Reef Flat and Beach Rock of Southern Tokunoshima, Ryukyu Islands

Reef Flat and Beach Rock of Southern Tokunoshima, Ryūkyū Islands

Tatsuo TAKAHASHI* and Motoharu KOBA**

Introduction

International research on 'sea-level movements during the last deglacial hemicycle about 15,000 years' is going to be stepped up as a key project for International Geological Correlation Programme, and investigators in Japan are preparing for the participation in this project. We too are advancing preliminary surveys on the coral reef coasts of Ryūkyū Islands for the problems of Holocene sea level. The present paper, as a part of these surveys, is the report on fringing reefs with small lagoons along the southern part (27°39'-42'N, 128°58'-129°1'E) of Tokunoshima Island.

It is a matter of course that coral reef responds sensitively to sea level change. In order to trace the fluctuation of Holocene sea level, it is necessary to clarify the mechanism of reef building and the relation of sea level to the formation of reef flat, beach rock, or notch. But views of workers do not always agree on these problems.

The main purpose of this paper is:

(1) to discuss the relation between reef flat and sea level.
(2) to scrutinize the origin of beach rock.
(3) to guess previous sea level from emerged beach rock and emerged notch.

1 Reef Flat

In order to identify the above features of this coast the shore profiles are levelled at 5m-intervals in about right angles to the shoreline, or at shorter interval on rugged relief (Fig. 1). The sea level in the profiles is calculated from the tide table at Naha, the standard port.

Shore profile of this coast is ordinarily composed, successively landwards, of considerably smooth inter-tidal reef flat covered with algae near mean sea level, shallow lagoon on a small scale, high tide reef flat with small lapie-like or serrated roughness, up-rush slope with 5°–10° dip or beach, and terrace several meters in height constructed of Kametsu Formation (limestone, late Pleistocene) or sand dune

* Institute of Geography, Faculty of Education, Okayama University, Okayama
** Institute of Geography, Faculty of Science, Tōhoku University, Sendai

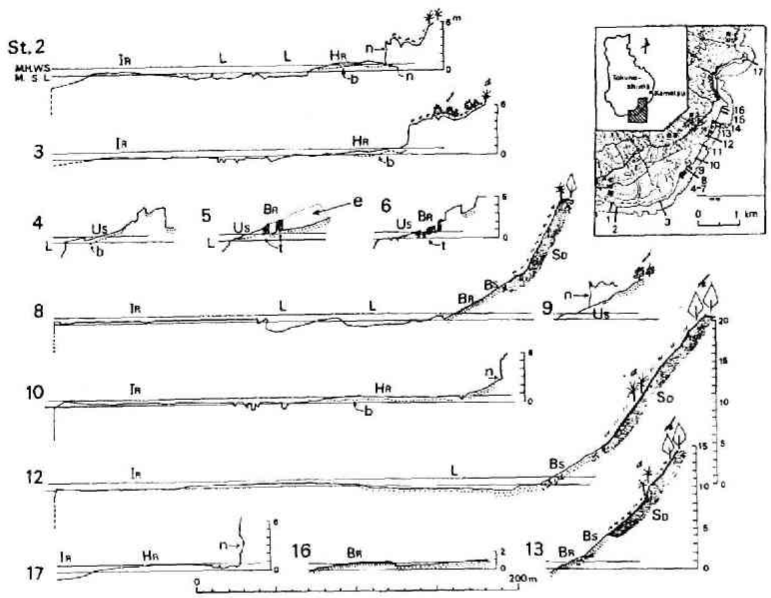

Fig. 1 Shore profiles on southern Tokunoshima
BR: beach rock, BS: beach sand, HR: high tide reef flat, IR: inter-tidal reef flat, L: lagoon, SD: sand dune, US: up-rush slope, e: ephemeral stream, n: notch, t: terrestrial brown soil, h: horsetail-tree, j: Japanese pittosporum, s: screw pine

overlying the front of the terrace. The seaside slope of sand dune is for the most part covered with herbal beach plants (*Zoisia tenuifolia* Willd., *Vitex rotundifolia* L., *Cassytha filiformis* L., *Cirsium brevicaule* A. Gray, *Lysimachia Mauritiana* Lam., *Spinifex littoreus* Merrill, or *Ipomoea pes-caprae* Sweet), and at some places with Japanese pittosporums (*Pittosporum tobira* Ait.) and screw pines (*Pandanus tectorius* var. *liukiuensis* Ward.). The top of sand dune is forested of horsetail-tree (*Casuarina equisetifolia* J. & G. Forst).

1) Inter-tidal reef flat

This reef flat extends broadly and almost horizontally near or slightly above mean sea level, and at its front it inclines slightly descending from mean sea level to low tide level without noticeable seaward rampart. The frontal rim is plunging steeply beneath low tide level to sea bottom more than several meters in depth. The reef flat surface looks considerably smooth, covered with algae at relatively less rugged part. Stripping off the thinly covering algae, truncated corals or trace fossils are exposed on the reef flat composed of coral limestone, but living corals cannot be recognized there except in the tide pool and at the frontal rim below

low tide level. This fact conspicuously suggests that the inter-tidal reef flat is erosional in origin.

Tayama (1952) stated on the coral reefs in Micronesia, 'the sea level coral reefs have been generally accepted as recent, but most of the present reef flats are abrasion surface, like pavements, displaying cross section of truncated reef building corals, benches, and mushroom rocks, and are relics of coral reefs of the age of the younger raised coral reef limestone'. On the contrary, Newell and Bloom (1970) concluded that the reef flats in the eastern Caroline and southern Marshall Islands (5°–10°N) generally were not simply erosional platforms but represented an equilibrium surface between upward accretion by reef-building organisms and erosion at the mean level of low tides.

In the northern Ryūkyū Islands it is recognized that the present reef-building is not so active as to construct a new reef flat above the low tide level in the near future and that inter-tidal reef flat is rather in the process of destruction than of construction by most investigators; for example, in Kuchinoshima (29°57'–30°N) and Nakanoshima (29°49'-53'N) (Saito, Kawaguchi and Koba 1971, Koba 1972), in Takarajima (29°7'–10'N) and Kotakarajima (29°13'N) (Hirata 1967, Takahashi and Fukumoto 1975), and in Okinoerabu (27°19'–26'N) (Koba 1974). It must have been warmer than at present for such broad coral reef to be constructed on this region. And after the stage of reef-building activity, lowering of sea level must have caused the erosional reef flat.

2) High tide reef flat

Inter-tidal reef flat looks smooth and green with algae cover and high tide reef flat is naked and serrated with many pinnacles. Accordingly, it is easy to distinguish between these two at a glance. Moreover, low cliff separates both. High tide reef flat is rugged and has many small lapies whose tops are horizontally located near high tide level. The rill bottom of lapie field usually continues to the surface of inter-tidal reef flat in level. Then it may as well be judged that the top level of lapie field is indicating a sea level higher than the present one. Fairbridge (1952) traced thus 2–3 feet sea level and 5–6 feet sea level at the coral reef coast of Australia.

The coexistence of two kinds of flats on shore profile is ubiquitous in Tokunoshima and Takarajima (Takahashi and Fukumoto 1975), but at non-calcarious coasts such two kinds of flats are difficult to distinguish (Takahashi 1974). It is impossible yet to explain sufficiently the reason of this difference.

2 Beach rock

Yonetani presented many papers on the beach rocks in northern Ryūkyū

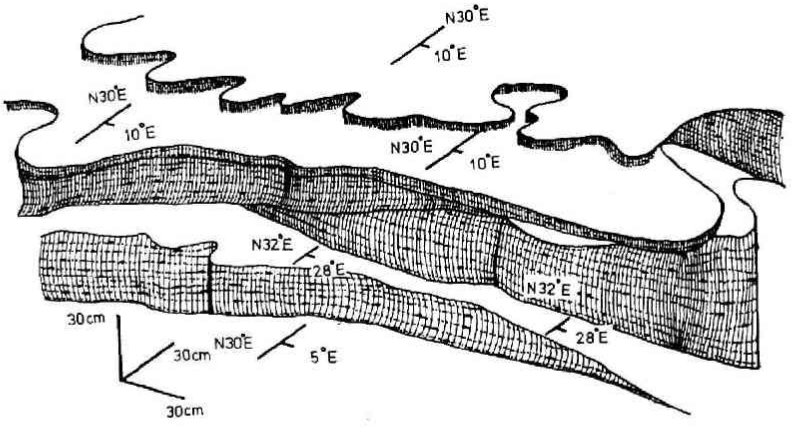

Fig. 2 Beach rock structure on southern Tokunoshima (A-type)
Beach rock is composed of bioclastics and non-bioclastics, 1–1.5 mm in average diameter and granule-pebble in size. This beach rock is eroded along bedding plane.

Islands (1963, 1963-67, 66). Beach rocks of southern Tokunoshima coast are classified into four types according to their features, or referring to Yonetani's descriptions.

1) A-type

There is typical beach rock on the beach in front of sand dune which consists of several beds, dipping seaward at 5°–10° and looks like micro-cuestas (St. 8, 13 and 14 in Fig. 1). Its upper limit is 2.5–3 m above mean sea level. It is composed of round bioclastics (coral, shell and foraminifera) and non-bioclastics, 1–1.5 mm in average diameter and granule-pebble in size (Fig. 2). Any remains and trace fossils of lagoonal organisms are not found in the beds. Cross lamination is recognized, but sorting is not good as a rule and it is difficult to recognize such sorted bedding in a bed or a band as Takenaga (1965) observed on the beach rock in Yoron. Such a sedimentary structure means that this beach rock is not originated from lagoonal deposits. The beach rock is eroded along bedding plane, and the exposed bedding plane suffers corrosion.

2) B-type

There are beach rocks plugged in crevice of up-rush slope at the mouth of small ephemeral stream (St. 5 and 6 in Fig. 1, and Fig. 3). The crevice is filled with terrestrial brown soil brought from the terrace behind, and the brown soil is covered by one or two beds of beach rock. The upper bedding plane of the beach rock continues to the surface of up-rush slope constructed with limestone (Kametsu

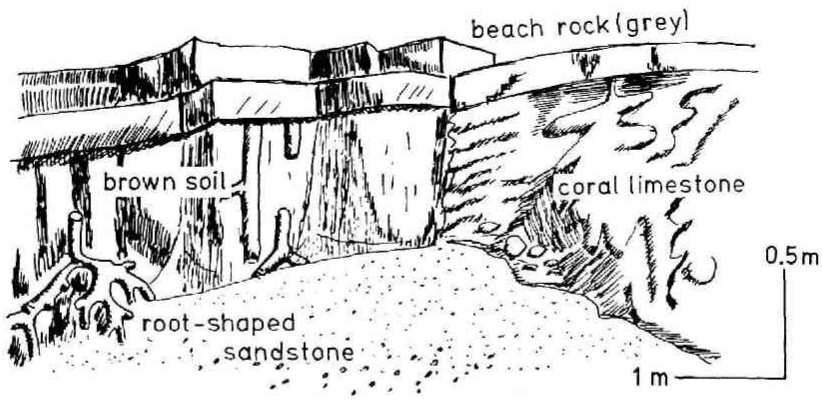

Fig. 3 Beach rock plugged in a crevice of up-rush slope at the mouth of small ephemeral stream (B-type)

Formation). The beach rock is composed mainly of littoral deposits (fragments of coral, shell, and foraminifera), and has no remains and trace fossils as evidence of lagoonal environment. Otherwise, terrestrial brown soil contains no marine materials, but some root-shaped calcareous sandstone of screw pine (Fig. 3).

Based on the above observations, the recent process is inferred as follows. Once screw pines grew on ground after the inflow of brown soil into the crevice of emerged up-rush slope through ephemeral stream from the rear. Then, with some submergence, beach sand was supplied there from the sea, and screw pines stopped growing, and their roots were substituted by calcareous sand. Beach rock and root-shaped sandstone were cemented of beach deposits. With the subsequent emergence, beach rock exposed itself and its upper surface suffered corrosion.

3) C-type

There is patch-like beach rock in small solution pool on up-rush slope (St. 4 in Fig. 1 and Fig. 4). From its existing state it is judged that the beach rock composed of sand which filled the solution pool has suffered corrosion with subsequent emergence. Some patch-like beach rocks on up-rush slope are seen up to about 3 m above mean sea level.

4) D-type

At the mouth of ephemeral stream there is beach rock composed of calcareous sand with terrestrial gravels (St. 15 and 16 in Fig. 1). The upper surface is horizontal or inclines seaward with dip of 1°–2° at most, which closely resembles, in dip, to the river bed of ephemeral stream.

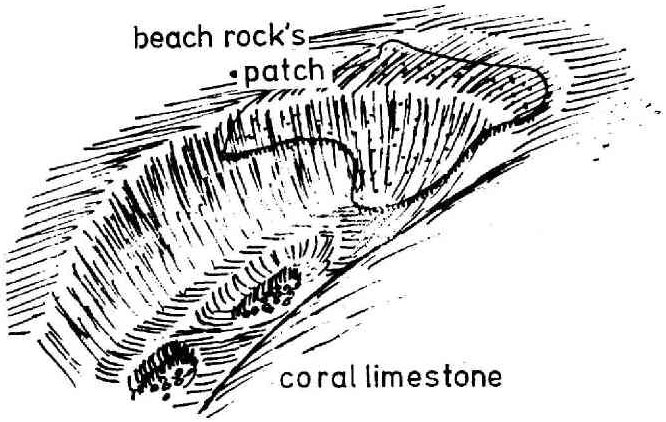

Fig. 4 Patch-like beach rock (C-type)

From the above observations, the features of beach rock in this coast are arranged as follows:

(1) Beach rocks are considerably concordant in dip with up-rush slope, beach, and river bed at the mouth of ephemeral stream, but some beach rocks are exceptionally not concordant with beach in dip (St. 13 and 14 in Fig. 1).

(2) The remains and the trace fossils of lagoonal organisms are not found in beach rock. The crusts of foraminifera of which the beach rock is composed, have been polished and have lost their spines.

(3) It is difficult to consider that bedding or lamina in beach rock was caused by the difference of grain size, because of the poor sorting of beach rock. The cross lamination is often recognized in beach rock.

Yonetani (1963, 63–67 and 66) attributed the origin of beach rock in northern Ryūkyū Islands to underground water, agreeing with Russel (1958, 59 and 62).

But Takenaga (1965) considered that beach rock on Yoron Island was caused by the stiffering of the stratum on lagoon floor, and by the consolidating in the inter-tidal zone, and the effect of underground water would be negligible. From the above observations we judge that beach rock in this coast originated not of lagoonal deposits but of beach deposits.

Following Russel's opinion that beach rock formed itself between high tide level and low tide level, emerged beach rock may be an available indicator of previous higher sea level. The upper limits of beach rock on this coast are 2.7 m (St. 4), 2.5 m (St. 5), 2.3 m (St. 6), 2.8 m (St. 8) or 1.9 m (St. 11) above mean sea level. And patch-like beach rocks are seen up to 3 m. These upper limits may

average 2.5 m above mean sea level.

Notch too is considerably available for judgement of previous sea level (Mii 1963, Takenaga 1968). The retreat points of notches on this coast locate 3 m or thereabout above mean sea level: for example 2.7 m (St. 2), 2.8 m (St. 9), 3.0 m (St. 10) or 3.2 m (St. 17).

It is difficult to decide whether beach rocks and notches were originated at the same age or not. Supposed that both are originated at the same age, the sea level which formed beach rock and notch is roughly presumed 2–3 m higher above present sea level.

As to the age of 2–3 m sea level, we leave the discussion for further report, as our carbon dating of corals in beach rock is in progress.

3 Summary

The features of the reef flats and the beach rock of southern Tokunoshima are summarized as follows:

(1) Inter-tidal reef flat and high tide reef flat are erosional platforms, and the latter is a product of sea level higher than present level.

(2) Beach rock of this coast was originated not of lagoonal deposits but of beach deposits.

(3) The sea level which formed beach rocks and notches was supposed relatively 2–3 m higher above present sea level.

This paper is dedicated to Professor Toshio Noh of Tohoku University, in commemoration of his retirement. We are deeply indebted to him for his continuing guidance and encouragement.

We wish to thank Professor Kasuke Nishimura of Tōhoku University for his critical reading of this manuscript.

References (* in Japanese)

Fairbridge, R.W. (1952): Marine Erosion. *Proceedings, Pacific Science Congress* **3** 347–359

Hirata, K. (1967): Distribution of Raised Reef Limestone and Present Reef-building Activity in Takara-jima and Kodakara-jima, Nansei Islands, Japan.* *Sci. Reps. Kagoshima Univ.* **16** 75–107

Koba, M. (1972): Raised Coral Reef of Kuchinoshima, Tokara, Japan.* *Mem. Kagoshima Geogr. Soc.* **20** 137–143

——— (1974): Coastal Geomorphology of Okino-erabu Island and Postglacial Sea Levels.* *Ann. Tōhoku Geogr. Assoc.* **26** 37–44

Mii, H. (1963): Relation of Shore Erosions to Sea Level.* *Jour. Mar. Geol.* **2** 8–17

Newell, N. and Bloom, A. (1970): The Reef Flat and 'Two-meter Eustatic Terrace' of Some Pacific Atolls. *Geol. Soc. Amer. Bull.* **81** 1881–1894

Russel, R.J. (1958): Preliminary Notes on Caribbean Beach Rock. *Louisiana State*

Univ. 1–9

——— (1959): Caribbean beach rock observations. *Zeitschrift für Geomorph.* **3** 227–236

——— (1962): Origin of beach rock. *ibid.* **6** 1–16

Saito, T., Kawaguchi, N. and Koba, M. (1971): On the Raised Coral Reef of Kuchinoshima and Nakanoshima, Tokara Islands.* *Mem. Kagoshima Geogr. Soc.* **19** 99–107

Takahashi, T. (1974): Geomorphology of Shore Platforms – Analytical and Genetical –. *Sci. Reps. Tōhoku Univ.* 7th Ser. (Geogr.) **24** 115–163

——— **and Fukumoto, H.** (1975): Coastal Geomorphology of Takarajima, Tokara Islands.* *Mem. Kagoshima Geogr. Soc.*

Takenaga, K. (1965): Beach Rock and Lagoon on Yoron Island, Ryūkyū Archipelago.* *Geogr. Rev. Japan* **38** 739–755

——— (1968): The Classification of Notch Profiles and the Origin of Notches.* *Jour. Geogr. Tokyo* **77** 329–341

Tayama, R. (1952): Coral Reefs in the South Seas. *Bull. Hydrographic Office* **11** 1–292

Yonetani, S. (1963): The Preliminary Studies on the Beach Rock of the Northern Part of Ōshima, South-West Japan.* *Geogr. Rev. Japan* **36** 519–527

——— (1963–67): The Beach Rock on the South-West Islands of Japan (1)–(5). *Cult. Sci. Rev. Kagoshima* Univ. **12** 1–24, **13** 83–94, *Cult. Sci. Reps. Kagoshima Univ.* **1** 13–20, **2** 23–34, **3** 95–109

——— (1966): The Beach Rock and its Analogous Land Forms.* *Geogr. Rev. Japan* **39** 12–22