

Stratigraphic Notes on Yoron-jima : With Special Reference to the Quaternary Deposits

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Abstract The Ryukyu Group (then, the Riukiu Limestone of Hanzawa, 1935) on Yoron-jima is reclassified into two formations, the older "Gusuku" and, the younger "Nama", on lithofacies of limestone which makes up the main part of each formation. The "Gusuku Formation" is generally composed of a calcite-cemented mixture of a variety of organic remains which were displaced, brecciated to well-sorted bioclastics, while the "Nama Formation" consists of a poorly-sorted and calcite-cemented limestone. Profusion of large reef-building corals in growth position on the western side of this island suggests that a part of the "Nama Formation" is reef-rock itself. Horizontal traceability of certain beds composed of the other sedentary organisms and poor sorting of the bioclastics in the "Nama Formation" on the eastern side also indicate that this formation was formed close to the habitats of the reef-forming organisms.

A similar contrast in lithofacies between two formations appears to be recognized in the Ryukyu Group on the nearby Okierabu-jima, just 25 km north of Yoron. The younger reefy Serikaku Formation (Nakagawa, 1967) on Okierabu-jima which yielded some fossil corals of 80,000 to 100,000 years old in deficient ^{230}Th and ^{231}Pa ages may be correlated with the "Nama Formation". It is further concluded that the "Gusuku Formation" was probably deposited during the interglacial stage centering around approximately 120,000 years ago, if its correlation with the Older Member of the Riukiu Limestone on Kikai-jima (Konishi *et al.*, 1970) can be accepted.

Introduction

The post-Miocene limestones which covered the Ryukyu Islands (Nansei-shoto) were divided into Early Holocene Raised Coral Reef and Plio-Pleistocene Riukiu Limestone by Hanzawa (1935). Yoron-jima in the Amami-o-shima island group was unfortunately excluded from his comprehensive work. Oba (1955, 1956) who mapped the

geology of the island for the first time, traced coralline limestones on the island and placed them in the Riukiu Limestone of Hanzawa. Since then, this island has been investigated geologically by Hirata (1956, 1958), Hatae *et al.* (Kagoshima Prefecture, 1963) and Nakagawa (1967, 1969). On Yoron-jima, the Riukiu Limestone, which can be referred to the Ryukyu Group of MacNeil' (1960) was split into two formations, Nama and Gusuku, by Nakagawa.




Yoron-jima is located at 563 km SSW of Kagoshima City and belongs to Kagoshima Prefecture. The approximate center of Yoron-jima is Long. 128°24' E. and Lat. 27°01' N. The island is 21.9 km in circumference and 20.82 km² in area. Though this island is on the whole low and flat, some scarps trending NNW-SSE and NWW-SEE are traceable across the island. In the northeastern part divided by these scarps, successive terraces and narrow troughs are arranged parallel to the NE coastal line, whereas the western division is flat lowland, being less than 30 m in altitude. The southeastern division comprises the greatest elevation. The most striking topographic characteristic of Yoron-jima is the development of barrier reef. The barrier reef conspicuously develops in northern to southeastern off-shore, off the coast from Chabana to Chichi-zaki via Yurino-hama. The continuous barrier breaks near Yurino-hama, which is a shoal, emerging from the sea-level only at spring low tide. The lagoon is shallower than 5 m in depth when the tide is low. The southern coastal line is bordered with the small scale fringing reef.

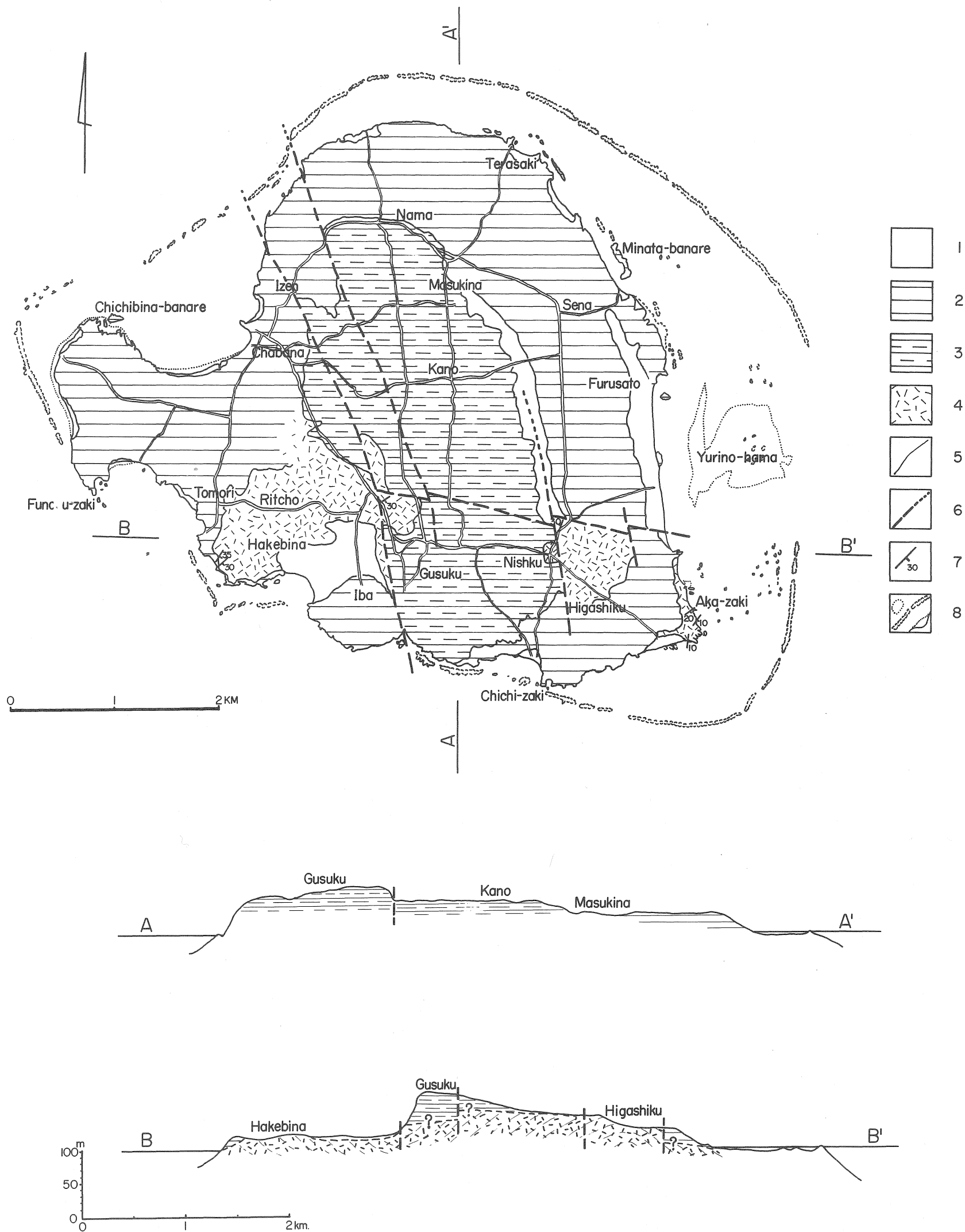
The purpose of this study is to elucidate the lithology of the Ryukyu Group on Yoron-jima, and the correlation among some coralline limestones in the Amami-o-shima island group.

I wish to express my thanks to Professor Kenji Konishi for suggesting this investigation as well as for constant guidance in the course of the work. A part of this work was financed by a Grant-in-Aid for Scientific Research from the Ministry of Education.

Outline of Geology

Geology of Yoron-jima is summarized as follows ;

Holocene	Reef Deposits, Beach Sand, Beach Rock, Gravel	
		Unconformity
Pleistocene	Ryukyu Group	{ <div> "Nama Formation"  Unconformity "Gusuku Formation" </div>
		
Late Paleozoic(?)	Ritcho Formation	



Text-figure 1 Geologic map of Yoron-jima

1. Holocene Deposits 2. "Nama Formation" 3. "Gusuku Formation" 4. Ritcho Formation
5. Boundary between stratigraphic units 6. Fault (dotted part, inferred) 7. Strike and dip of beds 8. Coral reef and tidal flat

In this paper, I follow principally to the stratigraphic nomenclature of Nakagawa (1967). As described below, however, the two formations of the Ryukyu Group were redefined and used in the different connotations from the original ones, hence, the quotation marks are tentatively affixed to the names of these formations.

Ritcho Formation As to this formation, I have no more than the data provided by Oba (1955, 1956) and Nakagawa (1967), and wish to describe very briefly.

The Ritcho Formation is mainly developed on the southern side of the island, the areas centering around Ritcho and nearby Higashiku, and partly along the southeastern coast, near Aka-zaki. The type locality is along the Hakebina coast. This is composed of limestone, slate, sandstone and greenstones, which were regionally metamorphosed showing an appearance of phyllite. The formation strikes N 10° to 60° E and has complex folding and faulting structures. As a whole, a syncline accompanied with an anticline can be inferred in this formation (Text-fig. 1). The formation is overlain unconformably with the Ryukyu Group, and its blocks are found in the basal part of the Ryukyu Group as boulders to sand grains. It appears to exceed more than 400 m in thickness, but the accurate thickness cannot be determined due to poor exposure.

Limestone of this formation is light-colored with irregularly interwoven dark-colored stripes and generally crystalline. Slate is dark-colored and accompanied with thin or lenticular beds of sandstone, medium- to fine-grained. Greenstones are generally fine-grained and occasionally associated with the thin layers of fine-grained sandstone. Besides these rocks, Nakagawa (1967) reported chert from this formation.

Ryukyu Group Except for the limited area where the Ritcho Formation and Holocene Deposits are developing, the Ryukyu Group covers widely over this island, an area of about 70 % of the total surface. This group consists of two rock facies, limestone and conglomerate. The limestone is generally indurated hard as cemented with calcite and makes up the main part of this group. It is mainly composed of fossil remains of corals, coralline algae, foraminifers, molluscs, bryozoans and echinoids. On the basis of faunal and floral assemblage of fossil remains and textural feature of the limestone, this group can be divided into two formations, "Gusuku Formation" and "Nama Formation". The conglomerate is predominant at the basal part of both two formations, and contains a lot of angular boulders derived from the underlying formation nearby. The gravels gradually decrease in grain size ascendingly from the base of this group. The Ryukyu Group is generally horizontal and partly inclines gently (less than 10°) seawards. This group on Yoron-jima seems not to exceed 70 m even in the maximum thickness.

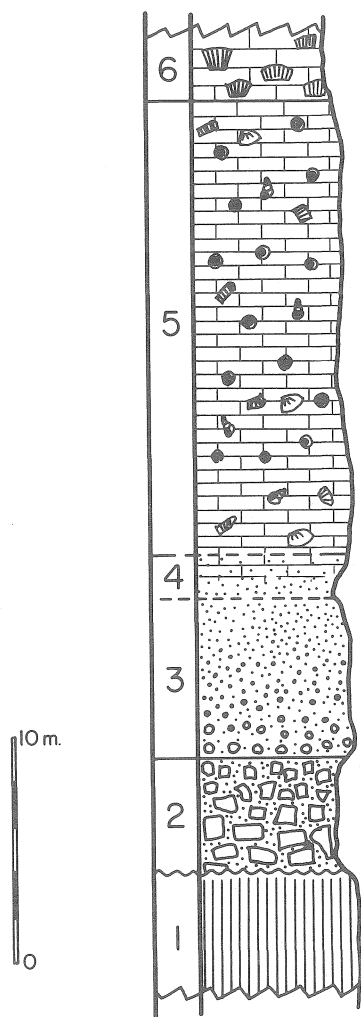
Because the basal conglomerates of both "Gusuku" and "Nama" Formations resemble lithologically, attention was drawn only to the limestones which make up the major part of each formation.

"Gusuku Formation" The "Gusuku Formation" is developed in the central and southern areas of Yoron-jima, where it crops out about some 30 m in elevation. As a whole, this formation is poor in facies change and consists of a calcite-cemented mixture of a variety of fossil remains, which are foraminifers, crustose coralline algae, molluscs, corals, bryozoans and echinoids in decreasing order of abundance. Among them, those of metastable phase such as spheres of coralline algae (high magnesium calcite) and coral (aragonite), are often recrystallized to such extent that their original internal microstructure cannot be observed. Bioclastic fragments in this formation are generally small, rounded and well-sorted.

Fossil corals also are represented with brecciated broken pieces of less than 10 to 20 cm in the maximum diameter. Except for the uppermost horizon, where the relatively large ones in growth position are found, the reef-building corals in this formation are preserved at random their burial orientation. The whole lithology of the "Gusuku Formation" and its stratigraphic relation with the underlying Ritcho Formation are best observed at the successive outcrops from Gusuku to Iba, as shown in Text-fig. 2.

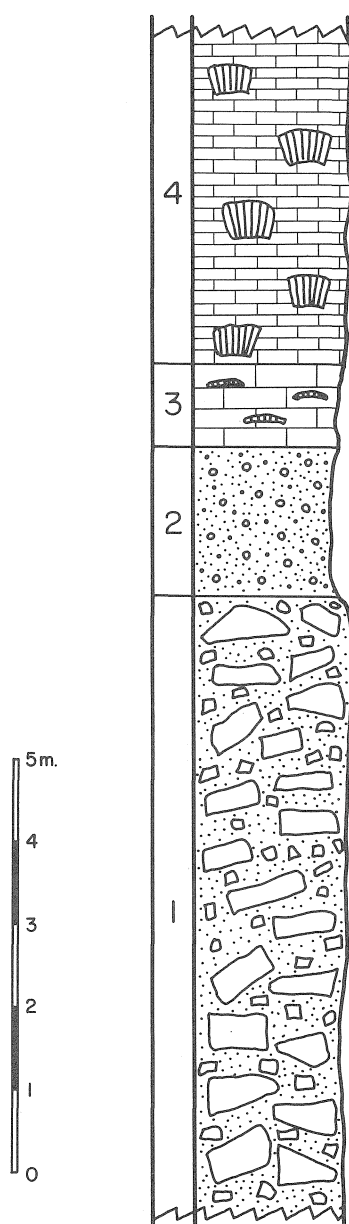
"Nama Formation" This formation less than 40 m thick is distributed on the terrace which occupies the altitude from 0 to 30 m. It is mainly composed of limestone cemented with calcite, whereas the basal part contains subrounded to angular pebbles as well as cobbles and boulders of limestone, sandstone and greenstone derived from the underlying rocks nearby. The bioclastics in this formation are also recrystallized, though they are less extensive than those in the "Gusuku Formation".

There may be a little, if any, differences in species of fossil remains between two formations of the Ryukyu Group on Yoron-jima. This formation, however, differs from the "Gusuku Formation" on the mode of occurrence of fossil corals, and is



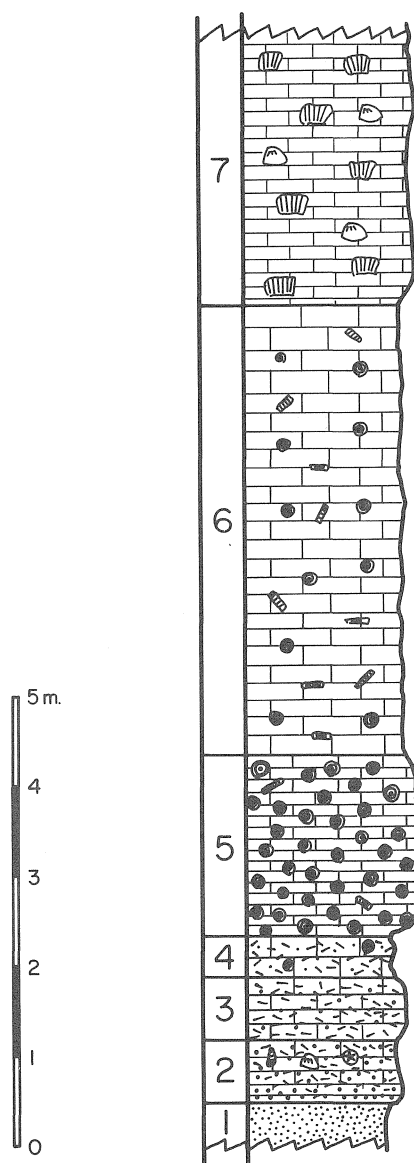
Text-figure 2 Columnar section of the "Gusuku Formation" from Gusuku to Iba

1. Ritcho Formation (strongly altered)
2. Boulder conglomerate
3. Cobble to pebble conglomerate (in units 2 and 3, grain size of gravels decreases gradually upwards)
4. Sandstone (coarse to medium grained, cemented hard with calcite in the upper part)
5. Calcite-cemented limestone (contains a variety of small and relatively well-sorted bioclastics)
6. Coral limestone (contains some fossil corals which range from 10 to 20 cm in the maximum diameter)



Text-figure 3 Columnar section of the "Nama Formation" at Funchu-zaki

1. Boulder conglomerate (often contains corals and other organic remains)
2. Cobble to pebble conglomerate (slightly cemented, grain size of gravels changes laterally)
3. Coral limestone (composed mainly of orbicular corals, *Fungia*; this unit is lenticular)
4. Coral limestone (very large corals in growth position are found abundantly)



Text-figure 4 Columnar section of the "Nama Formation" at the outcrop on the west of Furusato

1. Non-calcareous sandstone (medium to fine grained)
2. Granule conglomerate (contains many *Operculina* and a small amount of echinoids and molluscs)
3. Foraminiferal limestone (composed mainly of *Operculina*)
4. Foraminiferal limestone (contain fairly algal ball)
5. Algal ball limestone
6. Brecciated limestone (a variety of bioclastics is small and relatively well-sorted)
7. Coral limestone (corals are smaller than those in the unit 4 of Text-fig. 3)

strongly variable in local rock facies. This formation on the western side of this island is composed mainly of coralline limestone, whereas fossil corals occur only sporadically on the northern and eastern sides of the island, where large foraminifers and coralline algae are found in abundance (Text-figs. 3 and 4). Large corals, several tens of centimeters in diameter (often exceeding 1 m in the maximum), are characteristically conspicuous in this formation, and their majority hold the original growth position. The organisms other than reef-building corals, such as algal balls and foraminifers represented by *Operculina* are concentrated in some beds, being laterally traceable from the north of Masukina to the northeast of Higashiku via Furusato. These well-sorted beds are local exceptions within the poorly sorted reefy facies as a whole.

Holocene Deposits

A great variety of organic remains is accumulating on the bottom of the lagoon surrounding the island. The organisms living in the lagoon were ecologically studied in some detail by Tanaka and Itono (1968) and Hirata and Osako (1968).

Beach sand is developed mainly along the coast inside barrier reef, whereas along the southern coast it is only poorly distributed. It forms dune widely along the eastern coast, from the north of Aka-zaki to east of Furusato.

Beach rock is scattered on the coast of Yoron-jima, for examples, at the south of Minata-banare and Terasaki coast, and near Aka-zaki, Chichi-zaki and Funchu-zaki. This rock often reaches about 50 cm in thickness at the thickest part and dips several degrees seawards with remarkable stratification.

Finally, mention must be made of the gravels around Tomori. The diameter of gravels ranges from a few to 30 cm, and the matrix is generally clayey. The thickness of this gravel appears not to exceed 10 m in the maximum. The gravels consist of greenstone, slate, sandstone and limestone all that were derived from the Ritcho Formation.

Besides the Holocene deposits as above-mentioned, sedentary soil covers thinly this island.

Correlations of Ryukyu Group

Reef-building corals and *Tridacna* shells collected from the Ryukyu Group in the Ryukyu Islands have been dated by the deficient ^{230}Th and ^{231}Pa methods (Sakanoue, Konishi and Komura, 1967; Omura *et al.*, 1969; Konishi *et al.*, 1970; Omura and Konishi, 1970, 1971). However, the well-preserved aragonitic organic remains suitable for radiometric dating by these methods could not be found in the Ryukyu Group on Yoron-jima. This makes difficult to correlate directly the Ryukyu Group of the island with that of the other parts of the Ryukyu Islands. By a geomorphological approach with matching terraces between the Ryukyu Islands and Honshu, Nakagawa (1969) postulated that his Nama and Gusuku Formations correspond to Plains III and V on Honshu, respectively.

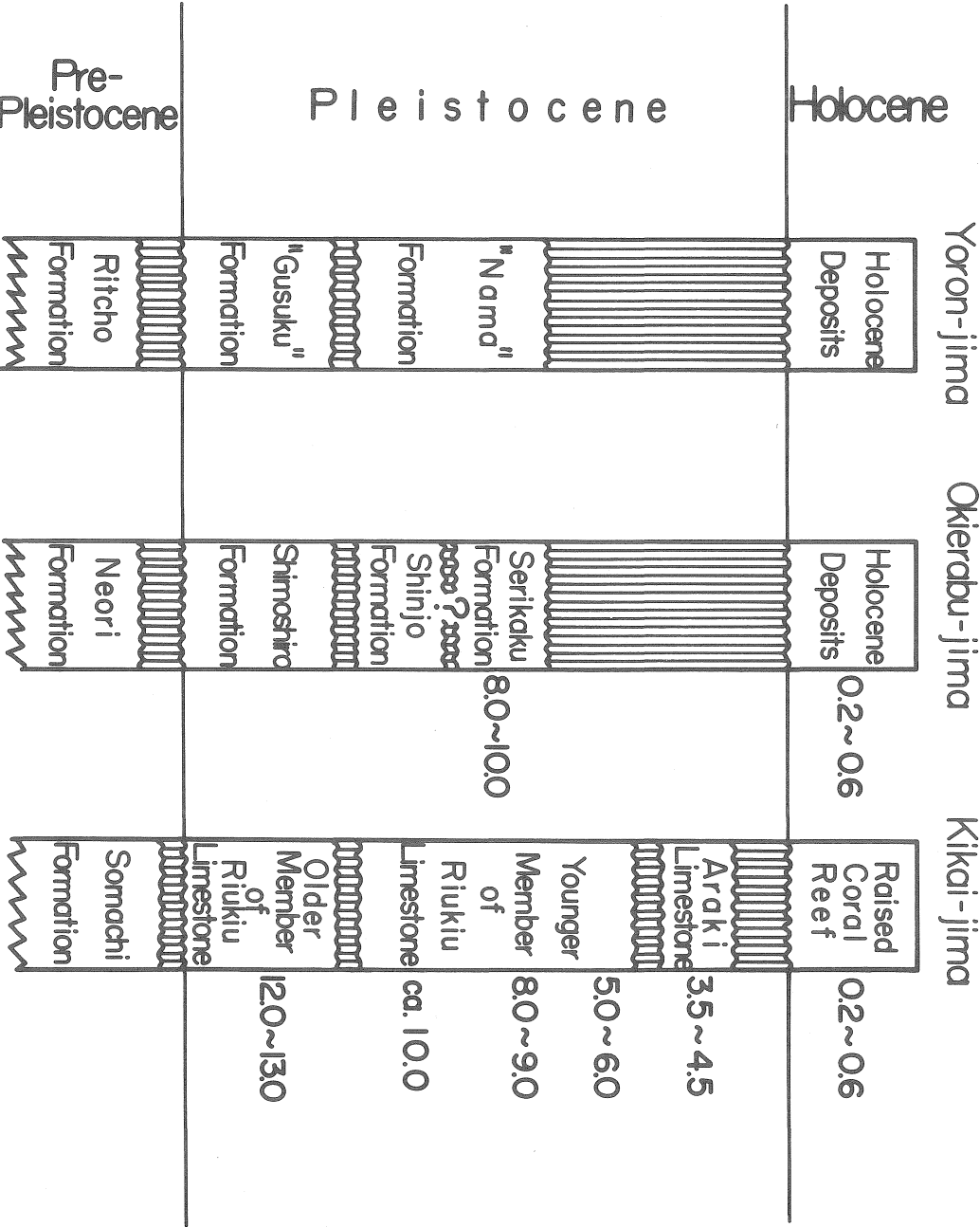
The differences in lithofacies of limestone between the "Gusuku Formation" and "Nama Formation" might be thought to have resulted from the change of the sedimentary environment due to either tectonic uplift of this island or drop of sea-level. The degree of mixing as well as sorting of bioclastics may suggest that the "Gusuku Formation" was deposited under a relatively deep-water condition, whereas the "Nama Formation" has formed probably under a shallow-water condition where most bioclastics were deposited close to their "source". This view may be supported by many fossil corals in growth position, horizontal distribution of certain benthonic organisms and poor sorting of bioclastics in the "Nama Formation". It may be postulated that Yoron-jima has been uplifted and the sedimentary environment of the Ryukyu Group had shifted to shallow in progression after deposition of the "Gusuku Formation". Downward sea-level changes also may cause the same result.

The Ryukyu Group on Okierabu-jima which is located only 27 km north of Yoron-jima appears to have preserved a similar history in the sedimentary record. It was subdivided into three formations, in descending order, Shimoshiro, Shinjo and Serikaku Formations by Nakagawa (1967). Among them, however, the Shimoshiro Formation is generally composed of calcite-cemented mixture of a variety of organic remains, whereas both Shinjo and Serikaku Formations are together regarded as shallow-water deposits according to the mode of occurrence of bioclastics. Thus, the Shimoshiro Formation lithologically resembles the "Gusuku Formation" on Yoron-jima, while the Shinjo and Serikaku Formations do the "Nama Formation". If this comparison can be extended as the probable correlations, it might be concluded that the "Nama Formation" was deposited at 80,000 to 100,000 years B.P. before the "Gusuku Formation" was formed, because four fossil corals from the Serikaku Formation near Kunigami-misaki of Okierabu-jima gave the dates of $92,000 \pm 2,000$, $95,000 \pm 3,000$, $92,000 \pm 3,000$ and $95,000 \pm 2,000$.

On Kikai-jima, the Ryukyu Group was stratigraphically investigated in detail by Schlanger and Konishi (1966) and Konishi and Schlanger (1967), and many of the well-preserved fossil corals were dated by the deficient ^{230}Th and ^{231}Pa methods (Sakanoue *et al.*, 1967; Konishi *et al.*, 1970). Their results are summarized in Text-fig. 5 in which my unpublished data are also included. From this text-figure, it can be suggested that the "Gusuku Formation" was probably deposited at the same time as the Older Member of the Riukiu Limestone on Kikai-jima, during the interglacial stage centering around approximately 120,000 years ago.

Both the Araki Limestone and Raised Coral Reef which are developed on Kikai-jima cannot be found on Yoron-jima. It may be due to a slower rate of uplift of this island as well as Okierabu-jima, as compared to Kikai-jima or it may be a result of uplift combined with later subsidence, as pointed out by Konishi *et al.* (1970). This interpretation is supported by the development of barrier reef surrounding this island, which may correspond to the reefs of either the Latest Pleistocene or Mid-Holocene or both, as interpreted by Hirata (1967).

The geologic history of Yoron-jima may be summarized as follows;



Text-figure 5 Correlation of the Ryukyu Group

(The values indicated aside each column are ²³⁰Th and ²³¹Pa ages, including some unpublished data. The column of Kikai-jima is essentially the same as that by Schlanger and Konishi, 1966 ; and the column of Okierabu-jima by Nakagawa, 1967, is revised slightly.)

(A) The Ritcho Formation was deposited within a eugeosyncline under the influence of volcanism in Late Paleozoic time. Subsequently, it was folded and faulted during Late Mesozoic and the subsequent time, and the sea bottom was brought within the photic zone later during the Quaternary Period.

(B) The "Gusuku Formation" was formed in warm water approximately 120,000 years ago.

(C) Though it was very slow, Yoron-jima was gradually uplifted and a part of it might be raised above sea-level. The "Nama Formation" was deposited in tropical shallow reefy water around the island. This event took place approximately 80,000 to 100,000 years ago.

(D) Barrier reef began to develop and Holocene sediments were deposited around and on the island. Faulting was and probably still is active to the present. Being accompanied with the uplift, the surface of the island was eroded and flattened to have resulted in a very smooth topography.

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Appendix : Alphabetical List of Place Names

Aka-zaki	(赤 崎)	Kunigami-misaki	(国頭岬)
Amami-o-shima	(奄美大島)	Masukina	(増木名)
Chabana	(茶 花)	Minata-banare	(ミナタ離)
Chichibina-banare	(チチビナ離)	Nama	(那 間)
Chichi-zaki	(チチ崎)	Nansei-shoto	(南西諸島)
Funchu-zaki	(フンチュウ崎)	Nishiku	(西 区)
Furusato	(古 里)	Okierabu-jima	(沖永良部島)
Gusuku	(城)	Ritcho	(立 長)
Hakebina	(ハケビナ)	Ryukyu (= Riukiu)	(琉 球)
Higashiku	(東 区)	Sena	(瀬 名)
Honshu	(本 州)	Serikaku	(瀬利覚)
Iba	(伊 波)	Shimoshiro	(下 城)
Izen	(伊 前)	Shinjo	(新 城)
Kagoshima	(鹿児島)	Terasaki	(寺 崎)
Kano	(叶)	Tomori	(供 利)
Kikai-jima	(喜界島)	Yoron-jima	(与論島)
Kotohira-jinja	(琴平神社)	Yurino-hama	(百合ノ浜)

PLATES

Explanation of Plate I

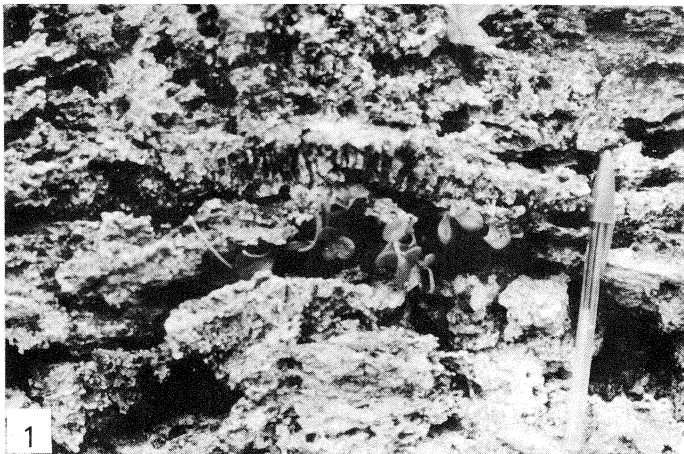
Figures 1 and 2 Photographs showing the mode of occurrence of corals at the uppermost horizon in the "Gusuku Formation"

Figure 1 An outcrop near Kotohira-jinja (Shrine), western of Gusuku; the pencil in the picture is 15 cm long. The head of the pencil points the growth direction of the coral.

Figure 2 An outcrop on the southeast of Chabana. Arows, being about 10 cm long, show the growth direction of the corals. Corals in this formation are generally small and are not necessarily regular in their growth direction.

Figure 3 The general appearance of calcite-cemented limestone in the "Gusuku Formation"; the lens-cap in the picture is about 5 cm in diameter. Organic remains in this limestone is recrystallized to such extent that their texture cannot be observed.

Plate I



Explanation of Plate II

Figures 1 and 2 Photographs showing the mode of occurrence of corals in the "Nama Formation" on the western side of Yoron-jima. Both pictures show the corals whose growth direction were kept upward as seen in the field.

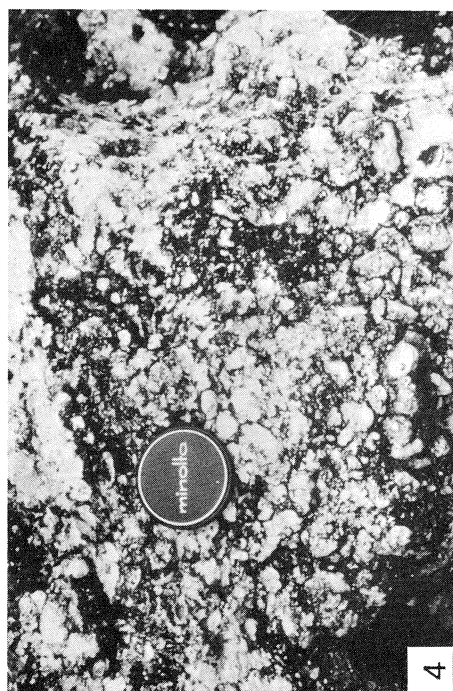
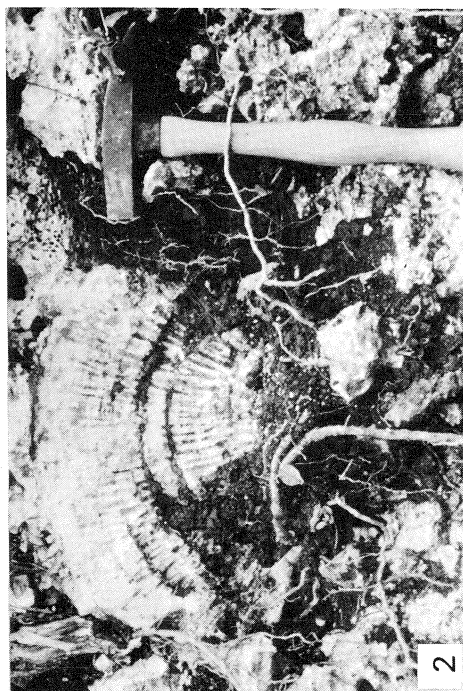
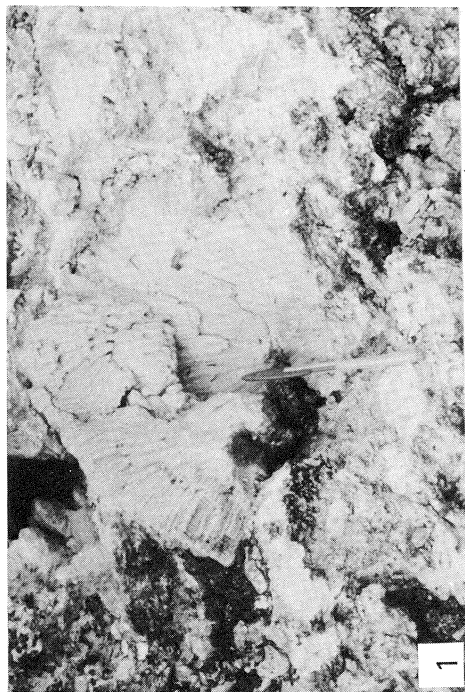
Figure 1 at an outcrop on the west of Tomori.

Figure 2 at an outcrop on the south of Izen; the head of the hammer in the picture is 18 cm in length.

Figure 3 Foraminiferal (*Operculina*) limestone at Sena.

Figure 4 Algal ball limestone at an outcrop on the west of Eurusato.

Plate II



Explanation of Plate III

- Figures 1 and 2 Photographs showing the bottom of lagoon, about 5 m in depth, 500 m east of Aka-zaki. It is worthy of notice that the great part of larger particles in sediment consists of coral remains derived nearby (Fig. 1) and that living corals are so poor in numbers of species that one might look for their habitat segregation (Fig. 2).
- Figure 3 Gravels near Tomori. This unit is non-calcareous and does not contain sizable organic remains.
- Figure 4 Beach sand on the beach near Furusato. The larger particles as shown in Fig. 1 are not seen at all.
- Figure 5 Beach rock on Hakebina coast. It contains many basement rocks such as the Paleozoic limestone and greenstone cropping out nearby.

Plate III

