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Notes on the Raised Coral Reefs in the Islands of the Riukiu Curve.

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With 2 Plates.

In the southern seas of Japan we meet with the reef corals of both recent and more remote ages. They are not only found in Formosa, our new territory, but also in the islands of the so-called Riukiu Curve.* The following notes which treat of these coral reefs are based upon observations made on my geological trip to those islands during the nine months from July 1899 to March 1900.

I. DISTRIBUTION OF RAISED CORAL REEFS IN EACH ISLAND GROUP.

The Riukiu Curve consists of many scattered groups of islands, arranged in a curve extending over hundreds of miles between Formosa and Kyūshū. The southernmost is called the Saki-shima

* The name was first proposed by Prof. B. Kotô, *Journ. Geol. Soc. Tōkyō, Vol. V. No. 49 (1897).* The word Riukiu is transliterated "Loochoo" on foreign maps.

group† (See Pl. II), on the north-east of which lies the Okinawa group. Immediately on the north of the Okinawa group there is the so-called Ōshima group, which, in fact, is merely its northern continuation. A row of very small islands lying to the north-west of the Ōshima group is called the Tokara group. Between these island groups and Kyūshū, there is the Ōsumi group consisting of a few scattered islands, the largest of which are Yaku-shima and Tanega-shima.

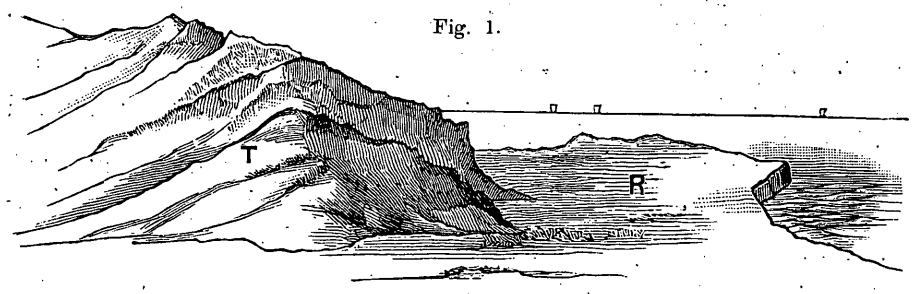
The Saki-shima Group.

The Saki-shima group is divisible into two subgroups, the Yaeyama and the Miyako. The former has, besides the two large islands of Iriomote and Ishigaki, ten smaller ones, called respectively Yonaguni-jima, Hatoma-jima, Kuro-shima, Aragusuku-jima, Nakano-gan-jima, Hateruma-jima, Taketomi-jima, Kobama-jima, and Kayama-jima.

Yonaguni-jima is situated in the westernmost part and prior to our acquisition of Formosa was known as the western limit of Japan. This island is divisible into eastern and western sections by two hill ranges called Urabu and Kobura, having a vast plateau between them. Raised reefs were observed over the whole area of this plateau and along the outer margin of the hill ranges. They are also widely distributed in the western and northern parts of the island, while in the other parts they are now found only in detached areas on the table-land of Tertiary sandstone. Although the culminating point of the hill ranges attains an elevation of 700 ft. and although the foundation covered by reefs is composed of the sediments of the Miocene epoch with a dip generally to the east and the strike running either

† *Shima* (pronounced *Jima* in combination) means island or islands.

Fig. 1.



T Tertiary sandstone. R Raised coral reefs.

from NNE to SSW or from N to S, yet the raised reefs are entirely composed of horizontal beds and form an extensive table-land less than 100 ft. in height (Fig 1). From the facts above stated it is to be inferred that the present island was formerly separated into two by a channel of shallow water, in which the coral polyps built their thick reefs, and that by a subsequent upheaval the two islands were united into a single one. The reefs are at present in two or more terraces near the shore, and their entire thickness is about 30 ft., while the elevation to which they have been upraised attains a height of several hundred feet above the level of the sea. The recent sand on the sea coast of the northern part of the island is nothing but a heap of the shells of the Foramimfera, *Calcarina spengleri* Linné.

Iriomote-jima is composed almost entirely of Tertiary sandstone, the layers of which are more or less regularly inclined, just as in Yonaguni-jima. The highest peak has an elevation of about 1,500 ft., but the raised reefs, only 30 or 40 ft. in thickness and quite horizontally bedded, are met with only here and there within a very limited area. In the south-eastern corner called the Haemi region, however, the reefs 20 or 30 ft. in thickness are seen in a continuous sheet on a table-land more than a hundred feet high : this is the case also in Yonaguni-jima.

Two small islands, Kayama-jima and Kobama-jima, have only a

few remains of ancient fringing reefs built upon the Palæozoic sediments. The northern half of Taketomi-jima is composed of Palæozoic rocks, chiefly of compact quartzite; but the southern half is covered entirely with a flat layer of raised reefs about 30 ft. in thickness. The raised reefs of Hatoma-jima, also about 30 ft. thick, completely surround a small Tertiary hill called Nakamori, which is situated in the center of the island and has an elevation of 117 ft. Kuro-shima, Aragusuku-jima and Hateruma-jima are all entirely made up of the raised reefs, the highest point of the last named island being 220 ft. The others attain an elevation of only 30 to 40 ft.

Ishigaki-jima, at the time of the formation of the raised reefs probably consisted of four small islands (Pl. II A. B. C. D), near which the fringing reefs were built. The fundament of these reefs evidently consisted of Palæozoic rocks, Tertiary limestone and sandstone, and the andesites, as they are now seen directly underlying the reefs which show no sign of disturbance since their formation. The distribution of the reefs is in three great groups. The first group is in the southern part of the island. It is widest in area occupying the coast region for about ten miles with a breadth of about two miles. The reefs form three successive terraces, the uppermost of which attains an elevation of about 100 ft. above the sea-level. This terrace extends from the northern part of Shiraho-mura to the neighbourhood of Moriyama-mura. The second terrace, 20 or 30 ft. lower than the first, extends from the vicinity of Miyara-mura to the southern foot of Bannā hill. The third or lowest terrace is found along the shore near Shika-mura and other villages. The second group was developed along the shores of the two supposed islands (C and D) which are situated to the north-east of the others (A and B). At the present time we see the table-land of Palæozoic rocks covered with coral reefs 20 to 30 ft. thick along the eastern and western coast of Ishigaki-jima,

while on its eastern coast the reefs have been almost entirely washed away and remain only in detached areas of small extent. The third group was found in a flat piece of land between the largest (A) of the four islands and the one (B) to the west of it; it also extended to the northern coast of the former. The remaining portions of the coast of Ishigaki-jima are at present covered with a few remnants of ancient low coral reefs. Generally speaking, the reefs of this island are not thicker than 30 or 40 ft. having been built on a wide plateau now raised in some places to an elevation of several hundred feet above the sea.

The Miyako subgroup consists of the islands of Miyako, Shimoji, Irabu, Kurima, Ikema, Ōgami, Tarama and Minna. A very noticeable fact is that all these islands, except one, are built entirely of the raised coral reefs. The island of Miyako, which gives the name to the subgroup, is the largest. It is wholly destitute of mountains. The surface is therefore quite flat, with a coast line of about 40 miles. The highest point has an elevation of 378 ft. and is called Nobaragoe, being situated near Nobara-mura. In the south-eastern part of the island the reefs are thicker than elsewhere and present a perpendicular cliff along the shore, while towards the west they slope down gradually until they pass into the Alluvial plain of the south-western corner of the island. As in other islands terraces are also observable in the reefs of the southern coast westward from Tomori-mura.

Irabu-jima attains an elevation of 300 ft. in its eastern part, whence it gradually slopes down towards the south-west. Ikema-jima, Tarama-jima, and Minna-jima have elevations of about 100 ft., 105 ft., and 15 ft. respectively. In Ōgami-jima the reefs are found only on the outer margin of the island. It should here be added that the above mentioned reefs are all horizontal, except in a very limited area in the southern part of Tarama-jima, where they incline towards the south at an angle of 30.°

The Okinawa Group.

This group is composed of the main island, Okinawa, (together with more than 17 dependent islands), and of the two subgroups of Iheya (with 5 islands) and Kerama (with more than 12 islands), and also four other islands named Kume, Tonaki, Aguni, and Tori.

Okinawa-jima has a coast line of about 200 miles, and is divided administratively into three districts or *gun*, called Kunchan, Nakagami and Shimajiri. In geological time, the Palæozoic mountain-range of which the first two districts are mainly composed, formed a long island, while the district of Shimajiri was entirely under water. During that time the reefs were built chiefly along the southern part, covering an extensive area of Tertiary rocks which now form the whole surface of Shimajiri, and also a part of the surface of the Palæozoic formation. The thickness of the reefs in Okinawa is small in comparison with their great extent, being considerably smaller than in the other islands, for instance, in the Miyako subgroup. The following table shows the elevations of raised coral reefs above the sea-level :

Ōmine-san (in Shimajiri)	121 ft.
Sunaga-jima (in Shimajiri)	142 ft.
Sōjun-yama (near Tomori in Shimajiri)	151 ft.
Shuri	496 ft.
Yoza-jima (in Nakagami)	557 ft.
Benga-dake (near Naha)	598 ft.

That the reefs do not attain a great thickness is shown by the fact, that when a boring is made from the surface, the underlying Tertiary (Pliocene) rocks are met with at the depth of about 30 ft. In a geological age not far removed from the recent epoch the district of Shimajiri was in all probability entirely covered with the coral reefs, and the scattered patches now seen here and there are to be looked

upon as mere relics of the once continuous rocks, slowly worn away by denudation (Pl II). The eastern half of the district forms a plateau several hundred feet in height. Towards the east it shows a steep escarpment generally with a belt of flat Alluvial plain lying at its base, while towards the west it slopes gently, often exhibiting terraces and ending at the shore in cliffs only a few yards in height. The raised reefs are found not only in Shimajiri, but also in the district of Kunchan, on the east coast near Kin and in the northern part of the tongue-shaped peninsula of Motobu on the west coast, forming in both places a plateau.

Running parallel to the longitudinal axis of Okinawa-jima and near its eastern coast, are six small islands. The base of these islands, except Ike-jima and Kudaka-jima, which are built up entirely of coral reefs and have an elevation of 30 to 40 ft., is also composed of Tertiary rocks, upon which the raised reefs are placed horizontally just as in Shimajiri. In Hianja-jima the eastern part is the most elevated, and the reefs are here developed to the greatest thickness.

In Sesoko-jima and Kouri-jima, the center of the island is composed of a Palæozoic limestone. This limestone is surrounded by a belt of reefs about 100 ft. in thickness, which in Sesoko present two or three terraces. Ie-jima, which is remarkable for having a huge pointed rock rising out of the surrounding hills in the central part of the island, has, for its fundament, Palæozoic rocks which are however for the most part covered with the coral reefs. The reefs form here as elsewhere an extensive plateau and have a thickness of perhaps 100 ft. or more. The above mentioned pointed rock is a compact Palæozoic quartzite. Minna-jima is a coral island only a few yards high, while Yagaji-jima has the reefs over only a very small area. The Kerama islands are, so far as I know, entirely destitute of raised reefs. According to Mr. T. Kuroiwa, the old coral reefs in Kume-jima and Aguni-

jima and in the Iheya subgroup and Kei islands are very limited in extent. In Kei-jima, the old reefs are found in small detached areas only in its western part, the rest of the island being composed of heaps of coral fragments of a very recent origin.

Far to the east of Okinawa-jima there are three isolated islands, known as South Borodino (Minami-ōagari), North Borodino (Kita-ōagari) and Rasa. The coral reefs seem to cap these islands and attain in the first a height of 250 ft. above the sea, while in the second and third the highest points are not over 150 ft. The reefs of South Borodino are said to form terraces. Another isolated group of small islands, called the Pinnacles, lies far to the north-east of the Yaeyama subgroup. In one of them called Hoa-pin-su (Waheizan) Mr. T. Kuroiwa saw the traces of old reefs on the southern, western and eastern sides.

The Ōshima Group.

Ōshima, with the four large dependent islands, Kikaiga-shima, Tokuno-shima, Okinoerabu-jima, and Yoron-jima, constitutes the Ōshima group, and lies immediately to the north of the Okinawa group.

In Okinoerabu-jima, the Palæozoic hills of small extent running from north-east to south-west, are found encircled by the raised reefs forming a large plateau, which attains an elevation of about 200 ft. above the sea, while the older rocks have, at a place called Ōyama, an elevation of 687 ft. In the reefs a few terraces are observable near the coast, where they show cliffs 20 to 30 ft. in height. Yoron-jima, which I was unable to visit, probably show a distribution of the reefs similar to that in Okinoerabu.

The foundation of Tokuno-shima is made up of Palæozoic and plutonic rocks, which rise to the height of 2,207ft. above the sea. The

reefs which are found upon this foundation form an extensive table-land in the southern, western and south-eastern parts of the island. Near Ketoku-mura in the north-eastern part of the island, the reefs are scattered in small areas and have a height of only about 50 ft., with a slight inclination towards the coast. They appear to have been originally built in the valleys of the Palæozoic mountains.

Kikai-ga-shima, with a coast line about 20 miles in length, consists of a Tertiary sandy shale, entirely covered with raised coral reefs, which in some places give rise to successive terraces. The shale is exposed only in the western and eastern parts, as at the steep cliff on the south of Sōmachi. Here it is covered with a reef from 30 to 40 ft. in thickness. The highest part of the cliff lies at Mābi, and is about 684 ft. above the sea-level.

Ōshima is a large island composed of Palæozoic rocks. The greatest elevation is found on a peak 2,300 ft. in height. The reefs are formed only upon the small tongue-shaped plateau on the north. On its eastern coast the reefs are elevated about 20 or 30 ft., while on the west they have been almost entirely eroded, leaving only on the north-western corner, some relics which are a few feet in thickness.

II. GENERAL CONSIDERATION.

The coral formation of more remote age, which always stands upon the eroded strata, forms fringing reefs on the islands composed of older rocks, or somtimes separate islands with entirely covered foundations. The latter type is observed at Hateruma-jima, Aragusuku-jima, Kuro-shima, Miyako-jima, Irabu-jima, Ikema-jima, Shimoji-jima, Kurima-jima, Minna-jima, Tarama-jima, Ike-jima and Kudaka-jima. Kikai-ga-shima, Hianja-jima and Miyagusuku-jima are a modification of this type and are reefs with their foundations exposed at the cliffs above the sea-level.

The recent coral reefs of southern Japan, scarcely exposed above the sea-water, are all fringing reefs; there being found neither atolls nor barrier reefs among them. The coral shows luxuriant growth along a line running parallel to the sea coast and at a few hundred feet from it. Between the fringing reefs and the sea-beach, there is, sometimes, a flat sandy bottom with a few groups of living corals. It is frequently so shallow, that we can wade across it at low tide. On the north-east of Miyako-jima, are the vast and dangerous rocks of Yaebise, consisting entirely of recent reefs, which are scarcely above the level of the sea at low tide. The islands known as Kikai-ga-shima, Miyako-jima and others must have been of this type in past time. The coral islands of recent formation are nothing but heaps of coral fragments; as Yuni lying between Hatoma-jima and Iriomote-jima, and the Kei islands on the west of Naha.

Although the strata of older sediments in the Riukiu Curve are all inclined, which is a result of the upheaval of the islands above the sea, the reefs lying upon them have as a rule remained horizontal, the exceptions being the locally disturbed ones found at Tarama-jima, Tokuno-shima, and other places. This shows that a gradual depression and elevation took place after the formation of the Riukiu Curve.

The raised reefs are mostly a true coral formation and homogeneous in structure. But in some places as at Tarama-jima there is, besides, a thick Foraminiferal deposit which attains a thickness of 10 ft. and is interbedded between two successive coral reefs. The species found in such a zone at Kamezu (in Tokuno-shima), Unten (in Okinawa-jima) and Yoda (in Okinoerabu-jima) is gigantic *Operculina* (Pl. I). In the south of Okinoerabu-jima the raised reefs consist essentially of corals, there being no layer of sand. Towards the north the coral layers are found interstratified with sand layers. At Kametoku in Tokuno-shima there are found thick beds of loose sand

and conglomerate in the reef coral. At Ōshima, we already find the greater part of the raised reef consisting of coral fragments, as well as of a brownish sand like some Diluvial deposits common in Japan. The fact seems to indicate an incomplete development of the coral formation on these islands and we may fix the limit of the coral reefs of the western Pacific at about 29° N.L.

When the recent corals are found close to an older reef, their boundary is not sharply defined; however they may be distinguished from each other by position, structure and colour. The older reefs are generally highly elevated while the recent ones are exposed only at low tide. The corals in the raised reefs have mostly lost their structure through the dissolving action of the water. I could only recognize among them the three species of *Favia*, *Porites* and *Fungia* (?). The older corals are also weathered and show a yellowish brown colour, and have sand-grains filling up the interstices of the skeleton. Finally the older reefs, on the exposed surface, are altered to a mass resembling *terra rosa*, frequently with a thickness of several feet. The recent corals show a well-preserved structure, and generally appear whitish in colour, only those on the surface being grayish.

All the raised coral reefs are homogenous in appearance throughout their whole thickness, there being apparently no mark of varying age in their different parts. The terraces in those reefs, as observed at Yonaguni, Ishigaki, Miyako, Irabu, Okinawa, Sesoko, Ie, Miyagusuku, Okinoerabu, Kikai, and other islands, may have been formed in the intervals between successive changes of sea-level, or the development of the coral formation from its beginning to its end may have been not equally extensive.

The elevations of the principal raised reefs are as follows:

Miñna-jima	10—20 ft.

Kuro-shima		20—30 ft.
Ike-jima	about	100 ft.
Tarama-jima		105 ft.
Kita-ōagari-jima		150 ft.
Rasa-jima		150 ft.
Hateruma-jima		220 ft.
Minami-ōagari-jima		250 ft.
Irabu-jima	less than	300 ft.
Miyako-jima		378 ft.
Shimajiri (in Okinawa-jima)		600 ft.
Kikai-ga-shima		684 ft.

The two islands between 600 and 700 ft. in height, namely Kikai-ga-shima and Okinawa-jima, are composed of foundation rocks capped with thin reefs. All the other islands are of coral formation, with other rocks hidden under the sea. Their heights are however too great to admit of an explanation of the origin by the Elevation Theory. But according to F. Dahl who maintains the Depression Theory, the reefs of the Bismarck Archipelago show the very great height of 300 metres, just as in the case of Miyako-jima and others. According to E.C. Andrews, most of the raised reefs of the Fiji islands have been elevated from 800 ft. to 1050 ft. above the sea. The reefs in Timor which are considered by K. Martin as belonging to the Diluvial epoch, attain the height of about 600 metres. Those in north Luzon which belong to Pliocene were upheaved even to the height of 1400 metres.

The foundation of the raised reefs consists of Tertiary and Palæozoic sediments as well as igneous rocks. In the Saki-shima group, the reefs lie upon inclined Miocene rocks: in the Okinawa group upon still more recent Tertiaries. In the Riukiu Curve, the raised reefs are covered only by the weathering product of the reef, and by no younger deposit. The loose sand resembling a Diluvial deposit is mostly found

interstratifying coral layers in the northern part of the Curve.

Fossils of Mollusca and Brachiopoda found in the raised reefs are mostly casts. Those from the vicinity of Naha and Shuri in Okinawa-jima belong to the genera *Fusus*, *Conus*, *Cardium*, *Mactra*, *Tellina*, *Tapes*, *Chione*, *Limopsis*, *Arca*, *Pectunculus*, *Pecten*, *Waldheimia* and *Terebratula*. *Waldheimia picta* Chemn., *Terebratula japonica* Sow. (young ?), and *Terabratula caput-serpensis* Linn., are well preserved. The most conspicuous fossil found in most of the reef is *Lithothamniscum nahaense* Heydrich which is a species founded by F. Heydrich after studying the specimens from Naha. His description is as follows (*Journ. Geol. Soc. Tōkyō., Vol. VII, No. 80, 1900*) :—

> Der Thallus bildet flache 0.3—0.5 mm. dünne über wilde fossile Korallen ausgebreitete Krusten. Die Ausdehnung der Krusten mag etwa 3—5 cm. betragen haben; ob dieselben grösser gewesen sind, lässt sich nicht mit Bestimmtheit angeben, da das Substrat häufig zerbrochen und durch Druck wieder fest zusammengefügt wurde. Das Dickenwachsthum ist in Folge dessen nicht sicher nachzuweisen; doch so viel steht fest, dass recht oft eine Schicht über die andere gewachsen ist, sodass 2-3 Thallusplättchen übereinander gelagert erscheinen. Eine ausgeprägte Basalschicht, wie sie bei ähnlichen recenten Formen sich vorfindet, ist nicht nachweisbar, sodass die Zellen fast überall regelmässig quadratisch mit etwa 12 μ. Seitenlänge erscheinen. Ob die im Querschliff gezeichneten zwei kleinen Bögen Conceptakel enthalten, konnte nicht festgestellt werden, wohl aber was durch Zufall ein kleines Stück Thallusoberfläche auf einen abgeschlagenen Stück Substrat freigelegt, welches Conceptakel enthielt. Dieselben sind etwa 200 μ. in Durchmesser und 60 μ. hoch mit scharf markiertem centralen Porus. Sie sind von flachgewölbter Form und liegen allem Anschein nach sehr flach, würden also bei zunehmendem Dickenwachsthum nicht in den Thallus versenkt werden.

Bryozoa are not rare in the raised reefs of Naha. The Echinoid, *Echinanthus testitudinarius* Gray, are found in Moriyama (in Ishigaki-jima), Unten (in Okinawa-jima) and Kametoku (in Tokuno-shima).

There are many species of Foraminifera and Radiolaria. *Textularia*, *Amphistegina*, *Triloculina*, *Planorbulina*, *Rotalia* and *Globigerina* have been collected from Shuri; *Rotalia* and *Amphistegina* from the Foraminiferal sand of Yōmura in Ōshima. A gigantic *Operculina* (Pl. I) is found numerously in the reefs of Okinawa-jima, Tokuno-shima and Okinoerabu-jima, and is always well preserved.

From the above description we may draw the following conclusions :—

1. The raised reefs in the Riukiu Curve are mostly later than the Tertiary, and are overlaid by recent rocks.

2. These reefs are horizontal, in contrast to the inclined beds of the substratum.

3. In the ancient time they either covered the rocky sea-bottom, or fringed the margins of islands.

4. The northern limit of the ancient reefs in the western Pacific is 29° N.L.

5. The maximum elevation of the raised reefs in the Riukiu Curve is 684 ft.

6. They are distinguished from the recent reefs by their position, structure and colour.

7. The raised reefs are often found in the shape of terraces.

8. The reefs exhibit a character like those now growing under the sea water of the same region, and have been upheaved after a gradual depression.

October 1900.

PLATE I.

Plate I.

Fig. I.—Gigantic specimens of *Operculina sp.* (natural size); from Kamezu in Tokuno-shima.

Fig. II.—Foraminiferal rock consisting wholly of the shells of *Operculina* (not reduced in size); from Yoda in Okinoerabu-jima.

Fig. I.

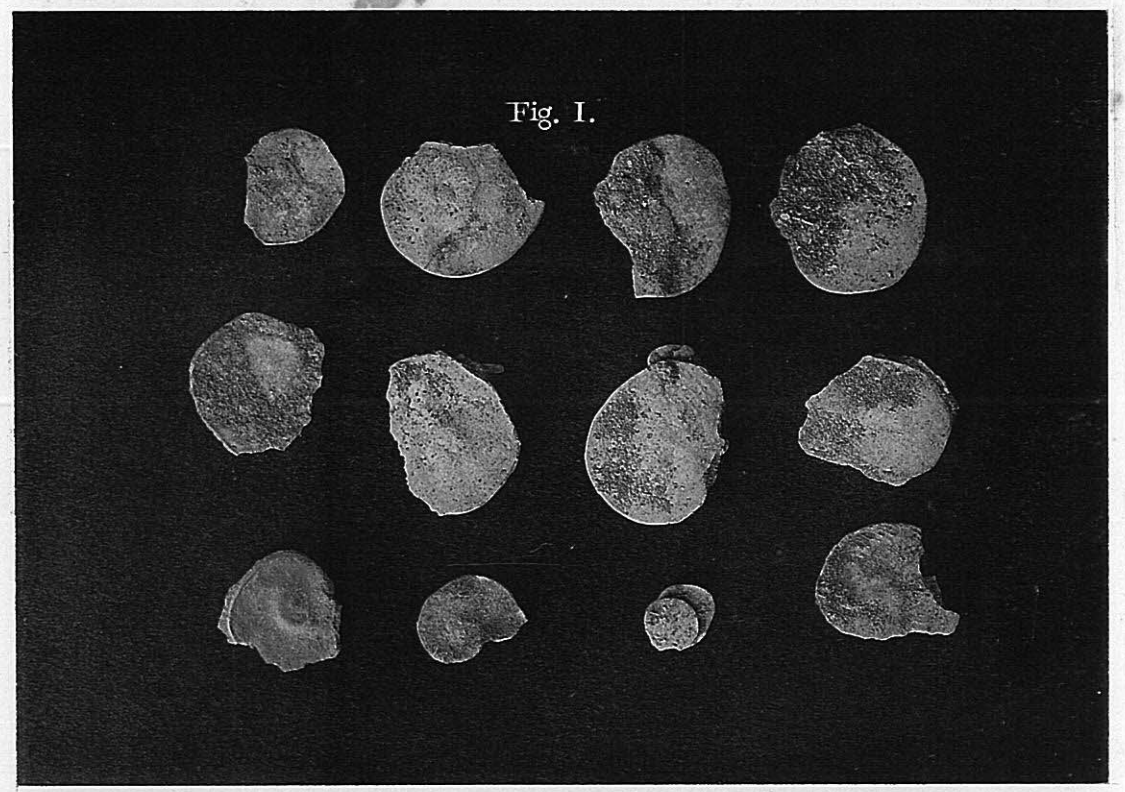
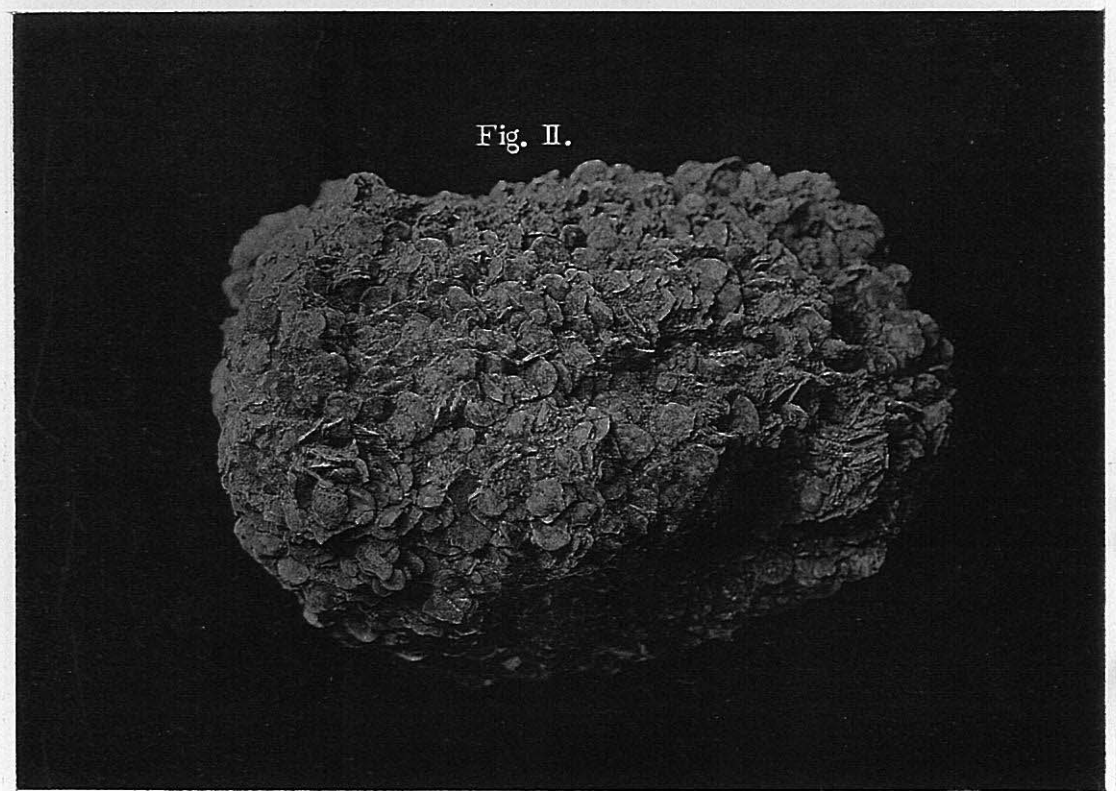


Fig. II.



Yoshiwara, On Raised Coral Reefs of the Riukiu Curve.

PLATE II.

Plate II.

The plate II shows the geographical distribution of the raised coral reefs in the Riukiu Curve.

Distribution of Raised Coral Reefs IN THE Sakishima Group, Riukiu. (Loochū).

Scale I : 560000.

Distribution of Raised Coral Reefs in the Okinawa Group, Riukiu. (Loochū).

Scale 1 : 560000.

Distribution of Raised Coral Reefs in the Ōshima Group, Ōsumi.

Scale 1 : 760000.

MAP OF THE RIUKIU CURVE.
(Dotted line showing the limit of Raised Coral Reefs).

Yoshiwara, *On Raised Coral Reefs of the Riukiu Curve.*