XXX.—*Observations on the Recent Calcareous Formations of the Solomon Group made during 1882-84.* By H. B. GUPPY, M.B., F.G.S., Surgeon H.M.S. "Lark." Communicated by JOHN MURRAY, Esq. (Plates CXLIV., CXLV.)

(Read 15th June 1885.)

PRELIMINARY REMARKS.

On account of the treacherous character of the natives of the Solomon Group, no extensive geological observations have ever been made in these islands since the period of their discovery by the Spaniards three centuries ago. For this reason my excursions in these regions were not free from personal risks; in many places they were considerably curtailed, and in some places they had to be abandoned altogether. Fortunately, however, I was able to make a detailed examination of several of the smaller islands, the natives of which had been first conciliated by the kindly tact of Lieut.-Commander C. F. OLDHAM, to whom I am indebted for much assistance in my pursuits. But from the circumstances in which I was placed, both on board and on shore, it was necessary, in order to accomplish much, to dare a little.

This archipelago includes seven or eight large islands, some of which are from 70 to 80 miles in length, and the highest from 8000 to 10,000 feet in height. Besides these, there are a great number of smaller islands and islets, some of volcanic and others of recent calcareous formations. Restricting my remarks to those islands which are wholly or in part composed of these calcareous rocks, I may observe that, although only able to become acquainted with a small portion of the Solomon Group, the islands which I examined represent the different types of islands that there exist. The larger islands, composed in mass of ancient volcanic rocks flanked on the lower slopes of their sea-borders by more recent calcareous formations, are represented by St Christoval. Among the smaller islands, the following types occur:—in the first place, there are those which are made up in bulk of a soft Foraminiferous deposit encrusted only by coral limestone, as in the island of Ugi. Then there are those which are composed in great part of these soft deposits and coral limestones, but partly also of volcanic rocks, as in the Shortland Islands. In the next place, there are islands, usually small and of no great height, which are entirely of coral rock, as in the case of Stirling Island. Santa Anna represents probably an uncommon type of island, being an upraised atoll with its foundations

exposed. The numerous islets formed on the coral reefs at the present sea-level do not come within the province of this paper.*

The methods employed by Mr MURRAY in the examination of these recent rocks are similar to those which he employed in examining the deep-sea deposits obtained in the "Challenger" and other Expeditions. The *Carbonate of Calcium* was determined by estimating the carbonic acid, weak and cold hydrochloric acid being used for this purpose. The part insoluble in the acid is designated "*Residue*," which by washing and decantation is separated, on account of the different densities of its constituents, into three parts—(a) *Minerals*, the contraction *m. di.* indicating their mean diameter in millimetres; (b) *Siliceous Organisms*, including also the glauconitic casts of Foraminifera and of other calcareous organisms; (c) *Fine Washings*, including those particles which, resting in suspension, pass with the first decantation. The numbers in brackets indicate the percentage in the whole deposit.† In addition to the foregoing method, sections of many of the rocks were employed in their examination.

THE ISLAND OF UGI.

The island of Ugi, which is six miles in length and between two and two and a half miles in breadth, rises to an elevation of about 500 feet above the sea. From some points of view it has the profile of a broad-brimmed hat, due to a pause in the elevating movement when the land was 200 feet lower than it is at present; but more commonly, losing its hat-shape, it appears as a level-topped island rising gently from the sea. Fringing reefs skirt the greater portion of its coast.

Its geological structure may be briefly described as composed in mass of a soft earthy bedded deposit, resembling the "volcanic muds" of the "Challenger" soundings, containing numerous Foraminifera, and encrusted near the coast by coral limestone which almost disappears in the higher regions.

The Coral Limestone.—Referring for a moment to the low-lying sea border of this island, which, elevated between 2 and 8 feet above the sea, is composed of calcareous sand, shells, and coral débris imperfectly mixed with soil, I pass on to the description of the coral limestone crust. This rock is occasionally exposed at the coast in cliffs not exceeding 16 or 18 feet high. In the northern part of the island I found an eminence of this coral rock rising

* In the examination of these calcareous rocks, as well as in the preparation of this paper, I have been assisted by Mr JOHN MURRAY, to whom, as well as to the ABBÉ RENARD, I have to express my indebtedness. I also desire to express my thanks to Mr MURRAY's assistants in the "Challenger" Office, Mr FRED PEARCEY and Mr JAMES CHUMLEY.

† For further information on this subject *vide* a paper on "The Nomenclature, Origin, and Distribution of Deep-Sea Deposits," by JOHN MURRAY and A. RENARD, in the *Proceedings of the Royal Society of Edinburgh*, 1883-1884, pp. 504-506.

to between 90 and 100 feet above the low-lying land at its base, and removed inland a few hundred yards from the coast. Its interior has been excavated into a suite of caverns known as the Waupa Caves. This was the greatest thickness of coral rock that I saw exposed in the island of Ugi; and I doubt if it anywhere much exceeds a hundred feet. As one ascends the slopes of the island this formation thins away, and only occasional fragments occur in the red argillaceous soil. The greatest elevation at which I found the coral rock was about 425 feet above the sea.

The Soft Foraminiferous Deposit.—This rock, which is exposed in the ravines and gorges excavated by the streams, forms the mass of the island. Closely resembling the prevailing formation of Treasury Island, described in another portion of this paper, it presents itself in the fresh condition as a chocolate-coloured argillaceous and somewhat friable deposit, in which Foraminiferous tests may be usually observed. It is often stained reddish-brown near the surface through the hydration of its iron oxides. Specimens of this rock, after being kept some time, become more friable and of a lighter colour. Subjoined I have given the characters of this deposit with the list of the Foraminifera, as determined by Mr MURRAY:—

A friable rock of a greenish-blue colour showing minute organisms imbedded. Its characters are those of the “volcanic muds” found in the “Challenger” Expedition around volcanic islands. It seems to have been formed in comparatively shallow water, although not sufficiently near to the surface to permit the reef corals to grow.

Carbonate of Calcium (13·93 per cent.) consists of Coccoliths, Rhabdoliths, Gasteropod and Lamellibranchiate shells, Echinoderm fragments, calcareous Algæ, and many pelagic and bottom forms of Foraminifera, (*vide* List).

Residue (86·07) of a slate colour, consists of—

- (a) *Minerals* (50·00) m. di. 0·3 mm. a few larger; felspar, magnetite (abundant), hornblende, augite; many fragments of volcanic rocks with pumice and glassy materials.
- (b) *Siliceous Organisms* (1·00); a few Sponge spicules.
- (c) *Fine Washings* (35·07), argillaceous matter, and many fine mineral particles.

List of Foraminifera.

Planispirina celata (few).
 Bolivina costata (rare).
 Textularia quadrilatera (rare).
 Bulimina sp. (many).
 Sagrina columellaris (common).
 „ striata (common).
 „ virgula (common).
 Uvigerina asperula (few).
 Globigerina bulloides (rare).
 „ „ var. triloba (common).

Globigerina rubra (common).
 „ dubia (few).
 „ inflata (few).
 „ conglobata (few).
 Sphæroidina dehiscens (few).
 Pullenia obliquiloculata (few).
 Pulvinulina menardii (many).
 „ „ var. tumida (many).
 Nonionina umbilicatula (rare).
 Polystomella craticulata (rare).

Additional List (relative frequency not ascertained).

Cassidulina crassa.	Pulvinulina elegans.
Bulimina marginata.	„ canariensis.
Uvigerina pygmæa.	„ menardii var. fimbriata.
Nodosaria soluta.	„ repanda.
Globigerina sacculifera.	Truncatulina sp.

This formation displays regular bedding, the beds being in some localities separated by thin bands, one to two inches thick, of a loose coarser-grained deposit of the same nature.* Having explored most of the principal streams, which are mostly confined to the west side of the island, I have shown the main results in the accompanying plan of Ugi (Plate CXLIV. fig. 1); whilst the ideal section (Plate CXLIV. fig. 2), which actually represents a section through the south portion of the island, will serve to illustrate the structural features, more particularly the curvature of the beds and the comparative thinness of the crust of coral rock. The tortuosity of the streams, with other circumstances, combined to hinder my efforts to arrive at a satisfactory explanation of the lie of the beds; and it was only after repeated tedious examinations of these stream-courses that I was able to reduce my observations to order. The dip varies usually between 10° and 15° , but it may rise to as much as 35° . In the higher parts of the island, near the sources of the streams, the beds are generally horizontal or very gently inclined. By referring to the plan of the island, where the arrows indicate the direction of the dip, it will be seen that the prevailing trend of the folds is N.E. to S.W.; but in the northern part of the island they run more N.W. to S.E. Although the series of curves into which these beds have been thrown are generally regular, yet the occasional sudden increase of the dip and the occurrence of local contortions are circumstances which afford evidence of the minor disturbances to which these beds have been subjected. The natural sections displayed in the sides of the ravines and gorges vary considerably in different streams, and in different parts of the same stream; most frequently, however, the stream appeared to have run along the crest of an anticlinal ridge. I should here allude to a common feature of these stream-courses, as well as of those of Treasury Island, viz., the extensive deposits of calcareous tufa which frequently encrust the sides of the gorges and constitute a series of step-like terraces over which the water flows in the higher parts of some of the streams; leaves, twigs, and shells are often thus imbedded.

I carefully searched these beds for enclosed organic remains in addition to the minute organisms there imbedded. Entire shells are rarely found, those referred to in the description of the composition of these rocks being the fine fragments of Lamellibranchiate and Gasteropod shells. I only came upon five

* In a limited locality in the south part of the island the rock was a very fine grained calcareous tuffa, containing a few siliceous marine organisms.

specimens of a small bivalve, which from its delicacy was often difficult to obtain in anything like a perfect condition. Dark patches, where the Foraminiferous tests occur in increased numbers, stain these deposits; and there are imbedded numerous small rounded masses of a concretionary nature, containing much peroxide of iron and a little peroxide of manganese. The upper surfaces of these beds are frequently marked by cracks, which have been filled with a material that projects above the surface of the rock on account of its greater durability; but from the moist and semi-consolidated state of the rock, these shrinkage-cracks must be viewed as of modern origin.

It is noteworthy that I did not find any volcanic rock *in situ* in this island.

In concluding my description of Ugi, I may refer to the pauses in the movement of upheaval which have left their marks behind them. On the north-west coast, I found in the faces of the cliffs of a small sheltered cove two lines of ancient erosion, the lower indicating an elevation of $4\frac{1}{2}$ to 5 feet as the most recent change in level, and the upper line indicating a previous upheaval of 6 to 7 feet. In the interior there is evidence of a long pause in the elevatory movement, when the island was about 200 feet lower than it is at present, which, as already stated, has given Ugi from some points of view the profile of a broad-brimmed hat. In the quiet waters of Selwyn Bay on the west coast, we find testimony of an upheaval still in progress. Reefs have been elevated in mass so that points of coral rock project between 1 and 2 feet above the high-water level. Mr STEPHENS, a resident trader at Selwyn Bay, tells me that during the past eight years the greater projection of these points of the reef has been a matter of observation to him; and that within that period the high-tide mark has receded between 12 and 15 feet, so that some cocoa-nut palms, which eight years since were within reach of the waves at high-water, are now only reached by the spray.

In the description of Treasury (page 555), I have referred to the two most recent lines of ancient erosion as corresponding with the two most recent upheavals of Ugi. In both islands there is evidence of a recent upheaval of about 5 feet, and of anterior upheaval of about 6 or 7 feet. Such coincidences in two islands situated towards opposite ends of the group, and lying about 400 miles apart, would appear to indicate the general character of the movement of elevation in the whole of the Solomon group.

THE ISLAND OF TREASURY.

The island of Treasury is of an oval shape, with a breadth of $5\frac{1}{2}$ miles, a length of 9 miles, and an elevation of 1150 feet above the sea. Viewed from

seaward, this island has a rounded profile, in this respect resembling the island of Ugi at the opposite end of the group, which has a somewhat similar geological structure. Its bold sea cliffs and the narrow ravines worn by the streams in the interior afford favourable opportunities of examining its geology; and it may be briefly described as composed in mass of a soft bedded Foraminiferous deposit, resembling the "volcanic muds" of the "Challenger" soundings, which is covered over by a crust of coral limestone that only attains any thickness near the coast, and is wanting altogether in the higher interior regions of the island. Its structure, however, is not so simple as that of its counterpart, Ugi Island, there being a greater variety in the characters of the softer deposit and of the harder coral limestone, while the nucleus of volcanic rock, around which these calcareous muds and coral rocks were formed, is here partially exposed. A casual observer by the ascent of a single stream would obtain a very imperfect, if not an erroneous, impression of the structure of this island; if he did not extend his field of observation beyond the beach, where the village of Saveki lies, he might carry away with him the impression that Treasury was of volcanic formation, an error into which he would not have been the first to fall. It was only by a laborious examination of nearly all the larger stream-courses and by numerous ascents to the summit from different sides of the island that I was enabled to form a true conception of its structure.

The Coral Limestone.—Having in another portion of this paper referred to the different kinds of coral limestones, so called, it will suffice for me to state here that I shall always employ this term as applying to a hard usually compact unstratified limestone in which the massive corals may be observed imbedded or which on examination exhibits coral structures.* A wide ledge of this coral rock, rising from about 50 feet above the sea near the coast to rather over 100 feet further inland, forms the sea-border around the greater portion of the circumference of this island. This ledge is covered by a reddish clayey soil, through which protrude occasionally large fragments of the massive corals. Up the hill-slopes the coral limestone may be traced on the surface as high as 300 to 400 feet above the sea; and fragments of the reef corals may be observed at heights varying between 150 and 200 feet. At elevations exceeding 300 or 400 feet above the sea, the coral rock usually disappears from the surface, or it may be only observed as small masses. However, in the same hill I found at a height of 675 feet an ancient reef-mass of true coral rock, running like a wall about 10 feet high for some nine or ten paces along the hill-slope; and at a height of 900 feet I came upon a small block of a *Porites* in a rotten condition. The average thickness of the coral rock at or near the coast where it is displayed

* Very frequently corals play only a secondary part in the building up of the rock which is largely composed of calcareous Algæ, fragments of Echinoderms and Molluscan shells.

in greatest mass, probably varies between 70 and 100 feet. At the sea-border, where it is exposed in a line of high inaccessible cliffs, it is riven into chasms and deep fissures by the action of the surf.

I should here refer to Stirling Island lying off the south coast of Treasury Island, and enclosing the harbour (*vide* Plate CXLIV. fig. 3). It is entirely of coral limestone, the islets in the harbour being of the same formation. Its general surface is level, with an average height of 40 to 50 feet, and a maximum height of 70 feet. In the bold cliffs, which form the weather coast of this island, there are numerous imbedded masses of the reef-building corals, many of them measuring 4 feet across, the majority of them in the position of growth,* but some of them inverted. It is worthy of notice that the large astræid and brain corals imbedded in the upper portion of the cliff-face were only half the size of those imbedded some 15 or 20 feet below.

The Soft Foraminiferous Deposit.—This rock, of which the mass of the island is composed, has very much the composition of the “volcanic muds” which were found during the “Challenger” Expedition in the vicinity of volcanic islands. It is usually soft and friable, and when unaffected by the hydration of its iron oxides is of a bluish-grey colour. It displays a regular stratification, and, as will be seen in the plan of the island appended where the arrows along the courses of the streams indicate the direction of the dip, the amount of inclination varies between 10° and 30°.† To the naked eye it usually presents no other conspicuous organic remains than the white specks of the more minute Foraminiferous tests and the larger macroscopic tests of such species as *Cristellaria calcar*, *C. mamilligera*, and others. A description of such a specimen is here appended:—

A friable rock, of a bluish-grey colour, showing minute organisms imbedded.

Carbonate of Calcium (7·74 per cent., the amount varying in different specimens between 5 and 25 per cent.) consists of Cocoliths; a few *Globigerina bulloides* var. *triloba*, a few *Globigerina conglobata*, and other Foraminifera, and fragments of Echinoderms. (*Vide* below for further list of the Foraminifera.)

Residue (92·26) slate colour, consists of—

(a) *Minerals* (60·00) m. di. 0·8 mm.; some fragments 1·0 to 2·0 mm.; felspar, magnetite, augite, hornblende, fragments of pumice, scorïæ, and other volcanic rocks, with many glassy fragments.

(b) *Siliceous Organisms*, none noticed.

* I paid especial attention to the position of the imbedded corals, and only found two inverted. The large shells of *Tridacna gigas* are also enclosed in the rock in the usual position occupied during the life of the mollusc.

† The general dip would appear to be away from the elevated interior of the island.

(c) *Fine Washings* (32·26), argillaceous matter and many fine mineral particles.

List of the Foraminifera contained in a Specimen of the Soft Foraminiferous Rock above described.

Miliolina oblonga (rare).	Sagrina columellaris (many).
Textularia turris (few).	„ virgula (many).
„ concava (few).	„ striata (many).
Gaudryina rugosa (few).	Truncatulina lobatula (many).
Clavulina communis (few).	„ rostrata (very common).
Vaginulina bruckenthali (rare).	„ haidingeei (few).
Bolivina punctata (many).	Globigerina bulloides (many).
„ hankkeniana (many).	„ „ var. triloba (common).
„ subangularis (few).	„ rubra (many).
Bulimina inflata (rare).	„ dubia (few).
„ affinis (many).	„ æquilateralis (few).
Nodosaria filiformis (rare).	„ (orbulina) universa (few).
Fronicularia inæqualis (rare).	Pullenia sphæroides (rare).
„ interrupta (rare).	Planorbulina larvata (rare).
Cristellaria articulata (rare).	Pulvinulina menardii (many).
„ crassa (several).	„ repanda (few).
„ calcar (several).	„ elegans (few).
„ latifrons (several).	Rotalia soldanii (few).
„ aculeata (several).	Amphistegina lessonii (rare).
Uvigerina pygmæa (rare).	Nonionina umbilicatulula (rare).
„ schwageri (many).	

In some localities this deposit becomes highly fossiliferous, when it generally assumes the character of a compact mottled grey limestone, and displays to the eye fragments of corals with Pteropod and Lamellibranchiate shells, &c. Interbedded with the softer rock, and offering a greater resistance to the action of water, its position is often marked by waterfalls in the stream-courses; but it is absent from the higher parts of the streams and from the central districts of the island. The following are the characters of this harder rock:—

A compact fossiliferous limestone, containing a good deal of volcanic débris, and probably formed in shallower water than the friable rock just described.

Carbonate of Calcium.—About 60 per cent., consists of fragments of Lamellibranchiate shells, coral, calcareous Algæ; and the following Foraminifera:—*Carpenteria*, *Globigerina bulloides*, *Polytrema rubra*, *Truncatulina*, *Lagena*, *Nummulina*, and *Cristellaria*.

Residue, 40 per cent., consists of—

- (a) *Minerals* (15 per cent.), felspar, magnetite, augite, hornblende, and glassy fragments.
- (b) *Siliceous Organisms*, none noticed.
- (c) *Fine Washings* (25 per cent.), consisting of argillaceous matter and fine mineral particles.

The softer friable deposit is alone found in the elevated interior of the island, where it is exposed in a line of inland cliffs 300 feet in height, lying

near the centre of the island and entirely composed of this formation. This was the greatest thickness that I saw exposed of this soft Foraminiferal deposit ; and since this line of cliffs represented a natural section of the summit, I may safely conclude that the elevated interior of the island is entirely of this formation, a *conclusion* which is supported by the existence of other sections almost as extensive in that region, and one which has an important bearing on the past history of Treasury Island. The beds in this line of inland cliffs dip westward 12° to 15° ; the vertical faces of the cliff being preserved by the scaling off of large slabs of rock along the lines of joint which correspond with the strike of the beds.* On the level summit, wherever a small rivulet exists, this soft Foraminiferous deposit is exposed. I now append the description of specimens of this rock obtained from the inland cliffs above referred to.

A very friable rock, of a greenish-grey colour, containing from 3 to 10 per cent. of carbonate of lime, which consists of a few Coccoliths, and the following Foraminifera:—*Cassidulina crassa* (rare), *Uvigerina asperula* (few), *Truncatulina lobatula* (rare), *Rotalia soldanii* (rare), *Pulvinulina elegans* (rare), and fragments of *Globigerinæ*.

Minerals, about 60 per cent., consisting of mica, quartz, magnetite, hornblende, augite, felspars, many glassy fragments, scoriæ, and green fragments—glauconite ?

Fine Washings, about 30 per cent., consisting of argillaceous matter, fine mineral particles, glassy fragments, and fragments of scoriæ.

Note.—This rock seems to have been formed in comparatively shallow water, as it is made up chiefly of the débris of volcanic rocks washed down from the land, and afterwards mixed with the remains of minute organisms which live near the coast.

Deposits yet more recent than those which compose the mass of the island, I found exposed in the banks of the lower parts of the streams opening on the south coast. Here is displayed a bluish calcareous loam-rock containing Foraminifera and numerous Molluscan shells. The following are its characters :—

A very friable rock.

Carbonate of Calcium (6·52 per cent.), consists of a few Coccoliths ; fragments of Echinoderm, Lamellibranchiate, Pteropod, and Ostracode shells ; a few Aleyonium spicules ; and some Foraminifera (*vide* List).

Residue (93·48 per cent.), greenish-brown in colour, consists of—

(a) *Minerals* (50·00) m. di. 0·3 mm. A great quantity of magnetite,

* At the foot of these cliffs a rich red ochre-clay has accumulated, probably as washings from the cliffs above. It contains only 15 to 20 per cent. of mineral particles, and exhibits but a very slight effervescence with dilute acid.

felspar, hornblende, augite, many glassy fragments, and fragments of black organic matter.

(b) *Siliceous Organisms* (2·00), a few glauconitic-like casts.

(c) *Fine Washings* (41·48), argillaceous matter, fine mineral particles, many glassy fragments, and a greenish organic-like matter.

Foraminifera.—*Globigerina bulloides*, and var. *triloba*; *G. (Orbulina) universa*, *G. dubia*, *G. æquilateralis*, *Pulvinulina menardii* and *P. elegans*, *Sagrina*, *Bolivina*, *Nonionina*, *Polystomella*, and *Biloculina*. All these Foraminifera are in a dwarfed stage.

Molluscs.—*Nassa*, *Cylichna*, *Tellen*, and another bivalve (in numbers), also *Conus*, *Natica*, *Turritella*, *Melania*, *Monodonta*, *Dentalium*, *Bulla*, *Leda*, *Arca*, &c.: Pteropods represented by *Creseis* (in numbers), and *Hyalaea* (a few).

Echinoderms.—A species, probably of *Spatangus*, in numbers.

Miscellaneous.—Partially carbonised stems of plants; fragments of branching corals and volcanic rocks, 2 to 3 inches in diameter and under. Frequently penetrated by small tubular cavities, filled with coarse sand and minute shells, being the burrows probably of some annelid or crustacean.

This deposit displays a rudely laminated structure, the layers between 1 and 3 inches in thickness being steeply inclined 70° towards the coast. It forms the level ground on which the village of Saveki stands, removed 10 to 20 feet above the beach; and may be shortly described as formed from the washings of Treasury Island previous to its last upheaval. A very similar deposit is now in process of formation in the deeper parts of the harbour in depths below the coral zone, evidently derived in great part from the large amount of sediment brought down by the streams during the rains. Probably the above loam-rock was formed in a similar manner and at similar depths (20 to 50 fathoms), and the dwarfed condition of its Foraminifera may be attributed to the injurious effect of the fresh-water of the streams.

Hard Foraminiferal Limestone.—I have included under this name rocks which occupy the position of the coral limestone at the surface, but to which the term of coral rock is scarcely applicable. They are usually hard, compact, and of a yellowish-brown colour, and are largely composed of Foraminifera. In Treasury Island, as in the Shortland Islands, they are not unfrequently found on the crest of hills, but I never observed them at a greater elevation than 750 feet above the sea. Further information on the characters of these rocks is given in the portion of this paper devoted to the consideration of the coral limestones, so called (*vide* pages 564 and 575).

The Nucleus of Volcanic Rock.—I referred above to the partial exposure of the nucleus of volcanic rock around and over which have been formed the Foraminiferous muds and overlying coral-reef formations that have been described in detail. The only locality where the volcanic rock is exposed to

view is near the south side of the island. The large stream that opens into the harbour close to the village of Saveki, cuts through, at a distance of some 300 yards in a straight line from the coast, an amygdaloidal dolerite. This rock, which is here exposed in mass, is often porphyritic in structure. Up the adjoining slope of the hill-spur on the right side of the stream, fragments of this and other volcanic rocks may be found on the surface. At the height of 300 feet it is exposed *in situ*; and at intervals on the hill slopes above small fragments of volcanic rocks of somewhat varying characters* may be observed, even up to 900 feet above the sea. I have little doubt therefore but that the mass of the spur, overlooking the village of Saveki on the west, is of volcanic formation, being merely encrusted by the recent Foraminiferous muds and coral rocks.

History of the Formation of the Island.—By a reference to the section of Treasury Island (Pl. CXLIV. fig. 4), its structural history will be readily understood. An ancient submerged volcanic peak, having been covered by a thickness of several hundred feet of deposits, for the most part resembling the muds now being formed around oceanic volcanic islands, has finally been encrusted with coral reefs and been elevated above the sea to a height of nearly 1200 feet. How far beneath the surface of the sea this volcanic peak may have been originally submerged, it is difficult to say. But as bearing on this question I may here quote from Mr MURRAY's description of a hard Foraminiferal limestone, which was found at the surface. "The organisms in this rock, as well as the minerals, are," he writes, "similar to those found in deposits of modern seas in depths from 500 to 800 fathoms, near volcanic islands." The class of hard Foraminiferal limestones has already been referred to in connection with Treasury Island (p. 554).

That there have been pauses in the elevatory movement, there can be no doubt; but only the latest have left their marks behind at the present day. Thus, the broad ledge of coral rock which forms the sea-border was the work of a lengthened interval, since which there has been an upheaval of from 50 to 100 feet. At that time (*vide* Plan and Section Pl. CXLIV. figs. 3 and 4) Stirling Island appeared at the surface as a line of barrier-reef off the weather coast of Treasury Island, from which it was separated by a deep lagoon-channel between 50 and 60 fathoms in depth—the present harbour. The islets of coral rock, that lie inside Stirling Island, may possibly mark the position of other volcanic peaks. We have, however, in the coasts of the harbour and in the cliffs of Stirling Island, evidence preserved of yet more recent pauses in the elevation. An old sea-level is indicated in several places, since which there has been an upheaval of some 10 or 12 feet. But the most modern upheaval is shown in the margin of recently elevated and often well-preserved corals,

* Augite-andesite and porphyritic felsite, &c.

exposed about a foot at high tide, which fringes the shores of the harbour. Allowing for the rise and fall of the tide in this region, I estimate this most recent elevation at not less than 5 feet. It is of importance to note, as indicating the coincidences in the elevatory movements in this region of the Pacific, that in the islands of Ugi and Santa Anna, which lie over 400 miles distant at the opposite end of the Solomon group, there have been modern upheavals of the same limited extent (*vide* page 549).

The first page in the history of Treasury Island, as an island, began when the submarine volcanic peak had been brought up to within the depths at which reef corals thrive, by the constant piling up of sediment assisted by the upheaving movements. During these movements, the barrier-reef, now represented by Stirling Island, was formed by the outward growth of the reef. Coral reefs, however, have played but a secondary part in the actual building up of the island of Treasury as a whole.

THE ISLAND OF SANTA ANNA.

The small island of Santa Anna, at the eastern extremity of the Solomon group, presents an example of a raised atoll. Having a nearly circular form with a length and breadth of $2\frac{1}{2}$ and 2 miles respectively, this island consists of a central basin surrounded by an elevated rim which is wanting at the middle of the west or lee side. The bottom of the basin, which extends downwards to about 100 feet below the sea-level, is occupied by two fresh-water lakes (*vide* Plan and Section of this island Plate CXLIV. figs. 5 and 6).

The elevated rim has a broad level summit, varying between a quarter and one-third of a mile in width, and elevated 200 feet above the sea, except on the south and south-west sides of the island, where it has only half this elevation. From the middle of this raised margin, on the east or weather side, there rises an elevated mass to a height of about 470 feet above the sea, which gives to the island, when viewed either from the eastward or the westward, a profile resembling a broad-brimmed low-crowned hat. On the flat summit of this elevated mass, there is a basin-shaped hollow between 100 and 150 yards across and 35 or 40 feet in depth (*vide* Section Plate CXLIV. fig. 5).

The central depression may be described as a somewhat symmetrically shaped hollow, the bottom of which, lying about 100 feet below the sea-level, is occupied by two fresh-water lakes, the waters of which are not affected by the rise and fall of the tide, although lying at or about the mean tide-level. The interior of this island is, in fact, a closed basin, which is completely cut off from the sea; and it may be aptly compared to a bowl of fresh water floating on sea water. But so low is the barrier that shuts out the waters of the ocean—a barrier which is composed for the most part of coral detritus, calcareous sand, and shells—that a depression of about 25 feet would admit the sea into the

lakes, and a continuation of the downward movement to the same extent would transform the interior of the island into a large salt-water lagoon. In my traverses across this basin-shaped interior I found evidences of the sea having very recently occupied its lower levels. In the marshy ground in the vicinity of the lakes I occasionally came upon the coral rock exposed in flat surfaces resembling those of the ordinary reef-flat, whilst in the drier regions the soil was mixed with calcareous sand and shell "débris;" and numbers of sea shells, of ancient appearance from prolonged exposure, lay on the surface or were buried an inch or two beneath the soil. Many of these shells, belonging to the Ostræidæ, Cardiadæ, Neritidæ, &c., were encrusted on their inner surfaces by a dried calcareous mud. On opening one bivalve shell, with the two valves in apposition, the ligament having decayed, I found its interior to a great extent filled by this dried calcareous mud, which, from the impression that it retained of the soft parts of the Mollusc, afforded proof that the shell-cavity had become filled with this material before decomposition had set in.

The lakes, I should have added, do not occupy the centre of the basin but lie towards the western side of the island, the centre being marked by an eminence of coral limestone, the level summit of which is elevated about 160 feet above the sea. In concluding my description of the interior of this island, I will refer to the basin of Port Mary Harbour which lies opposite the break in the elevated rim on the west coast. The shore-reefs, which skirt the circumference of Santa Anna, here enclose a remarkable circular lagoon 700 to 800 yards in width, which, entered by a narrow passage, affords a snug anchorage for ships during the S.E. trade. Its depth is about 100 feet (16 to 17 fathoms), thus corresponding with the depth of the basin in the interior of the island, from which it is separated by a barrier of coral detritus, calcareous sand, and shells, that a depression of about 25 feet would, as above observed, completely submerge.

It was only by a detailed examination of this island that I was enabled to learn its true structure. Contrary to my expectations I found that, instead of being composed in mass of coral rock, this upraised atoll had been formed around a submerged volcanic peak which had been first invested, in great part, by a deposit of calcareous mud on which the reef-corals had commenced to grow.

The most interesting locality for the examination of the structure of the island is situated on the north coast. A mass of crystalline granular volcanic rock, an altered dolerite, here protrudes *in situ* 6 to 8 feet above the level of the reef-flat, forming a conspicuous object on the shore, and covering a space of 10 yards in horizontal extent. This ancient peak, if I may so term it, has evidently been denuded by the waves at the present sea-level; and in places most exposed to the action of the sea its surface is formed of water-worn frag-

ments of its own substance joined together in a calcareous cement.* My interest was engaged in a further degree in this locality, on observing that in the vicinity of the protruding mass of volcanic rock the flat was composed in places, not of the ordinary reef-rock, but of a soft argillaceous light-coloured rock that effervesced with an acid. Walking in a few yards from the beach I clambered up a slippery slope † between huge masses of coral limestone that had been detached from a line of cliffs above; and in a few minutes I became aware that I had made a discovery of some importance. A vertical precipice of coral limestone, about 80 feet in height, here rested on a friable argillaceous rock, light brown in colour and sparingly Foraminiferous (*vide* diagram of this locality, Pl. CXLIV. fig. 7). Appended is the description of this rock which Mr MURRAY has given to me:—

A friable earthy rock of a yellowish-brown colour, which, from the small size of the minerals, the absence of Foraminifera that inhabit the bottom, and the scarcity of pelagic forms, resembles somewhat a deep-sea clay; and displays a thin coating of manganese peroxide between the small layers or folds of the rock. A detached concretionary block of manganese peroxide, one or two cubic feet in size, was observed by Lieut. MALAN on the reef-flat on the north coast of this island, not far from the locality where the clay above described was met with. The typical fragment which was brought home is, Mr MURRAY says, quite similar to smaller masses dredged by the “Challenger” and Blake.

Carbonate of Calcium (20·79 per cent.) consists of *Coccoliths*, *Globigerina bulloides*, *G. (Orbulina) universon*, *G. conglobata*, *Pulvinulina menardii*, and a few small fragments of Echinoderms.

Residue (79·21) reddish-brown in colour, consists of—

- (a) *Minerals* (35·00) m. di. 0·08 mm., felspar, hornblende, one or two fragments of magnetite, with a few glassy fragments.
- (b) *Siliceous Organisms* (1·00), fragment of a sponge spicule noticed.
- (c) *Fine Washings* (43·21), argillaceous matter, very fine mineral particles and some glassy fragments.

Such being the characters of the deposit underlying the coral limestone, as exposed in this natural section, I now come to the consideration of the coral limestone itself, which is a hard compact rock resting abruptly on the soft underlying deposit. Imbedded in the base of this cliff of coral limestone were two dome-shaped masses of Astræan corals of different species, one of them

* A small patch of massive coral, which still adheres to its surface, probably found attachment during the most recent upheaval of the island (*vide postea*).

† This slippery slope, which is of the argillaceous rock to be immediately referred to, is in part encrusted by calcareous tufa, containing, at an elevation of 15 feet above the sea, a few small angular fragments of volcanic rocks. These fragments would appear to indicate the vicinity of the parent mass further in from the reef-flat.

being apparently an "Orbicella" (Dana). The larger mass measured 4 feet across; and both were in the position of growth. These imbedded corals were elevated about 40 feet above the sea, and from their position in the base of the cliff they must have been buried beneath not less than 80 feet of coral rock; whilst below them, on which in fact they almost rested, was the friable earthy deposit, or in other words, the partially consolidated ooze on which the reef began to grow, or over which it extended by lateral expansion. A coating of calcareous tufa concealed from view the upper portion of the face of the cliff, and thus prevented my examining its structure. It was evident that the undermining action of water which found its way between the base of the cliff and its soft foundation, assisted by the earthquake-shocks to which this region is liable, had caused large masses of the cliff to become detached, thus exposing the foundation of these upraised coral reefs. Another locality in this island in which I was able to find the rock subjacent to the coral limestone was on the western slope of the summit at an elevation of 200 feet above the sea. Here I found a stream issuing from the line of junction of the coral rock and an underlying earthy friable rock. On the south shore of Port-Mary I found masses of red ochre, protruding above the reef-flat.

Before drawing any inferences as to the thickness of the coral limestone in this island, I will refer briefly to the elevated eastern portion of the rim (*vide* Plan and Section Pl. CXLIV. figs. 5 and 6). Near the summit, and at an elevation of 400 feet above the sea, I found a volcanic rock (a hornblende trachyte) exposed *in situ* in the bed of a rivulet. Small fragments of this and of one or two other volcanic rocks (mostly gabbros) occur mingled with masses of coral rock on the summit, and are frequent in the small basin-shaped hollow there situated. With these exceptions, coral limestone forms the surface of the most elevated portion of the island, sometimes displaying faces 25 feet in thickness even at the lip of the summit. The occurrence, however, of a rubbly conglomerate of various volcanic rocks (for the most part gabbros), cemented together by a calcareous material, at the foot of the eastern slope of the island affords sufficient evidence of the proximity of the parent rocks, some of the blocks being from a quarter to half a ton in weight. In accordance with the greater age of the eastern side of the island as dry land, we should have expected to find it almost stripped of its calcareous coverings.

From the foregoing remarks, the following conclusions may be drawn as to the history of the formation of this island. *A submerged volcanic peak, having been covered by the accumulation of a deposit resembling a deep-sea mud, became the base of a coral-atoll, which has been subsequently upheaved together with its foundations, to a height of nearly 500 feet above the sea. The thickness of the coral crust probably does not exceed 150 feet, thus corresponding with the limit of depth at which reef corals are supposed to thrive.*

An inspection of the diagram referring to the north coast of Santa Anna will show that probably the underlying soft deposit is not much over 30 feet in thickness in that locality.

The various stages in the movement of elevation which this island has passed through since it first appeared at the surface of the sea are worthy of notice. There was a time in its history when the present summit alone appeared at the surface of the sea as a tiny atoll encrusting a submerged volcanic peak, the remains of which still exist in the shallow basin on the summit before referred to. Then succeeded a period of upheaval, during which, without any lengthened pause, this tiny atoll was raised to a height of from 250 to 300 feet above the sea. This was followed by a prolonged interval of rest during which the main atoll was formed, differing however from the typical atoll in that a pinnacle-islet rose up abruptly to a height of nearly 300 feet from the middle of the east side of the reef. Then commenced another long period of elevation, prolonged to the present time, during which the rim of the atoll has been raised 200 feet above the sea, the waters of which have been excluded altogether. There were pauses during this stage of elevation, the most marked being midway in the stage when that portion of the rim on the south side, which is only 100 feet above the sea, was formed. But in the lower levels, wherever the land descends by a gentle slope to the coast, the retrocession of the sea may be traced in the successive linear heaps of coral masses, 1 to 2 feet in height, which mark slight pauses in the elevation. The most recent upheaval is shown in an ancient line of erosion removed usually from 5 to 8 feet above the present line of wave-action. Where the coast is cliff-bound, the present and ancient lines of erosion are displayed in the faces of the cliffs; but where the coast is low, the old sea-level is to be found in a line of erosion, often worn back into caves, displayed in the base of a line of inland cliffs which are removed at distances varying from a few paces to a hundred yards from the beach, a low strip of recently elevated land supporting cocoa-nut palms and other vegetation intervening.

In concluding this reference to Santa Anna, I will make a few observations on the small adjacent island of Santa Catalina, which from its profile has evidently experienced the same stages in the upheaving movement, which Santa Anna has undergone during its last elevation of 200 feet. Santa Catalina is a low level-topped island elevated about 180 feet above the sea. Here, we have another ancient and originally submerged volcanic peak, which, having become encrusted by coral reefs, has been upheaved to a height of nearly 200 feet above the sea. Although the coral rock apparently forms the whole island, it is in reality but an outer crust, investing as a nucleus some ancient peak once submerged. In the beds of two small streams on the summit, I found exposed in mass a breccio-conglomerate formed of fragments of various volcanic and

calcareous rocks imbedded in an earthy calcareous matrix, together with another dark coloured rock of doubtful volcanic origin. It is therefore apparent that this small island of Santa Catalina existed as a patch of coral reef contemporary with the existence of Santa Anna as an atoll; and that the breccio-conglomerate was formed when the submerged peak, on which the patch of coral reef had based itself, came within the limit of breaker-action.

THE SHORTLAND ISLANDS.

This small group of islands consists of one principal island, named Alu, with a number of smaller off-lying islands and islets. Alu Island, which has a breadth of eleven or twelve miles and an elevation of about 500 feet, is composed in its N.W. portion of old and originally deep-seated volcanic rocks (mostly quartz diorites); while the greater part of it, together with the off-lying lesser islands and islets, may be described as made up of more recent calcareous formations.

The accompanying section of Alu (Pl. CXLIV. fig. 8) will explain the structure of this island and will show the relation to each other of the volcanic rocks, the coral limestones (so called), and the soft Pteropod and Foraminiferous deposit which apparently makes up the mass of the island. The two off-lying islets, shown in this section, are two broken lines of barrier-reefs which skirt the weather or S.E. coast of Alu Island. The innermost (marked B) is an ancient reef which has experienced an elevation of about 200 feet above the sea; while the outer reef (marked C) has been in great part formed at the present sea-level, having in no part been upheaved more than 20 feet above the sea. Both lines of reef have within them a lagoon-channel, which in the case of the inner or ancient line of barrier-reef is shoaling and evidently filling up.

The Shortland Islands have been upheaved along an extensive line of barrier-reef that skirts the eastern extremity of the adjacent large island of Bougainville at a distance of about 15 miles from the coast; and a conception may be obtained of the history of their formation by referring to the section before alluded to. Here we have the original land of volcanic rock in the N.W. portion of the group, from which, as from a nucleus, line after line of barrier-reef has been advanced in a south-easterly direction based on a foundation of Pteropod and Foraminiferous muds, and forming ultimately as the upheaving movement continued the large island of Alu, which yet preserves in the ridges of its interior these ancient barrier-reefs now removed far from the coast and elevated some hundreds of feet above the present sea-level. If we may judge from the existence off the weather coast of the double line of barrier-reef, before referred to, the island of Alu is still extending itself in the same direction.

The Soft Pteropod and Foraminiferous Deposit.—This deposit, which in all

its characters resembles the formation of Choiseul Bay, subsequently to be described, apparently composes the bulk of the island of Alu. It is exposed in the banks of the streams that open on the S.E. coast; and may be followed up in the higher parts of their courses in the interior, being also exposed in the lower slopes of the inland ridges at an elevation of 200 feet above the sea. Bedding is rarely well displayed on account of the limited character of the natural sections, the beds displayed having, however, a gentle inclination. In the mass it has the appearance of an argillaceous, earthy, moist rock, containing the shells of Pteropods in abundance, such as *Hyalæa*, *Diacria*, *Cleodora*, *Creseis*, together with numbers of Gasteropod and Lamellibranchiate shells, such as *Murex*, *Nassa*, *Hemicassis*, *Mitra*, *Natica*, *Dentalium*. Foraminiferous tests are present in profusion, the large tests of such as *Cristellaria cultrata* and *C. rotulata* can be picked out by the fingers. The otoliths of fish are also abundant. In addition, I found some simple corals referable to the deep-sea genera, *Odontotrochus*, *Flubellum*, *Bathyactis* (*symmetrica*?), portions of the shells of a sessile Cirriped; and occasional leaves with their venation in a condition of fair preservation. The Pteropods, bivalves, otoliths, and Foraminifera, are from their numbers most characteristic of this deposit.

Mr MURRAY thus describes the characters and composition of specimens of this deposit:—

A very friable rock, chiefly composed of volcanic ashes with great numbers of minute imbedded organisms, and resembling the “volcanic muds” in character.

Carbonate of Calcium (33·67 per cent.), consists of Coccoliths, Otoliths, Gasteropod and Lamellibranchiate shells, Pteropod and Heteropod shells, Polyzoa, Serpulæ tubes, Ostracode shells, Echinoderm fragments, and many pelagic and bottom-living Foraminifera. (See list below.)

Residue (66·33), brown, consists of—

- (a) *Minerals* (40·00), m. di. 0·5 mm., some particles 1·0 mm.; felspar, magnetite, augite, hornblende, mica, quartz, &c.; and a great many glauconitic-like casts of Foraminifera.
- (b) *Siliceous Organisms*.—None noticed.
- (c) *Fine Washings* (26·33), argillaceous matter with fine mineral particles, and black fragments of organic matter.

List of Foraminifera.

Miliolina seminulum (rare).	Cristellaria cultrata (few).
Biloculina depressa „	„ calcar „
Reophax pilulifera (very few).	„ aculeata „
Bulimina marginata (rare).	„ italica „
Pleurostomella alternans (few).	„ echinata „
Chilostomella ovoidea (many).	„ vortex „
Cristellaria rotulata (few).	Uvigerina tenuistriata (common).

Uvigerina pygmaea (rare).	Globigerina aequilateralis (many).
Nodosaria hispida (few).	„ inflata (few).
„ papillosa „	„ orbulina (universa) (many).
„ raphanus „	Sphaeroidina dehiscens (many).
„ filiformis (rare).	Ramulina globulifera (rare).
Sagrina virgula (common).	Truncatulina præcineta (few).
„ columellaris (very common).	„ lobatula „
Lagena hispida (few).	„ haidingerii „
„ desmophora (few).	Pulvinulina menardii (common).
Globigerina bulloides (common).	„ „ var. tumida „
„ „ var. triloba „	„ elegans (few).
„ conglobata „	„ micheliniana „
„ dubia „	„ procera „
„ sacculifera „	Pullenia obliquiloculata (few).
„ rubra (many).	„ sphaeroides „

The Coral Limestone.—This rock is found capping the inland ridges (as shown in the section) where it does not attain a greater thickness than 30 to 40 feet, being usually much less. It displays considerable variety in its characters; and had I not satisfied myself of its true relation to the underlying soft deposit previously described, I should hesitate in coming to the conclusion that all the varieties belonged to an ancient barrier-reef. By striking the inland ridge (marked A in the section) where it approaches the coast and following along its crest for some three or four miles, one first finds capping the ridge and overlying the soft deposit a hard compact yellowish-white coral limestone containing many *Amphisteginæ*. Further along, as the ridge gradually rises from 150 to 200 feet above the sea, this coral rock displays itself as a chalky limestone capping the ridge and exposed in huge masses, with vertical faces 30 to 40 feet high, on its slopes. These large masses resembled much in their position and appearance ancient reefs still occupying the sites they originally held beneath the sea. The superficial position of this chalky coral limestone and its relation to the underlying soft Foraminiferous deposit are points of some interest.* Appended is the description given by Mr MURRAY:—

A compact chalk-like coral limestone of a cream colour, showing no definite structure, and resembling in section the Lower Chalk of Kent, if the corals are not taken into consideration.

Carbonate of Calcium (95·76 per cent.) consists of Lamellibranchiate shells, Polyzoa, Echinoderm fragments, corals, calcareous Algæ, and Foraminifera as *Nummulina*.

* I found a similar chalk-like coral rock in the small island of Biu which lies off the north end of Ugi Island. This island is only $1\frac{1}{2}$ miles in length and about a hundred feet in height in its centre where this rock was found. It may be briefly described as a patch of coral reef which has been elevated about a hundred feet. In the southern island of the Three Sisters, which are adjacent to Biu, I obtained from the elevated central portion hand-specimens of coral rock which were in part chalky. This island, like Biu, is simply a patch of coral reef which has been upheaved 60 or 70 feet above the sea. The present reefs which skirt the more elevated portion have a rude atoll form.

Residue (4·24), yellowish-red in colour, consists of—

- (a) *Minerals* (2·00) m. di. 0·1 mm.; magnetite, felspar, hornblende, augite, a few casts of small Gasteropod and Lamellibranchiate shells, and many little spheres.
- (b) *Siliceous Organisms*, none noticed.
- (c) *Fine Washings* (2·24), a reddish argillaceous and flocculent material and fine mineral particles.

Another sample of this chalky coral limestone, which was made up chiefly of decomposed coral and calcareous Algæ and held 99·23 per cent. of carbonate of calcium, approaches to a magnesian limestone, on account of the considerable amount of magnesia which it contains.* In a third sample the only recognisable organisms are calcareous Algæ.

As one proceeds further inland along the crest of the ridge, which pursues a very uniform direction, the chalk-like coral limestone is left behind; and rising gradually with the ridge crest to from 300 to 350 feet above the sea, one finds a yellowish-brown Foraminiferous limestone taking its place, both capping the ridge and overlying the soft deposit. The following are its characters:—

A hard compact Foraminiferal limestone, of a yellowish-brown colour. A few simple corals are imbedded in this rock, but the bulk of it is made up of pelagic and bottom-living Foraminifera.

Carbonate of Calcium (76·69 per cent.) consists of Echinoderm fragments, Pteropod shells, and Foraminifera, as follows:—*Globigerina bulloides*, *G. hirsuta*, *G. Orbulina (universa)*, *Pulvinulina menardii*, *Carpenteria*, *Nodosaria*, and *Amphistegina*.

Residue (23·31), consists of—

- (a) *Minerals* (6·00) m. di. 0·4 mm.; mica, a few perfect crystals of quartz, felspar, augite, and glassy fragments.
- (b) *Siliceous Organisms* (10·00), perfect casts of the Foraminifera of a reddish colour.
- (c) *Fine Washings* (7·31), broken down parts of casts of Foraminifera and a few fine mineral particles.

In the elevated barrier-reef through which the section passes, somewhat similar rocks are displayed. In this islet (marked B in the section), which

* Dr LEONARD DOBBIN, who determined for Mr MURRAY the carbonate of lime in the rock samples, writes:—"I would draw your attention to the result obtained in the case of the sample 'Shortland Island, No. 587,' where the usual calculation, from the observed weight of carbonic acid, seems to indicate an almost theoretical composition of calcium carbonate. As our method could not give such a result with pure calcium carbonate (the results being in every case at least 2 per cent. too low), I tried to find out the cause of this rather anomalous result. The first and most likely explanation was that the specimen contained considerable quantities of magnesium carbonate, and I find that is the correct explanation, as I found on examining it that a good deal of magnesia is present. I may add that the carbonic acid is not liberated from this specimen with anything like the rapidity with which it is liberated from the other specimens."

is named "Poperang" and has a height of 200 feet, the soft deposit is rarely, if ever, exposed, on account probably of the small erosive power of the streams. Here we find the chalky limestone containing 95 per cent. of calcium carbonate and composed of fragments of Molluscan shells and of Echinoderms, with calcareous Algæ, and the following Foraminifera :—*Globigerina*, *Polytrema*, *Carpenteria*, and many *Amphisteginæ*. On the slopes also is exposed a hard Foraminiferal limestone, chiefly made up of the tests of pelagic and bottom-living Foraminifera, and containing 82 per cent. of calcium carbonate. The Foraminifera found in specimens of this rock had crystals of calc spar in their cavities ; they include the following :—*Globigerina bulloides* and other species, *G. Orbulina (universa)*, *Pulvinulina menardii* and *miceliniana*, *Pullenia obliquiloculata*, *Planorbulina*, *Polytrema*, *Rotalia*, *Calcarina*, &c.

But the bulk of this islet of "Poperang" is of a unique formation, which may be termed the Rhynconella limestone on account of the number of Brachiopod shells of that genus that are there imbedded. This limestone may be briefly described as a hard grey rock containing numbers of Brachiopod, Gasteropod, and Lamellibranchiate shells, with many simple corals of deep-sea genera, imbedded in a calcareous matrix largely composed of the tests of Foraminifera. I did not observe bedding in this limestone. Further details of the imbedded organic remains and of the composition of the rock are subjoined.

The Brachiopod shells all belong to the same species of *Rhynconella*. Mr DAVIDSON, to whom they were submitted for examination, is inclined to look upon them as belonging to *Rhynconella Grayii*, a species represented hitherto by a single specimen discovered in the British Museum amongst other natural history objects from the Fiji Islands (?) collected by Mr J. M'GILLIVRAY. This unique specimen was described by Mr S. P. WOODWARD and figured by Mr DAVIDSON, in the *Annals and Magazine of Natural History* as far back as 1855 (vol. xvi. p. 444, plate 10, fig. 16). Since that time no other recent specimen has been discovered. Hence has arisen the difficulty in pronouncing as to the identity of species since the comparison of a number of fossil specimens with a single recent living one does not afford sufficient material for exact determination.* I am indebted

1, 2, *Rh. Grayii*, Solomon Group.
3, *Rh. Grayii*, Fiji Island.

* The appearance of this solitary specimen of *Rhynconella Grayii*, which is contained in the British Museum collection, might suggest its having been washed out of some recent deposit. I am informed, however, by Mr DAVIDSON that portions of the mantle, peduncle, and some muscular fibres were still attached to the shell.

to Mr DAVIDSON for the accompanying figures of the fossil and living specimens. The Gasteropod and Lamellibranchiate shells are such as live in the shallow waters at the present day. A few *Pteropod* shells occur in the rock belonging to *Hyalæa*; and some *Serpula* tubes are also found. The Simple Corals belong to the deep-sea genera, *Leptocyathus*, *Stephanophyllia*, *Odontocyathus*, *Flabellum*, &c.; but since the shells with which they are associated are of shallow-water habit, as I am informed by Mr E. SMITH, this limestone would appear to be a comparatively shallow-water deposit. The Foraminifera forming largely the matrix of the rock include the following pelagic species :—*Pullenia obliquiloculata*, *Globigerina hirsuta*, *G. æquilateralis*, *G. Orbulina (universa)*, *Pulvinulina menardii* and *miceliniana*, &c.

The composition of this limestone is as given below :—

Carbonate of Calcium (75·23 per cent.) consists chiefly of Foraminiferous tests of pelagic species with fragments of Echinoderms, Gasteropods, Lamelli-branches, and Brachiopods.

Residue (24·77) consists of—

- (a) *Minerals* (10·00); felspars, augite, hornblende, and glassy fragments; often surrounded by a red coating, apparently a silicate.
- (b) *Siliceous Organisms* (11·77), a very large number of casts of the Foraminifera of a red colour.
- (c) *Fine Washings* (3·00), broken parts of Foraminiferous casts.

Such then are the characters of this limestone rock. The occurrence in it of a species of *Rhynconella* closely allied to, if not identical with, a species that is represented only by a solitary specimen which was described thirty years ago, is one of the more noticeable features in connection with this rock. Another feature is the imbedding of corals belonging to deep-sea genera in a comparatively shallow-water deposit.

Coming now to the outer line of barrier-reef (marked C in the section) it will be sufficient to describe it as formed in great part at the present sea-level. The elevated portion, which has been raised some twenty feet above the sea, is formed in many places of massive reef-corals imbedded in the position of growth.

CHOISEUL BAY.

The large island of Choiseul, as viewed in profile from the islands of Bougainville Straits, has the appearance of a level-topped ridge destitute of peaks, and not elevated more than from 1500 to 2000 feet above the sea. A line of barrier-reef skirts the west end of the island and encloses Choiseul Bay which receives the waters of three large streams that flow through wide belts of mangrove swamps in the lower parts of their courses. About half a mile

from its mouth one of these streams, in cutting across the extremity of an outlying spur of the neighbouring hills, exposed a soft earthy rock bedded with a gentle inclination of 2° to 3° , and abounding with organic remains. This rock resembles the prevailing formation of Alu, the principal island of the adjacent Shortland Islands already described. Further up the stream, the same deposit was exposed in the banks, until I reached a narrow gorge rather over a mile direct from the coast, the sides of which were of a chalky coral limestone. This limestone I traced up the slopes of an adjoining cluster of hills to an elevation of about 120 feet above the sea. A grained limestone* then appeared at the surface, and composed the summit of the hill, which was elevated about 200 feet above the sea.

Subsequently I ascended another stream which opened into the bay. After following its course through the mangrove belt for about two-thirds of a mile, I struck off on foot through the swamp, and came upon a mound about 35 feet high—an outlier of the neighbouring hills—which rose up like an island from the midst of the swamp, and was formed of the same deposit, similarly laden with organic remains, as that which I had observed during my ascent of the neighbouring stream. Ascending one of the outlying hills to a height of about a hundred feet above the sea, I found the same deposit, but not sufficiently exposed, however, to display bedding.

Unfortunately the uncertain reputation of the natives restricted my field of observation. I was, however, able to satisfy myself that the mass of the low-lying land near the coast was of this soft earthy deposit, the characters of which will be now described.

When in the mass, it has the appearance of an argillaceous earthy rock, somewhat moist and effervescing with an acid; and displaying to the eye numerous Pteropod shells of the genera *Hyalæa*, *Diacria*, &c., Lamellibranchiate and Gasteropod shells, the tubes of *Dentalium* being especially noticeable; otoliths of fish; macroscopic tests of such Foraminifera as *Cristellaria cultrata*, *Nodosaria soluta*, &c., together with numbers of shells of the more microscopic kinds; and, lastly, often fragments of leaves. Subjoined is the description given by Mr MURRAY of samples of this deposit:—

A very friable rock, of a greenish-grey colour, having the composition of a Foraminiferous ooze mixed with much volcanic débris (it resembles the Shortland deposits in all its characters).

Carbonate of Calcium (33·14 per cent.) consists of otoliths of fish, Pteropod and Heteropod shells, Gasteropod and Lamellibranchiate shells; Serpula tubes, Ostracode valves, Echinoderm fragments, with many pelagic and bottom-living Foraminifera (*vide* List).

* This grained limestone has not been examined by Mr MURRAY. It, however, closely resembles in appearance the Foraminiferal limestones of Alu, and is probably of the same character.

Residue (66·86), of a dark green colour, consists of :—

(a) *Minerals* (40·00) m. di. 0·3, some fragments 1·0 to 2·0 mm.; mica, quartz, felspar, hornblende, magnetite, augite; many glassy fragments. A few beautifully formed quartz crystals were found in this rock.

(b) *Siliceous Organisms*.—None noticed.

(c) *Fine Washings* (26·86).—Green organic-like substance with argillaceous matter and fine mineral and glassy fragments.

Many glauconitic-like casts of most of the organisms mentioned above were also obtained in this rock.

List of Foraminifera.

Biloculina ringens (rare).	Cristellaria compressa (rare).
Miliolina seminulum (several).	„ dentata (rare).
Reophax pilulifera (few).	„ italica (few).
Textularia sagittula (rare).	Globigerina bulloides (common).
Bulimina marginata (rare).	„ „ var. triloba (common).
Nodosaria soluta (several).	„ sacculifera (common).
„ raphanus (rare).	„ dubia (many).
Rhabdogonium tricarinatum (rare).	„ æquilateralis (few).
Virgulina subsquamosa (few).	„ Orbulina (universa) (many).
Uvigerina tenuistriata (many).	Sphæroidina dehiscens (many).
Sagrina virgula (common).	Pullenia obliquiloculata (rare).
„ columellaris (common).	Cymbalopora poeyi? (few).
„ striata (few).	Truncatulina lobatula (rare).
Frondicularia alata (rare).	„ rostrata (many).
Cristellaria cultrata (few).	„ præcineta (many).
„ papillosa (few).	Ramulina globulifera (rare).
„ calcar (few).	Pulvinulina menardii (common).
„ aculeata (few).	„ „ var. tumida (common).
„ articulata (few).	„ elegans (few).

The chalky coral limestone, before referred to as forming the sides of a gorge in the higher part of one of the streams, presents most of the characters of true chalk. It was exposed in faces 20 feet in thickness; but I was unable to ascertain its position relative to the soft Foraminiferous deposit exposed in the sides of the stream lower down. However, a similar chalk-like limestone in the Shortland Islands overlies the softer deposit, as noticed in the description of those islands.

Mr MURRAY describes the characters of specimens of this interesting rock which I sent to him, as follows :—

A friable chalky coral limestone rock, of a light creamy colour, showing no definite structure.

Carbonate of Calcium (94·19 per cent.) consists of Lamellibranchiate shells,

coral, *Serpula* tubes, Echinoderm fragments, Alcyonium spicules, and Foraminifera, as *Globigerina*, *Polytrema*, *Rotalia*, and *Nummulina*.

Residue (5·81) of a light brown colour, consists of—

(a) *Minerals* (2·00), m. di. 0·1 mm.; felspar, augite, hornblende, magnetite, and a few glassy fragments.

(b) *Siliceous Organisms* (1·00); a few fragmentary sponge spicules.

(c) *Fine Washings* (2·81), consisting of a flocculent substance.

Sections of this rock show specimens of all the organisms mentioned above, together with calcareous Algæ and *Carpenteria*.

In concluding these observations on this locality, I may remark on the probable geological character of the elevated interior of this portion of Choiseul Island. Judging from my partial examination of the lower slopes, and from the significant profile of the high land behind, I think it probable that the western portion of this large island will be found, on examination, to exhibit the same geological structure as that which characterises the islands of Treasury, Ugi, and other islands in the Solomon group.

ST CHRISTOVAL.

The large island of St Christoval, which is rather over 70 miles in length and about 4100 feet in elevation, may be taken as probably representative, respecting its raised calcareous formations, of the larger islands of the Solomon group. My examination of the island was considerably curtailed on account of the uncertain disposition of the natives. I was able, however, to obtain a general acquaintance with the north coast and its vicinity, together with such knowledge of the interior of the island as a traverse across its breadth from Wano to Makira and various ascents, never exceeding 1400 feet, could afford me.

The north coast is skirted by a margin of low-lying land of varying breadth, which in its turn is fringed by shore-reefs along a large portion of its extent. This low-lying margin is either of calcareous sand, shells, and coral detritus, imperfectly mixed with humus, when it is raised from 2 to 4 feet above the sea; or it is of coral rock elevated 5 or 6 feet at the sea-coast, and rising to some 15 or 20 feet as one proceeds inland.

The general character of the mountainous interior is that of a parallel series of long level-topped and gently rounded ridges, separated by deep valleys from each other, and composed, as far as my limited field of observation enables me to judge, of ancient volcanic rocks. From the elevated interior several lofty spurs descend with a gentle slope and even profile to the north coast, where they protrude as bold headlands that often retain an elevation of 800 or 1000 feet. My observations have shown that the masses of these headlands are of old basic rocks; whilst more recent calcareous formations encrust their

lower slopes. Such is without doubt the geological structure of Cape Keibeck, which has an elevation of over 1100 feet at the coast. I traced the coral limestone as high as 500 feet above the sea when examining this cape, this being the greatest elevation at which the coral rock came under my observation in St Christoval. In many parts of the coast a fawn-coloured crystalline limestone, with homogeneous texture, in which sometimes reef débris can be observed, in fact just such a rock as might arise from the consolidation of the white ooze of coral reefs, takes the place of the coral rock. I followed it up to about 500 feet above the sea. It is probably of no great thickness, its relation to the underlying volcanic rocks being often displayed in the courses of the smaller streams.

I will here relate my experience in the case of a hill that lies on the east side of Wano Bay, since it is very typical of my experiences in other parts of this coast. During two different ascents, in which I purposely avoided the courses of the streams, I traced the coral rock on the surface to a height of 150 feet above the sea, and at the summit, 400 feet up, I found the fawn-coloured limestone before alluded to. In no place during these ascents did I find a fragment of volcanic rock at the surface; but when, taking advantage of the deep gulleys that had been worn by the streams into the mass of the hill, I availed myself of the rude sections of the hill's substance there displayed, I found in position the old volcanic rocks (altered dolerites).

These volcanic rocks are not uncommonly exposed protruding in mass above the flats of coral formation which skirt the coast. Doleritic rocks project through the coral rock on the point east of Wano Bay; whilst in the vicinity of Cape Keibeck, a dolerite, from which the coral rock that originally invested it has been but partially removed, protrudes in mass to a height of 10 or 12 feet above the reef-flat. Pebbles and small blocks of volcanic rocks are frequently to be observed in the reef-rock all along this north coast of St Christoval.

With reference to the estimation of the thickness of these encrusting calcareous deposits, I have no certain data. The fawn-coloured limestone, as has been remarked above, can be of no great thickness; whilst the coral limestone, which I rarely saw exposed in faces exceeding 20 feet in height, probably constitutes a thinner crust than I have found in other parts of the group. Without doubt these calcareous envelopes originally extended to far higher levels, from which they have been stripped by the agency of subaerial denudation, which in these regions of great rainfall must be very rapid. From my observations of the rainfall in this archipelago, I am inclined to estimate the annual amount at usually not much under 150 inches.* Of the rapid

* This estimate refers only to the coast. In the elevated interiors of the larger islands the annual fall is probably twice as much; whilst on the lofty summits of Bongainville and Guadalcanar the rainfall is still greater.

degradation of the surface which these calcareous districts undergo during a heavy fall of rain, of as much as 2 to 3 inches in the same number of hours, I have been a frequent witness. In a few minutes the whole hill-slope discharges a continuous sheet of muddy water, the rivulets swell to turbid streams, and the water rushes down the permanent courses with the roar of a mountain torrent. After the rain-storm has passed away, the band of muddy water that fringes the whole length of coast, to a distance of one-quarter or one-third of a mile from the shore, indicates the loss of material which the land surface has sustained.

The bedded Foraminiferous deposit that forms the mass of the neighbouring island of Ugi is rarely represented among the coast formations of St Christoval. I came upon it only once in position exposed in the banks of a stream near the coast.* The coral rock and the fawn-coloured limestone here appear as a rule to rest directly on the volcanic rock. Occasionally in different parts of the coast I found a coarsely grained deposit composed of the water-worn débris of volcanic and coral rocks with a few shells imbedded.

THE FLORIDA SUB-GROUP.

From the few traverses which I made in this sub-group I learned that the western islands are more of volcanic formation, whilst the large island on the east side of the narrow passage which bisects the main mass of land is composed on the surface largely of recent calcareous formations. It is to this eastern island that I will restrict my remarks. Traversing it in a S.W. direction from the vicinity of Mboli Harbour to the village of Gaeta, I found an argillite and a dark trap-rock scantily exposed in the lower hill-slopes. At a height of 500 feet a grained limestone associated with a limestone conglomerate appeared at the surface. The coral limestone occurred at an elevation of 600 feet above the sea, and formed the surface up to rather over 900 feet—the greatest elevation I attained. In one locality it displayed a joint-structure. Descending on the other side of the range, the grained limestone occurred at the same height, and I traced these calcareous formations down to about 200 feet above the sea. In the vicinity of the village of Gaeta, which is elevated rather over 100 feet, a volcanic rock appeared at the surface and was exposed in the bed of a neighbouring stream.

I subsequently made an excursion into the interior of the island for a distance of between two and three miles N.N.E. from Gaeta. I traversed a region of coral limestone gradually rising until an elevation of about 350 feet

* A similar rock, but sparingly Foraminiferous, occurs on the slopes of Cape Keibeck at an elevation of 500 feet above the sea.

was attained, when I descended into a deep valley and followed up the bed of a large stream, which finally emerged from a cavern of considerable dimensions in the face of a hill of coral limestone. This cavern was first visited by the Rev. Mr PENNY of the Melanesian Mission, and was subsequently explored by Bishop SELWYN, to whom I was indebted for the opportunity of examining it. The interior, the entrance to which is between 60 and 70 feet in height, presents the usual features of these subterranean cavities. A series of lofty chambers, connected by narrow passages and containing numerous stalactitic and stalagmitic columns in all stages of formation, some of them between 1 and 2 feet in diameter—such is the character of this cavern which Bishop SELWYN found to be about 750 yards in length. I emerged from the farthest mouth into the bottom of a deep valley, across which the coral limestone hill lies as a dam through which the stream has found its way. In the bed of the stream, as it follows its subterranean course, there are numerous blocks and pebbles of a dark crystalline volcanic rock and of a marley rock, of which I was unable to find the parent rocks in the valley above. They are probably traversed by the stream in its passage through the hill, where they would be concealed from view by the stalagmitic and stalactitic deposits. The marl presumably represents the immediate foundation of the limestone, and will be found to cover the crystalline volcanic rock. From the presence of these rocks in the bed of the stream as it flows through the caverns, I suspect that these subterranean passages traverse the base of the limestone ; and on this supposition the thickness of this coral limestone would be not greater than the height of the hill which is pierced by the stream, *i.e.*, about 150 feet.

The general conclusion that I formed of the structure of this eastern island of the Florida Sub-group was, that the calcareous rocks were merely superficial formations encrusting a nucleus of volcanic rocks which has been occasionally exposed to view by the denuding forces.

THE CLASSIFICATION OF THE SOLOMON ISLAND RECENT FORMATIONS.

These rocks may be grouped into two chief classes, according to the proportion of volcanic débris they contain.

The First Class comprises those rocks which, being largely composed of such volcanic débris mixed with the tests of Foraminifera, Pteropods, and other Molluscs, have a composition very similar to that of the volcanic muds at present forming around oceanic volcanic islands in the Pacific. These rocks contain both pelagic and bottom forms of Foraminifera, lists of which have been given in the previous pages. The soft rock, resembling a deep-sea clay, which underlies the elevated reef-mass at Santa Anna, may be referred to this principal division of the rocks ; but, as shown in the description on page 558,

it differs essentially from all the other deposits of the class. Four prevailing kinds of these rocks may be distinguished.

- (1) A friable rock, containing from 5 to 20 per cent. of carbonate of lime, and displaying to the eye only the white specks of minute Foraminiferous tests with a few of macroscopic size, such as *Cristellaria cultrata* and *Nodosaria soluta*, Molluscan shells being rarely observed. Rocks of this character form the masses of Treasury and Ugi Islands; and their composition is described in detail in the sections treating of those islands (*vide* pages 547, 551, 552).
- (2) A very friable rock, containing from 30 to 35 per cent. of carbonate of lime, and inclosing in great numbers the shells of Pteropods, Gasteropods, Lamellibranchs, together with otoliths of fish, simple corals, and numbers of Foraminiferous tests, many of them macroscopic. Rocks of this character largely compose Alu, the principal island of the Shortlands, and are exposed in the low hills in the rear of Choiseul Bay (for the detailed descriptions, see pages 562, 567).
- (3) A hard grey fossiliferous limestone, containing usually about 60 per cent. of carbonate of lime, and much volcanic débris. It is chiefly composed of the broken down fragments of corals and Lamellibranchiate shells, with calcareous Algæ, and a few Foraminifera. This rock is exposed in the lower courses of the Treasury Island streams, where it gives rise to water-falls on account of its greater hardness. Its further description is given on page 552.
- (4) Coarse rocks, composed of the fragments of volcanic and coral rocks in rounded grains. Occasionally larger fragments, together with shells, are imbedded. These rocks occur on the northern slopes of St Christoval, near the coast.

The Second Class includes those rocks which are largely composed of coral, Molluscan shells, Foraminiferous tests, and calcareous Algæ, with but a small proportion of volcanic débris. The share that each of these four principal constituents takes in the building up of the rock differs widely; and on this basis the following groups have been made. Yet to the great majority of these rocks, if not to all, the term of coral limestone is quite applicable in its widest sense. Probably, however, the term "coral-reef formation" would be preferable, as including the variously composed rocks that are being formed in connection with coral-reefs. Whether the rock is formed by the upward growth of successive tiers of large masses of reef-corals, or whether it is formed from the fragments of such corals broken off by the waves and mixed with shells and other organisms in varying proportions, such as must be forming on the outer slopes of reefs, it has the same coral origin. For the same

reason, the calcareous muds and sands found at the bottom of the lagoons are of coral origin, representing as they do the final stages of the process of degradation. The variety in character exhibited in the following groups of coral limestones may be thus in a great measure explained :—

- (1) Coral rocks, properly so called, which are merely the massive reef-corals in different stages of fossilisation. The porous and small-celled corals, as the *Poritidæ*, are the first to lose their characteristic structure, usually passing through a drusy stage, when they present a saccharine appearance, and finally, by the continued percolation of water charged with *calcium carbonate*, assuming a compact texture exhibiting no coral structure to the eye. Such coral rocks are best observed at the coast.

Here I may refer to a peculiar variety of coral rock which is not uncommon on the south side of Treasury Island on the higher slopes of the hills, as high as 750 feet above the sea. It is a hard, compact, partly crystalline greyish rock, chiefly made up of a coral belonging to the *Fungidæ*, which Mr J. J. QUELCH, to whom fragmentary specimens were submitted for examination, has identified as being with very little doubt *Leptoseris striatus* (Kent), a species founded for the reception of a rare coral collected by Capt. Sir E. BELCHER at Borneo, (the only other recorded specimen being from Madagascar (?). This coral is not included amongst my collection of reef-corals in the Solomon Islands. It may probably, however, occur in the deeper water.*

- (2) Coral rocks, which are chiefly made up of calcareous Algæ,† fragments of Molluscan shells, corals, and Echinoderms, the interstices being filled up by the tests of Foraminifera and other small calcareous organisms. In the composition of such rocks, coral fragments take only a secondary part. The majority of coral limestones that I found in the Solomon Islands may be referred to this division. They are usually white in colour, but often reddish or yellowish brown, being hard, compact, and sometimes partly crystalline in texture, and often displaying a fragmental structure. The percentage of calcium

* In one of the islands of the Pelew Group, Professor SEMPER observed that the base of the coral cliffs was formed entirely of species of *Lophoseris* mixed with other deep-sea forms, the higher portion of the cliffs containing *Astræidæ*, *Poritidæ*, *Madreporidæ*, &c. *Lophoseris* and *Leptoseris* belong to the same sub-family of the *Fungidæ*. See *The Natural Conditions of Existence*, &c., p. 275, London, 1881. I am inclined to consider this variety of rock in Treasury Island as representing the base of the elevated reef-masses, since it only occurs on the higher and more denuded slopes.

† Some specimens of coral rock which I obtained at Santa Anna were entirely formed of the joints of a calcareous Alga, resembling apparently the genus *Halimeda*, which are found commonly in the soundings off the outer edge of the present coral reefs.

carbonate in this group varies between 90 and 95, the *residue* consisting of the minerals named in the subjoined analysis, of Foraminiferous casts, and argillaceous matter.

The Composition of a Typical Sample.

Carbonate of Calcium (94·47 per cent.), consisting of the various materials mentioned above.

Residue (5·53), consisting of—

- (a) *Minerals* (1·00) m. di. 0·2 mm.; augite, hornblende, felspar, magnetite, and a few glassy fragments.
 - (b) *Siliceous Organisms* (2·00), casts of Foraminifera, &c., of a red colour.
 - (c) *Fine Washings* (2·53), broken down parts of casts of Foraminifera, fine mineral particles, argillaceous matter, and a red material—probably oxide of iron.
- (3) Compact fawn-coloured crystalline limestones of a homogeneous texture, apparently formed by the consolidation of the ooze found at the bottom of the lagoons inside coral-reefs. These rocks are of common occurrence on the lower slopes of the large island of St Christoval, where they overlie the volcanic rocks of the district. They are sometimes coarse-grained.
- (4) Chalk-like coral limestones, which contain about 95 per cent. of calcium carbonate, and are chiefly composed of the fragments of Molluscan shells, Echinoderms, corals, calcareous Algæ, and Foraminifera. These rocks, therefore, in their general composition resemble the rocks of the second group of coral limestone differ conspicuously in their chalk-like appearance and in being more friable. They occupy, however, the usual surface position of other coral rocks (as shown in the description of the Shortland Islands, page 563), although being by no means of common occurrence. They may sometimes be found in the central elevated portions of islands like Biu, which have been formed by the partial upheaval of coral reefs. I found them only on four occasions in the Solomon group, viz., at Alu, Choiseul Bay, the Three Sisters, and Biu Island. Their composition is described at length in pages 563, 568.
- (5) The Foraminiferal limestones, which are grey or yellowish-brown in colour, hard and compact in texture, and are chiefly made up of the tests of pelagic and bottom-living Foraminifera. They contain generally from 75 to 85 per cent. of calcium carbonate, their typical

* White men resident in the group tell me that chalk-like rocks are found in the island of Ulaua, which lies near the Three Sisters.

composition being described on page 564. They usually, like the coral limestones, are found at the surface; and in the island of Alu they overlie the soft Pteropod deposits, as described on page 564. In Treasury Island they occur on the tops of the lower hills.

In the island of Treasury, however, I found exposed in a stream-course a Foraminiferal limestone of somewhat different character, and occupying the usual surface position of the coral limestones. Appended is the description of this rock.

A hard, compact, grey, Foraminiferal limestone, showing a simple coral imbedded, the whole rock chiefly composed of pelagic Foraminifera.

Carbonate of Calcium (66·26 per cent.) consists of the following Foraminifera—*Globigerina bulloides hirsuta*, *G. (Orbulina) universa*, *Pullenia obliquiloculata*, *Pulvinulina menardii*, *Amphistegina*.

Residue (33·74), brown colour, consists of—

- (a) *Minerals* (20·00) m. di. 0·5 mm.; felspar, hornblende, augite, magnetite, mica, and many glassy fragments.
- (b) *Siliceous Organisms* (3·00), casts of Foraminifera.
- (c) *Fine Washings* (10·74), argillaceous matter and fine mineral particles.

The organisms in this rock, together with the minerals, are similar to those found in deposits of modern seas near volcanic islands at depths of from 500 to 800 fathoms. The Foraminifera are identical with those found in the surface waters of the tropics at the present day.

- (6) The *Rhynconella* limestone, which was only found in one locality, viz., in the islet of Poperang in the Shortland Islands, may be briefly described as composed of a large number of Brachiopod, Lamelli-branchiate, and Gasteropod shells, together with many simple corals of deep-sea genera imbedded in a matrix largely formed of pelagic Foraminiferous tests. A detailed description of this limestone is given on pages 565 and 566.

THE OCCURRENCE OF FLINTS.

This paper would be incomplete without a reference to the occurrence of flints in these islands. They are usually found where the soil has been disturbed for purposes of cultivation; and I was *never successful in finding their source*. They occur, however, together with a chalky rock, on the beaches of the island of Ulaua. Having been unable to visit this island, I would recommend future visitors who may land there to pay attention to this

point, which was one constantly before my mind during my examination of the calcareous formations of these islands. The explanation of their origin held by many natives is that they have fallen from the sky; and since many of these flints have all the characters of flint implements of the palæolithic type, we are thus reminded of a similar superstition prevalent amongst the agricultural classes of some of the English counties as to the source of the polished stone implements named "celts." (For further information on this subject *vide* some notes of my own read by Professor LIVERSIDGE before the Royal Society of New South Wales [*Journal* for 1883, vol. xvii. p. 223.])

CONCLUSION.

[*Added December 16, 1885.*]

From the general character of these calcareous formations it may be safely inferred that they will be found wherever there has been elevation during the recent period in regions where coral reefs are flourishing. Amongst other localities we may look to the West Indies, the Indian Archipelago, New Guinea (more particularly the south coast), New Britain, New Ireland, the Santa Cruz Group, the New Hebrides, the Loyalty Islands, New Caledonia, and the Fiji and Tonga Groups, as likely to possess at the sea-border formations of a similar character.

I have thought it best to add to the completeness of this paper by making a few general remarks on the general bearing of these observations.

In this, the largest of the Pacific groups, I not only found existing fringing-reefs, barrier-reefs, and atolls, but I discovered pre-existing reefs of these three chief classes, which have been recently elevated to a height sometimes of several hundred feet above the sea. My observations on these recently elevated reefs and their foundations have enabled me to approach the problem of the formation of coral reefs by the inductive rather than by the *a priori* method, for it is evident that in passing from the consideration of a probable cause of the formation of existing reefs to the examination of ancient reefs that have been raised with their foundations above the sea, we enter a domain of greater certainty. I will begin by briefly restating the principal points of this paper.

In the first place, there are numerous small islands and islets less than a hundred feet in height, which are composed entirely of coral limestone. Then there are islands of larger size, which are composed in bulk of partially consolidated volcanic muds, such as are at present forming around oceanic volcanic islands. Coral limestones encrust the lower slopes of these islands, and do not attain a greater thickness than 150 feet. In the next place, we have islands of similar structure, but possessing in their centre some ancient volcanic peak

that was once submerged. Then there are islands in which the volcanic peak has become an eccentric nucleus, from which line after line of barrier-reef has been advanced overlying the volcanic muds, islands in which I did not find the coral limestone of a thickness of 100 feet. Then we have the upraised atoll, such as Santa Anna, which, within the small compass of a height of 470 feet, displays the several stages of its growth,—first, the originally submerged volcanic peak, then the investing soft deposit, and over all the ring of coral limestone that cannot far exceed 150 feet in thickness; lastly, we come to the mountainous islands formed of old volcanic rocks, such as St Christoval, which, although over 4000 feet in height, showed to me no calcareous envelopes at a greater height than 500 feet above the sea, the coral limestone crust being even thinner than in the smaller and more recent islands.

I purpose now to draw four limited inferences from these facts of observation, without reference to any particular view that may be held on the subject of the formation of coral reefs, and to compare such inferences with the prevailing views on that subject.

(1) *That these upraised reef-masses, whether atoll, barrier-reef, or fringing-reef, were formed in a region of elevation.*—This is self-evident. The last upheaval that occurred, of which I found proofs in different parts of the group, was to the extent of about 5 feet, but at the present day there are signs of this movement being still in operation; and for the purposes of future observation I have established datum-marks in different islands. This, therefore, being a reign of elevation, it is apparent that that portion of Mr DARWIN's theory of coral reefs, which ascribes the formation of atolls and barrier-reefs to a movement of subsidence, cannot be applied to the islands of the Solomon Group, since we here find upraised atolls and barrier-reefs associated with existing reefs of the same description. This conclusion accords with the results obtained by Professor SEMPER in the case of the Pelew Islands, and by Professor A. AGASSIZ in the case of the Florida reefs.

(2) *That such upraised reefs are of moderate thickness, their virtual measurement not exceeding the limit of the depth of the reef-coral zone.*—Amongst the numerous islands which I examined I never found one that exhibited a greater thickness of coral limestone than 150 feet, or at the very outside 200 feet. One of the corollaries of the theory of subsidence is concerned with the great thickness of atolls and barrier-reefs. My observations in this region, and it is such regions that can alone afford such evidence, show that atolls and barrier-reefs can be formed with no greater thickness than they would possess in accordance with the depths in which reef-corals thrive, the vertical thickness of the reef not exceeding the depth of the reef-coral zone. . . . The only objection worthy of attention that has been advanced against the atoll-theory

of Mr DARWIN was, in the opinion of Sir CHARLES LYELL,* the circumstance that, as far as was known, no bed or formation of coral of any thickness had been discovered. This objection, which was proposed by Mr MACLAREN in 1842, derives additional force at the present day in the light of my observations in the Solomon Islands.

(3) *That these upraised reef-masses in the majority of islands rest on a partially consolidated deposit which possesses characters of the "volcanic muds," which were found during the "Challenger" Expedition to be at present forming around volcanic islands.*

(4) *That this deposit envelops anciently submerged volcanic peaks.*

These two latter conclusions corroborate in a remarkable manner the views, based on the observations of the "Challenger" Expedition, which Mr MURRAY has advanced. I will cite the structures of two islands to illustrate these views. In the small island of Santa Catalina I found that the elevated reef was based on volcanic rock with the intervention of a thin brecciated conglomerate. In the island of Treasury I found the volcanic rock covered by a soft partially consolidated volcanic mud, which attained the thickness of some 300 or 400 feet, and was itself encrusted on the lower slopes of the island by the elevated reef-mass. In the one island the volcanic peak had been first exposed to breaker-action before the reef-corals established themselves. In the other island the submerged volcanic peak was first brought within the reef-coral zone by the deposition of layers of volcanic mud, assisted by the movement of elevation.

With reference to my own bias on this subject, I may here add that during the first eighteen months I passed in the Solomon Islands I was only acquainted with the theory of subsidence; and that after having failed to make my observations harmonise with the theory of Mr DARWIN, I collected my facts with a very confused idea of the direction towards which they were tending. It was therefore a cause of great satisfaction to myself when I first became acquainted with the views of Mr MURRAY.

I will close this paper with a few remarks on the amount of elevation that has occurred in this region in recent times. It is, however, difficult to gauge it. So great has been the subærial denudation in these islands, that although the elevatory movements have brought up to our view a deep-sea clay with its concretions of manganese and a Foraminiferal limestone that was probably formed in a depth of from 500 to 800 fathoms, two rocks which occur in islands at opposite ends of the group, yet, notwithstanding this great upheaval, the calcareous envelopes usually disappear from the slopes of the large volcanic islands at heights of 500 or 600 feet above the sea, and never came under my observation in such islands at greater elevations than 900 feet. In the

* *Principles of Geology*, 12th edit., vol. ii. p. 612.

calcareous islands the greatest height at which the soft deposits occurred was 1150 feet, which was the greatest elevation at which I found any of the recent calcareous formations in this group. They probably occur in the western end of Choiseul at an elevation of 1500 feet and over.

EXPLANATION OF PLATES CXLIV., CXLV.

Heights in feet; depths in fathoms. Arrows indicate the dip; horizontal beds shown by a cross, thus +.

PLATE CXLIV.

- Fig. 1. Plan of Ugi Island, $\frac{1}{2}$ inch to a mile.
 Fig. 2. Ideal section of Ugi Island, intended to illustrate the relative thinness of the coral limestone.
 Fig. 3. Plan of Treasury Island, $\frac{1}{2}$ inch to a mile.
 Fig. 4. Ideal section of Treasury Island, adapted to show its principal structural features.
 Fig. 5. Plan of Santa Anna Island, $\frac{1}{2}$ inch to a mile.
 Fig. 6. Section of Santa Anna Island, drawn on a true scale of 2 inches to a mile.
 Fig. 7. Diagram showing the relative position of the raised coral rock and its foundation to the mass of volcanic rock *in situ* on the reef flat; north coast of Santa Anna Island.
 Fig. 8. Ideal section of Alu Island, showing the relation to each other of the coral limestone, the soft Pteropod and Foraminiferous deposit, and the volcanic rock.

PLATE CXLV.

- Fig. 1. Section of a compact grey Globigerina limestone from Treasury Island (see page 576). The rock contains 66.26 per cent. of carbonate of lime, consisting chiefly of species of pelagic Foraminifera, such as *Globigerina bulloides*, *G. hirsuta*, *G. (Orbulina) universa*, *Pullenia obliquiloculata*, and *Pulvinulina menardii*; *Amphistegina*, and one or two other bottom living Foraminifera. The organisms are cemented by carbonate of lime, sometimes crystallised in rather large grains (*d*). The mineral particles consist of (1) plagioclase-felspar, presenting the extinctions of labradorite; sometimes these crystals are twinned following the albitic law (*c*); sometimes they are twinned following the law of pericline. The crystal (*e*) shows a plagioclasic section, exhibiting at the same time the twinning, following the law of albite and pericline; (2) fragments of hornblende; one of these (*a*) is cut perpendicular to the crystallographic axis, and presents the hexagonal contours, and the cleavage lines crossing at an angle of 124° ; (3) fragments of augite; the section (*b*) of this mineral presents two individuals grouped with their axes parallel; the section is octagonal, and crossed by the cleavages at right angles; (4) fragments of magnetite and biotite.
- Fig. 2. Section of a tufa of an augite-andesite, from the central region of Treasury Island (see page 551). The rock contains 7.74 per cent. of carbonate of lime, which consists of a few coccoliths, several species of *Globigerina*, and fragments of Echinoderms. The ground-mass is composed of particles of volcanic glass, magnetic particles, and small decomposed mineral fragments. The larger minerals are lamellæ of plagioclase (*d*), twinned following the albitic law, with the extinction of labradorite; also twinned, following the law of Baveno (*a*); sections of augite (*b*) more or less parallel to the axis, with a twinning following the orthopinakoid; and crystals of augite (*c*) with a black glass particle attached, proving that the crystal was not formed *in situ*; also some hornblende. The presence of the *Globigerina* and Echinoderm particles show that the tufa was formed under water in which the surface organisms lived.

- Fig. 3. Section of a compact coral limestone from N.E. side of Treasury Island, consisting almost entirely of crystallised carbonate of lime, and fragments of the following organisms:—Gasteropod and Lamellibranch shells, Echinoderms, corals, calcareous Algæ, *Serpula* tubes, and Foraminifera of the genera *Carpenteria*, *Polytremia*, *Tinoporus*, *Gypsina*, *Calcarina*, *Amphistegina*, *Cyclotypeus*, *Nummulites*, *Globigerina*, and *Pulvinulina*.
- Fig. 4. Section of a compact Rhynconella or Foraminiferal limestone, from Poperang Island (see pages 565 and 566), containing 75.23 per cent. of carbonate of lime, which consists chiefly of pelagic and other Foraminifera, shells of Rhynconella, and fragments of Gasteropods, Lamellibranchs, and Echinoderms. A considerable quantity of the carbonate of lime is crystallised with a rhombohedral cleavage (*c*). The interior of the Foraminifera shells is frequently filled with a reddish substance. The mineral particles are—(1) fragments of plagioclase very much altered, with the twinning of albite and pericline (*d*); (2) hornblende, often zonary (*a*), with inclusions of apatite (the little white spot in the section) or twinned (*b*); and (3) black mica (*e*).