# 久米島に於ける隆起珊瑚礁の生態学的研究

# ECOLOGICAL STUDIES ON THE CORAL REEFS OF KUME ISLAND I. DISTRIBUTION OF THE CORAL REEFS

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## Introduction

This paper is a preliminary report of an investigation of the coral reefs of Kume Island, situated in the inner row of the Ryukyu Islands. The author will deal mainly with the distribution of the raised coral reefs of the island. Discussions on the geological history of the raised reefs will be presented in a future report, together with the results of the ecological studies on the recent coral reefs.

Not much is known about the coral reefs of the Ryukyu Islands. Most of the papers dealing with the subject have been written by Professor K. Hirata of Kagoshima University who has concentrated his previous studies of coral reefs on Yoron Island (Hirata, 1955, 56, 58). The author and Hirata have conducted preliminary surveys of five islands in the Ryukyu Chain (Hirata and Yamazato, 1958). More detailed studies have been and are still being carried on by the author and Hirata on the coral reefs of Okinawa Island (Hirata and Yamazato, in press).

From his studies in Yoron Island, Hirata made some conclusions about processes of the coral reef formation, geological history of the raised reefs and other related problems. Whether his conclusions are generally applicable to the reefs of the marginal belt of the coral distribution is one of the purposes of a series of studies by Hirata and the author. A discussion of Hirata's hypotheses, however, is not included in this paper but will be given in future papers.

## Outline of geology of the Island

Kume lies about 80 km. west of Naha in Okinawa Island, and has roughly a trapezoid shape. It is topographically divisible into two triangular areas, northern and southern, by a lowland streching from Gima eastward (Fig. 1). The highest point in the northern area is Ō-take (326 m.) which is situated close to the north and the northwest coasts, and the highest point in the southern area is Ara-take (287m.) which is situated close to the southwest coast.

Geology of the island had been studied by Hanzawa (1935) in his extensive research on the entire group of the Ryukyu Islands. The higher parts of the island are superficially formed of andesitic agglomerates and andesite lavas, which, according to Hanzawa, are directly continuous with a underlying formation of tufaceous sandstones and bluish-grey shales. Hanzawa regarded the former formation as the upper and the latter as the lower part of Shimajiri Beds. Shimajiri Beds are defined as Tertiary marine deposits consisting of soft bluish grey marls and soft brownish sandstones rich in fossils of marine organisms. These beds are distributed extensively in many islands of the Ryukyu Chain. Andesitic agglomerates and andesite lavas were ascribed by Hanzawa to volcanicity which first manifested itself in the late Shimajiri stage, probably late Pliocene, in the inner row of the Ryukyu Islands to which Kume belongs.

The western part of the northern area is formed of limestone, which, according to Hanzawa, is situated above the Shimajiri Beds and called Ryukyu Limestone. Terraces both on andesitic agglomerates and limestone areas are covered by gravel beds of lateritic soil and pebbles. These beds are designated as Kunigami Gravel. Coastal plains in Janado, Shimajiri, Gima and Torishima are formed of Alluvial sand deposits. Sand dunes are well developed along the shore lines of the western northern area, Janado and two dependent islets, Ō and Ōha.

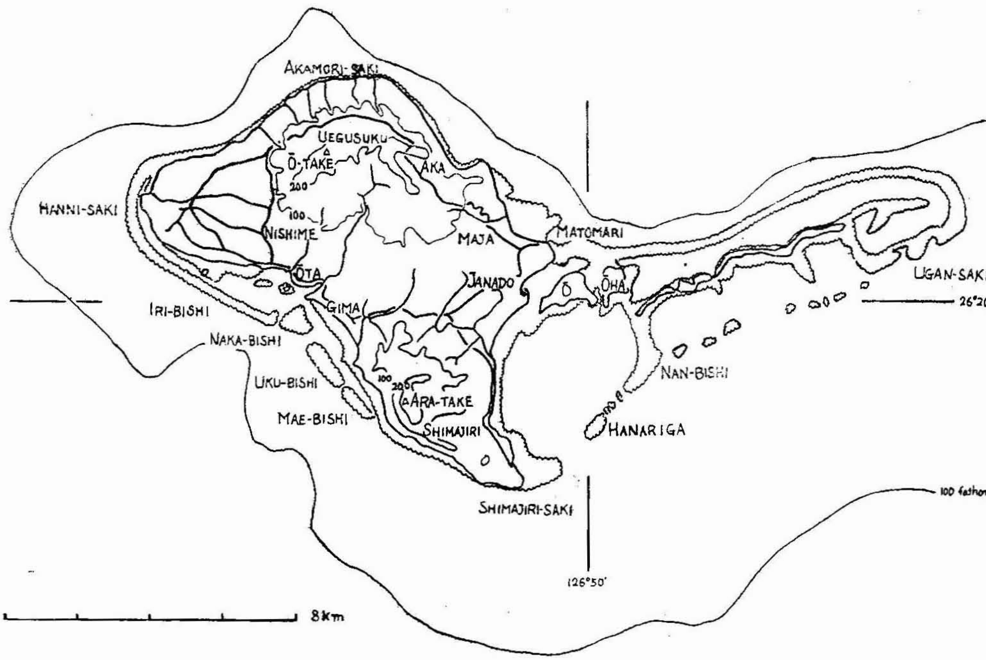


Fig. 1. A map of Kume Island, illustrating present fringing and barrier reefs.

**Present fringing and barrier reefs**

The fringing reefs are developed along the whole length of the coast line, that on the northern coasts being wider (500 meters or more at the widest point) than that on the southern coasts. The foundation of the fringing reef on the coast 1.5 km. west of Aka is formed of Shimajiri Beds consisting of tufaceous sandstones and bluish grey shales (Pl. Fig. 14). It is exposed at several points on this coast, and the reef over it is about 50 cm. thick. The foundation is also exposed on the coast of Tako which is about 6.5 km. west of Aka (Pl. Fig. 15). Here, it is formed of andesitic agglomerates which constitute the upper part of Shimajiri Beds, as mentioned above. The thickness of the reef at this eroded point is about 30 cm.

The reef is not this thin at all points. The thickness of the reef was estimated to exceed 3 meters on the coast of Aka and 1.5 meters on the coast of Kitahara which is about 8 km. west of Aka. Since the present fringing reef on the coast of Aka forms a coastal terrace, on which the village is located, at the foot of a steep fault scarp, it is clear that the reef was formed after a faulting had occured. The fact that the reef has about the same thickness at two points located about 5km. apart, may indicate that there has been no tilting of the foundation in this region since the reef has been formed.

Development of the barrier reefs is remarkable on the southern coast. The one which runs from Hanni-saki to the west foot of Ara-take is 200 to 300 meters in width and is dissected by three boat channels. Individual reefs are called Iri-bishi, Naka-bishi, Uku-bishi and Mae-bishi from northwest to southeast. While the former one stands above a normal high tide level, the latter three expose themselves at normal low water. The width of the lagoon inside is 1.5 km. at maximum (off Ota in Fig. 1) and narrows northwestward and southeastward. A channel between Naka-bishi and Uku-bishi forms a submarine valley having a depth down to 49 meters at its mouth, which curves northwestward between Naka-bishi and the coast of Gima, and terminates at the mouth of the Kominato River, sending a branch to the mouth of the Shirase River. The depth is about 22 meters near the point Hana-saki. According to Hanzawa, this valley is traceable down to a depth of 700 meters. The presence of this valley is also indicated by a 100-fathom contour line, shown in Fig. 1.

There are several depressions filled with fresh water on the fringing reef along the north coast of the western northern area. The largest is an elongate one of about 1 km. long and 100 to 200 meters wide, lying with the long axis parallel with the coast line (Pl. Fig. 2). The source of water of these depressions is subterranean. These depressions may have been formed through dissolving action of water. As is shown in Fig. 3a, the fringing reef is convex outside and concave inside in the cross section. The depressions are formed on the inner concave surface of the reef.

The lagoon inside the reef, Iri-bishi, or at least its distal part might have originated as solution depressions, eventually uniting with each other and making contact with the sea, finally becoming a long narrow lagoon. Presence of numerous flat topped limestone rocks in the lagoon mentioned (Pl. Fig. 6), scattered all over from the shore to the reef, may be an indication of the former contiuity of the reef with the shore. There are also many flat topped limestone rocks in the lagoon inside the reefs, Uku-bishi and Mae-bishi, and the same thing may also be applied to these reefs. The reef, Naka-bishi, may have originated as a barrier, since the reef is separated from the shore by a fairly deep submarine valley.

The barrier extending from Shimajiri-saki northeastward to the Islet Ōha is always submerged except at the lowest low waters. It encloses a deep oval lagoon, and is divided into three parts by two channels. The reef between the two channels is called Hanariga and the one continuous with the Islet Ōha, Nan-bishi. The channel between the reef at Shimajiri-saki and Hanariga has a depth down to 49

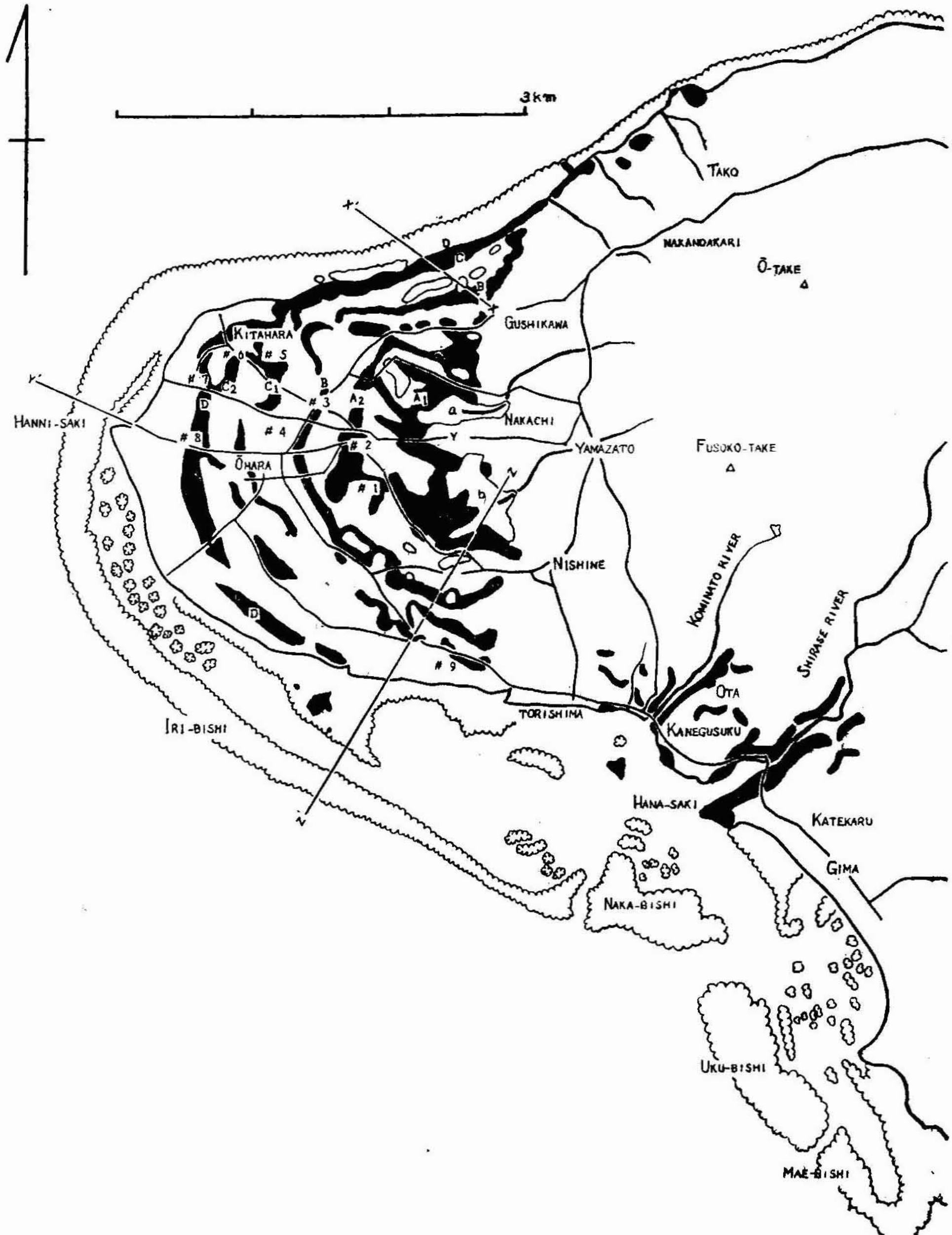


Fig. 2. Distribution of the raised coral reefs in Kume Island. Exposed raised reef limestone is shown in black. Those marked $A_1$, $A_2$, B, $C_1$, $C_2$ and D indicate limestone terraces in the limestone area. Those marked # 1 to # 9 indicate wells whose depths were measured (See Table 1).

maters, and the one between Hanariga and Nan-bishi, down to 18 meters. The lagoon gradually shallows up toward the shore line.

The barrier which extends from Matomari eastward is the most remarkable, having a length of about 11 km. It rests on the insular shelf extending eastward to the west coast of Okinawa Island. The shelf is steep-sided in the north, where a 600-meter contour line runs parallel with the northern side of the barrier within a distance of 1 km. The eastern extremity of the barrier is called Ugan-saki, where it bends southward and then westward to connect with a sand bar which extends parallel with the barrier and connects with the proximal end of Nan-bishi in the west. The lagoon inside the barrier and the sand bar is not deeper than 1. 5 meters except at its distal end where it attains a depth of 6 meters. The distal end of the barrier does not submerge at high waters but the proximal end does.

It is interesting to note that the barriers expose themselves at normal high waters at the western (Iri-bishi) and eastern (Ugan-saki) ends of their distribution and submerge at normal low waters in the central southern part (Hanariga and Nan-bishi). It is more reasonable to attribute this condition to a tilting of the original level surfaces of the barriers (uprise at both ends or subsidence in the central southern part), than to the formation of the barriers at different levels. The fringing reef at Aka and Maja is higher than that in the other parts of the island and offers an evidence for a uprise in the central northern area.

## Raised coral reefs

The distribution of the raised coral reefs in Kume Island is mainly limited to the western part of the northern area (Fig. 2). This part, which will be designated as the limestone area hereafter, is bounded in the east by a line parallel with, and running some distance west of, a road connecting Torishima and Nakandakari. Along the coast, the reef extends its distribution beyond the eastern boundary of this area and reaches as far east as the coast of Tako in the north and the east bank of the Shirase River in the south. Raised reef limestone on the coastline is usually exposed but that in the interior is mostly covered by a sheet of lateritic soil and gravels.

Although, Hanzawa distinguished the latter from the former and called it Ryukyu Limestone, the author was not able to see any clear-cut difference between exposed and unexposed limestone. Hence, a term raised coral reef is applied to both of the reefs on the coastline and in the interior in this reports, as has been done by Hirata and Yamazato (in press) to the reefs in Okinawa Island.

### Distribution of the raised reefs in the limestone area

Limestone in this area is exposed as concentric belts on the different contour lines, as illustrated in Fig. 2. For the most part, these belts constitute the elevated outer margins of the terraces of concentric arrangement, with the inner parts of the terraces covered by Kunigami Gravel. Although, it is not clearly defined at several points, these limestone belts may be interpreted as the raised coral reefs of several steps, probably of five, and is nominated $A_1$, $A_2$, B, C and D from the interior to the coast. The altitudes of these raised reefs are 40 to 45 meters ($A_1$ and $A_2$), 30 to 40 meters (B), 20 to 25 meters (C) and 5 to 15 meters (D). Since reefs $A_1$ and $A_2$ have the same altitude, they may represent fringing ($A_1$) and barrier ($A_2$) reefs formed under a single sea level.

The reef $A_1$ encloses two large depressions or dolines which will be described later. The reef B is most clearly defined on the north coast (Pl. Fig. 2), where it attains an altitude of about 40 meters. It is fairly clearly defined at its southern proximal end but is not clearly defined at its distal end, where it does not rise above the lower terrace. The reef C is also clearly defined on the north coast, but is not so in the central and southern parts, where it is divided into two discontinuous belts, $C_1$ and $C_2$. However, these two belts may not represent different reefs but only a single one, since there is no intermediate reef on the north coast (Pl. Fig. 2), where each step of the reef is most clearly defined. The limestone pinnacles (Pl. Fig. 7) found on a 20-meter contour line near Ohara may represent the remaining rocks of a formerly continuous ridge. The irregular shape of the reef C may have resulted from strong destructions, owing either to unusually severe subaerial erosions or to a comparatively weak nature of the reef, or both.

The reef D is represented by a 5-meter bench on the seaward cliff of the 20-meter reef on the north coast. It may be a raised reef, or it may not actually be a reef but a mere wave-cut bench. The author, at present, lacks any positive evidence to prove which is the case. There are several 5-meter ridges on the broad surface of the present fringing reef (Pl. Figs. 8 and 9), projecting seaward and proximally connected with the 5-meter bench. Several mushroom rocks of about the same altitude are also found on this coast, scattered on the surface of the fringing reef (Pl. Fig. 9). The seaward-projecting ridges are not found elsewhere, but mushroom rocks are present on the beach near Torishima (Pl. Fig. 10) and on the beach about 1.5 km west of Torishima (Pl. Fig. 11). There is also a limestone islet of 10 meters in altitude on the latter beach (Pl. Fig. 11). All of the bench, ridges, rocks and islet are continuous with the basal fringing reef and are only topographically distinguishable from the latter. It is clear that all of these have been formed under a single sea level either by coral growth or by marine erosions on the pre-existing reef of a higher elevation.

A sand dune attaining an altitude of 20 meters is developed on the west coast outside the lowest reef (D) (Pl. Fig. 1). It may be possible that the sand dune is formed on a reef platform which may be either a part of the present fringing reef or that of the raised reef D. A part of the latter was actually observed under the sand dune where it was exposed on a brook bed on the coast about 1.5 km west of Torishima.

**Thickness of limestone in the limestone area.**

There are many dolines on this area, the majority of them occuring interior to the raised reef B. Their shape is variable from circular to elongate. Some dolines have vertical sides of limestone, but most of them have sloping sides covered with lateritic soil and gravels. The dolines are provided with one or more drainage holes on the bottom, and there is no surface drainage system in this area, water being collected into the dolines, and being draind through the drainage holes.

Two large dolines lie on the eastern boundary of the limestone area, separated from each other by a ridge which is projecting westward from the andesitic agglomerates area. Their western sides are formed of limestone of the reef $A_1$ as was mentioned above, and their eastern sides are formed of andesitic agglomerates. Both of them have a drainage hole closer to their western limestone sides, with a brook leading into the drainage hole from the eastern sides. Most of their bottoms and eastern gently sloping sides are cultivated as rice fields. Since the altitude of the bottom of the northern doline is about 18 meters and that of the southern doline is about 10 meters, and since the altitude of reef $A_1$, which forms the western sides of the dolines, is 40 to 45 meters, therefore the depths of the northern doline are 20 to 27 meters and those of the southern dolines are 30 to 35 meters. The depths of the dolines suggest that the thickness of limestone at the two points exceeds 27 and 35 meters respectively.

The depths of several wells at different altitudes were measured to the underground water level. Locations of these wells are marked on a map in Fig. 2, and their depths are shown in Table 1.

Table 1. Depths of the wells of the limestone area and altitudes of underground water levels.

| Well | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Altitude (m) | 35 | 40 | 30 | 25 | 20 | 12 | 10 | 9 | 12 |
| Depth (m.) | 27 | 24 | 28 | 23 | 23 | 11 | 10 | 10 | 10 |
| Altitude of Water Level (m.) | 8 | 16 | 2 | 2 | -3 | 1 | 0 | -1 | 2 |

The bottom materials of two wells were examined and found to be composed of coral sand and gravels. Although, there is no well which was sunk so deep as to show the underlying formation of limestone, it has been reported to be formed of Shimajiri Beds (Hanzawa, 1935). Since it is reasonable to assume that the underground water level is in parallel with, and a few meter above the surface of the underlying formation, one can draw a rough picture of the topography of the underlying formation upon an examination of the water level at different locations shown in Table 1. The cross sections of the limestone area shown in Fig. 3 were drawn in this way. A study of these cross sections leads to the conclusion that the underlying formation forms a broad once-submarine platform, gently sloping seaward, on which limestone was formed as concentric reefs.

Since no well is so deep as to reach the underlying formation, the thickness of limestone exceeds the depth of a well at its location. Therefore, the thickness of limestone exceeds 23 meters at the reef C, 28 meters at the reef B and 24 meters at the reef $A_2$. The limestone thicknees at the reef $A_1$ exceeds 27 meters in the north and 35 meters in the south, as is indicated by the depths of two dolines. These thickness measurements are greater than the 20 meters suggested by Hirata to be the maximum thickness of reefs in Yoron Isalnd (Hirata, 1956). The fact that the bottom materials of two wells are composed of coral sand and gravels, suggests that the coral reefs were formed on the foundation rock which is composed of coral sand and gravels, probably derived from pre-existing reefs or brought by currents from the vicinity. Thus, the figures given above may represent the thickness of the reef limestone plus that of the foundation rock.

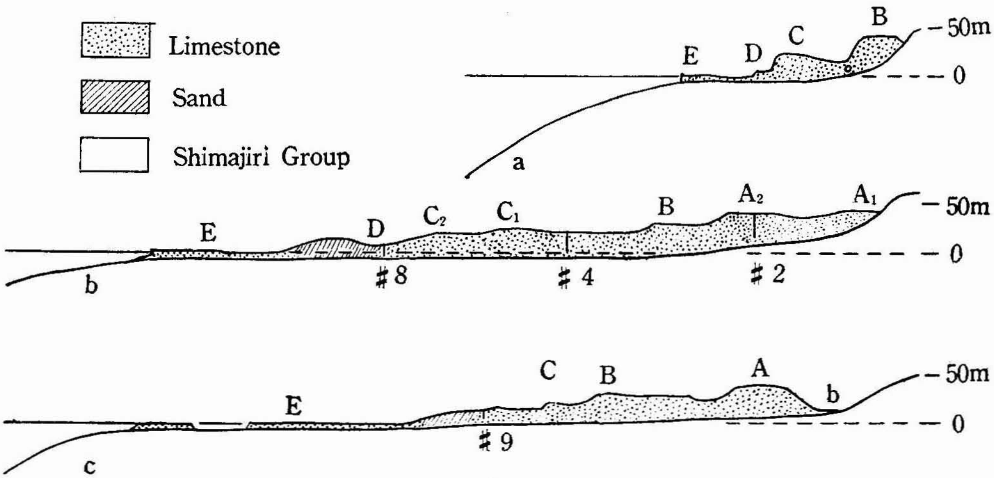


Fig. 3. Schematic illustrations of limestone terraces in the cross sections of the limestone area along the lines X-X′ (a), Y-Y′ (b) and Z-Z′ (c) on the map of Fig. 2. Vertical lines with marks # 2, #4, # 8 and # 9 indicate depths of nearby wells. A mark o in a. indicates a site of an exposed underground stream.

**Raised coral reef on the coast east of the limestone area**

On the coast between Nakandakari and Tako, limestone is found only on the spur heads, as is clearly illustrated in Pl. Fig. 5. Limestone is completely absent from the interior. Even the valleys formed between spurs lack limestone. The upper surface of limestone on each spur head forms a 20-meter terrace which extends over the spur slowly ascending to its base. There is a bench with an altitude of 5 to 10 meters on each seaward cliff of limestone. The altitudes of these terraces and benches of limestone correspond to those of reefs C and D on the limestone area, indicating the former being the eastern counterparts of the latter. There is no limestone terrace which corresponds in altitude to reefs A and B. Absence of limestone except from the spur heads may be an indication of the post-coralic formation of the valleys between spurs. If this is the case, the limestone rocks on the spur heads may be the remaining portions of the originally continuous belts of the coral reef. The belts may have been completely eroded away between the spur heads as the valleys cut through their ways.

Limestone is completely absent from the coast east of Tako. Spurs on this coast lack limestone on their heads, and end in simple cliffs rising from the surface of the present fringing reef (Pl. Fig. 13). Absence of limestone should not be accounted for by a submergence caused by a tilting of the foundation, for there is no indication of an eastward descent of limestone terraces, which would be the case if there had been any tilting since the reefs have been formed. It was suggested in a foregoing discussions that there has been no tilting of the foundation on the coast under discussion since the present fringing reef had been formed. This indicates a stable nature of the foundation rock in this region, and therefore, there may have been no tilting since the time when the raised reefs had been formed. Limestone disappears suddenly at a point, suggesting an effect of a faulting. But there is no indication of a post-coralic faulting which may have caused a complete submergence of limestone on the eastern coasts.

Since both tilting and faulting are not probable reasons for absence of limestone from the eastern coasts, reasons must be sought elsewhere. Absence of limestone may be explained by either one of the following reasons; the coral reef was never formed on this coast owing to some unfavorable condition for coral growth; or the coral reef was formed but only so weakly that they were completely eroded away. Limestone on this coast is very heterogeneous, containing numerous andesitic boulders and pebbles. The heterogeneity may be an indication of a weakness of limestone. The present reef on this coast is more severely eroded away than that on the coast of the limestone area. These facts favor the latter of the foregoing reasons for the absence of limestone from the eastern coast.

Contrary to the post-coralic formation of the valleys on the north coast, the valleys which form the beds of the two rivers may have been formed before the coral reefs were formed. The foundation of andesitic agglomerates is exposed beneath the reef on the banks of the then-submarine valleys. The reef limestone extends from the mouth to the interior for a distance of 1. 5 km. on the Shirase and for a distance of 1 km. on the Kominato. It is probable that the valleys eroded their ways through the reef limestone for such a distance without causing much abrasion to the remaining portions. Presence of a submarine valley which extends its way up to the two rivers may also be an indication of the pre-coralic formation of the valleys.

From the foregoing observations, the following conclusions may be made on the raised coral reefs.

1. Coral sand and gravels deposited on a broad submarine platform of the limestone area provided a favorable foundation for the coral growth. This resulted in a formation of the well developed coral reefs in this area.

2. On the other hand, coral sand and gravels were not deposited on the coasts east of the limestone area, owing to the steeper sloping of the andesitic agglomerates formation. The exposed andesitic agglomerates formation does not offer a favorable foundation for the coral growth, as is the case with the Shimajiri Beds in Okinawa Island. Comparatively poor development of the coral reef on the coasts east to the limestone area may be accounted for by this condition of the foundation.

3. Complete absence of the coral reef from the eastern part of the northern area and from the entire southern area may also be accounted for by the unfavorable condition of the foundation. The reef may have been formed so poorly in those areas that it was completely eroded away, or the reef may not even have been formed.

4. Discontinuity of the reefs on the coasts east of the limestone area may have resulted from the poor development of reefs through differential erosions. The erosions may have been so severe as to form the steep-sided valleys, on the banks of which blocks of the reef limestone were left. Or, the reefs may have originally been discontinuous, the reef having been formed on the banks of pre-existing valleys, as is evidenced by the rivers, the Shirase and the Kominato.

## Summary

1. The present fringing reef in Kume Island is more or less well developed along the entire length of the coast line. It is better developed on the northern coasts where it forms broad platforms with a maximum width of more than 500 meters.

2. The present barrier reefs are well developed off the southwestern coast and southeastern coast, and east of the east coast. The barrier reefs expose themselves at high water at the west and east ends of their distribution, and submerge at normal low water in the central southern part, indicating a land uprise at both ends or subsidence in the central southern part.

3. The distribution of the raised coral reefs is mostly limited to the western part of the northern area, where five steps of limestone terraces are distinguished. The raised coral reefs extend their distribution on the coasts east of the limestone area, where two steps (on the north) or three steps (on the south) of limestone terraces are distinguished.

4. The raised reefs are well developed in the main limestone area, having a thickness of over 35 meters, which is unusually thick compared to that (less than 20 meters) estimated for the reefs in Yoron Island by Hirata (1956). It was explained that the figure represents not only the thickness of the coral reef but also that of the basal formation of coral sand and gravels. The thickness of the raised reef on the coasts east of the main limestone area does not exceed 20 meters.

5. Difference in coral reef development in different areas is accounted for by the nature of the foundations (See 1. through 4. in a preceeding page).

## Acknowledgement

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## Explanation of plate figures

### Plate I

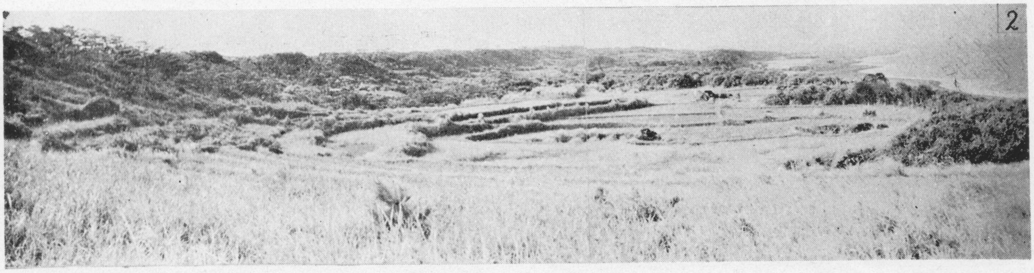
1. Reef at Hanni-saki; the inner flat has been eroded; the outer flat extends eastward to form the barrier (Iri-bishi). A sand dune on the left is covered by casuarine woods.
2. A 20-meter terrace with rice fields on the north coast. Ridge at the back is a 40-meter raised reef; no reef is found between the 20- and 40-meter reefs. The fringing reef in the upper left corner has a large depression filled with fresh water.
3. A 20-meter raised reef (upper) and 5-meter one (two men standing) on the north coast. That part of the fringing reef which appears in front does not submerge at normal high water.
4. 20-meter and 40 meter raised reefs on the northwestern coast. A part of the 40-meter reef can be recognized on the left.
5. Coral limestone on the heads of four spurs on the coast of Tako. The furthest spur with a sea arch is the eastern limit of the limestone distribution on the north coast. The nearest two spurs have 5-10-meter benches on their heads; limestone on each spur head attains an altitude of about 20 meters.

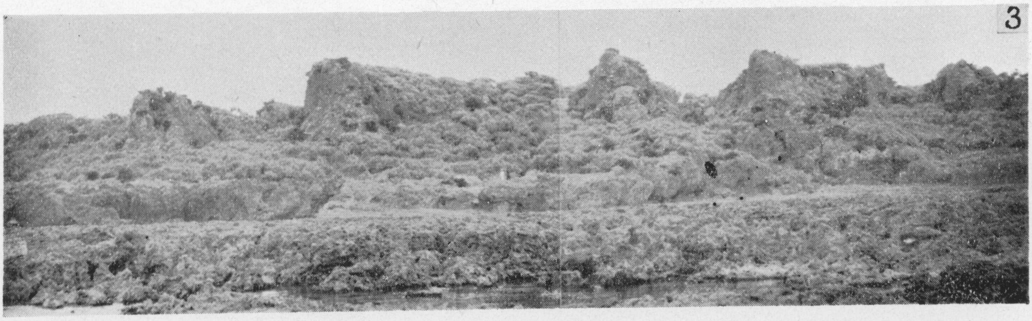
### Plate II

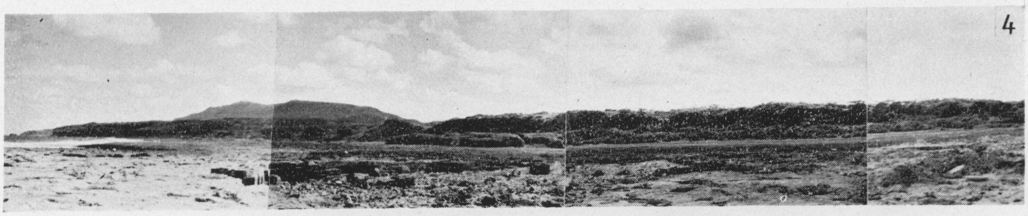
6. Flat topped boulders in the lagoon inside the barrier, Iri-bishi.
7. Limestone pinnacles on a 20-meter contour line; these may represent the remaining rocks of the 20-meter raised reef.
8. A seaward projecting ridge on the fringing reef on the north coast; it is about 3 to 5 meters in altitude and is connected proximally to the 5-meter strandline raised reef.
9. A mushroom rock and a seaward projecting ridge on the north coast, about 500 meters west of the ridge shown in 8. A wave cut bench on the outer edge of the fringing reef is seen in the center
10. Mushroom rocks on the beach near Torishima; they are 5 to 10 meters in altitude. The barrier on the back is a part of Iri-bishi.
11. A limestone islet and mushroom rocks on the beach about 1km. west of the rocks in 10; the altitude of the islet is about 10 meters.

12. A limestone islet off Torishima; it is about 15 meters in altitude. A part of the 20-meter reef on the eastern bank of the Shirase River is seen on the left; this reef marks the eastern limit of the limestone distribution on the south coast.
13. Wave cut spur heads in the non-limestone area on the north coast near Uegusuku.
14. Exposed foundation rock of Shimajiri Beds, covered by a sheet of the fringing reef, about 1.5 km. west of Aka.
15. Exposed foundation rock of andesitic agglomerates (the black horizontal belt), covered by a sheet of the fringing reef limestone on the coast of Tako which is about 5 km. west of the point shown in 14.

## Plate I


## Plate II