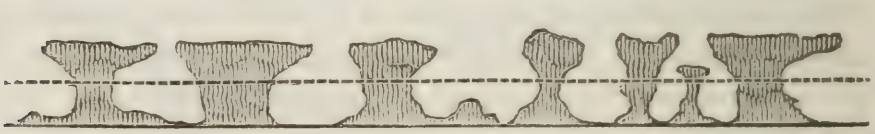
At Carlshoff Island, in about 15° 30′ S. lat. and 145° 30′ W. long., near the north-west side of the lagoon, and a short quarter of a mile from the sea beach, is a pool of tolerably fresh water, between fifty and sixty yards round, and five feet deep, which appears to have been formed like the dry hollows at Christmas Island.

But in nothing perhaps throughout the coral seas, are the proofs of re-elevation more conspicuous than in the large tabular masses of reef-rock which have been spoken of as lining the weather shores of many Paumotus. At Serle, Vincennes, (a few miles West of Raraka,) King's, Carlshoff, Honden, Tooa, Aitóho, and Dean's or Prince of Wales' islands, these constitute one of the most prominent features. At the last named, they are strewn along the coast for upwards of thirty miles, and some of the masses, as nearly as I could estimate, were a hundred feet long. It is not improbable that the whole coast here may be a reef raised three or four feet. The enormous size of the rocks in some instances, renders it almost incredible that any surf could have been sufficiently powerful, to tear from the reef and remove them to their present situation.



Not having landed here, but only seen these ledges through a glass while coasting the island at a mile's distance, I cannot of course speak positively on this question, or as to their exact size ; but as regards the latter, any person who has made the experiment, will admit that in viewing objects on a beach in this manner, their magnitude is more apt to be under than over-estimated. In most cases, however, there is no doubt but that these blocks are erratic, and originally constituted

the impending shelf of the surface plateau, which from their being torn off now presents at its edge only a steep slope. That this shelf could not have been formed while the plateau was at its present elevation, is apparent not merely from the fact that the surf would prevent its construction, but because as the appearance of the whole reef testifies, it is not covered with a depth of water adapted to the operations of the polypes on such a scale. The fragments must also have been removed to the locality they now occupy, while the reef was at a lower level, since the surf at present scarcely reaches them except during heavy gales. That a considerable re-elevation has taken place since they became fixed where we find them, is evinced by the manner in which their sides and faces have been hollowed out by the action of the waves. Had no change of level occurred, we should naturally expect to see the greatest excavation near their union with the subjacent reef, where they are unceasingly exposed to the flux and reflux of the tide, whereas it is frequently near their upper third, and a portion of it above high water mark, giving to the smaller masses a great variety of configuration, as may be seen in the following sketch of a cluster on the reef at King's island.



The interrupted line in this and the preceding cut indicate the line of high water in ordinary tides.

I incline to a belief that the fissures described as existing in the thin shelves of coralline limestone surrounding some islands, should be included among the evidences of re-elevation. The character of their stratification shows that these were originally deposited on a horizontal plane, and their present dip of 5° or 6° seaward, may have been occasioned by the upward pressure of the submerged summit below the bed of the lagoon, which would also be likely to cause in strata of their extent and tenuity, such rents as I have mentioned. This is certainly the case with similar formations on the east-

ern coast of Kauai, whose dip is 10° or 12° so that the edges of the laminæ at their landward termination, crop out a foot or more above the beach.

Throughout the volcanic islands of Polynesia the tokens of recent elevation are every where conspicuous in a greater or less degree. At the Society and Samoan groups may be seen above water at low tide, corals *in situ*, whose upper portion and frequently the entire mass is blackened, and their polypes destroyed by exposure.

At the north-west end of Manua, (the easternmost of the Samoas,) fragments of coral, whose quantity and size are such as to render it impossible that they were placed there by other than natural agency, are to be seen at least eighty feet above the sea, on a steep hill-side rising half a mile inland from a low, sandy plain abounding in marine remains. These fragments are imbedded in a mixture of decomposed lava, mould and sand, and some of them are of such magnitude that four stout natives could not turn them over. The immediate coast is rocky and precipitous, the material, a partially decayed lava having a stratified character, but the strata much distorted and dislocated and in many places rent vertically asunder. At this end of the island there is no reef, properly so called, the water shoaling gradually from thirty fathoms at a quarter of a mile distance, till it breaks within a few yards of the beach. There are, however, numerous scattered patches and detached clusters of coral from a depth of ten fathoms to where the sea breaks.

At Tahiti I was informed, that on the sandy isthmus connecting the mountainous peninsulas of Tobreonu and Tiarabu into which that island is divided, eight or ten feet below the surface was a solid bed of coral rock, about the same number of feet above the sea. That this was formerly a reef connecting two islands is the more probable from there being here an interruption of the present shore reef, the deep water continuing quite to the beach.

At the Hawaiian islands, which are still the seat of volcanic action on a magnificent scale, the elevation has been much greater and its proofs more apparent than perhaps in any other

region of Polynesia. The islands of Maui, Molokai, Oahu, and Kauai, abound in such evidences, of which I will specify here only a few of the most striking.

At Oahu on the south side, the whole plain on which the town of Honolulu is situated, is an elevated coral reef, extending between three and four miles from east to west, and varying from half a mile to a mile in breadth. The landward side of this reef is highest, being, as well as I can remember, about twenty feet above the sea. In certain parts, like that for instance on which the town is built, the reef is covered to a depth of from two to five feet with ashes and fine scoriaceous sand, which were probably ejected from the now long extinct craters of Puiwa, just behind the town, and Leahi* about four miles east of it on the coast, chiefly, however, from the former, at whose foot the plain terminates, about a mile from the sea. Below this volcanic sand is sometimes found a stratum of slightly cemented coral sand, containing shells and Echinides of species identical with those now living in the vicinity. In other places, as on the plain at the entrance of the Manoa valley, between Honolulu and Waikiki, the reef is entirely bare, with every hollow and gulley as distinctly defined as they are on the present shore reef. A short half mile west of Honolulu and half that distance from the sea, at the mouth of a branch of the Nuuanu valley, a considerable stream flows through a section of this elevated reef some twenty feet deep. A mile and a half farther west there is a similar section at the mouth of the Kalihi valley. These appear to have been anciently passages in the reef, and show that it is composed of the same genera of corals (principally Porites) as constitute the mass of the recent reef. In the district of Ewa, fourteen miles west of Honolulu, on the left bank of Pearl river a few rods from its mouth, there is a bed of oyster shells, twelve feet in thickness and more than a hundred yards in length, whose lowest portion is full five feet above the sea. They are for the most part entire and in a fine state of preservation, the internal polish yet uneffaced and

* Puiwa is the "Punchbowl hill," and Leahi the "Diamond Head," of the foreigners.

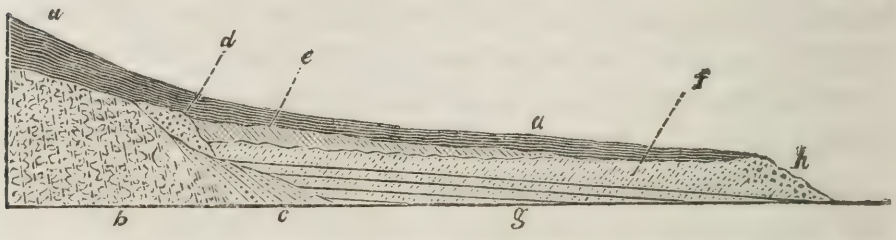
not tacky or "*happante*" to the tongue. They bear a very close resemblance to our *O. borealis*, and it is remarkable that although imbedded with it are found many shells which still inhabit the adjacent coast in great numbers, the Ostrea is apparently an extinct species. It was seen no where else in the Pacific, neither so far as I could ascertain, is it met with either fossil or recent on any other part of this coast.

From Waialua on the north-west side of Oahu I received specimens of a very hard and compact breccia of shells and coral, said to be taken from cliffs of the same material twenty feet high, which the description sent with the specimens left me little doubt, were the remains of an ancient cemented coral beach.

On the coasts of Kauai there are frequent elevated beaches. One of these at Kalihiwai, on the north side of the island, three fourths of a mile inland, is composed of a slightly coherent conglomerate of coral and shells raised about fifteen feet. Aged natives dwelling in the neighborhood, affirmed to me that the sea had retired within their remembrance an eighth of a mile, and that in their youth, old men had told them that they in their boyhood fished in canoes at a spot now full one third of a mile from the sea, which since that period, as they forcibly expressed it, "*ihanauia ka lepo hou*," literally, had brought forth the new earth. Four or five miles west of this, the river Hanalei, flowing through a plain of the same name in the district of Waioli,* displays on its banks rather more than a quarter of a mile from the sea, the section of an ancient beach about five feet higher than the present one, and composed of materials similar to that of Kalihiwai. This line of beach extends from the base elevated table land, forming the eastern boundary of the plain in a westerly direction three miles across, to the foot of the lofty ridges of Mamalahoa and Puünauekia its limits on the opposite side ; following the cur-

* Waioli signifies "the singing" or "the joyful water," and is applied to this region by the Hawaiians, whose names are always not less poetical than descriptive, on account of the numerous glittering cascades that come singing and leaping down from the lofty mountains by which it is girt on all sides but the seaward one.

vature of the hills to the south, and sometimes almost skirting them at from the fourth of a mile to a mile from the shore. The figure below represents a north and south section of the plain, from just back of the ancient beach to the sea, on a scale of 2.5 inches to a mile, and 10 feet to the inch.



a. Surface soil, twelve to fourteen inches deep below the old beach, and eighteen to twentysix inches deep above it.

b. A decomposed lava ten or twelve feet thick, gradually passing into the solid rock.

c. A mixture of decomposed lava, surface mould, and coral and shell detritus.

d. Ancient beach of coral rubble, shells, and volcanic earth and sand.

e. A stratum of like materials with *c*. ten inches thick at its commencement, but gradually attenuating as it approaches the sea till at one-fourth of a mile from it, it is lost.

f. A stratum of fine volcanic sand, chiefly comminuted crystals of olivine, and fine coral detritus and shells.

g. Thin laminæ, the planes of whose stratification are parallel, formed by a concretion of the materials of *f*. and having thin layers of loose sand interposed.

h. Present beach—coral rubble, shells and sand, chiefly coral detritus.

These laminæ were evidently formed by successive horizontal depositions, but have since been tilted up so as to dip about 5° north to the sea. Proceeding inland, after passing the line of old beach, the surface soil is twice the thickness of that on the seaward portion of the plain, and rests on the stratum of decomposed lava. The layer of mixed earth, sand and shells, was no doubt washed from the stratum at the time when the sea was at the old beach. The bed of sand and detritus on which this mixed layer, and after its disappearance, the surface mould rests, is full of slight inequalities, as if rippled up by the wind or sea. Probably the former was the real agent after its elevation. In the opinion of several intelligent residents, this plain has been formed merely by long continued additions to the beach, but there are several facts contradictory of this.

From all the evidence I could collect, either by personal observation or inquiry, it is my belief that the sea instead of augmenting the coast, is yearly encroaching upon it and regaining its previous loss by elevation. The surf which rolls in from the broad open bay of Hanalei, especially during the winter months, with tremendous violence, must operate destructively upon a beach shelving into deep water so abruptly as this.

There is a short beach a mile and a half perhaps from that of Hanalei, between the river Lumahae and the ridge of Puünauekia, which during the winter is sometimes three hundred yards wide, and is every summer narrowed to twenty or twentyfive yards, yet no corresponding increase takes place during the latter season in the main beach. Yet it is evidently the waste of this which contributes to widen the other, it being the only one in the vicinity capable of furnishing the material. If the plain was of gradual formation by successive increment, as a natural consequence the surface soil would be deepest on the inland or older portion, whereas it is of the same thickness one hundred yards from the sea as at the ancient line of coast. Moreover, a transverse section of both the ancient and modern beaches, exhibits a ridge composed of coral in considerable fragments, entire shells, Echinides, &c. mixed with a rather coarse coralline sand, and if the intervening space were merely a succession of similar beaches there is no reason why it should not be similarly constituted. But instead of this it contains only a few scattered corals in small pieces, the shells in it are small and broken up and the sand is very fine, much of it being of volcanic origin; the whole appearing like the finer and heavier particles, now being washed from the beach and carried seaward by the recoil and undertow of the surf. Adding to these facts that of the dip northward, of the lower bed of laminar concretions, I think the plain of Hanalei should be classed among the instances of elevation by subterranean forces. The manner in which the strata of cemented coralline sand are tilted up in the vicinity of Wailua has already been described. At Anahola a few miles north of this, half a mile from the sea is

a remarkable beach, more than a mile in length, consisting of a mixture of loose corals, shells and sand, deposited in very regular curved strata. From this and all the other old beaches a sandy plain, with a thin coating of soil extends to the present coast.

That section of the coast at Kauai, designated by the natives as Na Pali, or "the Precipices," which from Hamakoa on the north, to Lapa on the west, extends about twelve miles in an unbroken, inaccessible wall of sub-columnar lava, from eighteen hundred to twentyfive hundred feet high, exhibits continuous traces of exposure to the action of the waves, several feet above the line of cavities now being worn by the surf.

At Molokai, an island a few miles north-west of Maui, Mr. B. Munn, teacher for the Mission, assured me that he had seen masses of coral apparently in their original position, imbedded in calcareous rocks, one hundred and even one hundred and fifty feet above sea level. I suspect, however, that here is some error, either of calculation or observation, having seen nothing on any of the other islands to warrant the belief in such an elevation as this would indicate. Still from the testimony of all the missionaries, there can be no question of the fact that there are really in Molokai raised coral beaches of height at least equal to those of Oahu and Kauai.

By the statements of several persons who have long been residents on Oahu, the elevation there is at present going forward at a very perceptible rate. Henry A. Peirce, Esq., an American merchant who has dwelt at Honolulu for upwards of sixteen years, and whose high intelligence and habits of close observation entitle his opinion on this point to much respect, has informed me that large portions of the reef on both sides of the harbor, which at his first arrival were never uncovered by the sea, have since then risen so much as to be now bare every tide at low water; other parts which were within his knowledge exposed only at that stage, are now naked an hour before it, and the sea has in the same time rece-

ded as much as thirty feet from places where canoes were accustomed to land.*

It is to be remembered that throughout this group of islands, earthquakes are of very frequent occurrence, especially at Hawaii, the principal one, and seat of the great volcano of Kilauea, where several occur almost every year. At Hilo, or Byron's Bay, about thirty miles north-east of the crater, during the month of November, 1838, upwards of fifty shocks were experienced within eight days, and not less than twelve more counted in a single night. There is another active volcano in the Vichis, or Fejees, and several more in the islands to the southward and westward of them, nor is it at all improbable that throughout the entire extent of Polynesia, the internal fires are raging below the ocean's bed, and by their upward forces constantly tending to elevate the existing islands.†

* Among the evidences of the slow increase of corals, alluded to on page 67, were included through inadvertence, experiments made at long intervals on the depth of channels and upon well known reefs. These should be set aside, since it is clear that such depth might be increased or diminished by a subsidence or elevation of the reef, and therefore no correct inference as to the growth of the corals composing it can be drawn from such experiments.

† Its bearings on this question, the singularity of the phenomena it records, and the limited circulation of the work in which it appears, will, I trust, be deemed sufficient apologies for introducing here the account of an extraordinary oscillation of the sea, published in the Hawaiian Spectator, for January 1838, by T. C. B. Rooke, F. R. C. S., a resident of Honolulu.

" On the evening and night of the 7th Nov. 1837, a most remarkable commotion of the sea was witnessed at Honolulu, in many respects similar to that witnessed at these islands in May, 1819. One inch and a half of rain had fallen during the previous twentyfour hours; the wind was fresh from the. north-east, squally at intervals. The atmosphere was clear and cool,—Therm. 74.5. The Barometer had gradually fallen during the four previous days, but this evening had again risen to 30.06, at 6 o'clock, when the alarm was given that the sea was retiring. The first recession was the greatest,—something more than eight feet; but being unprepared to make observations at the moment, the exact fall was not measured. The reefs surrounding the harbor were left dry, and the fish aground were mostly dead. The sea quickly returned, and in twentyeight minutes reached the height of an ordinary high tide; scarcely remaining stationary, it again receded and fell six feet. This was repeated at intervals of twentyeight minutes. On the third rising it was four inches above ordinary high water mark, and fell again six feet four inches. After the fourth rising, the length of time occupied by the rise and fall varied, and the

Before closing these imperfect reminiscences, a few remarks may be added, respecting Matea, or Aurora Island, a coral reef

rise and fall diminished gradually, but not regularly. At 11, P. M. the Thermometer stood at 74, Barometer 30.04; wind freshening and frequent showers; the ebb now occupied twenty minutes, and the flow ten. At 11.30 it became calm with constant rain. Thermometer 73.5; Barometer 30.03. The ebb and flow still continued, occupying the same space of time, but the rise and fall decreasing. This continued during the forenoon of the 8th. The rapidity with which the water fell, varied in different parts of the harbor. On the east side, the greatest rapidity noticed was six inches in a minute; but on the north, at one time during the third recession it fell twelve inches in thirty seconds. At no time did the water rise higher than a common spring tide; but the fall was about six feet below low water mark. The same occurrence is related to have taken place in 1819, when the tide rose and fell thirteen times in the space of a few hours. On neither occasion was there any perceptible motion or trembling of the earth, or unusual appearance of the atmosphere.

On the leeward side of Maui the same rise and fall took place as at Honolulu, but on the windward part of the island the sea retired about twenty fathoms and quickly returned in one gigantic wave sweeping every thing before it, houses, trees, canoes, and every moveable object exposed to its fury. At a small village, called Kahului, in the district of Wailuku, on the sea retiring, the amazed inhabitants followed it as it receded, eagerly catching the stranded fish, shouting and hallooing with pleasure, when suddenly the sea rose perpendicularly before them like a precipice, and rushing to the beach, buried the assembled multitudes in the flood, and overflowing the shore, swept away every house in the village but one; the canoes and property of the natives were all destroyed. Happily, owing to the amphibious education of the people, but two lives were lost here, but as the same occurrence happened all along the seaside we shall probably hear of more deaths.

At Byron's Bay, on Hawaii, the same phenomenon took place. An unusual number of persons were collected together attending a protracted meeting, consequently every house was crowded. At half-past 6 the sea retired at the rate of four or five knots an hour, reducing the soundings from five to three and a half fathoms at the anchorage, and leaving a great extent of the harbor dry. Hundreds of curious souls rushed down to witness the novelty, when a gigantic wave came roaring to the shore at the rate of six or eight knots an hour, rising twenty feet above high water mark, and fell on the beach with a noise resembling a heavy peal of thunder, burying the people in the flood, destroying houses, canoes, and fish-ponds, washing away the food and clothing of the inhabitants, large quantities of animals, fire wood, and timber collected on the strand for sale. The cries of distress were horrible; those in the water unable to swim among the wreck of houses, and pieces of timber, struggling for their lives, and those on shore wailing for their friends and relatives. The British whale ship Admiral Cockburn was at anchor in the Bay, and to the timely aid and humane exertions of her master, (Lawrence,) and crew, many are indebted for their lives; but for the assistance rendered by their boats many who were stunned and insensible would have been carried out to sea, and perished, as the natives had not a single canoe left that would float. Every thing was destroyed;

which has been elevated about two hundred feet, lying some thirty leagues from Tahiti, in a N. N. E. direction. This island presents a perpendicular wall on all sides but the north-east, where it slopes rather steeply to the water. The greater portion of this wall has no attached reef, and rises abruptly from the ocean, which at one hundred yards distance is perfectly blue; but there are occasionally crescent-shaped tracts of low land between the sea and base of the cliff, which previous to the elevation of the island may have formed small bays, and from these extends a narrow coral plateau. At the inland termination of these plains, is a large talus composed of massy fragments fallen from the cliff, in all probability ruins of the anciently projecting shelf. Their whole surface is worn by the water into deep inequalities, so sharp and rug-

those who escaped with their lives had neither food nor raiment left. In Kanokapa and Kaahelu alone, sixtysix houses were destroyed, and eleven persons lost their lives; four men, two women, and five children; at Waiolama and Hauna, a woman and child were drowned; at Kauwala one woman lost her life. The amount of damage done has not yet been ascertained, nor is it known how many times the sea rose and fell. There was no shock of an earthquake felt at Hilo, or elsewhere, although it is ascertained that the volcano of Kilauea was unusually disturbed the previous evening, the fires were suddenly quenched, and yawning chasms burst open in previously tranquil places, accompanied with violent explosions. Inquiries have been made of masters of vessels who were to the north and to the east of the islands on the 7th, at various distances, but none of them noticed any thing unusual in the sea, or atmosphere. That this apparent submarine volcanic action has taken place at some distance from the islands is proved by the wave striking the different islands simultaneously and apparently in the same direction; but at what distance we have no means at present of determining. Perhaps the internal fires have found a new vent, which may be laying the foundation of a new group of islands in our neighborhood. It is now nineteen and a half years since a similar phenomenon occurred here, but not so violently as the last, nor was it attended with any loss of life."

Cases of the sea during earthquakes retiring for a short time to return with overwhelming force, are but too familiar matter of history. Such are the wave which utterly destroyed old Callao in 1746; that witnessed during the great earthquake of Lisbon, and more recently, in those which have been attended with such fearful consequences along the coast of Chili; but I am not aware that there is on record any parallel to such a series of alternating ebb and flow of the sea, unaccompanied by any perceptible commotion of the earth, as is here described by Dr. Rooke. That it was nevertheless occasioned by the throes of pent up subterranean fires at some remote point, there can I think be little question.

ged as to render walking, or to speak correctly, clambering over them a difficult and fatiguing task. At the foot of the cliff, back of the lowland, are frequent caverns, from whose roofs depend numerous stalactites from the size of a pipe-stem to that of a man's body, the little drops of water at their extremity sparkling like so many diamonds wherever the light from a crevice falls upon them. The floors are also covered with stalagmitic incrustations in every degree of hardness, and assuming a great variety of forms. Those into which I entered, descended for a few feet at an angle of about 30°, like an arched vault, and then expanded into an irregular circular grotto, with a level floor, whose ceiling was from four to fifteen feet in height. Some of these caves are capable of holding at least three hundred persons.

From one of the plains on the north side, where there is a village with some two hundred and fifty inhabitants, a steep ascent leads to the summit, which presents a broad table land, declining a few feet toward the centre, where we may suppose the lagoon to have been situated. Near the eastern extremity, a few yards from the bank, are two knolls gently rising to a height of perhaps forty feet, which I presume to be remains of the ancient fragmentary ridge, formed when this table land was the surface reef, the main portion having been undermined and worn away by the action of the surf on the south-east or windward side during the period of elevation. To this cause, I imagine, is also to be assigned the sloping form of the island in that direction, while the sheltered leeward side has preserved its original sheer descent. The dense growth of forest, and tangled luxuriance of under growth, prevented any minute observation during my hurried visit, but I recollect that the whole surface of the table land, and the ascent of the cliff for eighty or a hundred feet below it, was covered with fragments of coral conglomerate, the species imbedded in which were the same with those found on the reef below. Indeed, the entire mass of the island is a reef-rock in various stages of consolidation, the lower portion approximating to a solid limestone, the cellular coralline structure being in some fragments hardly perceptible, and the

imbedded shells frequently losing their texture, becoming blent with the rock, and presenting merely casts.*

The island appears to have been elevated at two successive periods, between which it remained stationary for a considerable time; as rather more than half way up the cliff is a horizontal belt of deep excavations, exactly resembling those now worn at its base by the sea. This belt is not absolutely continuous, being interrupted at intervals by spaces where the action of the water is not discernible. Such, however, should a third elevation occur, would be the condition of the present base of the cliff, at which the line of excavation is apparent only in those portions exposed to the action of the surf. Viewed from a distance, the belt appears distinctly to divide the cliff into two nearly equal portions, and in several places where this latter forms an angle, large perforations are visible, which must have resulted from the wearing away of the rock by the surf.

Thus have I, hastily and at random, as promised in the outset, thrown together some of my reminiscences of these interesting regions. At a future day I may be enabled (abandoning the indefinite specifications whose occurrence I am well aware is too frequent in these remarks, but which under the circumstances are unavoidable,) systematically to arrange my observations, and give the details with the minuteness and precision demanded by the importance of the subject.

Since the remarks upon the influence of tides upon reef channels, in a preceding portion of this communication, have been in press, it has occurred to me that in connection with that topic it will be proper to specify several erroneous assertions relative to the tides generally throughout Polynesia; which derive importance from the name of their authors justly possessing much weight, not less with scientific readers than the public generally.

* Specimens of shells in this state are also found occasionally in the tabular masses of reef-rock, on the shores of some lagoon islands. These fragments, like the rock at Matea, indicate by their structure that the main body of the reefs is not a homogeneous coral rock, but a conglomerate of large pieces of coral and shells, filled in and cemented together by a detritus of similar materials.

Capt. Beechey, in the "Voyage of the Blossom," part I. Chap. IX. Lond. Ed., speaking of tides in the harbors of Tahiti, remarks, "At Toanoa, it is usually low water about six every morning, and high water half an hour after noon," and attributes this peculiarity to the sea breeze by day, forcing the water into the harbor, which is a lagoon between the reef and shore; adding, "as the wind abates, the water subsides, and the nights being generally calm, the water finds its lowest level by morning."

Now the first of these propositions, though strictly true, is only a partial statement, conveying, and (as is evident from the context) designed to convey, the idea that the flood tide lasts only about six hours, while the ebb continues for eighteen, from noon of one day till six the next morning. The second quotation contains a positive mis-statement. In the first place, at Toanoa, as in all the harbors of Tahiti and the other Society Islands, it is full sea regularly twice in twentyfour hours, and always about noon and midnight; and low water about six o'clock, morning and evening. The mornings are calm for perhaps eleven months in the year, the trade wind or sea breeze commonly setting in about eleven o'clock, and prevailing in its greatest strength from noon till four or five P. M. It then dies away, and by eight or nine P. M. there is a dead calm which continues till the next forenoon.

Thus instead of the tide being forced into the harbor by the sea breeze, we find that a great part of the day and all the night flood takes place during a calm, whereas during the afternoon, the water ebbs rapidly against the full power of the breeze. Even if Capt. B. were correct, in regard to the duration of the ebb and flood, his explanation would not reach the case of those harbors on the leeward side of the islands, where the trades are not felt, and yet the tides follow the same course as those on the opposite side.

In Kotzebue's account of his voyage round the world, he also has given currency to very inaccurate statements on this subject. In his remarks on Tahiti, we find the following passage. "Every noon, the whole year round, the moment the sun touches the meridian, the water is highest, and falls with the sinking sun, till midnight."

It would be a difficult matter, to crowd in as few words a greater number of errors than are here contained. They convey a false impression that the tides are governed entirely by the sun; represent them as diurnal instead of semi-diurnal, and name as the hour for the daily recurrence of low water, that when it is actually full sea. Neither is it always high water, as he asserts, "the moment the sun touches the meridian," though this, compared with the rest, is but a trivial misrepresentation.

Capt. Beechy also remarks in the work cited, that "the tides in all harbors formed by coral reefs, are very uncertain, and are almost wholly dependent on the sea breezes." So far however is this from being the case, that throughout the Harvey, Samoan, and Tonga Groups,* for days together at certain seasons, there is no sea breeze whatever; the tides obey the moon with a regularity as undeviating as in any other part of the world, although the majority of the numerous harbors in the two latter are formed by coral reefs. As great regularity prevails also in the recurrence of the abnormal tides of the Society Islands, except when interrupted by occasional heavy gales, and these for the most part blow either across or opposite to the direction of the trade winds.

In a paper professing to be an "Extract from Lieut. Malden's Official Account of the Sandwich Islands," published in the Appendix of Lord Byron's voyage in H. M. Ship Blonde, p. 256, Lond. Ed., 1826, are these remarks in reference to the tides at Hawaii, "The tide was observed to rise about four feet, and to be high water at sunset, and low water at daylight, being influenced by the sea and land breezes. This regularity would probably not take place in the winter months, when they do not prevail."

This is also incorrect in every particular, save the height of the tides. They do not statedly occur at the times here given, neither are they affected to any extent by the prevalence or absence of the breezes, and I am at a loss to imagine upon what grounds Lieut. M. predicated such a statement as

* I include the Tonga or Friendly Islands on the authority of Rev. Mr. Williams, who had spent some time among them.

the above. Had he lacked opportunity during his stay at Honolulu of observing for himself, there were certainly foreign residents enough there, missionaries and others, who could have furnished him with more correct information on this subject, had he sought to obtain it. The truth is, that unless retarded or accelerated by occasional storms, the flood and ebb at these islands, from one year's end to another, summer and winter, in breeze and calm, follow the course of the moon as regularly as do the tides in Boston Harbor. The rise and fall of the tide, varies in different harbors, from four to five and a half feet. Having resided for six months in the Hawaiian Group, traversed the four principal islands in various directions, and beside making careful inquiry of the residents, examined no less than twelve harbors, including nearly all of any consequence, some of them open roadsteads, others formed by small bays, and a large proportion by coral reefs; I can speak with some confidence on this point.

All my visits to islands in coral archipelagos having been very brief, I am unable to state what is the course of the tides among them, but incline to believe that at the detached Paumotus, they obey the usual laws. On landing a second time at Bellinghausen's Island, which is about two hundred and seventy miles west of Tahiti, I found the reef quite bare, at the same hour that it was overflowed on my first visit, some months previous. At the full and change of the moon, the rise at Ocean Island is about twentytwo inches, while at Christmas Island it is five feet, but the tides on both are normal, by the accounts of those who have been wrecked and resided on them for several months.

I hasten to terminate these discursive remarks, (already extended far beyond what was contemplated at the commencement,) by offering a few suggestions relative to a subject which it appears to me has by no means received, hitherto, an attention commensurate with its importance. I allude to the temperature of the ocean, in its influence upon the growth and geographical distribution of corals.

It is a remarkable fact, and one for which I am not aware that any explanation has been offered, that while in the Paci-

fic and Indian Oceans, coral abounds every where between the tropics for a space of about six thousand leagues from east to west, it does not exist on the west coast of South America (at least south of the eighth parallel of latitude,) nor do we meet with any coral islands within the whole space of nearly eight hundred leagues to the westward of it.

Even at the Galapagos, situated directly upon the Equator, there are no traces of a coral reef. This absence of coral formations in portions of the same parallel in which their most profuse display is presented, has by some been referred to one of those inexplicable, apparent caprices of nature, beyond man's ability to fathom, analogous to the well-known fact, that certain classes of plants which flourish luxuriantly in the other hemisphere, will not thrive at all in situations and climates seemingly in every respect adapted to their growth, in our own. It is my impression, that in the Atlantic the same absence of coral characterizes a large portion of the South American coast, and the outlying intertropical islands, such as Trinidad, Martin Vas, and Fernando Noronha; while it abounds in the same parallels north of the line, among the Antilles, and even in the latitude of 32° we find a very considerable group of coral reefs, and islands of coral limestone. At the Cape Verde Islands, and I think the Canaries also, we have again an entire absence of such formations, although the former are 17 degrees nearer the Equator than Bermuda.

On the east coast of South America, this may perhaps be attributed partly to the immense bodies of fresh water poured into the Atlantic from those great streams, which rolling in turbid floods through a course thousands of miles in length, empty themselves at various points from near the Equator to the latitude of 35°. It is well known to what an astonishing distance their waters are carried along the coast, unmingled with those of the ocean, and loaded with a fine, impalpable mud. This must unquestionably be highly deleterious to the coral polypes, if not sufficient to utterly prevent their growth, as they require the purest ocean water for their successful developement.

But I am persuaded, after a careful examination of the facts,

that the absence of coral on the other side of the continent, and in the wide space between it and the low islands of Polynesia, is to be attributed to the prevalence of cold currents, which proceeding northward from the Polar regions are perceptible the whole distance from Cape Horn to Callao, and I presume much further to the north, in a temperature of the ocean too low for the existence of the coral animals, and that in a similar low temperature we are to seek for the cause of their absence at the Cape Verde Islands. I have already alluded to the greater heat on the southern part of our coast and the Bahamas, produced by the vicinity of the Gulf Stream.

A like temperature prevails along the southern shore of Cuba, and the islands in its vicinity, and though unable to speak positively, from having no data, as to the Bermudas, I have no doubt from their proximity to the Gulf Stream, that they are washed by an equally warm sea. Now let us glance for a moment at the facts bearing on this question, in regions situated in corresponding parallels of latitude, where no coral formations exist. At Valparaiso, in lat. of 33° south, and thence as far as the 20th parallel, in the month of November, the surface temperature of the ocean near the coast has been found to range from 58° to 60° ; at Callao, in the lat. of 12°, from 58° to 62°, and thence in a north-westerly direction to the Galapagos, to increase gradually to 68° and 70°. Among these islands, at the same season, its average was not above 68°, and at some of them it did not exceed 62°. But leaving these islands and proceeding south-west, we find it steadily rising, till on the skirts of the Dangerous Archipelago it is up to 78° and 79°, nearly 20° higher than on the coast in the same parallel. And here we enter upon the coral formations. Among the Paumotus, the field of their most lavish display, the temperature varies from 77° to 83° ; at Tahiti from 77° to 80°, and about the same at the large groups to the west of it. At the Hawaiian Islands, lying between 19° and 22° north latitude, it is as high sometimes as 81°.

In our own hemisphere, among the Antilles, Bahamas, and along the southern coast of Florida, I have found the temperature of the water near the shore, at different seasons, from 78° to 82°, and in all these regions coral reefs abound.

At the Cape Verde Islands, and in the neighborhood of Trinidad, Martin Vas, and Fernando Noronha, it falls to 69° and 71° ; and these islands, as was before remarked, are entirely destitute of coral formations. It is not unlikely that there are cold currents from the Antarctic along the East as well as the West coast of South America, which combine with the fresh water of its large rivers in preventing such formations upon a certain portion of it, but this I have at present no means of determining, being without any data as to the temperature north of 35° on that side. It appears to me, that such coincidences as the facts here submitted prove to exist, between certain temperatures of the ocean and the absence or presence of coral reefs, can scarcely be considered by any reflecting mind, as merely casual ; and that there are strong grounds for believing that we have here a clue to the real cause of the singular absence of recent coral formations in certain regions corresponding in every thing save temperature to those where they are most profusely scattered. In order to enable us, however, satisfactorily to determine how far their geographical distribution is affected by such causes, it is essential that we should be furnished with a connected series of observations on the oceanic temperatures at the surface and to certain depths, along both sides of the African continent, the coasts of Australia, and among the coral archipelagos of the Indian seas ; together with that of the seas beyond the limits of such formations, in both hemispheres. Such observations might easily be made on board our national vessels, by direction of the Navy Department, and published in the form of tabular reports at the expiration of their cruise. The Department would, I presume, scarcely refuse to issue the requisite instructions, upon suitable representation. There are also many intelligent commanders in our merchant service, who only require that their attention should be directed to this matter, in order, as I am confident, to ensure their cordial coöperation. By the mass of information which would thus be brought together we might also expect that much light would be thrown on questions relative to oceanic and (as connected with these,) atmospheric phenomena, our knowledge

of which is yet in its infancy. Other advantages to the cause of science, which we cannot now anticipate, would doubtless result from such a course, as it frequently occurs that in the collection of facts bearing on a particular subject, something is elicited leading to important conclusions in regard to others having at first sight no connection with it.

While convinced in my own mind of the truth of the suggestions here offered, in regard to the absence of coral formations in certain regions, I feel conscious also that the data upon which they rest, though certainly presenting a strong case as far as they extend, are after all but limited in comparison with those still deficient. I submit them for what they are worth. What this may be, time and more extensive observation must determine. Claiming only to have at least sought a more rational method of accounting for the peculiarities here pointed out, than that of supposing them altogether fortuitous, I shall rejoice if the end show that I have contributed in the slightest degree, or in a single point of view, to the advancement of the great object to which we are all, according to our opportunities, devoted.

In the operations of Nature, or rather of Deity, there is nothing the result of blind chance, and though there may be particular phenomena, which in our present ignorance of the laws controlling them, we are unable to explain; it is not the less certain that these laws really exist, and that patient research will yet be rewarded by their discovery. The day will come, and we may hope is even now dawning upon us, when error and misconception shall vanish before the advance of science, as the morning mist from the strength of the noontide sun; when with the clouds dispersed which yet partially obscure even the brightest intellect, the veil shall be lifted from Nature's most secret mysteries, and those things which we now behold but as "through a glass, darkly," be all revealed in the clear effulgence of immutable Truth.

Errata. Page 78, line next to the bottom, for "Silurian," read Cambrian.
Page 79, 10th line from top, for "regions," read rigors.
Page 147, 9th line from bottom, for "base elevated table land," read base of the elevated table land.