ROSE ATOLL, AMERICAN SAMOA.

By ALFRED GOLDSBOROUGH MAYOR.

(*Read April 22, 1921.*)

His Excellency the late Commander Warren Jay Terhune, U. S. N., then Governor of Samoa, was so kind as to invite me to accompany him on the U. S. S. *Fortune* to visit the little known Rose Atoll in S. Lat. 14° 32′, W. Long. 168° 12′, and we spent twenty-four hours upon this island from June 5 to 6, 1920. There has been no scientific account of the island since 1839.

The island is an atoll, the lagoon being encircled by a narrow ring of limestone composed chiefly of lithothamnium, which is everywhere nearly awash at low tide, excepting on the northeast side, where there is a narrow entrance about six to nine feet in depth, out of which a current constantly flows. The ring of limestone which surrounds the lagoon is quite uniformly about 500 yards in width, while the central lagoon is about two miles wide and appears to have a maximum depth of not more than eight fathoms. There are only two small islets upon the atoll rim, Sand Islet and Rose Islet. The only map of the atoll is U. S. Hydrographic Chart of the Samoan Islands No. 90, based on the survey of the U. S. Exploring Expedition in 1839. This shows Rose Islet as occupying the entire width of the atoll rim, whereas at present it is confined to the inner half of the width of the reef rim. Moreover, this chart shows trees covering the entire area of the islet, whereas at present only the southern half of the islet bears trees. The chart states that Rose Islet is 33 feet high, but at present the land of the islet is 11 feet above high tide, and the tallest trees, as measured by means of a sextant, are about 80 feet high, and thus the total height of the landfall as seen from the ocean is about 90 feet.

Rose Islet is at present about 240 yards S.S.W.–N.N.E., and about 200 yards wide. The southern and southeastern half of the islet is densely covered with a forest composed exclusively of

Pisonia grandis trees, casting so complete a shade that no other plants grow beneath them, save only a single cocoanut palm, which was probably planted by Governor Tilly's party about fifteen years ago. This forest forms a nearly symmetrical dome, the leaves and branches on its confines extending quite to the ground. The largest trees are near the southern end of the grove, and about three feet above the ground one of these trees had a girth of 25 feet 7 inches, and was about 80 feet high. The ground under these trees is covered with a rich chocolate-colored humus, which is of considerable depth near the southern end of the grove.

Apart from this grove of pisonia trees and a half dozen cocoanuts planted by Governors Tilly and Terhune in 1902 and 1920, there are only two other species of plants upon the islet. These have been identified by Professor William A. Setchell and are a pink-flowered creeping *Boerhaavea diffusa* with stems rarely more than 3 feet long; and a thick-stemmed succulent *Portulaca* n. sp. with small yellow flowers. Both of these plants grow fully exposed to the sun on the coral breccia and calcareous sand which surrounds the pisonia grove, and none are found under the shade of the trees.

On the south side of Rose Islet the sand beach is reduced to from 1 to 5 feet in width at low tide, and cliffs of coquina from 5 to 8 feet high front the sea. A few feet inland this rocky ledge rises to a height of about 11 feet above high tide level. The pisonia grove appears to be confined to this region of coquina rock and does not appreciably extend out over the loose calcareous breccia which has been washed in upon the islet in time of storm.

The tree-covered rocky center of the islet is composed of a coquina consisting chiefly of wave-worn fragments of lithothamnium, and also rare and occasional pieces of broken coral such as *Favites*, *Porites*, *Symphyllia*, *Pocillopora*, and still more rarely *Acropora*. Imbedded in it are many wave-worn half-valves of *Tridacna*, and Gasteropod shells, and spines of Echini such as *Cidaris* were found, as was also the much-corroded ulna and part of the skull of a small Cetacean about the size of a black-fish, the latter being embedded in the coquina about 8 feet above high tide level.

A large amount of organic matter dark brown in color and derived

"A Memorial to Alfred Goldsborough Mayer"

Apart from this grove of *Pisonia* trees and a half-dozen coconuts planted by Governors Tilly and Terhune in 1902 and 1920, there are only two other species of plants upon the islet. These have been identified by Professor William A. Setchell, and are a pink-flowered creeping *Boerhaavea diffusa* with stems rarely more than 3 feet long, and a thick-stemmed succulent *Portulaca* nov. sp. with small yellow flowers. Both of these plants grow fully exposed to the sun on the coral breccia and calcareous sand which surrounds the *Pisonia* grove, and none is found under the shade of the trees.

On the southeast side of Rose Islet the sand-beach is reduced to from 1 to 5 feet in width at low tide, and cliffs of coquina from 5 to 8 feet high front the sea (fig. 6). A few feet inland this rocky ledge rises to a height of about 11 feet above high-tide level. The *Pisonia* grove appears to be confined to this region of coquina rock and does not extend to any great extent over the loose calcareous breccia which has been washed in upon the islet in time of storm.

The tree-covered rocky center of the islet is composed of a coquina consisting chiefly of wave-worn fragments of lithothamnium and also rare and occasional fragments of broken coral, such as *Favites, Porites, Symphyllia, Pocillopora,* and still more rarely *Acropora*. Embedded in it are many wave-worn half-valves of *Tridacna* and gasteropod shells, and spines of *Echini* such as *Cidaris* were found, as was also the much corroded ulna and part of the skull of a small cetacean about the size of a blackfish, the latter being embedded in the coquina about 8 feet above high-tide level. A large amount of organic matter, dark brown in color and derived from the decomposed roots of the *Pisonia* trees, permeates this coquina to a depth of several feet. All of the fossils found embedded in the coquina are forms now living on the reef-flat, which have simply been tossed on shore by the waves. Professor C. B. Lipman found that this coquina in contact with the soil contains 12.05 per cent of phosphoric acid.

On the wave-washed southeastern shore of Rose Islet some modern beach-rock has been formed and projects a few inches above high-tide level; but this is more recent than the rocky matrix of the islet, which is now emerged about 11 feet above high-tide level.

Sand Islet, which lies north of Rose Islet, is a mere accumulation of fragments of lithothamnium, shells, and broken coral and is devoid of vegetation and only about 5 feet above high-tide level. The sea must wash completely over it in time of storm.

Several hundred boobies (*Sula*), most of which had half-grown young, were nesting on the coral breccia of Rose Islet (fig. 7), while others had constructed nests of sticks high among the branches of the *Pisonia* trees. A few boatswain-birds with eggs were also nesting in the trees, and several nearly grown young of the noddy (*Anous*) were running over the ground, while adult noddies and sooty terns visited the island at night. Frigate-birds were hovering over the island, but none were nesting. Wilkes states that the noddies and sooty terns were nesting on Rose Islet on October 7, 1839, and these species were still nesting when Governor Terhune visited the island on January 10, 1920.

A small brown-gray rat was abundant and specimens of it were presented to the Bishop Museum in Honolulu, where they were identified by Mr. J. F. G. Stokes as being a Malayan form which appears to have become widely spread over Polynesia, being possibly introduced by the early Polynesians themselves, who esteemed them for food, and took much delight in hunting them for sport. Apart from these very tame and abundant rats, the only other animals we observed were a small brown, short-tailed lizard, identified by Dr. Thomas Barbour as *Lepidodactylus lugubris* (Dumeril and Bibron), and which is widely distributed over Polynesia, and the larva of a sphinx moth of the genus *Celerio* (Oken) feeding upon the *Portulaca*. A few gnats and an occasional house fly which may have been introduced from the U. S. S. *Fortune* were the only other insects we observed.

The upper surface of the atoll-rim which encircles the lagoon is a hard, smooth-floored flat with but little loose sand upon it, and in most places it is awash at low tide, although in others it projects as a hard, smooth ledge about a foot above low tide of the neap tides.

This hard, smooth upper surface of the atoll-rim, veneered everywhere by a layer of lithothamnium, is characteristic of the wave-washed surface of offshore and barrier reefs of the Pacific. The condition over a fringing reef is quite different, for here loose fragments are washed inward from the seaward edge and backed up against the shore. Thus the whole surface, excepting only the wave-washed outer edge, is covered with small, loose fragments which could not remain upon an atoll-rim or a barrier reef, for they would soon be washed off into the lagoon. The relatively loose nature of the material forming the shoreward parts of fringing reefs at once distinguishes them from offshore reefs. Professor W. M. Davis's attempt, following Darwin, to institute a class of "offshore fringing reefs" is not justified, the structure of the two forms of reefs being widely different. As a matter of fact, reefs along Pacific shores are either barrier reefs or fringing reefs, and one is never in any doubt in distinguishing the one from the other.

Hundreds of large blocks of limestone lie scattered over the flat, wave-washed rim of Rose Atoll (fig. 2). These loose boulders are quite uniformly about 5.5 feet high, and only when tilted are they any higher (fig. 3). In addition to these boulders there are a few others which are mushroom-shaped and still remain attached to the floor of the atoll-rim, of which indeed they form an integral part. One of the most remarkable of these mushroom-rocks lies to the eastward of Rose Islet, and is supported upon so slender a pedicel that it would seem as if the next storm must cause it to topple over. In many places over the flat, wave-washed floor of the atoll-rim one finds remnants of pedicels which once supported "mushrooms." In addition, some of the boulders have become secondarily cemented to the floor of the flat by the growth of lithothamnium around their bases. The largest boulder we observed lay loosely upon the reef-flat east of Rose Islet and was somewhat tilted by being jammed against another rock. It was 12 feet 5 inches long, 8 feet wide, and 7 feet 6 inches high, and as its specific gravity was 2.3, it apparently weighs 46 tons.

The appearance of these boulders supports the view that the atoll-rim was once about 6 or 8 feet higher, in respect to sea-level, than at present, and has been cut down to present sea-level in recent times. The "negro heads" are simply mushroom rocks which have been completely undercut, so that they now lie loosely upon the floor of the flat.

It can be seen that the surface of the present reef-flat consists chiefly of lithothamnium, a beautiful bright pink variety of which (*Porolithon*) forms a veritable veneer almost to the exclusion of other forms of life. Professor Alexander H. Phillips made an analysis of this lithothamnium and found it to contain 74.4 per cent of calcium carbonate and 19.47 per cent magnesium carbonate. Also, rock from the solid floor of the atoll-rim west of the main entrance to the lagoon gave 83.86 per cent of calcium carbonate and 14.36 per cent of magnesium carbonate, while a large loose boulder from the same region consisted of 77.28 per cent of calcium carbonate and 18.3 per cent of magnesium carbonate. Professor C. B. Lipman found that the largest erratic boulder on the reef-flat east of Rose Islet contained 79.5 per cent calcium carbonate and 14.54 per cent magnesium carbonate. It will be recalled that Högbom found the magnesium carbonate in various species of *Lithothamnium* to range from 3.76 to 13.19 per cent. (See J. W. Judd, Funifuti Report, 1904, p. 377.) Also, in 1917, F. W. Clarke and W. C. Wheeler (U. S. Geological Survey, Professional Paper No. 102, p. 44) analyzed 16 species of calcareous algæ of the genera *Lithothamnium*, *Archæolithamnium*, *Lithophyllum*, *Amphiroa*, *Phymatolithon*, and *Goniolithon* and found the calcium carbonate to range from 73.63 to 88.11 per cent, while the magnesium carbonate ranged from 10.93 to 25.17 per cent. The same authors (*loc. cit.*, p. 11) found that in madreporarian reef-corals the calcium carbonate is more than 99 per cent and the magnesium carbonate less than 1 per cent; whereas in alcyonarian corals, exclusive of *Heliopora*, the magnesium carbonate ranges from 6.18 to 13.79 per cent, thus being comparable in amount with its proportion in lithothamnia.

It thus appears that the loose boulders lying upon the atoll-rim have the same general chemical composition as the living lithothamnium of the rim itself, and are remarkable in that they contain a large amount of magnesium. In fact, these boulders are only remnants of the old rim, which was once about 6 or 8 feet above sea-level, but has been almost entirely planed down to the level of the present surface of the ocean, leaving only an occasional mushroom-rock or a pedicel as a vestigial remnant of the old rim.

Inspection shows that the solid rock of the atoll-rim and also the boulders lying upon it consist chiefly of *Lithothamnium* compacted into a mass of chalky whiteness superficially resembling dolomite and having a specific gravity of about 2.3, thus being higher than that of a pure coral limestone, the specific gravity of which would range from 1.85 to 2. A pure dolomite containing 45.65 per cent of magnesium carbonate should have a specific gravity of about 2.9.

There are a few fossil corals, chiefly *Pocillopora*, embedded in the rock of the atoll-rim and the boulders, but the whole visible rock of the atoll consists so largely of *Lithothamnium* that we may call it a "*Lithothamnium* atoll" rather than a "coral atoll."

The flat upper surface of the atoll-rim is in most places planed off nearly to low-tide level, but it is veneered with a vigorous growth of a beautiful pink *Lithothamnium* which has been determined by Professor W. A. Setchell as *Porolithon* sp. closely allied to *P. craspedium*. In most places this *Lithothamnium* forms irregular, more or less connected patches growing on the smooth, hard floor of the flat. West of the main entrance to the lagoon, however, it grows in long, nearly parallel, flat-topped, overarching ridges, all parallel with the line of the wave-fronts of the breakers as they surge over the reef (fig. 3). These ridges are about 6 inches high and from 6 inches to several feet in width and with channels of similar width between them.

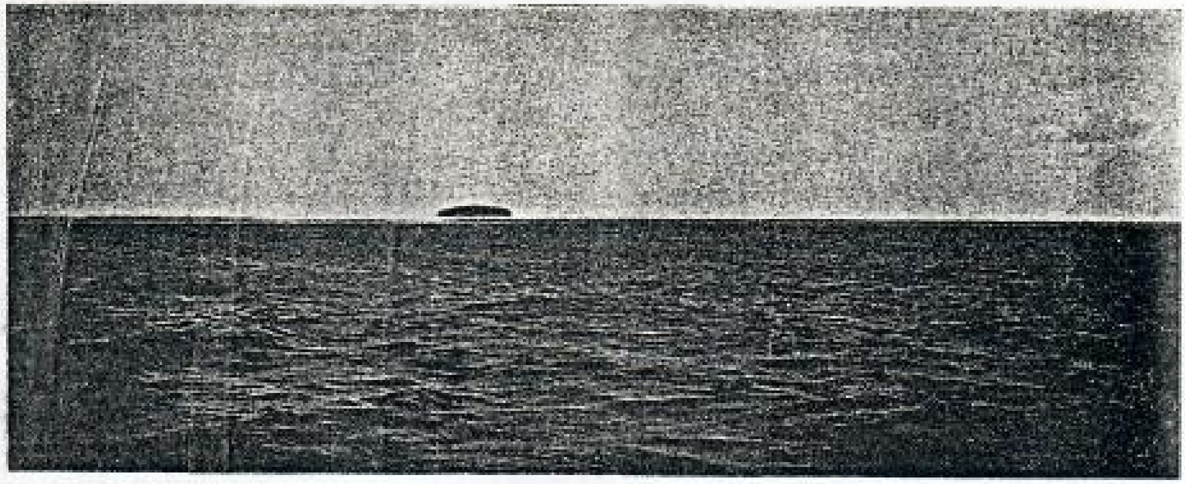
Lithothamnium grows in greater profusion over the reef-rim of Rose Atoll than in any other Pacific reef I have seen, but apart from the single species of pink *Lithothamnium* there are remarkably few organisms growing in the shallows of the reef-flat. Occasionally we find a pale olive-green *Porites*, allied to *P. lutea* M. Ed. and H., and there are a few small stocks of *Favites* or *Symphyllia;* but *Acropora* and *Pocillopora*, which are the dominant forms in most breaker-washed reef-flats of the Pacific, are practically absent from Rose Atoll, except at the extreme edges of the atoll-rim fronting the lagoon or the sea, where a few stunted specimens of these genera occur.

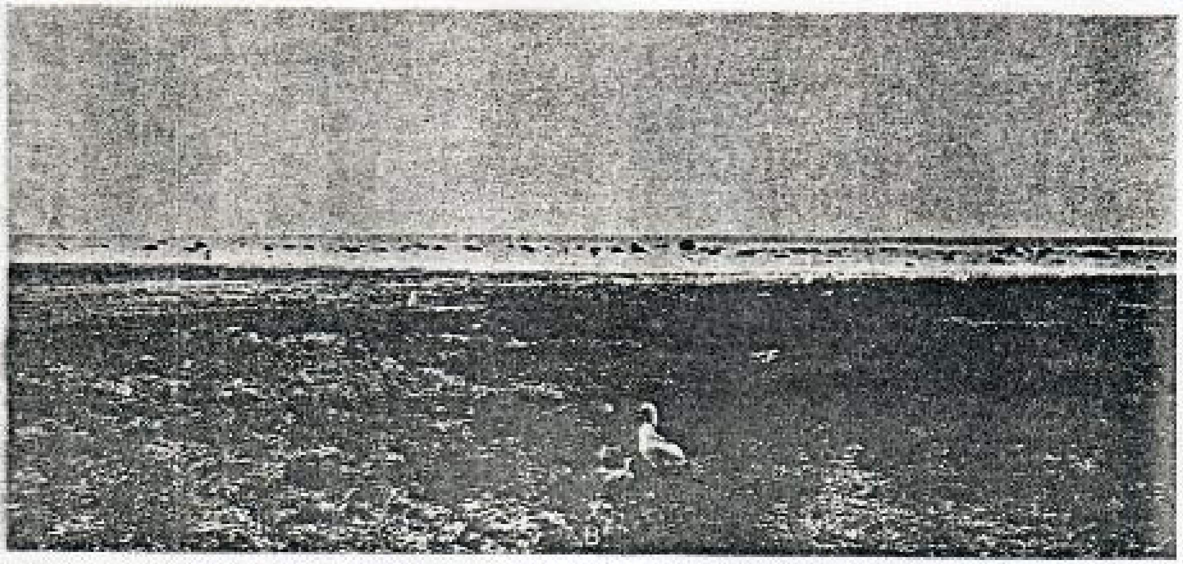
I did not find upon the Rose Atoll reef-rim a single specimen of branched *Acropora* related to *A. muricata*, nor did I see *Acropora hyacinthus*, or *A. leptocyathus*, which are dominant forms on the seaward edges of reefs elsewhere in Samoa.

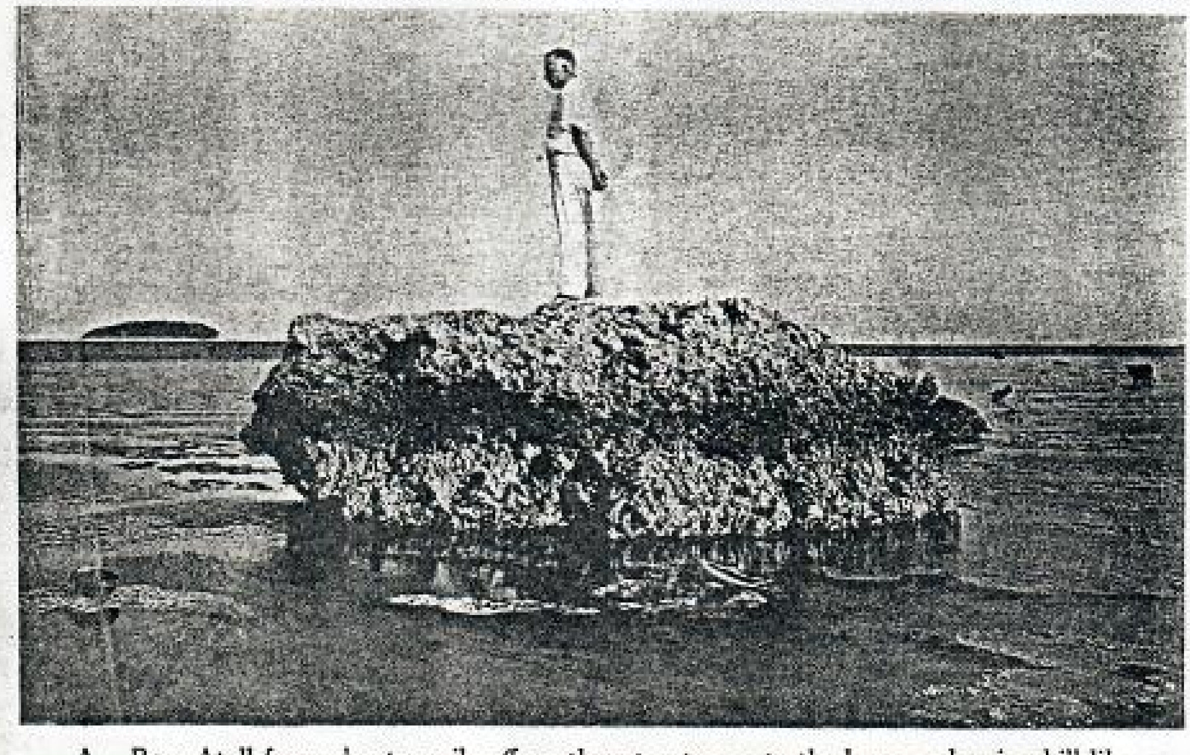
Holothuria were fairly common, as were also small specimens of the giant clam *Tridacna*, and among echini a few *Cidaris* and black, long-spined *Diadema* were seen; and the bright-green seaweed *Caulerpa* was here and there found in the troughs between the ridges of *Lithothamnium;* yet apart from the single species of pink *Lithothamnium*, all other organisms were a negligible factor on the upper surface of the atoll-rim.

It is important to observe that among the hundreds of loose boulders scattered over the flat upper surface of the atoll-rim there are a few which still retain their connection with the floor of the flat and project above it as "mushroom" rocks, thus indicating either that the atoll-rim has risen 6 to 8 feet or that sea-level has sunken to this extent. The evidence, however, tends to sustain the view that sea-level has become lowered and not that the atoll-rim has risen, for there is no visible tilting of the rim; and moreover, all the volcanic islands of American Samoa are surrounded by a bench of volcanic rock which is uniformly about 10 feet above present high-tide level and is backed by sea-cliffs, thus suggesting that these islands have remained stationary while sea-level has become lowered.

In this connection it may be of interest to observe that with the exception of Mangareva, which is volcanic, and Makatea, which is elevated coral limestone, all of the atolls of the Paumotus exhibit a bench of old limestone now several feet above present high-tide level. It will also be recalled that David and Sweet, in their







A.—Rose Atoll from about a mile off northwest entrance to the lagoon, showing hill-like contour of grove of Pisonia trees.
B.—Boulders on reef-flat east of Rose Islet.
C.—Boulder on reef-flat west of main entrance to lagoon, showing rows of Archæolithothamnium growing in shallow water of reef flat.

bases. The largest boulder we observed lay loosely upon the reef flat east of Rose Islet and was somewhat tilted by being jammed against another rock. It was 12 feet 5 inches long, 8 feet wide, and 7 feet 6 inches high, and as its specific gravity was 2.3, it apparently weighs 46 tons.

The appearance of these boulders supports the view that the atoll rim was once about 6 to 8 feet higher than at present, and has been cut down to present sea level in recent times; most of the mushroom-rocks having been completely undercut so that they now lie loosely upon the floor of the flat.

It can be seen that the surface of the present reef flat consists chiefly of lithothamnium, a beautiful bright pink variety of which forms a veritable veneer over its surface. Professor Alexander H. Phillips made an analysis of this lithothamnium and found it to contain 74.4 per cent. of calcium carbonate and 19.47 per cent. magnesium carbonate. Also rock from the solid floor of the atoll rim west of the main entrance to the lagoon gave 83.86 per cent. of calcium carbonate and 14.36 per cent. of magnesium carbonate; while a large loose boulder from the same region consisted of 77.28 per cent. of calcium carbonate and 18.3 per cent. of magnesium carbonate. Also, Professor C. B. Lipman found that the largest loose boulder on the reef flat east of Rose Islet contained 79.5 per cent. calcium carbonate and 14.54 per cent. magnesium carbonate. It will be recalled that Högbom found the magnesium carbonate in various species of lithothamnium to range from 3.76 to 13.19 per cent., and Clarke and Wheeler[1] found from 10.93 to 25.17 in 15 species, and thus the Rose Island species seems to be peculiar in possessing a fairly high magnesium content.[2]

It thus appears that the loose boulders lying upon the atoll rim have the same general chemical composition as the solid rock of the rim itself and are remarkable in that they contain a large amount of magnesium. In fact, these boulders are only remnants of the old rim which was once about 6 or 8 feet higher than at present, but has been almost entirely planed down to the lowered level of the present surface of the ocean, leaving only an occasional mushroom-rock on a pedicel as a vestigial remnant of the old rim.

[1] U. S. Geol. Survey, Prof. Paper No. 102, 1917.

[2] See J. W. Judd, Funafuti Report, 1904, 1904, p. 377.

Inspection shows that the solid rock of the atoll rim and also the boulders lying upon it consist chiefly of lithothamnium compacted into a dense mass of chalky whiteness superficially resembling dolomite, and having a specific gravity of about 2.3, thus being higher than that of pure coral limestone, the specific gravity of which would range from 1.85 to 2. A pure dolomite containing 45.65 per cent. of magnesium carbonate should have a specific gravity of about 2.9.

There are a few fossil corals, chiefly *Pocillopora*, imbedded in the rock of the atoll rim and the boulders, but the whole visible rock of the atoll consists so largely of lithothamnium that we may call it a "*lithothamnium atoll*" rather than a "coral atoll."

The flat upper surface of the atoll rim is in most places planed off nearly to low tide level, but it is veneered with a vigorous growth of a beautiful pink lithothamnium which has been provisionally determined by Professor W. A. Setchell as *Porolithon* related to *P. craspedium*. In most places this lithothamnium forms irregular, more or less connected, patches growing on the smooth hard floor of the flat. West of the main entrance to the lagoon it grows in long nearly parallel, flat-topped, over-arching ridges all parallel with the line of the wave fronts of the breakers as they surge over the reef. These ridges are about 6 inches high and from 6 inches to several feet in width, and with channels of similar width between them.

Lithothamnium grows in greater profusion over the reef flat of Rose Atoll than in any other Pacific reef I have seen; but apart from the single species of pink lithothamnium there are remarkably few organisms growing in the shallows of the reef flat. Occasionally we find a pale-olive-green *Porites*, allied to *P. solida*, and there are a few small stocks of *Favites* or *Symphyllia*; but *Acropora* and *Pocillopora*, which are the dominant forms in most breaker-washed reef flats of the Pacific, are practically absent from Rose Atoll, except at the extreme edges of the atoll rim fronting the lagoon on the sea, where a few stunted specimens of these genera occur.

Agreed

I did not find upon the Rose Atoll reef rim a single specimen of branched *Acropora* related to *A. muricata*, nor did I see *Acropora arcuata* or *A. leptocyathus*, which are dominant forms on the sea-washed edges of reefs elsewhere in Samoa.

Holothuria were fairly common, as were also small specimens of the giant clam *Tridacna*, and among echini a few *Cidaris* and black long-spined *Diadema* were seen; and the bright green seaweed *Caulerpa* was here and there found in the troughs between the ridges of lithothamnium; yet apart from the pink lithothamnium all other organisms were a negligible factor on the upper surface of the atoll rim.

It is important to observe that among the hundreds of loose boulders, or "negro heads," scattered over the flat upper surface of the atoll rim there are a few which still retain their connection with the floor and project above it as "mushroom" rocks, thus indicating either that the atoll rim has risen 6 to 8 feet or that sea level has sunken to this extent. The evidence, however, supports the view that sea level has become lowered, and not that the atoll rim has arisen; for there is no visible tilting of the rim, and, moreover, all the volcanic islands of American Samoa are surrounded by a bench of volcanic rock which is uniformly about 10 feet above present high tide level and is backed by volcanic sea cliffs, thus indicating that these islands have remained stationary while sea level has become lowered.

In this connection it may be of interest to observe that with the exception of Mangareva, which is volcanic, and Makatea, which is elevated, coral limestone, all of the atolls of the Paumotus exhibit a bench of old limestone now several feet above present high tide level. It will also be recalled that David and Sweet in their account of the Geology of Funafuti[8] conclude that in this atoll there must have been either a land-elevation or a sea-sinking of at least 6 to 10 feet. In 1913 we observed a sea bench of about 3 feet around both the volcanic and continental islands of Torres Straits.

As there are fossil corals and lithothamnium in the highest parts of the boulders and mushroom-rocks on the rim of Rose Atoll, it appears that the climate was tropical when the sea stood at least 8 feet higher than at present and cut the bench around all the volcanic islands of American Samoa.

[8] Funafuti Report, 1904, p. 84.

In the Funafuti boring the percentage of magnesium in the core ranged from 4 per cent. at a depth of 4 feet to 16 per cent. at 15 and 26 feet, below which it declined to 3 per cent. at a depth of 60 feet. Judd attributes this high percentage of magnesium to the supposed leaching out of calcium by the sea water, but we know that the surface waters of the tropical Pacific are super-saturated in respect to calcium carbonate, and that calcium carbonate is therefore practically insoluble in this surface water. Judd admits that there is much lithothamnium in this upper part of the core of the boring, but unfortunately he made no analysis of the magnesium contents of any lithothamnia at present growing upon the Funafuti reef; and, judging from the conditions at Rose Atoll, I am inclined to believe that the magnesium in this upper part of the Funafuti boring is due solely to its being largely composed of lithothamnium, and not to any leaching out of calcium carbonate. This conclusion is supported also by the fact that in the Funafuti boring between 100 feet and 637 feet in depth the magnesium carbonate was nowhere greater than 5.4 per cent.; yet if calcium leached out in water about 26 feet deep, why did it not leach out at these greater depths where conditions of temperature and carbon dioxide more favorable for solution than on the surface?

Wilkes, 1852, Narrative of the U. S. Exploring Expedition, Vol. 1, p. 155, states:

> Some boulders of vesicular lava were seen on the coral reef (of Rose Atoll) they were from 20 to 200 pounds in weight and were found among blocks of coral conglomerate. (See also Couthouy, 1844, *Boston Journal of Nat. Hist.*, vol. 4, p. 138.)

I was unable to find any volcanic rock upon Rose Atoll, and it seems probable that Wilkes or Couthouy mistook some dark-colored scoreaceous-looking, weather-worn limestone boulders for lava.

Summary.

The visible parts of the rim of Rose Atoll is composed of lithothamnium rather than of coral, and is apparently chiefly constituted of the same pink-colored species of lithothamnium (*Porolithon*) now found growing over the shallows of the reef flat.

The atoll rim was once at least 8 feet higher than at present, and has been cut down to present sea level by the lowered ocean of modern times.

In common with Rose Atoll, all the volcanic islands of American Samoa indicate that sea level was once at least 8 feet higher than at present.

The rock of the atoll rim contains from about 14 to 19 per cent. of magnesium carbonate, due to its being composed largely of lithothamnium, but not due to any appreciable dolomitization of the limestone after its formation.

As fossil corals and lithothamnium are found in the highest parts of the remnants of the old atoll rim, it appears that the climate of American Samoa was tropical at the time when the rim stood at least 8 feet higher than at present.

TOBIT'S BLINDNESS AND SARA'S HYSTERIA.

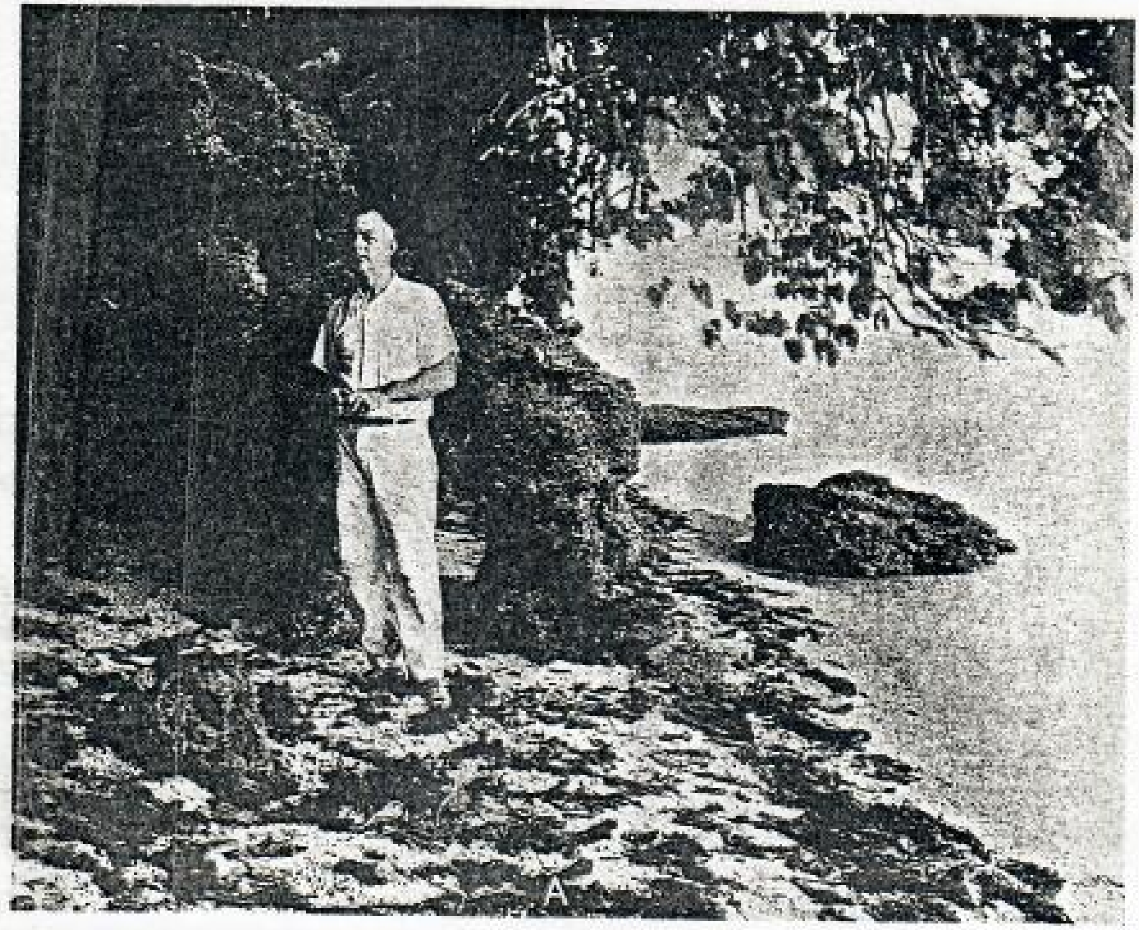
By PAUL HAUPT.

(*Read April 23, 1921.*)

In the apocryphal book of Tobit, which seems to have b
written by a Persian Jew for the encouragement of his coreligion
in Palestine at the beginning of the Maccabean rebelli bout
167, we read that Tobit's son, Tobias, cured his father's blind
with the gall of a fish he had caught in the Tigris, while the l
and the heart of that fish, burned on embers of incense, expelled
demon Asmodeus who had tormented Tobias's bride, Sara,
years. This demoniacal possession may have been hystero-epile
hysterics and epileptics were supposed to be possessed by dem
(*cf.* Mark 9, 17–26).

The "New Standard Dictionary" says that in Lesage's oper
"Le Diable Boiteux" Asmodeus is the name of the demon
conducts Don Cleofas in his nightly adventures. In this sati
novel, which appeared in 1707, Asmodeus is identified with
capricious god of sexual passion, Cupid, and his lameness is sai
be due to the fact that he had an encounter in France with
demon of selfishness, Pillardoc. The fight was fought in the a
regions, and Asmodeus was hurled to earth. *Cupido* pers
fication of desire, passion, concupiscence which is symbolized in
Biblical story of the Fall of Man by the Serpent (PAPS 50, 5

[1] AAJ = Haupt, "The Aryan Ancestry of Jesus" (Chicago, 1909) = *Open Court*, vol. 23, pp. 193–209.—AJP = *American Journal of Philolo* AJSL = *American Journal of Semitic Languages*.—ASKT = Haupt, kadische und Sumerische Keilschrifttexte."—BA = "Beiträge zur As logie."—AV = Authorized Version.—BK = Brockhaus's "Konversations- kon, Neue revidierte Jubiläums-Ausgabe."—BL = Haupt, "Biblische L lieder" (1907).—BT = Lazarus Goldschmidt, "Der babylonische Talmu CD = Century Dictionary.—DB = Hastings, "Dictionary of the Bible." = Cheyne-Black, "Encyclopædia Biblica."—EBR = "Encyclopædia B nica," eleventh edition.—ET = *Expository Ti*...—GJV = Schürer, schichte des jüdischen Volkes."—JAOS = *Journal of the American O*



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A.—Coquina ledge on southeast side of Rose Islet.
B.—Booby with two young, one much older than the other, resting on the breccia near edge of the Pisonia grove of Rose Islet.

SUMMARY.

The visible part of the rim of Rose Atoll is composed of *Lithothamnium* rather than of coral, and is chiefly constituted of the same pink-colored species of *Lithothamnium* (*Porolithon*) now found growing over the shallows of the reef-flat.

The atoll-rim was once at least 8 feet higher than the present sea-level, and has been largely planed down to present sea-level by the (possibly lowered) ocean of modern times.

In common with Rose Atoll, all the volcanic islands of American Samoa indicate that sea-level was at least 8 feet higher than at present.

The rock of the atoll-rim contains from about 14 to 19 per cent of magnesium carbonate, due to its being composed largely of *Lithothamnium*, but not due to any appreciable dolomitization of the limestone after its formation.

As fossil corals and *Lithothamnium* are found in the highest parts of the remnants of the old Atoll-rim, it appears that the climate of American Samoa was tropical at the time when the sea may have stood at least 10 feet higher than at present.

Need p. 74+

Manua
p 10
Rose
"unimportant"
p 21

HISTORY OF SAMOA

BY

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CHAPTER I.

INTRODUCTORY DESCRIPTION.

STRUNG loosely out, west by north along and across the parallel of 14° south latitude, and between 168° and 173° west longitude, there lies in the Western Pacific Ocean a volcanic chain of four main islands and a number of lesser subjacent islets. The chain, or group, is now collectively known by its native name, Samoa.

Westernmost sits Savaii, the largest and most lofty island of the four, fifty miles long and twenty-five across at its broadest, in shape a rough rhomboid humping itself to a great central height. On Savaii has been considerable recent and much remote volcanic activity, so that the greater part of the surface of this island is unsuited for habitation. And though larger it is neither so fertile nor so populous as Upolu, next east of it and the principal island of the group. Upolu is a high ridge forty-five miles long and at its greatest width some thirteen miles, on the northern side of which, about midway of its length, is Apia, the natural capital of all Samoa. These two, Savaii and Upolu, and the smaller islands adjoining, notably the inhabited islets of Manono and Apolima lying between them, comprise the territory of German or Western Samoa, now in British military occupation.

Nearly forty miles to the eastward of Upolu and a little south lies American Samoa, the first and main island of which is Tutuila, stretching east and west eighteen miles. Here on its southern side is Pago Pago, the sole real harbour of the group which the United States Government has improved by the establishment of a naval station. Further east is the little group known as Manu'a, comprising the islands of Tau, Ofu and Olosega, and, still further east and again a little south, the small uninhabited and unimportant Rose Island.

All the islands are of volcanic origin and formation, with the exception of Rose Island which is a coral atoll, and all the main islands are high. In Upolu mountains rise to three thousand feet, in Savaii to over four thousand feet. Dark forests richly clothe the ridges to their summits, for there is a plentiful rainfall throughout the group; the more lively green of cocoanut cultivation as abundantly covers the lower planes. The slopes of all are thus luxuriantly wooded, except those portions of Savaii where more recent lava flows

have scarred long and broad avenues to the sea. Seaward, many parts of the islands, and especially of Upolu, are surrounded by coral reefs enclosing shallow lagoons that form good fishing grounds for the natives and safe and pleasant waterways for their canoes and boats of passage.

Within the group have dwelt, for so long that their foreign origin was one hundred years ago quite unknown to them, a handsome branch of the pleasant peoples of Eastern and Central Polynesia. Of light reddish-brown colour, with straight hair and pleasing features, well-framed and stately, the Samoans have for the main part yet preserved the native beauty and amiability of their race. To those who have dwelt in their midst they appear essentially material, yet fond of extending as of receiving courtesy and even flattery; childlike, but by no means devoid of deceit; hospitable indeed, but supplicatory, for they are polite communists; free, yet rarely viciously immoral. If admiration of them is tinged with a certain disappointment, affection surely remains. The whole of the native population now lives on or near the coast; the mountains, save where plantations mark the lower slopes, are all in their forest vestments. Roads or tracks follow the shore line of the three larger islands. In Upolu, and in parts of Savaii, the wayfarer may pass through village after village, often with but little break between, and there will be unfolded before him brown-thatch, mushroom-shaped houses bowered in banana groves and clumps of bread-fruit, screw-pine and towering cocoanut palm, with many a dainty glimpse beyond of reef and sea. Except in the hottest hours of the day the natives are abroad in pleasant, sensible discharge of their daily duties, and from each busy group there is always some gay remark, some kindly invitation or greeting, for the passer-by. Nearly every village now has, close to shore and track, its washing and bathing pools, stone-lined, where cool hill-springs gurgle up—and these are lively centres of gossip and flirtation.

The latitude of the group postulates tropical climes and tropical warmth. Yet the heat of Samoa is not equatorial and the air, while generally relaxing and moisture-laden, is tempered by high lands and by fairly constant breezes from the surrounding seas. Hurricanes, the scourge of much of the Pacific, are here unknown, though severe northerly gales are to be expected, generally without disappointment, in the late months of the wet and boisterous summer season. Few who are of European descent will prefer the climate of Samoa above that of the more temperate zones; there is, it

may be said, little natural comfort for the normal European who must take constant precaution against small tropical sickness and inconvenience, particularly during the first half-year of residence and always and more particularly where his women-folk and children are concerned; yet the climate, for low latitudes, is not unhealthy and malaria and severer fevers are unknown. Venemous snakes do not exist; the centipede and the scorpion are there, but one hardly ever hears of their bites; and the chief troubler of mankind is the persistent mosquito with his train of filarial disorders. Agricultural work is impossible for whites, prolonged sedentary employment injurious. Clearly the islands, small, mountainous, tropical, are unsuited for extensive European settlement. And yet it is a noticeable feature that Europeans who have made lengthy stay rarely retire from the group, it is thought from choice as well as from force of circumstances. The islands are said to take hold of a man, softly and so that he does not care. Certain it is that the climate forbids to Europeans for more than a few years the continued exercise and enjoyment of mental and physical vigour. Excessive use of alcohol, mental or physical strain as well as mental or physical neglect, but hasten the process, and, if persisted in, are provocative of neurasthenia and a general weakening of the powers. It becomes in the end easier to talk about things than to do them—to talk lightly and with repeated phrase, even to the extent of deceiving oneself; and the European is then no longer fitted for the life he has come from—but he will have broken himself into the islands....

The normal population of Western Samoa consists approximately of 500 whites, 1,000 half and other castes, and 36,000 natives; that of Eastern or American Samoa of some 180 whites, 300 half and other castes, and 7,500 natives. The fertile portions of the group are largely under cultivation and are capable in places of extension and of supporting a considerably larger native population. As is the case in many other South Sea groups native cultivations are mostly of cocoanut, but also and extensively of banana, breadfruit, yam and taro; the European plantations consist in the main of cocoanut, cocoa and rubber. The Samoan in his own surroundings makes an indifferent hired man, and in consequence indentured Chinese and Melanesian plantation labour has been introduced into Upolu and to a small extent on Savaii. In August 1914 there were some 2,200 Chinese labourers, mostly on Upolu. The number has been reduced by repatriations to 1520. The

Melanesians number 600, mostly Solomon Islanders, and are employed upon the extensive plantations of the Deutsche Handels und Plantagen Gesellschaft of Hamburg and in lighterage work in the roadstead of Apia.

Except for the naval station at Pago Pago the group is easily self-supporting. The total annual trade, imports and exports, of the whole group rarely exceeds in value half a million pounds sterling, and ninety per cent. of this comes from Western Samoa.

The capital, Apia, is a straggling yet busy little port and centre of trade and government, built along the shore road of a wide, reef-bound bay that affords a good anchorage in the steady trade winds, but is a danger spot for ships during northerly summer gales. The future trade of the port appears to be in the hands of the half-castes, among whom are now numbered some of the leading merchants of the town. The name, Apia, is that of a native village forming but a small part of a town which carries a total and varied population of some thousands and embraces many villages. Trading stores—for there is still no specialisation in shops—and government buildings flank the beach; behind are widespread suburbs and native settlements. Minor industries are beginning to make their appearance. Outside Apia the country and its people rest quietly in a golden warmth and sunshine, and the outer trader lazes his days away. "The people of Apia" said an old chief of Upolu once to the writer "are restless and wicked." That is as may be. The steamer passenger who sees from the deck of his vessel what appears to be a drowsy little South Sea town will on landing behold much activity in motor and horse traffic and no little coming and going of many nationalities.

This then is the present setting of the stage on which the events of the chronicle that follows have taken place. Not so bijou as Tonga, far less important than Fiji, Samoa forms a small entity, self-existing yet having much in common with both, as they have with all the tropical islands of the Pacific. Much that is preposterous has been said and written of Samoa, as of other spots where life may differ somewhat from the usual standards. It can at once be admitted, in truth and without any obloquy, that it is not a great place, that it probably never will be. But the little country and its kindly native people, as easy as any in the world to control, deserve in the future a fuller measure of sympathetic understanding and of quiet equitable government than was, as the diligent reader may discover, for long their portion in the past.

CHAPTER II.

EARLY HISTORY.

(Before 1830)

PRIOR to 1830, in which year agents of the London Missionary Society established a mission, very little of Samoa was known to the civilised world. The posts which mark that olden time have nearly all gone; the modern ones that have been reared in their place are not always of undoubted authority. It has been said that the present Polynesian inhabitants are the successors of an ancient fair-skinned megalithic people. More writers than one have recorded that the island of Upolu, probably though by no means certainly the oldest formation of the group, contains a relic of megalithic man in the Fale-o-le-fe'e, or House of the Cuttlefish, which one learned ethnologist has described as "an ellipse of giant stone columns, no mean rival of our Stonehenge." At the risk of a diversion the truth concerning this travellers' tale must be set down. The interesting relic is situate some eight miles inland of Apia, on a little flat in the upper waters of one of the larger streams of the island. There is, at the upper end of the flat, a basaltic cliff, thirty feet or so high, from which has dropped a number of small stone columns. And of these some have been, very imperfectly, set round in an ellipse—the shape of the ordinary native house—a few yards below. None of the stones bear any evidence of dressing. None are deep set in the ground. None are too large or too heavy for one man to lift. The writer has sacrilegiously tried them all, after lunch be it said, and dropped them back into place again. A few stones have been laid horizontally to form a square—the chair of the fe'e. There are pretty native stories concerning the stones, in age anything from eighty years up, but these must be gathered elsewhere. The point is that there is nothing to indicate any pre-Polynesian antiquity, and that there was required no colossal effort in the building. The relic (if a theory is worth anything) may be the posts of a fale tele or large house built in a spot chosen for defence or as a retreat in war. There are native stories to support this view. It may have been originally roofed with wood and thatch which long ago have rotted into the warm damp bush. Or, as not seldom happens to many undertakings of these carefree people, it may have been always incom-

plete. With the relation of one further truth this digression is ended. As the writer smoked, the two sweet-natured Samoan giants who had accompanied him on his pilgrimage slashed away with their long knives the undergrowth from the site of the relic, and then—they deliberately grunted into place another two stones for the house of their romantic fish! Had reincarnation brought auld Edie Ochiltree and Bill Stumps together in this outer Eden?

There is, it may be conceded, nothing known in Samoa to indicate a race prior to its present native Polynesians. That they however have long resided in the group is clear. They have no suggestion in their legends, as the Maoris have, of migration from other lands. To them Samoa is the earth. The god Tagaloa, who dwelt in space and made the Heavens, and of whom it is not known how or whence he came, had a grandson called Lu. On one occasion Tagaloa, being annoyed with the boy, seized and beat him with the handle of the great god's fly-switch. Lu escaped, ran down to Earth, and named it Samoa.

From their appearance, from their undoubted relationship to other Polynesian peoples, it is probable that the Samoans are of an original Caucasian stock with which through the ages many strains, almost certainly including the malayoid and not entirely excluding the negrito, have combined to produce a distinctive people. The question of the origin of the Polynesian has been much discussed by ethnologists, and where they differ and local evidence is, and apparently has long been, non-existent, the modern historian may with justification plead a great uncertainty. Probably several migrations from Southern Asia found their way to Polynesia. Professor Macmillan Brown traces, following Mr. S. Percy Smith, a last great migration, possibly two or three centuries before the christian era, from the coast south of the Punjaub, through part of the present Dutch East Indies, south of Celebes, along the north-east coast of New Guinea, and through the Solomon Islands, the New Hebrides and the Fiji group, to Tonga or Samoa. This, says Professor Brown, was "undoubtedly their route"; their final centre of dispersion in Polynesia was probably Samoa. It should be noted, *per contra*, that Dr. A. K. Newman is often very much of a different opinion.

A most interesting, practical, and experienced paper on this subject—the ethnology of the Pacific—was presented by the Revd. S. J. Whitmee F.R.G.S. to the Philosophical Society of Great Britain in 1879.

That Samoa was the cradle of much Polynesian settlement seems highly probable. It is quite likely that many hundreds of years ago Samoa produced masterful seafarers who scoured the wide Pacific and established the people of many islands. The Rev. J. B. Stair has collected interesting native records of such voyages. Ease of living, a softening climate, abundance in their own fair lands seem gradually to have changed the race to a domestic people. From being raiders they became the raided. Fijian conquerors are said to have established themselves in Manu'a in the dawn of known Samoan history, and to have received tribute from all Samoa. There are many Samoan legends which have as heroes and heroines princes and princesses of Fiji—legends which show ancient knowledge of the Fijian people and customs and indicate intercourse between Samoa and Fiji. Later the Tongans, probably after many raids, established themselves on Savaii, crossed to Upolu, and were eventually beaten from the group by the first Malietoa who arranged between Tonga and Samoa a treaty of peace which has been continuously observed by over twenty generations of the Malietoa family. Traces of these occupations are doubtless seen in the curling hair and darker skins of some of the people to-day.

Such tradition as has yet been preserved to the Samoans groups itself naturally under the three heads of war, national custom and legend, and family descent. Matters of family descent were carefully transmitted from father to son through many generations—the favoured place being the village green on the white nights of the increscent moon—and pedigrees are still given in the establishment of family names with definite assurance and with the agreement of opponents; national customs have greatly survived, but with modification; their legends, quietly slipping from the memory of the people, have been extensively recorded by many earlier settlers, and especially by missionaries. All these matters are exceedingly interesting, but are somewhat uncertain and can have place in this history only where it is necessary in individual cases to make reference to them. Of war more must be said. Warfare has ever been a recognised occupation of the younger men. The island of Upolu, from the earliest times of which we have information until quite recently, seems rarely to have been free from hostilities more or less extensive. It is certain that within the past two centuries Upolu has carried a population much in excess of its present numbers, for the traces of wider habitation are yet in many of its forests.

In 1830, and for years before, war made hideous ravages. The causes were often trivial, the methods a curious admixture of childish regard for ceremony and of craft, of careless generosity and of cruelty. Clubs and spears of various patterns and slings were the usual weapons. Both land and sea forces were employed, either separately or in conjunction, and sea-fights seem to have been at times as destructive of life as were battlefields ashore. It is not possible to give chronological order to the traditions of these internecine wars. The pioneer missionary John Williams, in 1832, found that the people of Manono had a record kept by means of collected stones of one hundred and ninety seven battles. And it was but two years before, in August of 1830, that Williams, landing on Savaii from his schooner *Messenger of Peace*, saw across the strait in Upolu "the mountains enveloped in flames and smoke" and on enquiring the cause was informed "that a battle had been fought that very morning and that the flames which we saw were consuming the houses, the plantations and the bodies of women and children and infirm people" who had fallen into the hands of the conquerors.

There is no record of cannibalism ever having been a prevailing custom in Samoa as was so taxes, levied principally for the payment of native officials. The sum—commonly known as the tax surplus—remaining after payment of officials and cost of handling the crop is refunded to the natives at the end of the season. On the whole of the balance of the crop the natives are advanced an amount fixed by the government, and the excess of this is also paid them at the end of the season. The government determines the amount of taxation each of the three native districts shall pay, but the incidence of the tax and its collection are fixed from the district itself.

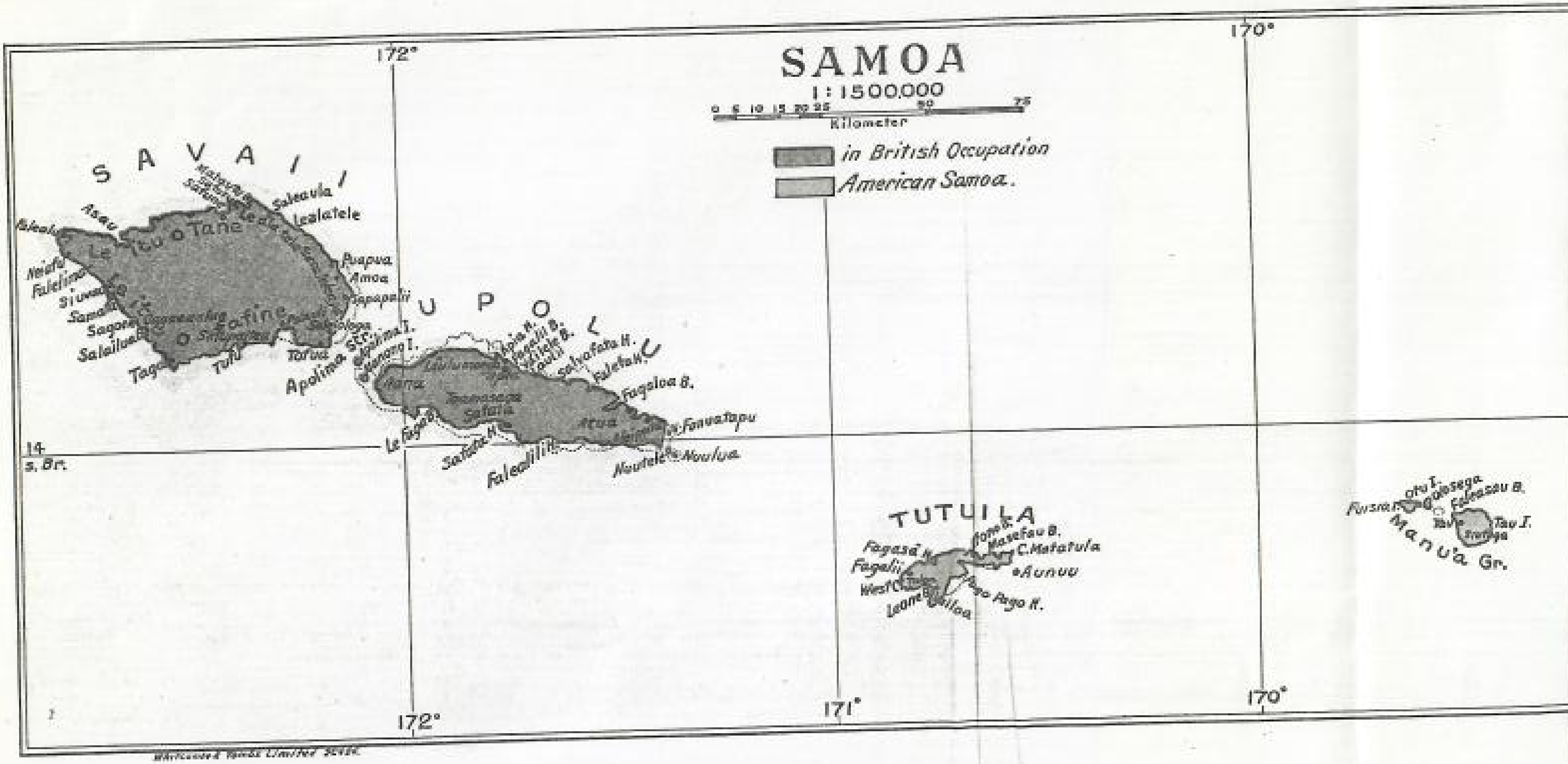
Under this system the quality and price of the copra exported has been vastly improved, and in the first ten years of American occupation it had increased in quantity ninefold.

The manufacture, importation without permit, and sale to natives of intoxicants has been forbidden unde heavy penalty. Alienation of native land is allowed only by permitted leases up to forty years. The naval government has undertaken the entire medical work of the territory, for there are no civil practitioners in American Samoa. A well-equipped native hospital has been built just outside the station with a dispensary erected by the natives and a drug store. Branch dispensaries have been opened at Leone and Manu'a. Every effort

is made to endeavour to teach the Samoans care of the sick and the laws of hygiene.

In 1914 a Government Bank was established, the deposits of which are guaranteed by the island government. This has proved a great benefit to the residents.

By such means the accustomed life of the natives and their self-government were, so far as modern conditions allow, preserved. The story of the American occupation is entirely free from any occurrence of disturbance or native trouble. Indeed in the lives of the Samoans during this period one incident alone calls for record. In January 1915 a violent storm devastated the little Manu'a group, wrecking nearly all the houses on the islands and destroying native plantations and cultivations. It was estimated that sixty-five per cent. of the cocoanut palms were blown down. The group has since largely recovered, but no copra has yet been exported. Relief was necessary and it was promptly and generously given. In addition to local assistance Congress in March granted an appropriation of ten thousand dollars in aid of the sufferers, and the Red Cross Society of the United States two thousand dollars towards the purchase of supplies. These grants went far to alleviate the suffering which without them must have followed the event.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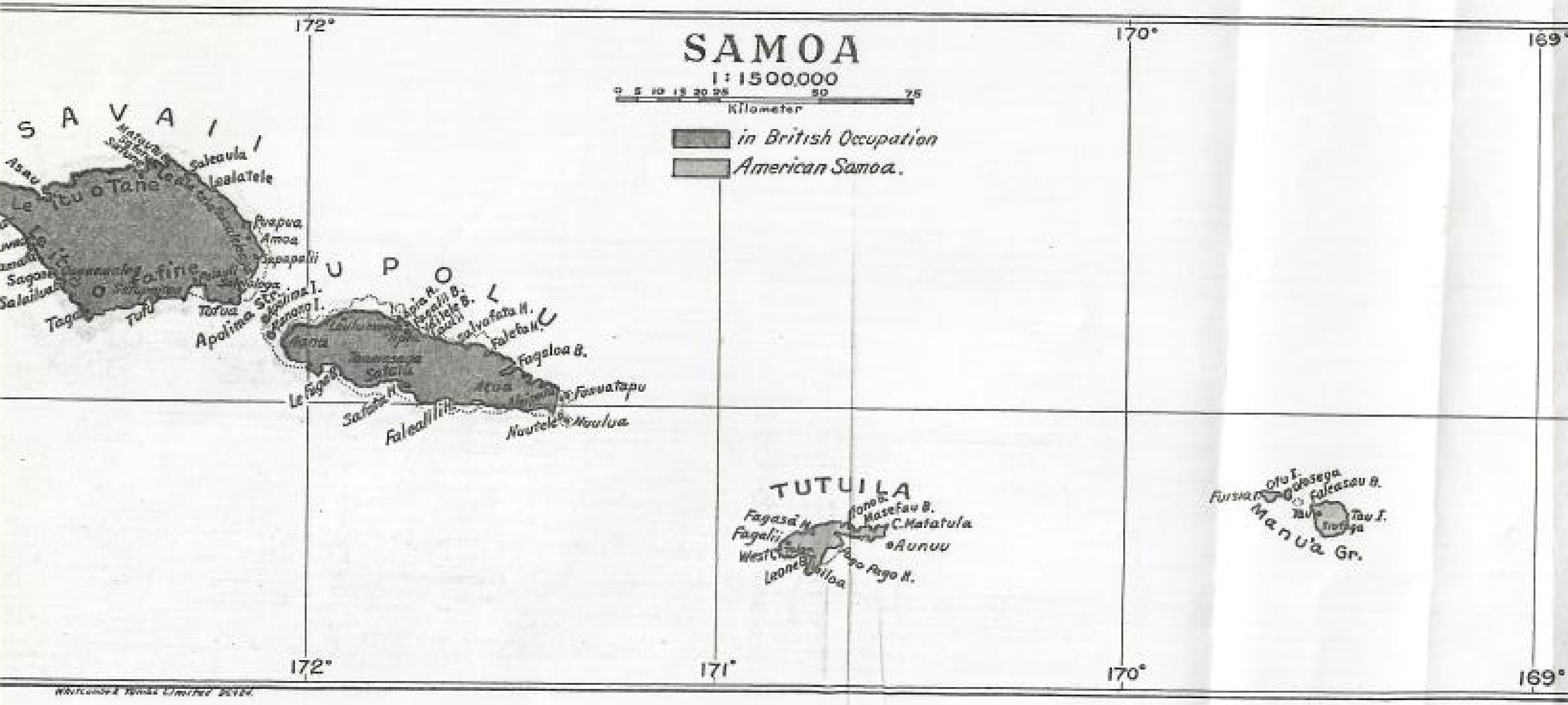
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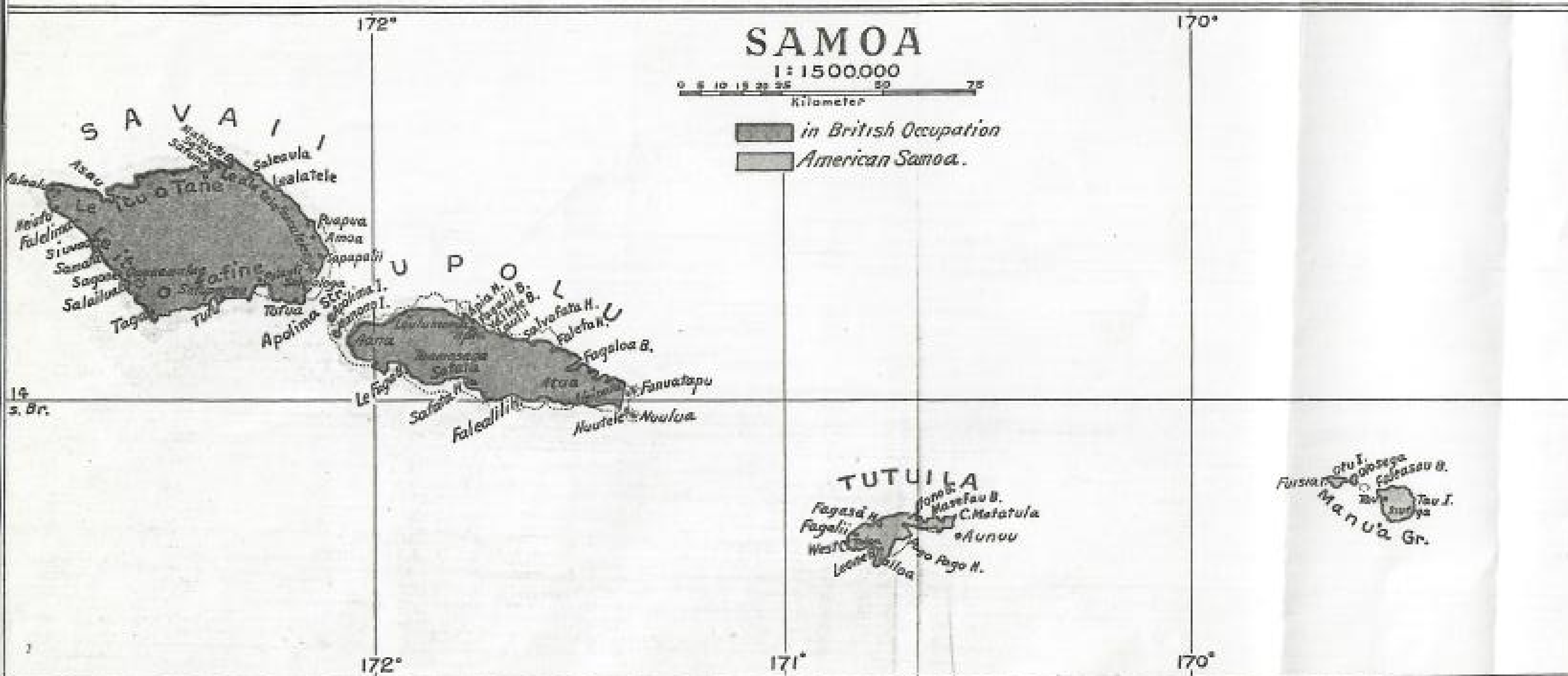

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Luisa and Emma.

"Turtle & Shark" legend

Aletta Lewis

THEY CALL THEM SAVAGES

1938

262pp

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out of one's eyes and enabled one to see as clearly in water as in air. When I swam about amongst the fish I felt as intimate with them as Nelson with the pigeons in Trafalgar Square; I almost felt as though I were one of them.

By nature I am lethargic. My instincts all try to lead me towards a static condition. Not only do I hate getting up in the morning, but I am just as loath to go to bed at night. I never start dressing for a party without cursing myself for having accepted the invitation; and then I wish it didn't end so early. On the other hand, my mind conflicts with my instincts. I know perfectly well that it will be quite delicious to be curled up in bed, and that I shall thoroughly enjoy my party when I get there. Before long my mind was arguing with my instinct.

He said: 'Look here, you lazy thing, you've had quite enough of Pago Pago. It's time you stirred yourself.'

My instinct cringed: 'It's very comfortable here,' she said, 'and look what a lot of painting I am doing.'

'Nonsense,' said that aggressive old mind, 'what's the use of painting people you don't understand?'

'I know Luisa quite well now. After all, I've only been here a fortnight and I've got to find my feet.'

My mind was firm. He ticked off her points one by one, and made them sound very unconvincing. 'To begin with,' he said, 'you know nothing about Luisa. You don't know any of her family and you don't even know how she lives when she is not posing in front of you like a lay figure in the position you stuck her in. To go on with, you've been here nearly three weeks. To-morrow's steamer day, don't forget (and while we are on the subject, have you got your letters written?). As for your feet'—this was said very grimly—'you'll find them all right before I've done with you.'

My instinct was all a-tremble by this time. 'How you do go on at me,' she whined. 'You had better do something about it if you feel like that. I think you're most tiresome—just when I have settled down comfortably and all. Anyway, this sort of thing isn't my job. If I did anything you'd only say it was the wrong thing to do, or else I'd done it badly. Speak to

the Governor yourself if you want to, but leave me out of it.'

I did speak to the Governor and to Mrs. Graham several times—both separately and together.

He said: 'You can't leave us until we have found a suitable place for you to go to. Don't worry—we're in no hurry to have you go.'

She said: 'How come? Aren't you happy with us? Don't go yet. We do so enjoy our arguments with you. Besides, next week we are all going to Aunu'u to a feast, and I've got an idea that the Logans would put you up for a while. They're almost sure to be there and we could talk to them then. He's chief pharmacist's mate at Amouli.'

It had been the same before.

'Next week,' they had said, 'there will be a lot of Samoans come to Pago Pago for Flag Raising Day. We will be able to fix you then.'

But Flag Raising Day had come and gone with nothing settled. They had promised that it would be a good opportunity to observe Samoan types. And so it was; but it did not provide a Samoan home.

Nevertheless I would not have missed that day for the world. Chiefs from all over the islands had come, each with a party to compete in all sorts of contests. They had canoe races; races in climbing coco-nut trees; races in plaiting baskets out of coco-nut leaves; races in husking a coco-nut, breaking the shell in half, and extracting the meat; dancing competitions; singing competitions; and, to wind up the day, there were paddling and rowing races in the harbour. It was all intensely interesting and impressive. I had been introduced to His Excellency Tufele, Governor of Manua, a most important chief, who had suggested that I should go and stay in his household at a later date. I intended to accept his invitation if it proved possible, but as some sixty miles of sea lay between Tutuila and the Manua group of islands I did not then know how it was going to be done.

'Now,' Mrs. Graham said, 'we will try the Logans.'

Meanwhile I had a little string of my own to pull ; and when they proposed one afternoon that we should drive out to the village of Vaitogi, there was my opportunity.

Dr. Mead had suggested that I should go to Vaitogi where the chief's daughter was her friend. So here was a chance to look her up.

It was a lovely drive round the coast of the island westwards. Sometimes we drove across sandy beaches, each with its little group of houses, its bath and its lavatory ; and sometimes, when the land jutted out into the sea in a rocky point, our route was a narrow track through luscious vegetation.

Vaitogi was an open, spacious village. As soon as we pulled up, curious natives made a ring round the car.

Mrs. Graham said : 'We must see the shark and the turtle.'

'These Samoans will show us,' said the Governor.

Half a dozen men conducted us to a high promontory of black rock. Huge waves were incessantly breaking at its foot, tossing great white clouds of spume high up into the air and then receding, leaving a deep clear sea below. The men chanted a weird song, sounding somehow supplicatory. Now and again they would extend their arms over the water, their fingers undulating, and cry '*La-la-lei, la-la-lei, la-la-lei.*' We would join in when they did that.

Suddenly—'There's the turtle,' whispered Mrs. Graham, gripping my arm. 'There's another,' said I, excitedly pointing at it, and nearly falling in.

'You mustn't point,' hissed the Governor. 'It's a native tabu.'

In the end we had seen seven turtles and one shark in the deep water between the waves. We were all drenched with spray by that time and bracingly excited.

'What is it all about ?' I asked.

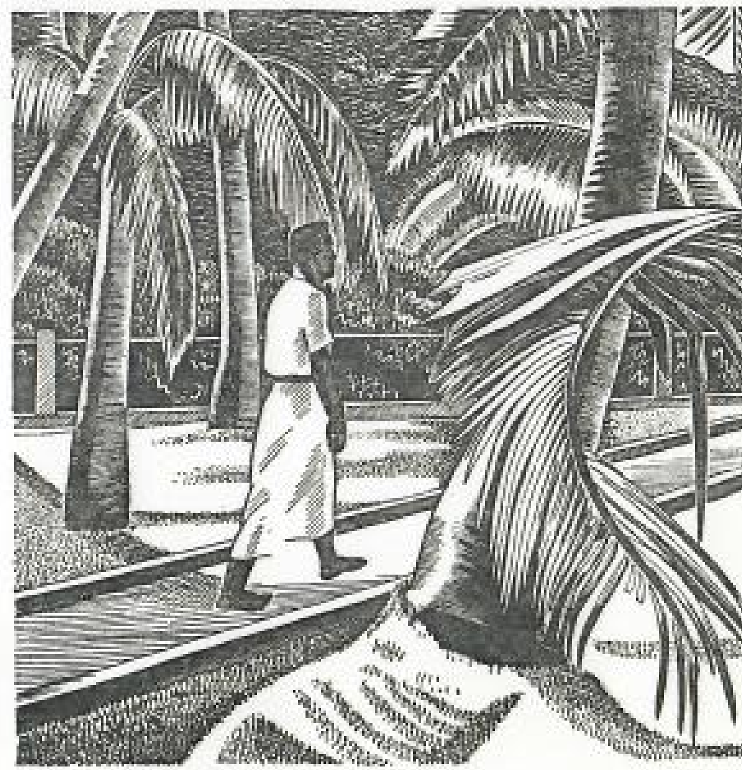
'There was once a prince in Vaitogi,' they began. 'He was a fine young man ; but he fell in love with a girl of low rank. He even wanted to marry her, but his father would not have it. In despair the prince and the girl came to these rocks and threw themselves into the sea, whereupon he was changed into a shark

and she into a turtle. Whenever the people come and sing their song to them they come in to listen.'

I sighed. 'It's a lovely story ; but I would like to know where the extra six turtles come in.'

'We don't mention them,' said the Governor darkly.

I inquired for Dr. Mead's friend, but found she was not there any more. They told me she had married an American seaman and was living near the naval station. It was very disappointing. I didn't want to meet her so much after that, and I never bothered to look her up.



developed by the seaward thrust of the continental crust-block, of which Australia and New Zealand and their island satellites are the emerged parts. In any case the similarity of these troughs to the foredeeps farther north leads to the inference that the formation of the southern troughs was genetically associated with the continental border. If the local subsidence responsible for the Tonga Deep was continued into modern times, the Samoan ridge may be presumed to have been carried down with it. Local sinking of this kind is obviously not to be expected in the Pacific archipelagoes, far from any continent.

The stressed condition of the earth's crust, in and around the Tonga Deep, is shown by the high seismicity of the region. The older stone buildings of Samoa, such as the church at Asili and the Missionary Society headquarters at Leone, are badly cracked by earthquake shocks. For many years the seismographs of the Apia Observatory have recorded such vibrations. As yet we lack evidence as to whether the crustal slips represent further deepening of the Tonga trough or represent readjustments of the crust in consequence of deformation completed during the Tertiary orogenic revolution.

PREVIOUS WORK ON THE GEOLOGY AND GEOGRAPHY OF AMERICAN SAMOA.

In the *Abhandlungen der bayerischen Akademie der Wissenschaften* (math. phys. Classe, Band 24, 1907, pp. 509–541), I. Friedlaender has given the best general account of Samoan geology yet published. The petrography of his collections is described by M. Weber on pages 289–310 of the same volume. Friedlaender appended a bibliography, practically complete for the date of writing. Later publications, by A. G. Mayor, R. T. Chamberlin, and the writer, appear in the Year Books and special publications of the Carnegie Institution of Washington.[1]

The United States Navy Department has prepared excellent contour-maps of Tutuila and the Manua subgroup on the scale of 1 : 40,000. All of these appear on Chart No. 2924, issued by the Hydrographic Office at Washington. The accompanying Plate A, a reduced copy of the chart, also shows the many soundings made around Tutuila out to the depth of 100 fathoms. Owing to the kindness of Dr. G. W. Littlehales, hydrographer of the department, the writer was able to use these valuable maps in manuscript form. The geological map of Tutuila (Plate B) is based on one of these manuscripts.

During his stay in Samoa, Friedlaender made a special search for continental rocks such as granite, gneiss, schists, and quartzite. Apart from ship's ballast and imported stone implements, he found none. The experience of the present writer and of his colleagues has been the same. Except for thin veneers and intercalations of limestone, the island group seems to be wholly volcanic. Friedlaender notes the possibility that the volcanoes of the Hawaiian and Samoan chains may rest on geanticlines, analogous to that which is known to form the foundation of the Fijian volcanoes. There is no direct evidence favoring this hypothesis; it seems as likely

[1] See also *The Geology of Western Samoa*, by J. A. Thomson, New Zealand Journal of Science and Technology, vol. 4, 1921, pp. 49–66.

that the Samoan ridge is entirely due to volcanic extravasation. The relation of the Samoan chain to the Tonga Deep, above suggested, is not opposed to the second explanation of the great ridge.

Friedlaender described analogies between the Hawaiian and Samoan chains. At the eastern extremity of the northern chain is its largest island, Hawaii, with two vents active in recent years; at the opposite end is an atoll. At the western extremity of the Samoan chain is its largest island, Savaii (the name being the Samoan equivalent of the word "Hawaii"), with two vents which were active since 1900; at the opposite end of the chain is Rose Island, an atoll. The progress of erosion in the different Hawaiian islands shows a rather systematic increase of age for the island surfaces, in order from east to west. Here the analogy is more remote, for the lavas of Tau appear almost as fresh and undamaged by erosion as the staple lavas of Savaii. Between Tau and Olosega islands is the site of a submarine eruption, in 1866, again showing that the eastern half of the Samoan chain has witnessed volcanic discharge more recently than that registered at even the youngest vents of Tutuila, in the middle part of the chain. Tutuila is the most deeply eroded of all these islands, unless Rose atoll represents the case of the complete planation of a volcano formerly standing well above sea-level. Eastern Upolu is in part dissected, but on the whole the erosional relief of Upolu is at a stage intermediate between the erosional reliefs of Tutuila and Savaii.

Friedlaender (p. 533) sketched the geology of the different islands, and emphasized his observations on the eruption that took place at Matavanu, Savaii, at the time of his visit. In regard to the three largest islands he stated:

> The east-west directions of the mountain summits and the north-south directions of the igneous dikes are clearly apparent in each case. All three islands agree in showing that a principal crater is not present, that the western part of each island is the younger, and that at the eastern extremity of each island, a tuff crater, younger than the principal island and apparently of submarine origin, has been developed.

GEOLOGY OF TUTUILA AND AUNUU ISLANDS.

CONDITIONS OF FIELD WORK.

The strongly dissected surface of Tutuila is covered with a dense tropical jungle, except along the shores and in the comparatively small inland areas devoted to cocoanut, taro, and breadfruit plantations. (Plate 1.) Were it not for the numerous native trails, exploration of the interior would mean slow and tedious work. Most of the surface rock is deeply lateritized, good outcrops usually appearing only in stream courses or along the steep cliffs. Structural and petrographical studies are made much more satisfactorily along the shore, where outcrops of strong rock are nearly continuous; here, too, the trails are the best in the island. Thus, in spite of the jungle, 8 weeks sufficed for a fairly good reconnaissance of Tutuila.

It may be added, for the benefit of future explorers, that shelter and native food can be secured in almost every bay, the extraordinarily hospitable natives having occupied the shore wherever there is the least semblance of a harbor for their little fleets of outrigger canoes. White man's supplies can be had at Pago Pago and at Leone, the two best centers for field work.

erosion, would be later events in the development of the east-west section of Pago Pago Bay.

Further, it is possible that the drainage was initially concentrated in depressions caused by moderate explosions along the axis of the bay. In that way the relatively great size of this drowned valley could be understood, even on the supposition of an almost purely erosional origin. The problem is, then, only partly solved. The safest judgment seems to be that the valley occupied by Pago Pago Bay is essentially an erosional feature, engraved in a structurally complex mass of rocks, including the Matafao breccia. The bay itself is most simply explained as due to the drowning of the valley when Tutuila subsided; a small part of its depth may be due to stream erosion during one or more glacial stages of the Pleistocene, when the base-level was specially low.

GEOLOGICAL HISTORY OF TUTUILA AND AUNUU ISLANDS.

From the alignment of the Samoan Islands and their much more numerous volcanic vents, the ultimate cause of the basaltic eruptions is probably to be traced to a fissure or belt of fissures traversing the suboceanic crust and at least 300 km. in length. The reasonableness of this assumption appears only after an inductive study of the world's volcanic chains, and will not be discussed here. The remarkable degree of parallelism among the volcanic chains of the mid-Pacific suggests a common condition for the development of their respective belts of fissuring. This generalization represents a fundamental problem as yet unsolved. Groll's and other modern maps of the Pacific isobaths show a large number of northwest-southeast wrinkles on the Pacific floor, with amplitudes of from 1,000 to 1,200 or more meters. Are these warps due to stresses set up in the sub-Pacific crust by ancient torsion of the earth? The subsequent adjustments of the crust toward a geoidal figure might be expected to produce local tensions along northwest-southeast lines.

A combination of moderate upwarping and volcanic eruption has possibly been responsible for the initiation of the Samoan and other ridges of the Pacific floor, though the steepness of the upper slopes points to a volcanic origin for the higher part, and the greater part of the volume of each ridge. The oldest exposed lavas of Tutuila are probably as old as the Pliocene; the youngest are clearly Recent.

Eruption of dominantly basaltic lavas is the first actually demonstrated stage in the evolution of Samoa. The oldest visible lavas of Tutuila, however, include not only the primitive basalt but also the interbedded products of its differentiation—mafic basalts, trachydoleritic types, and possibly andesitic basalts. The latter rocks were due to local and temporary changes of magma, and the true basalt has been erupted at intervals, from the beginning of discoverable Samoan history almost to the date of the last eruption. During geologically recent times normal basalt has flowed out at many points in the Manua subgroup as well as in western Samoa.

In Tutuila the long stage of basaltic development was followed by the series of major explosions that produced the Pioa and Matafao breccias. Soon after came the eruptions of the Pioa rhyolite and the Matafao, Papatele, Afono, and Vatia trachytes, which seem to have been erupted contemporaneously or nearly so. These rock bodies, filling necks and craters and to some extent dike-fissures, opened in the older lavas and breccias, are best regarded as differentiates of primitive basaltic magma. As in Hawaii, the Society Islands, etc., the alkalic types of Samoa are in such volumetric and chemical relations to the basalt that no other hypothesis appears tenable.[1]

The trachytic eruptions took place so long ago that the alkalic bodies and their enveloping rocks have been considerably denuded. During the denudation no volcanic vent appears to have been active in Tutuila. The detritus resulting from the erosion was carried out to sea and built into a broad shelf which completely encircled the volcanic torso. From the magnitude of the erosive work, one must be inclined to date much of it as far back as early Pleistocene, if not Pliocene, time.

When the ocean-level fell, because of the formation of the Pleistocene ice-caps, the Samoan islands, then existing, like most others in the open ocean, probably lost their defense by vigorously growing coral reefs. For a long period the shelf deposits and the weak reef-rocks already formed were subjected to re-gradation by the powerful waves and currents of the Pacific. Thereby the surface of the shelf was lowered, the shelf slightly broadened, and the volcanic part of Tutuila more or less strongly cliffed.

With the return of glacial water to the ocean, the sea-level rose, the temperature and other conditions for reef-growth improved, and an interrupted barrier reef was built near the edge of the shelf. This reef is probably to be assigned to an interglacial stage of the Pleistocene period.

The next important event was subsidence, to the extent of 45 to 65 meters, speculatively related to the deepening of the adjacent Tonga Deep. The movement appears to have been differential, so that the surface of the barrier reef is now not quite level. The old lagoon shows corresponding variations of depth, in spite of gradational processes. In part the drowning of the Tutuila valleys is referred to this subsidence.

After the sinking, eruption was renewed. Perhaps the first result was the formation of a composite cone, just north of Aunuu Island, the relics of which, as west-dipping flows and tuffs, are preserved along the Tutuila shore between Utumea Point and Cape Matatula. However, there is a bare possibility that this cone was formed synchronously with the Aunuu Island cone.

Clearly later than the subsidence was the eruption of the Leone basalt from one or more fissures which roughly paralleled the island axis. The lava flowed over the shelf between Tafuna and the meridian of Leone, and attained such volume as to fill a part of the lagoon where it was about 40 fathoms deep. Soon after the fissure eruption, perhaps within a few days, the two tuff cones at Steps Point and probably also the Aunuu Island cone were built up. The vents at Steps Point passed through old coral reefs, for fairly abundant fragments of corals and other fossiliferous reef limestone occur in the tuffs.[2] These craters are situated just over the area

[1] R. A. Daly, Jour. Geol., vol. 19, 1911, p. 289; *Igneous Rocks and their Origin*, 1914, p. 395 ff. W. Cross, Prof. Paper, No. 88, U. S. Geol. Survey, 1915, p. 87.

[2] No dolomite was found among the fragments, one of which, analyzed by Professor Phillips, gave 97.21 per cent $CaCO_3$ and 1.65 per cent $MgCO_3$ (spec. No. 2640).

where old reef-rock would be expected if a barrier reef had been actually drowned by general subsidence of the island.

At the close of this latest eruptivity, the sea-level stood about 6 meters higher than at present. There it remained long enough for notable marine erosion of pyroclastics and massive lavas on all sides of Tutuila. The resulting cliffs ranged in height from 10 to 100 or more meters and are still largely intact. The waves could exert their full force on the island, because, as first observed by Mayor, there were no reefs then growing on Tutuila. The later, probably eustatic, sinking of sea-level to the extent of about 6 meters, exposed the new rock-benches and sea-caves.

Finally, the conditions again became right for the vigorous growth of corals, and narrow reef fringes and patches have been formed along the shores of Tutuila and Aunuu islands; how far the contemporaneous growth of corals has locally shallowed the water over the drowned barrier, as at Taema Bank, is unknown. The widths of the reefs, interpreted with the known rate of coral growth, are compatible with the conclusion that the eustatic shift of sea-level took place not more than about 4,000 years ago. The living reefs are accordingly ascribed to the latter part of post-Glacial time. The reason for the lateness of the colonization by the corals initiating these reefs remains a mystery. The interruption in reef growth may well be due to chilling and the special muddying of the shore waters during the glacial stage or stages following the inter-Glacial development of the barrier reef; but there seems to have been also some special influence at Tutuila, which prevented the prompt occupation of its shores by corals in the Recent period.

Wave-cutting, the formation of beaches, spits, and landslides, the further widening and deepening of valleys, and coral growth are processes now modifying Tutuila.

OBSERVATIONS ON THE MANUA SUBGROUP OF ISLANDS.

Through the courtesy of the late Governor W. J. Terhune, the writer was enabled to reach Ofu, Olosega, and Tau islands by taking passage on the United States naval tug *Fortune*. A few days were permitted for a reconnaissance of the geology of the three islands; in this work Dr. Mayor gave valued help. Rapid as the examination had to be, some of the results seem worthy of record.

TAU.

Tau is 10.8 km. in length, by 6.8 km. in maximum width (Plate A). Its summit, at 3,056 feet (931 meters), is nearly central. From that point the surface descends northward, eastward, and westward in relatively smooth curves, in principle like those characteristic of Savaii, Hawaii, and other young, exogenous lava domes. The map shows the descent on the south to be precipitous for nearly 350 meters, this cliff running in a course nearly parallel to the shore of the broad bay on the south side of the island. From the foot of that cliff the slope is gentle for the distance of about a kilometer, but there the surface drops precipitously, 450 meters, into the sea. The writer was not privileged to study this slope. Friedlaender states that the two precipices appear to represent the walls of volcanic sinks (Einsturzkratern). His suggestion is of interest as indicating possible homologies with the great slippings or founderings which seem to have been responsible for the present shapes of Olosega and Ofu islands.

The shore cliffs of northern Tau range from 50 to 150 meters in height. Their bases are now being attacked by the surf, but faulting may have been partly responsible for these cliffs also. If wave-cutting were assumed to be the sole cause, it would be difficult to explain the much feebler development of cliffs at the eastern (windward) end of Tau. On the other hand, the whole island was nipped by the waves when sea-level stood about 6 meters higher than at present. At that time the western shore was benched, with the formation of cliffs 20 to 80 meters high and of rock-benches now standing 2 to 3 meters above high-tide level (Plate 8, A). The correlation of the benches with those of Aunuu and Tutuila has already been noted.

The constructional form of Tau has been very little changed by stream erosion, in spite of rapid gradients. The deepest gorge observed is about 5 meters in depth. Except the cliffs above-mentioned, the chief breaks in the generally smooth profiles are those due to a few low crater-rings at the higher levels. Lateritization of the lavas rarely attains the depth of more than a few centimeters.

Healthy patches of coral occur here and there along the shore, but no continuous fringing reef has been recorded on Tau.

The reconnaissance covered merely the shores and shore-trails of western Tau. All the igneous rocks collected proved to be typical basalts bearing abundant olivine. The flows vary from 5 to 25 or more meters in thickness. Many have ropy surfaces; a few were seen to contain lava tunnels with lava stalactites. Other flows are clinkery, tending toward typical aa or block lava.

Beds of tuff or agglomerate are rare, Tau being essentially the product of successive flows of basalt. However, at the northwest corner of the island, the flows are overlain by two tuff craters, which have been breached by the sea. Each cone has a crater about 600 meters in diameter. The tuffs, in places agglomeratic, are composed of fragments of much altered basalt and of coralliferous limestone; locally, numerous nodules composed of interlocked olivines (90 per cent) pyroxene (6 per cent) and magnetite (4 per cent) were observed.[1]

It may be noted that geological exploration in Tau is now difficult on account of the nearly complete destruction of the forest by the hurricane of 1915. The force of that wind may be appreciated from the reported fact that the sheet-iron roof of a Tau church was carried bodily to Olosega, a distance of about 8 km. Wholesale felling of trees, followed by the speedy growth of jungle in the "down timber" has made travel exceedingly slow and laborious.

OFU AND OLOSEGA.

Ofu and Olosega are twin relics of a single basaltic island which in size was originally comparable with Tau (Plate A). From Nuu islet to the most easterly cliff of Olosega is a distance of 9.2 km. Ofu measures 5.4 by 3.0 km.; Olosega, 4.5

[1] As at the Steps Point cones on Tutuila, the limestone fragments in the Tau tuffs have not been dolomitized. One specimen (No. 2648) gave Professor Phillips 92.28 per cent $CaCO_3$ and 1.06 per cent $MgCO_3$; another (No. 2650) gave 96.68 per cent $CaCO_3$ and 0.82 per cent $MgCO_3$.

by 2.9 km. A tide-way, 200 meters in width, separates them. The maximum heights of Ofu and Olosega are respectively 484 and 639 meters (Plate 8, B).

Each island is strongly cliffed on all sides. Yet more clearly than in the case of Tau, the greater precipices are not essentially the product of wave-cutting. The western slope of Ofu and the eastern slope of Olosega, though somewhat furrowed by stream erosion, largely preserve the constructional profiles of a volcanic cone. The foot of each of these slopes has been benched by the waves, the true sea-cliffs reaching heights of 100 meters or more. The northern and southern slopes give magnificent panoramas of rugged, cliffy slopes, reaching heights of 500 to 600 meters. These are particularly impressive to east and west of the strait between the main islands, where the rocks form a shark's-tooth ridge of fantastic outlines (Plate 9). The whole forms one of the grandest sights in the ocean, recalling the famous Nuuanu Pali near Honolulu.

Three different explanations of these Samoan precipices are conceivable. The curved ground-plan of each set of cliffs suggests an origin in a double evisceration through volcanic explosion, each ragged wall being the emerged part of the rim of a caldera. Or each wall might be considered a fault-scarp, the limit of a sink, analogous to the sinks at Kilauea or Mokuaweoweo in Hawaii. Thirdly, the cliffs might be considered to be the scars left by two gigantic landslips, involving, here again, the bodily or piecemeal foundering of large fractions of the original island.

If the caldera hypothesis were correct, some débris of the great explosions might be expected to appear on the constructional slopes of Ofu and Olosega. This test was applied to the eastern side of Olosega (Plate 9, A). The volcanic rocks were there found to be deeply lateritized, and furrowed by shallow, stream-cut valleys, which themselves have been truncated at the west-facing cliffs. This topographic relation clearly resembles that shown by the truncation of the much deeper valleys of southeastern Oahu at the Honolulu Pali. The shallow runways of eastern Olosega, even within 100 meters of the line of truncation, are locally veneered with large and small, hard, typically water-worn pebbles of basalt. The scattered gravels were obviously rounded by streams which, not long ago, headed far to the westward of the line of truncation, on high ground. One can not avoid the conclusions: that the broad southern embayment embraced by the two islands was very recently occupied by a high conical mass of land; and that the present surface of eastern Olosega is practically identical with that there existing just before the original Ofu-Olosega Island underwent its catastrophic change. On this surface, so well preserved, not a trace of recent explosive débris could be found. The caldera hypothesis is, therefore, extremely improbable, for an explosion on the scale demanded could hardly fail to lodge many rock-fragments on the undamaged surface of the volcano. The freshness of the gravels disproves the idea that the débris of explosion could, since the explosion, have become so weathered as to merge with the prevailing laterite and thus become hard to distinguish.

It is not so easy to decide between the merits of the sink and landslide hypotheses. The former implied some failure of the underpinning, because of deep-seated changes after the original cone was built—a process which has ruled at many volcanic centers. As Lindgren has suggested, the majestic cliff of Molokai, in the Hawaiian group, was apparently formed in this way. A similar mechanism may have developed the Honolulu Pali, where actual fault-planes (though of small throw) can be observed. Neither in Ofu nor in Olosega was such direct proof of ordinary faulting discovered.

The evidence for or against explanation by landslides is largely buried under the ocean water. Detailed soundings might give the facts enabling a choice between this and the sink hypothesis. Until that choice is warranted, it seems safe to describe Ofu and Olosega as remnants of a single island which has been recently dismembered through partial foundering. The events of 1888 at Bandai-San, Japan, prove that steam explosions may induce or accompany land slipping on a gigantic scale, but the proof of such coöperation in the Samoan case has not been forthcoming. The facts above cited tend rather to exclude explosion as an important factor in the formation of these spectacular cliffs. About two-thirds of the original island has probably sunk out of sight. Whether the cause of the foundering was deep-seated (forming true sinks) or was centered on the special plasticity of out-sloping rock-layers in the body of the original cone (forming landslips) must be left for future investigation. Similar problems are suggested by the topography of Tau, as of many other volcanic masses in the Pacific. An example is seen in the Haleakala "rent" of Maui, interpreted by J. D. Dana as possibly a case of an arrested landslip.[1]

Ofu and Olosega, in contrast with Tau, are principally composed of pyroclastic material—basaltic agglomerates and tuffs. Basaltic flows are irregularly inter-bedded and, in their turn, dominate at the northwestern end of Ofu and at the southeastern end of Olosega. In the former area, north and south of Aloafao, the basalt is poor in olivine. Elsewhere olivine is generally abundant, in well-formed phenocrysts. High up on the southeastern face of Ofu, a thick flow is composed of coarsely porphyritic olivine-basalt of striking appearance; it forms huge blocks in the talus.

At the shore, directly south of the summit of the razor-back ridge in eastern Ofu is a typical volcanic neck. Elliptical in cross-section, it measures about 25 by 45 meters in horizontal diameters. The neck is constituted of a coarse, massive, olivine-gabbro porphyry which is chemically like the flow just mentioned. The flows and agglomerates traversed by the neck, and probably the porphyry itself, are cut by a dike of olivine-free diabase bearing nodules of basic plagioclase.

The great precipices, especially those on the south side of each island, are riven by a multitude of thin trap or basaltic dikes. These are usually nearly vertical and trend north 60° to 70° east. At the shore, on the east side of the strait between the main islands, the basaltic flows are cut by 20 dikes in a single cross-section only 25 meters long. Dike networks are common in the Olosega cliff, which reminds one strongly of the precipice on Rakata Island of the Krakatoa group. In fact, the slipping or foundering at Ofu and Olosega has given an excellent opportunity to study the internal structure of a typical basaltic cone of the explosive type.

[1] J. D. Dana, *Characteristics of Volcanoes*, 1891, p. 278.

Both Ofu and Olosega are rather deeply lateritized, as well as somewhat dissected by streams, but, because of the more fragmental and porous nature of their rocks as compared with the strong, massive flows of Tau, it is unsafe to conclude that Tau is younger than these other islands.

The brown tuff-cone of Nuu Island is evidently very young. It is being attacked on all sides by the waves, which have cut three Gothic-arch tunnels clear through the islet. The tunnels vary from 70 to 100 meters in length; through them the surges rush with picturesque effect.

BEACH-ROCK IN SAMOA.

In general the beach sands of Samoa, whether calcareous or silicious, are loose and not consolidated. Locally, however, the sands have been more or less firmly cemented, forming "beach-rock." On Tutuila examples may be seen (see Plate A): at the angle of Pago Pago Bay, where the axis of this wide inlet turns westward; opposite Tower Rock and also about 600 meters north of that point; near Amaua; between Alofau and Round Bluff; along the eastern shore of the island; at the entrance to Vatia Bay, western side; in Amanave Bay; and at Leone. Along the southwestern shore of Ofu Island, beach-rock identical in habit with the calcareous beach-rock of Tutuila and with material collected at Tortugas, Florida, was found.

In most cases the Samoan beach-rock is medium to coarse, calcareous sand, cemented with calcium carbonate. At Vatia the detritus is a very coarse conglomerate composed of wave-worn pebbles and trachytic boulders, up to a meter in thickness, mixed with coral débris and shells; the cement again calcareous. The Leone beach-rock consists of an olivine-rich sand, derived from the neighboring ledges of tuff and fresh lava, together with a small percentage of calcareous, detrital fragments; the whole cemented by calcium carbonate.

The lithification has affected the beach materials between high-tide level and a level a few centimeters below that of the low spring tides. At every locality the length of this lithified part of the beach is not more than a few hundred meters, the beach-rock at each end passing rather abruptly into the ordinary, mobile sand or gravel. A similar relation to the loose sand is seen in cross-sections. Each mass of beach-rock is thus a plate of lenticular cross-section, from a meter or less to about 2 meters in maximum thickness; usually from 3 to 10 meters in width; and from 100 to 300 meters in length. The plate dips seaward, at nearly or quite the same angle as the surface of the unconsolidated beach at each end.

The cause of the lithification is an old problem, encountered by geologists working on the shores of the eastern Mediterranean, Brazil, the Florida Keys, and many parts of the tropical Pacific. A few months before visiting Samoa, the writer had been studying the problem, as illustrated at Tortugas, Florida, where Dr. Mayor had indicated its importance and arranged facilities for the study. The mode of cementation at Tortugas was not to be easily discerned, so that the discovery of a sensibly identical type of beach-rock and also a radically different type, in Samoa, was welcomed as giving wider opportunity to test the various published hypotheses of origin.

The nature and amount of the cement naturally claims first attention. Tests with cobalt nitrate, checked by microscopic examination, showed this to be aragonite in all Florida and Samoan samples, including the volcanic-sand rock at Leone. This introduced carbonate occurs in needles that project at high angles to the surfaces of the sand grains, in much the same way as the aragonite tufts in the cavities of the Funafuti coral-rock, described by Cullis.[1] The needles in the beach-rock are invariably very small, ranging from about 0.02 mm. to 0.06 mm. in length. Though the aragonitic deposit in some cases had a ruling thickness of only 0.05 mm., these rocks were well bonded. In no instance could calcite be identified in the cement itself. The amount of the cement varies within the same limits as at Tortugas, where determinations were made in 1919; these will serve also for the Samoan beach-rock.

During the process of measuring the porosity of the Tortugas rock, the specific gravity of the loose beach-sand was also determined. This incidental result may be worthy of statement. Fine-, medium-, and coarse-grained samples were taken at the laboratory wharf, at the north end of Loggerhead Key. They were composed essentially of fragments of coral, shells, and calcareous algæ, without any visible silicious material whatever. The few chitinous grains may be neglected. Five samples gave respective specific gravities (28° C.) of 2.77, 2.83, 2.84, 2.86, and 2.88, with an average of 2.837. Since the specific gravity of calcite is about 2.72 and that of aragonite about 2.94, the sand was seen to contain nearly equal proportions of the two carbonates.

The porosity of the sands from the same locality was found to average nearly 40 per cent.

Three measurements of the porosity of old beach-rock, collected at the lighthouse dock on the east side of Loggerhead Key, gave 14.7, 14.8, and 16.5 per cent. These values are fairly characteristic of the more thoroughly indurated beach-rock at Tortugas. The porosity of the average beach-rock is higher, and that of the recently (since 1910) and more imperfectly lithified material at the laboratory wharf is of the order of 35 per cent.

With these data, checked by study of thin sections, the cement of the Tortugas rock was found to vary between the limits of 5 per cent and about 30 per cent of the volume of the whole rock. Thin sections showed that lithification is already pronounced when the cement amounts to only 7 per cent of the rock, by volume.

The foregoing figures well serve, in principle, also for a quantitative description of the Samoan beach-rock. Such correspondence in the nature and amount of the cement, the constant relation of beach-rock to tide-levels and beach-slope, the narrow range of thickness for the beach-rock plates, and, as noted below, a constant relation of the plates to offshore shelves exposed to the power of the open ocean, all suggest a common cause for this kind of lithification. That the cementation has not been essentially due to the solution and re-deposition of the detrital material itself is shown in the Leone case, where the detrital grains are olivine, augite, tachylite, and other silicious materials, with a very small percentage of carbonate

[1] C. G. Cullis, Report of the Royal Society Committee on Funafuti, 1904.

grains. Moreover, a comparison of the Floridan and Brazilian beach-rocks proves that the lithification is not a direct function of the amount of detrital carbonate in the sands. The former, composed of practically pure carbonate sands, are no better consolidated than the Brazilian rocks made up of dominant quartz.[1] The Leone rock clearly suggests another source for the carbonate represented in these cements.

A field relation, common to all the Samoan occurrences, is the restriction of the beach-rock to points well exposed to ocean waves and situated to landward of shallow shelves of some width: it was never found along shores protected from heavy wave-action during exceptional storms. The same is true wherever the writer has seen beach-rock along the Florida coast. The remarkable developments on the Bahaman and Brazilian shores seem to be similarly conditioned. Further, Dr. Mayor stated orally that, during his extensive travels in tropical seas, he had never seen beach-rock on other than exposed shores.

Another generalization may be made for the Samoan examples. The formation of beach-rock is there independent of the topography just back of the beach. The lithification has been brought about immediately in front of high, steep cliffs as well as in front of low flats; at points far from any fresh-water stream; and at points close to the mouths of creeks or in front of poorly drained, low ground.

Branner[2] summarized his explanation of the Brazilian beach-rock, thus:

The hardening of beach sands may be produced in the following ways:

1. By carbonated rain-water dissolving out the lime carbonate in the upper portions of calcareous sands and depositing it in the lower portions.

2. By the escape of carbon dioxide from the sea-water when the surf breaks upon the beaches.

3. By the escape of carbon dioxide from sea-water where it is warmed by the tropical sun.

4. By the submarine escape of carbon dioxide about volcanic vents.

These processes may have contributed somewhat to the hardening of the Brazilian reefs, but they do not seem competent to account for them altogether. These theories are especially incapable of accounting for the lithification of beaches behind older reefs.

The distribution of the consolidated beaches of northeast Brazil leads to the inference that the consolidation is directly related to the density of the sea-water. The geology and climatic conditions over the adjacent land are, however, important factors in the hardening of the reef sands. It seems probable that the consolidation of the reef sands would not take place if the rainfall were large enough and constant enough to keep the mouths of the streams open and the water of the streams fresh.

In a region of concentrated rainfall and long drouths the river mouths become temporarily closed, and the abundant aquatic and other life in the lagoons thus formed contributed to the organic acids of the waters, which, upon penetrating the wall or dam of beach sand, first dissolves the lime, and then redeposits it when it comes in contact with the dense seawater on the ocean side. In this manner some portions of the beaches have been hardened, while others have remained incoherent.

Branner's hypothesis can not apply at Tortugas, in the Bahamas, or in Samoa, where the climatic and topographic conditions are not of the kinds postulated. The density of the sea-water is of course important, but, since tropical waters seem

[1] J. C. Branner, Bull. Museum Comp. Zool., vol. 44, 1904, p. 175.
[2] J. C. Branner, Bull. Mus. Comp. Zool., vol. 44, 1904, p. 196.

everywhere to be practically saturated with calcium, local lithification is evidently, as Branner remarked, due to a more special control.

In some respects Field's explanation is similar. His brief statement may be quoted in full:

> My theory is that after an exceptionally severe storm, during which fresh sand is swept upon the beach in places and the beach itself scoured in others, the bulk of the key sands above tide-water level are saturated with a strong (rain-water) solution of calcium carbonate. This solution continues to trickle out through the *beach* sands, at ground-water level, for several days and, upon exposure to the air, deposits calcium carbonate in the spaces between the bits of shell, thus forming the "beach rock." The precipitation of the $CaCO_3$ is probably due to the relief of pressure, the escape of CO_2, and the consequent lowering of the solubility of the $CaCO_3$. The fact that the "beach rock" can not owe its origin to the action of putrefying matter in place, such as sea weeds, etc., is, I believe, proved by the total absence of any carbonaceous material in the rock itself.[1]

Field's hypothesis was intended by him to cover the problem only so far as it refers to the Florida beach-rock and its true homologues. However, its application to Tortugas itself raises difficulties. It offers no explanation of the local, sporadic development of beach-rock along the keys. The seepage of rain-water obviously affects the whole of each beach, yet many Florida beaches show no trace of lithification at all, or inclose but quite limited patches of the rock. Like Branner's hypothesis, it does not explain the temporary nature of the conditions leading to the cementation. In Florida, Brazil, and Samoa, new beach-rock is not now being formed at many points, where in fact the beach-rock is in process of destruction by the waves.

It is incredible that the purely calcareous beach-rocks of Florida and of Samoa, in essentials perfectly similar, have been formed by quite different processes. The writer was able to make a direct test of the Field hypothesis, as a conceivable explanation of such rock, at Siufaga village, on the shore of Tau Island. The village lies on a narrow strip of coral sand, fronted by a storm-beach and backed by a low, swampy, heavily vegetated flat. From the rainy, volcanic slopes farther inland, much fresh water enters the swampy belt and percolates through the coral sand. The seepage is so rapid that the sea-water is kept largely excluded from the interstices of the storm-beach. Hence the natives are able to get potable water at low tide, by scooping out holes in the sand just in front of the lapping waves and nearly a half meter below mean-tide level. The conditions specified by Field's hypothesis seem, thus, to be here ideally met; yet there is no lithification of this beach. The case at Siufaga also shows that Branner's hypothesis can not be valid there.

Field's explanation can not, of course, apply in the case of the olivine sand at Leone; nor will it do to assume a different cause of lithification, for the aragonitic cement of the Leone rock and the general field relations are too similar to the beach-rock at Tortugas. As Branner concluded, the topographic and climatic conditions of the Brazilian coast are not favorable to the explanation of the famous stone reefs by the seepage of rain-water falling on the corresponding beaches.

[1] R. M. Field, Carnegie Inst. Wash., Year Book No. 18, 1919, p. 198.

A different line of thought was suggested to the writer by the fact first observed by Dr. Mayor and his associates at the Tortugas laboratory. The destructive hurricane of 1910 piled a large amount of calcareous sand on the site of the laboratory wharf. Much of this sand seems to have been torn out of the broad shelf offshore. Less than two years afterwards, the sand between tide-marks had already become lithified to a depth reaching a maximum of about 75 cm., resulting in an elongated lense of typical beach-rock. The cementation took place under the cover of 25 to 100 cm. of sand, which was not lithified. By 1919 the cover was largely removed and much of the beach-rock itself was already cut away by the surf.

This sequence of events has led to the inquiry whether beach-rock in general owes its origin to the sudden driving of shelf sands on to the shore by major storms. The observed relations of beach-rock plates to shelves and the open ocean, as above described, agree with this suggestion. Some of the Samoan plates are situated at the inner edges of reef flats which are significantly covered with negro-heads in special abundance; the latter demonstrating former wave-action of extraordinary violence. If such facts from the field be assumed to show that hurricane control has been important, one is naturally led to consider what special property of shelf sand might initiate the lithification.

Ordinary beach sands are comparatively free from organic material other than clean fragments of shells and skeletons. On the other hand, shelf sands in the tropics are charged with considerable amounts of decaying animal and vegetal matter and with living bodies. To get some idea of the amount of carbonaceous material in the sand of the Tortugas shelf, a large sample was secured, with the use of a diving helmet, about 100 meters from the laboratory wharf, at a depth of about 2.5 meters. While digging up the bottom sample, some of each shovelful (perhaps one-fifth) was lost. The rest was fractioned and treated with caustic alkali; the soluble, organic material was found to be roughly 5 per cent of the sample by weight.

The shelf sand cast on the shore by a hurricane is, then, likely to be specially "dirty." Bacterial decomposition of this organic matter must tend to cause a precipitation of calcium carbonate from the sea-water which slowly creeps through the sand because of tidal and other changes of level. Incipient cementation of the sand may be postulated as a reasonable consequence.

However, bacterial action does not seem competent to explain all of the cement in average beach-rock, making up 10 to 30 per cent of the whole volume. It is practically certain that the original mass banked up by a great storm would not contain enough decomposable organic matter. On the other hand, the bacterial decay is conceived to be important as a fixing agent; the initial cement, so developed, suffices to prevent differential movements among the sand grains until other, quantitatively more potent, causes of precipitation have had time to do their work.

Several chemists have shown that tropical sea-water is saturated with calcium carbonate under ordinary surface conditions. Is it not possible that the new, clean carbonate, formed by putrefaction, may act as a nucleating agent and cause further precipitation of the cement? Two other conditions for supersaturation are more obviously to be considered. At low tide the sand and inclosed sea-water are heated by the sun's rays, carbon dioxide escapes, and calcium carbonate must be thrown out of the sea-water solution. Secondly, the sea-water of the breakers and the water moving slowly through the beach sand are mixed with air. Under the varying pressures produced by the waves, air is forced through the interstitial water. As Johnston and Williamson point out, such aeration should lead to supersaturation.[1] The precipitation resulting from the two causes is practically confined to the thin layer of the banked-up sand, lying between high-tide level and a level a little below low-tide mark—exactly the position where beach-rock occurs. So long as the initially cemented sand keeps its proper relation to the breakers, and is, for example, not too deeply covered with imported sand, the cement can thicken and grow more resistant to blows; until the original interstices have become more or less completely filled. On the other hand, the conditions of shore erosion may lead to the destruction of the new bank before a strong rock could be formed.

This hypothesis seems to explain the characteristic lithological features of beach-rock; its sporadic appearance on tropical beaches; its relations to wave-belt and tides; its limited thickness; and the seaward dip of the plates or lenses of beach-rock. That ordinary, clean sands are not cemented is explained by their incessant or periodic movement through wave-action, and by the lack of any special cause for bonding, preliminary to the more important cementation through the aeration and heating of the sea-water. Field's objection, that, on the hypothesis just outlined, there should be a notable proportion of decomposable organic matter in a given sample of beach-rock, whereas he finds it to be absent, is not well taken; for the actual cleanness of the beach-rock is just what would be expected if bacterial decomposition had been thorough.

The offered explanation evidently needs checking by experiment. In May, 1919, with the help of the staff of the Marine Laboratory at Tortugas, a large cask was filled with shelf detritus, dug up at a point offshore from the laboratory. The sides and ends of the cask were perforated, to permit of the easy flow of sea-water through the mass, and the whole was buried at the proper depth in the beach. It was hoped that, after a year or two, the cask might be opened, with the object of seeing whether its contents had become in any degree cemented together. Unfortunately, the hurricane of September, 1919, tore up the cask and carried it several hundred meters along the key. There left exposed to the air, this material can not be used as a test. The experiment should be duplicated. On the other hand, this hurricane itself improved upon an artificial experiment. Like that of 1910, it threw up on the beach a large quantity of shelf-sand, which, a year afterwards, was found by Dr. Mayor to have been hardened into beach-rock.

[1] J. Johnston and E. D. Williamson, Jour. Geol., vol. 24, 1916, p. 739.

SUMMARY.

The principal conclusions of this paper may be thus summarized:

1. Of the Samoan chain of volcanoes Tutuila and the Manua subgroup of islands have been studied. Tau, Ofu, and Olosega are essentially basaltic throughout. In Tutuila, an exogenous lava-dome, basalt dominates, but its differentiates—trachydoleritic basalt, trachydolerite, trachyandesite, limburgite, highly mafic olivine-gabbro, alkalic trachyte and alkalic quartz-trachyte (rhyolite)—are also represented. The more alkalic bodies have the forms and structural relations of volcanic necks, endogenous domes or crater-fillings, and dikes, which cut the dominant basaltic flows.

2. In chemical composition the average basalt of Tutuila is almost identical with the average basalt of Hawaii and approximates to the average plateau basalt of the world.

3. The alkalic trachytes, trachyandesite, and trachydolerite of Tutuila are regarded as differentiates of ordinary basalt, a magmatic type common to both of the so-called "Pacific" and "Atlantic" suites. Once again the division of igneous rocks into "Pacific" and "Atlantic" suites is seen not to be supported by either geographical or chemical relations.

4. The cause of the differentiation of alkalic trachyte from basalt represents an unsolved problem. The influence of volatile matter—water or carbon dioxide or both—in special abundance may be an important control in the process, but actual proof of this has not been forthcoming. The origin of the abundant pyroxene andesites elsewhere is a closely related question.

5. At least in part the Pioa dome of Tutuila is a quartz-bearing trachyte, approaching a true rhyolite. The quartz is micropoikilitic and identical in habit with the quartz of closely similar quartz-trachytes of Ascension Island and of East Africa. The Pioa rock exemplifies the very rare cases where free, "primary" quartz has been found in lavas of the open-Pacific region, and is perhaps farther removed from visible terranes of "continental" rocks than any other lava bearing primary quartz hitherto recorded in the Pacific. The question is raised whether the edge of Australasia really extends as far east as Samoa.

6. A possible explanation of the common eruptive sequence—basalt, trachyte, basalt—at volcanic centers is proposed.

7. Three new examples of rapid change of color of igneous rocks, when exposed to the air, are described.

8. At the surface of each layer the tuffs of Tutuila were hardened immediately after deposition. This lithification is another problem awaiting solution.

9. Physiographically speaking, Tutuila is the oldest of the Samoan islands. Its oldest supermarine lavas are no younger than an early stage of the Pleistocene period and may be Pliocene, if not older. The youngest eruptives are quite recent. From their degree of dissection the Manua group of islands may be assumed to date from late-Pleistocene or Recent times.

10. Tutuila has subsided some tens of meters. Its sinking seems to have been connected with the formation of the adjacent Tonga-Kermadec Deep.

11. After that subsidence the shores of Tutuila, the Manua group of islands, and Rose atoll have emerged about 6 meters. The emergence appears to be due to a world-wide sinking of sea-level, not more than 4,000 years ago.

12. Before the 6-meter emergence Tutuila was not defended by coral reefs, as Mayor discovered. The cause of their absence is not understood, though it may be associated with the conditions of the last glacial stage of the Pleistocene period.

13. The facts observed in Samoa are consistent with the writer's Glacial-control theory of the living coral reefs, but these islands do not offer definite criteria for any general explanation of the reefs. Emphasis is once more laid on the reasonableness of assuming that atolls and barrier reefs were very rare or even non-existent before the first glacial stage of the Pleistocene period, and that the platforms now crowned with atolls and barrier reefs are shelves and banks, largely detrital, formed during pre-Glacial time because of the absence of reefs other than those of the fringing class. A cause of the narrowness of all pre-Glacial (fringing) reefs is suggested.

14. The remarkable topography of the twin islands, Ofu and Olosega, finds satisfactory explanation in a double foundering. Until the submarine relief is determined by soundings, it does not seem possible to decide whether the foundering was due to ordinary faulting or to landsliding on a grand scale.

15. The origin of beach-rock is discussed in the light of field and laboratory studies at Tutuila, at the Manua group of islands, and at Tortugas, Florida. Preference is given to the view that the formation of beach-rock is controlled by the action of major storms, which quickly pile up shelf-sediments along the littoral. In their new position these sediments are liable to rapid lithification and are thus unlike beach sands of the usual type.